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27 Greville Street, London EC1N 8TN
Tel: 020 7404 3334 Fax: 020 7404 8843
e-mail: gagtl@btinternet.com Website: www.gagtl.ac.uk

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Open channels in near-colourless synthetic moissanite

Taijin Lu, James E. Shigley and John I. Koivula

Gemological Institute of America (GIA), GIA Gem Trade Laboratory, 5355 Armada Drive, Carlsbad, California 92008, U.S.A.

ABSTRACT: Open, tube-like channels are one of the most noticeable internal features visible in some gem-quality synthetic moissanite. These channel inclusions can reach exterior surfaces, or they may terminate against other internal defects or fractures. They usually display a hexagonal cross section, and are elongated in a direction parallel to the optic axis of the host crystal. Their appearance differs from that of natural etch channels seen on rare occasions in some gem diamonds. The origin of the channels in synthetic moissanite is discussed. They are thought to result from the relaxation of strain around a kind of enlarged screw dislocation in the crystal during the crystallization.

Introduction

Near-colourless synthetic moissanite (silicon carbide, SiC, 6H polytype) was first introduced as a new diamond simulant into the jewellery marketplace at the beginning of 1997. Since that time, gemmologists have focused on establishing practical identification criteria, or developing simple testing instruments, for its detection (Nassau *et al.*, 1997; Nelson, 1998; Hodgkinson, 1998a,b; Shigley *et al.*, 1998; Zhang and Li, 1999; Nassau, 1999). With the exception of its non-isotropic optical character, specific gravity and distinctive inclusions, many of the remaining gemmological properties of synthetic moissanite are similar to those of diamond. However, the separation of synthetic moissanite from diamond should not be difficult for trained gemmologists. Shigley *et al.* (2000) recently published a chart of gemmological properties, with illustrations of the distinctive visual characteristics of synthetic moissanite (as compared to those of both diamond and cubic zirconia, CZ).

Like many gem materials, synthetic moissanite has its own internal characteristics that can be seen with magnification. Lower-clarity faceted synthetic moissanite may contain inclusions, the most common being subparallel, needle-like, open channels. In this article, detailed features of these channels, such as their size, crystallographic orientation and relationships with other features, are described. A possible formation mechanism for these channels in synthetic moissanite, and comments on the differences between them and the rare etch channels observed in natural diamonds, are also discussed.

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Review of synthetic moissanite crystal growth

Synthetic moissanite crystals (in the form of boules) are grown by a seeded sublimation method, derived from the 'Lely' process (see Davis *et al.*, 1990; Stein, 1993; Nassau, 1999). In this process, silicon carbide (SiC) is vaporized and then is condensed to a solid without ever passing through a liquid state. Crystallization of SiC takes place in a radio frequency-heated graphite furnace at temperatures around 2300°C. A porous graphite cylinder is placed inside a graphite crucible in the furnace. The space between the crucible wall and the porous cylinder is filled with SiC powder as source material, and at the bottom of the crucible, the seed is positioned in the coolest region of the furnace. SiC, vaporized from the feed powder, passes through the porous cylinder to crystallize on the seed, forming a crystal boule of synthetic moissanite. The temperature of the seed is between 2150 and 2350°C. The temperature gradient within the growing crystal is about 20°C per cm. The temperature difference between the SiC feed powder and the seed is about 100°C. More detailed information on the SiC crystal growth techniques can be found in Davis *et al.* (1990), Nakashima *et al.* (1996), and Nassau (1999).

Materials and methods

The US manufacturer does not distribute rough samples, so our observations have all been made on approximately 300 polished pieces of faceted synthetic moissanite with various shapes (including a polished cube). These pieces represent a good sample of the kind of material that has been sold for use in jewellery by the manufacturer Charles and Colvard (formerly C3 Inc.).

Standard gemmological equipment was used to document these samples (as described in Nassau *et al.*, 1997). In addition, strain images were observed at magnifications of 7× to 45× using a Nikon microscope fitted with crossed polarizing filters and a specially designed immersion cell containing methylene iodide (RI 1.74). To check the detectability and visibility of the channel inclusions under the microscope, a fibre optic light source was placed at various incident angles to the immersion cell.

Results

From our observations, the channel inclusions appear to be elongated empty tubes (see *Figure 1*). Their diameters generally range from about 10 to 50 µm, but can occasionally reach 500 µm (Stein, 1993). The lengths of the channels also vary, ranging from 0.2 mm to 6.0 mm; in some faceted pieces they can extend across the entire sample.

The channels are commonly parallel or sub-parallel to each other, and are elongated along the optic axis of the host crystal (*Figure 2*). Channels rarely appear to radiate from a source, an optical effect which can be due to multiple reflection in faceted samples (*Figure 3*). Occasionally, a slightly bent or discontinuous channel was seen (*Figure 4*). The number and location of the channels vary depending on the samples. High-clarity pieces of synthetic moissanite are relatively free of channels, whereas in low-clarity samples the channels can be quite abundant.

In most samples, the channels were observed to start and finish at polished surfaces, due to the fact that the samples were faceted from a region of the crystal at some distance from the seed where the channels originate. At these surfaces, the terminations were difficult to see because of their small diameter, but they could be located from strain patterns visible under crossed polarizing filters.

In some samples, the channels terminate at internal defects. The types of defects seem unimportant in terms of channel terminations, but the sizes of these defects are usually greater than the diameters of the associated channels. *Figure 5* shows several examples of channel terminations by (a) a hexagonal plate-like inclusion (negative

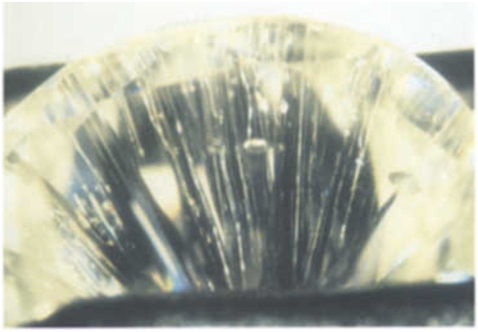

Figure 1: Needle-like channels observed in a faceted synthetic moissanite. Magnification 10× transmitted light. Photo by J. Shigley. © GIA.

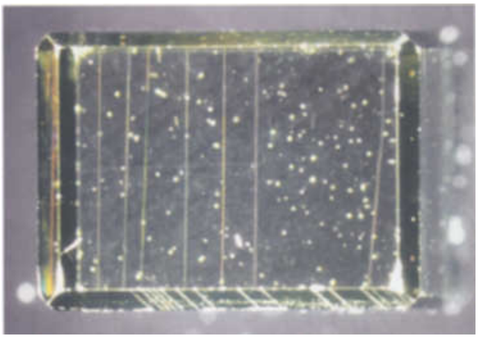

Figure 2: Parallel channels elongated along the optic axis observed in a synthetic moissanite cube. Magnification 10×, transmitted light dark field. Photo by T. Lu. © GIA.

crystal?), (b) a fracture, (c) an amorphous carbon inclusion (Koivula, 2000) and (d) a cavity larger than the channel diameter.

Channels were easily observed by both bright field and dark field illumination, but their appearances are different under these two lighting conditions. In bright field illumination, the channels appear as black lines (e.g. *Figures 4 and 6*), while in dark field illumination they appear as bright lines due to light scattering (see *Figures 1 and 3*). Channels can be easily seen in all orientations of the crystal, except when looking parallel to their elongation direction (the optic axis direction). By simply rotating the sample off parallel to the elongation direction, the channels will usually be seen.

Double images of inclusions were sometimes seen (*Figure 7*). This doubling becomes more apparent as the angle increases between the optic axis of the crystal and the direction of observation.

Possible formation mechanism of the channels

Despite much study, the formation mechanism of the channels is still uncertain. To understand the possible formation mechanism of the channels in synthetic moissanite, a basic knowledge of the SiC crystal growth and possible post-growth reactions is important (see Davis *et al*., 1990; Stein, 1993; Nassau, 1999). As mentioned above, synthetic moissanite crystals are

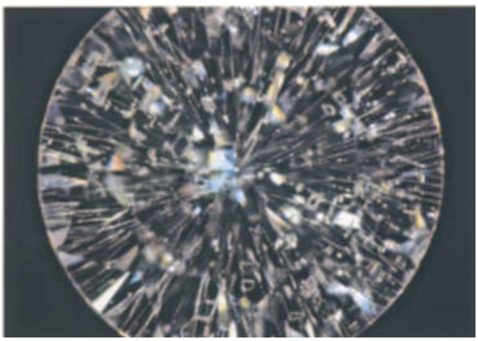

Figure 3: In this view, the channels appear to radiate because of facet reflection. Magnification 5×, transmitted light dark field. Photo by J. Koivula. © GIA.

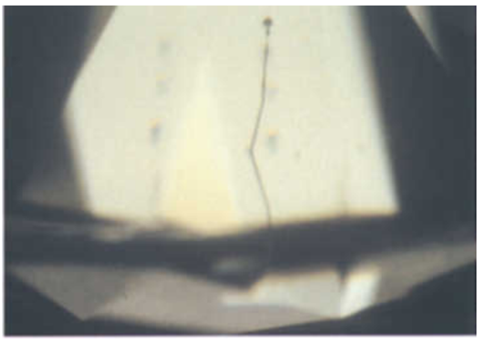

Figure 4: Bent channels were occasionally observed in synthetic moissanite. Magnification 5×, transmitted light. Photo by J. Shigley. © GIA.

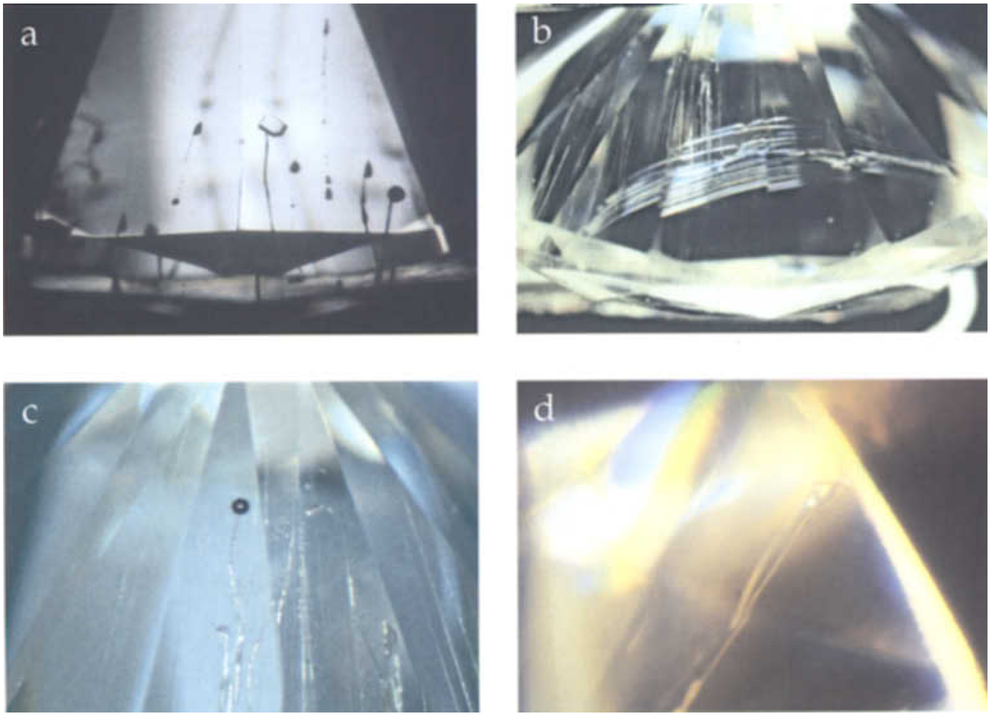

Figure 5: *Several examples showing the channels terminated by a) plate-like inclusions (negative crystals), magnification 10×, photo by J. Koivula; b) a fracture, magnification 10×, photo by J. Shigley; c) an amorphous carbon inclusion, magnification 15×, photo by J. Koivula; and d) a cavity larger than the channel diameter, magnification10×, photo by T. Lu. All the photos were taken in dark field illumination. © GIA.*

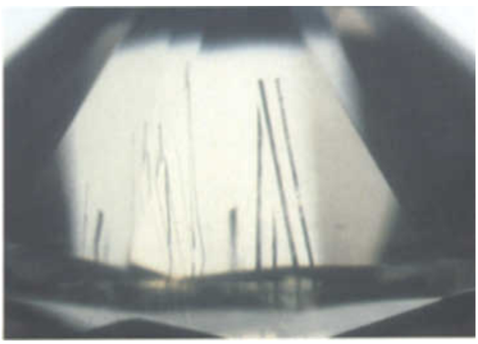

Figure 6: *The channels appeared as dark lines in a faceted synthetic moissanite. Magnification 10×, transmitted light dark field. Photo by J. Shigley. © GIA.*

Figure 7: *Double images of plate-like inclusions observed in a faceted synthetic moissanite. Magnification 20×, transmitted light dark field. Photo by T. Lu. © GIA.*

grown by a sublimation process. The channel inclusions aligned along the direction of growth of the crystal have been called micropipes, macro-defects, vertical defects, or holes by the scientists who study crystal growth (Stein 1993; Dudley *et al.*, 1995; Heindl and Strunk,1996; Nakashima *et al.*, 1996; Ohtani *et al.*, 2001). The formation mechanisms of these channels are not fully understood, although several mechanisms or combinations of mechanisms have been proposed (Sunagawa and Bennema, 1981; Stein, 1993; Dudley *et al.*, 1995; Tsvetkov *et al.*, 1998; Ohtani *et al.*, 2001). Basically, most proposed mechanisms are interpreted in the framework of Frank's model of 'hollow core of dislocations' (Frank, 1951). The origin of the hollow cores is due to relaxation of crystallographic strain around combined multiple c-screw dislocations which had acquired a very large Burgers vector during the crystal growth stage. In Frank's model, if the Burgers vector of a screw dislocation exceeds a critical value (approximately 1 nm, which is much larger than the lattice unit cell) then it is, due to the very high strain energy, energetically more favourable to remove the crystal material near the dislocation line and to create an additional surface in the form of a channel. Heindl *et al.* (1997) provided experimental support for this theory by measuring the total step heights and radii of the channels with an atomic force microscope and compared these data with the ideas proposed by Cabrera and Levine (1956) who extended Frank's model with respect to kinetic aspects. Recently, Ohtani *et al.* (2001) proposed a surface step model by which they try to explain how dislocations are brought together to produce the channels, and why such enlarged screw dislocations are stable in the crystal.

Another proposed formation mechanism for the channels suggests that they are a product of a secondary evaporation during the post-growth stage following

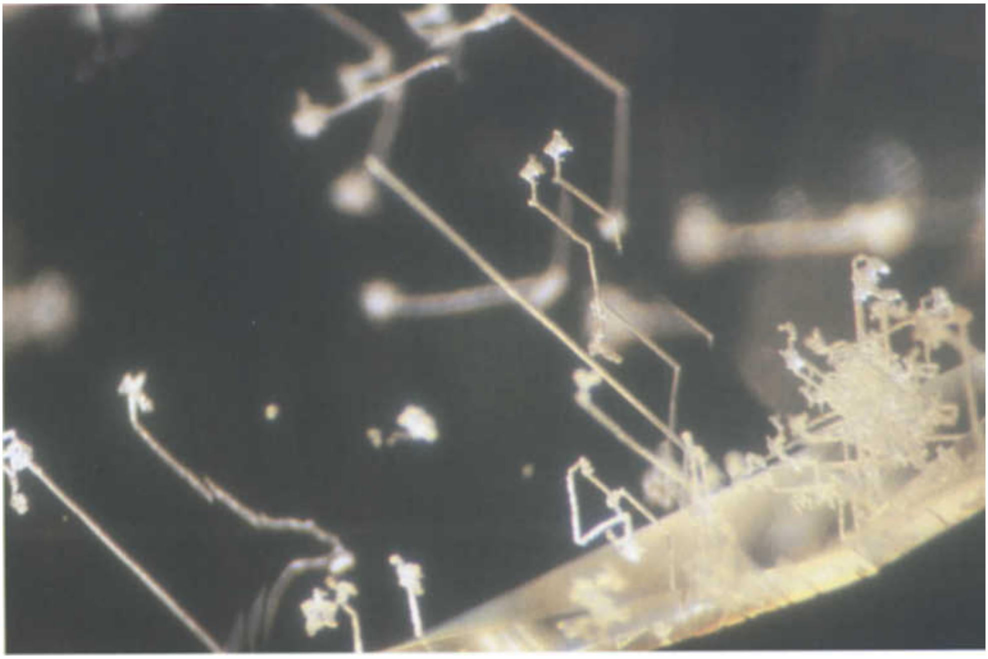

Figure 8: *Etch channels observed in a natural diamond crystal. Magnification 25×, transmitted light dark field. Photo by J. Koivula. © GIA.*

Table I: Comparison of channels in synthetic moissanite and natural diamonds

	Channels in synthetic moissanite	*Channels in natural diamonds*
Appearance	Usually elongated hexagonal tubes, 10 – 50 µm in diameter, and 1 – 5.0 mm in length. Oriented parallel to the *c*-axis of the crystal. Occasionally slightly bent.	Usually elongated tubes with various widths and lengths, and a square, rectangular, or hexagonal cross section. Channels may be zig-zag or bent. Channels taper as they extend inwards, and may be striated perpendicular to the length.
Associated other defects	Sometimes terminated by plate-like inclusions (negative crystals), dark spots (amorphous carbon) and fractures. Plate-like inclusions or other tiny inclusions may be seen.	Some are terminated by inclusions. Other minerals, cleavage planes, growth zoning and colour zoning may be seen.
Visibility in different conditions	Dark lines under bright field light, bright lines under dark field illumination. Multiple images may be seen due to birefringence.	Dark lines under transmitted light, bright lines under dark field illumination. Usually associated with a strong strain pattern.
Possible formation mechanisms	Formed by relaxation of crystallographic strain around enlarged screw dislocations during the crystallization.	Formed by a natural chemical dissolution process during post-growth stages along dislocation bundles.

crystallization (Stein, 1993). However, this hypothesis does not provide an explanation of the possible destinations of the evaporated material when the bottom and top of the crystal are closed.

Our observations appear to support the model of hollow cores of enlarged screw dislocations generated during the crystal growth stage. Once the channels are generated, they will extend to the as-grown surface unless they meet other internal defects and/or fractures with a greater diameter, which cause the channels to terminate (see again *Figure 5*). Therefore, the overall number of the channels will be reduced with increasing distance from the seed surface.

Distinguishing channels in synthetic moissanite from etch channels in natural diamonds

Open channel structures can occur in many natural gemstones (such as beryl, diamond, garnet, spodumene and topaz). They are rarely observed in synthetic gem materials, although some have been seen in synthetic quartz after chemical etching (Iwasaki, 1977). Because synthetic moissanite is a diamond simulant, we compared the differences in appearance between the etch channels observed in natural diamonds (*Figure 8*) and the channels seen in the synthetic moissanite (see *Table I*). We believe that channels in both materials are formed in association with dislocations, but by different processes. In synthetic moissanite, the channels are formed by relaxation of crystallographic strain around the screw dislocations with a very large Burgers vector. These screw dislocations started from irregular sites in the SiC crystal at or near the seed during the crystallization. In contrast the channels in natural diamonds are formed by chemical dissolution extending inward from the crystal surface along dislocations during the post crystal growth stage (Koivula, 2000; Lu *et al.*, 2001).

Conclusion

The open channels can be an important identification characteristic of synthetic moissanite. These channels usually start from irregular sites at or near to the seed and are elongated along the optic axis. They exhibit a hexagonal shape in cross-section, and some are terminated by plate-like inclusions, amorphous carbon inclusions, or fractures inside the crystal. They may be formed by relaxation of crystallographic strain around enlarged screw dislocations during the crystallization. Their appearance is different from the etch channels observed occasionally in natural diamonds.

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A comparison between a flux grown synthetic ruby and an untreated natural ruby

J.M. Duroc-Danner, FGA, GG

Geneva, Switzerland

ABSTRACT: Flux grown synthetic rubies appear occasionally set in traditional jewellery, most often wrongly taken for a natural stone. Some untreated metamorphic rubies have properties that overlap those of flux grown synthetic rubies (especially the 'fingerprints' and features of the infrared spectrum), making a separation more difficult. Such is the case for the flux grown synthetic and Mong Hsu ruby analysed in this article.

Introduction

Recently the author was asked to identify a 3.54 ct pear-shaped red stone of a pleasing colour, set in a pendant, framed by brilliant-cut and marquise-cut diamonds, mounted in 18 carat white gold (*Figure 1*), and an unmounted 3.28 ct cushion-shaped red stone of a very convincing colour, cut and general appearance (*Figure 2*). The measurements, weight and gemmological properties of these two stones are described below.

Gemmological properties

The 3.54 ct pear-shaped red transparent gemstone (length 12.76 mm, width 8.68 mm, depth 4.26 mm), and the 3.28 ct cushion-shaped red transparent stone (length 8.80 mm, width 8.32 mm, depth 5.43 mm), both displayed a vitreous lustre.

The refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. The indices obtained from the table facet were ω = 1.768, ε = 1.760, giving a birefringence of .008, with optic sign (-), and showing that the table facet was cut perpendicular to the *c*-axis (confirmed by a uniaxial interference figure obtained on each stone's pavilion, made visible by a glass sphere between crossed polars).

Under a calcite dichroscope, with fibre optic illumination, strong dichroism in pale yellowish-red to deep red was observed in the stones' girdle planes.

The absorption spectra were observed in daylight conditions through a Beck spectroscope and revealed a spectrum typical of chromium, a fluorescent line in the red at 695 nm, with three fine lines visible in the blue at 478, 474, and 469 nm, and a very strong broad band from the blue to the violet at 460 to 400 nm.

The stones were examined with a Multispec combined LW/SW ultraviolet unit and fluoresced a strong red in SW but moderate dark red in LW.

The specific gravity (SG) was obtained by hydrostatic weighing in distilled water using a Mettler PL 300C carat scale, and the stones were found to have a value of 4.00.

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Figure 1: *The 3.54 ct pear-shaped flux grown ruby surrounded by brilliant- and marquise-cut diamonds.*

Figure 2: *Enlarged view of the 3.28 ct cushion-shaped ruby. Notice the important break visible in the bottom right corner of the stone.*

The inclusions were examined using a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate.

The main features encountered in the 3.54 ct pear-shaped stone were:

- Parallel colour zones showing straight and angular (V-shaped) growth features (*Figure* 3).
- Numerous dark and opaque, small to large, thin to rather thick, hexagonal, triangular and rod-like platinum platelets were easily seen (*Figure* 4).
- A long, and extremely thin 'phantom-like' acicular inclusion (unidentified, *Figure* 5).
- Unmelted flux residual filling a large inclusion (*Figure* 6).
- Veil-like 'flux feathers' (*Figure* 7).

Figure 3: *Parallel angular (V-shaped) growth zones observed in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 40×).*

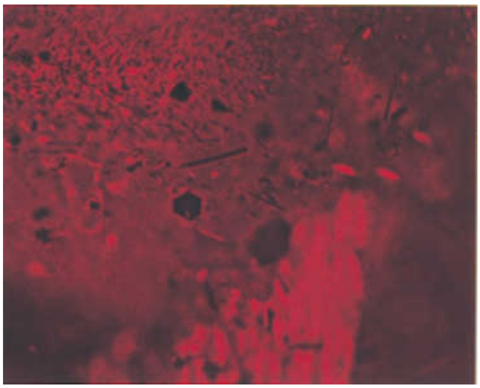

Figure 4: *Dark or opaque hexagonal, triangular and rod-like platelets of platinum are present in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 50×).*

Figure 5: *A long and extremely thin phantom-like acicular inclusion (unidentified) in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 60×).*

Figure 6: *A large inclusion filled with flux residuals in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 60×).*

- Blue zones confined to some of the flux inclusions.

In the 3.28 ct cushion-shaped stone the main features are:

- An important break in one of the corners of the cushion-shape (*Figure* 2).
- A large oval-shaped open cavity on the pavilion (*Figure 8*).
- Parallel colour zones showing straight and angular (V-shaped), growth features.
- A long, white and extremely thin undisturbed acicular inclusion (unidentified, *Figure* 9).

Figure 7: *A veil-like 'flux feather' in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 60×).*

Figure 8: *A large oval-shaped open cavity on the pavilion of the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 10×).*

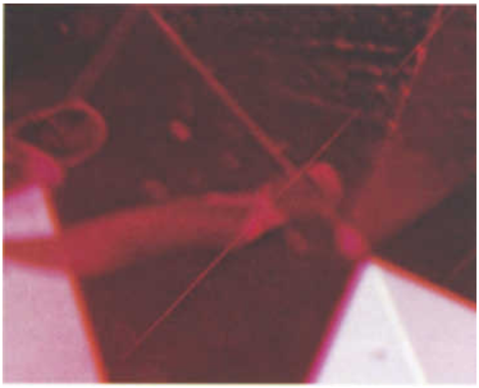

Figure 9: *A long and extremely thin undisturbed white acicular inclusion in the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 40×).*

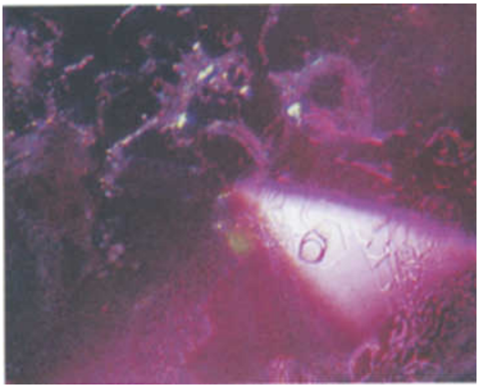

Figure 10: A 'fingerprint' showing a pattern of 'phantom-like' negative crystals of colourless transparent hexagonal outline, sometimes accompanied by two-phase inclusions (most probably CO_2), observed in the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 40×).

Figure 11: A 'feather' filled with precipitated substances (not analysed), observed in the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 40×).

- Numerous 'feathers', some showing twisted, wispy veil-like 'feathers', others displaying a pattern of 'phantom-like' negative crystals of colourless transparent hexagonal outline, sometimes accompanied by two-phase inclusions (most probably CO_2 fluid inclusions, *Figure 10*), or filled with precipitated substances (not analysed), giving rise to patterns reminiscent of those observed in amethysts and described as 'zebra stripes' (*Figures 11 and 12*).
- When the stone, immersed in methylene iodide was observed between crossed polars through a horizontal microscope it showed polysynthetic twinning that penetrated the entire stone (*Figure 13*).

Infrared absorption (FTIR) spectra were obtained for both stones with a Nicolet Magna-IR ESP System 560 spectrometer. Both displayed rather featureless IR spectra in the region of 2400-3400 cm^{-1}, and four peaks only were present at 2852 cm^{-1}, 2873 cm^{-1}, 2916 cm^{-1} and 2955 cm^{-1}. These correspond to those released by our fingers

Figure 12: Enlarged view of the 'feather' in Figure 11 with patterns reminiscent of those observed in amethysts and described as 'zebra stripes'. (Dark field illumination, 80×).

Figure 13: Polysynthetic twinning that penetrates the entire stone, observed in the cushion-shaped Mong Hsu ruby of 3.28 ct. (Immersed in methylene iodide and between crossed polars, 40×).

or Blu-tack (paste used to hold the sample to be tested), or residues of plastic or resin, and therefore must be considered as an artefact (David *et al.*, 2001).

The fact that the cushion-shaped ruby of 3.28 ct does not exhibit a peak located in the region of 3310 cm^{-1} present in all the tested samples of heat-treated metamorphic rubies confirms, with the inclusions observed, that the present stone has not suffered high temperature heat-treatment, thus proving the colour origin to be natural (McClure and Smith, 2000).

Discussion

It is a well established fact that inclusions will generally provide identification characteristics to distinguish natural from synthetic, treatments undergone, and sometimes a key to the possible origin of the gem examined. Platelets similar in appearance to platinum platelets but of ilmenite or hematite can be present in natural corundum (see Gübelin and Koivula, 1986; Hughes, 1997; Kane, 1981, 1982).

Had the 3.54 ct pear-shaped synthetic ruby been cut from part of the crystal free of platinum platelets but with the straight and angular growth markings (observed in most natural corundum), acicular inclusions (one of the main characteristics of a natural corundum) and 'fingerprints' (also very deceptive since these can look very similar to those observed in natural corundums from Mong Hsu, Myanmar), its identification would have been more difficult and could have bluffed many a jeweller and stone dealer.

Concerning the 3.28 ct cushion-shaped ruby, the large break on one corner is most probably due to an accident during setting or unsetting the stone in jewellery. It is very unusual to receive for testing a stone so badly damaged prior to being repaired.

The cutting style, referred to as 'antique cut', is most often observed in fine quality natural rubies, but can (like any cutting style) also be observed in synthetics. The cut cannot therefore be used as a firm indicator of a natural stone.

As for the large oval-shaped surface cavity on the pavilion, it could correspond to a possible 'earth hole' observed on many rough alluvial corundums. In heat-treated corundums (where temperatures as high as 1300 to 1900°C are used), similar 'openings' which have been treated with a 'firecoat' such as borax (hydrous sodium borate), may be filled with glass; this filling then can be removed by hydrofluoric acid, leaving an open cavity (Peretti *et al.*, 1995; Themelis, 1992). However, since the infrared spectrum indicates that the stone has not suffered high temperature heat-treatment, the surface cavity is probably original.

The parallel colour zones showing straight and angular (V-shaped) growth features, the long and extremely thin acicular inclusion, the numerous feathers, the polysynthetic twinning and fluid inclusions (Koivula, 1986), are all characteristics reported in natural corundum.

According to the fluorescence, the infrared spectrum and the low content of iron impurity in this ruby, it is probably of metamorphic origin, and its inclusions are similar to those in rubies from Mong Hsu (Peretti *et al.*, 1995).

Conclusion

The physical and optical properties are consistent with those of corundum, variety ruby, either natural or synthetic.

The inclusions observed in the 3.54 ct pear-shaped ruby are characteristic of flux fusion synthetic corundum, variety synthetic ruby, and correspond to those described in the literature (Kane, 1981, 1982; Gübelin and Koivula, 1986; Liddicoat, 1989; Nassau; 1980; Scarratt, 1999; Webster, 1994).

The appearance of the 3.54 ct pear-shaped is a reminder that flux grown synthetic rubies (considered a sophisticated synthesis compared to the more widely produced Verneuil flame fusion or Czochralski 'pulling' synthetics) appear from time to time on the gem market and are mistaken for natural ruby.

The 3.28 ct cushion-shaped ruby, with at first sight similar characteristic inclusions, is more tricky and needed a combination of a very close examination of its internal characteristics and infrared spectroscopy to understand its nature and confirm its origin and colour.

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Symmetrical clouds in diamond – the hydrogen connection

Wuyi Wang and Wendi Mayerson

GIA Gem Trade Laboratory, New York, NY 10036, USA

ABSTRACT: Diamonds with symmetrical clouds (composed of numerous micro-inclusions) are investigated. Infrared absorption analysis of selected regions with varying cloud densities reveals a close relationship between the intensity of hydrogen absorption and the density of the cloud. The symmetrical clouds follow the <100> direction of the diamond. These observations support the hypothesis that hydrogen in diamond is physically bonded at internal surfaces such as the inclusion-host interfaces, and impurities of hydrogen combined with the high surface energy of the {100} faces could be the controlling factors for the formation of the symmetrical clouds. Such diamonds could form at a relatively stable environment in the Earth's upper mantle, and exhibit a special type of natural beauty.

Keywords: diamond, hydrogen, infrared, symmetrical cloud

Introduction

Clouds are fairly common inclusions in natural diamond. Under a microscope at approximately 30× magnification, it is clear that such clouds are composed of numerous micro-inclusions. Most clouds are irregular in shape, and usually occupy less than 20% of the diamond's volume (Izraeli *et al.*, 2001). Several examples of regular and symmetrically shaped clouds have also been reported (e.g. Humble, 1982; Koivula, 1999; Koivula and Tannous, 2001). In contrast to individual mineral inclusions such as olivine and garnet in diamond, little is understood of the mineralogy and chemistry of the micro-inclusions in clouds. In particular, the mechanism responsible for forming symmetrically shaped clouds and their crystallographic relationship with the host diamond is not widely understood.

Diamond is well known for its relatively pure chemical composition (~99.9% carbon). However, very low concentrations (tens to hundreds of parts per million by weight) of impurities may occur as trace elements in diamond, which strongly affect its colour and other physical properties. Common impurities include nitrogen, hydrogen and boron. The existence of hydrogen in natural diamond was first reported by Chrenko *et al.* (1967). Following an extensive investigation of hydrogen in diamond, Woods and Collins (1983) concluded that hydrogen was practically of universal occurrence in type Ia natural diamonds, and was bonded to the diamond lattice. Two fundamental absorptions at 3107 and 1405 cm^{-1} in the infrared absorption spectrum are due to C-H stretching and bending vibration, respectively. A close relationship between micro-inclusions and hydrogen in diamond was proposed, that is, the most likely

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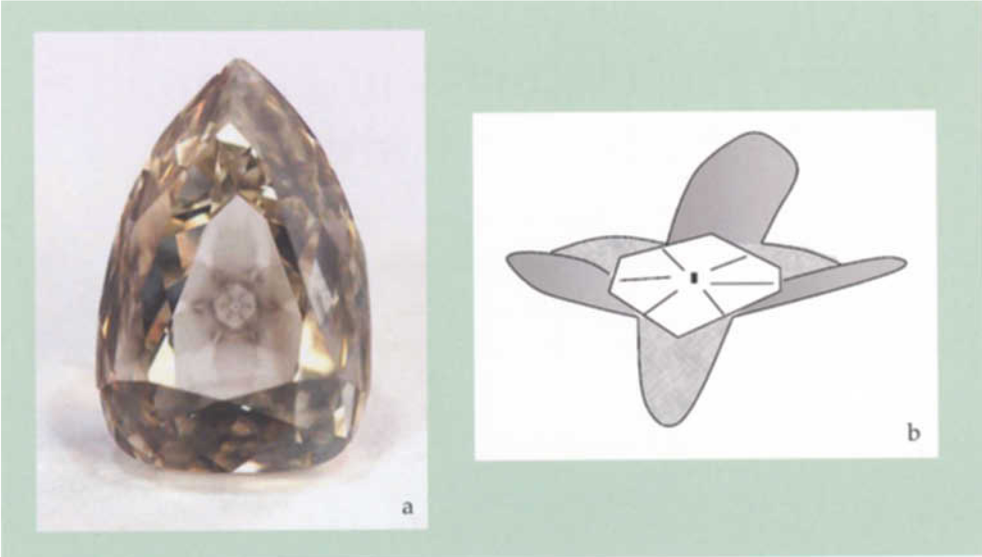

Figure 1: (a) Fancy brown-greenish yellow diamond of 3.02 ct (9.64 × 6.39 × 5.48 mm), with a pear-shaped modified brilliant-cut, containing a flower-shaped cloud (sample A). The cloud, which is composed of tiny needle-like inclusions, can be clearly seen through the two large parallel facets. (b) Three-dimensional map of the flower-shaped cloud. Starting from a small black inclusion, the shape of the cloud changes from six one-dimensional rays to six two-dimensional petals. Three petals radiate upward and the other three downward, thus the axis of the flower cloud is parallel to the <111> crystal direction. Photograph by Elizabeth Schrader.

bonding sites for hydrogen in diamond would be at internal surfaces such as inclusion-matrix interfaces (Melton and Giardini, 1974, 1975; Woods and Collins, 1983; Fritsch and Scarratt, 1993). However, few direct observations of this relationship have been published. Using recently developed quantitative microscopy with a 15 MeV Si^{7+} microbeam for minor distributions of bulk hydrogen in solid samples, Maclear *et al.* (1998) found a striking correlation between the hydrogen distribution and the optically visible micro-inclusions in a natural diamond. This is the first direct evidence associating aggregations of hydrogen with clouds of micro-inclusions in natural hydrogen-rich diamonds. It should be noted that these observations were limited to surface/near-surface hydrogen only.

In this study, we report on two hydrogen-rich diamonds with symmetrically shaped clouds. Using gemmological observations and results of instrumental analysis, the physical location of the hydrogen impurities and the possible significance of hydrogen controlling the formation of such symmetrically shaped clouds in natural diamonds are discussed.

Materials and methods

For this study, we examined two diamonds, each containing a symmetrical six-petalled flower-shaped cloud.

Sample A

A 6.23 ct partly rounded rough octahedral crystal with a translucent etched surface (Mayerson and Reinitz, 2000). Through two natural cleavage surfaces, the flower-shaped cloud was quite visible. We had a second chance to examine sample A after it was cut into a 3.02 ct pear-shaped modified brilliant (*Figure 1a*). The faceted stone measured 9.64 × 6.39 × 5.48 mm and was colour graded as Fancy brown-greenish yellow. Specifically cut to display the flower-shaped cloud, this

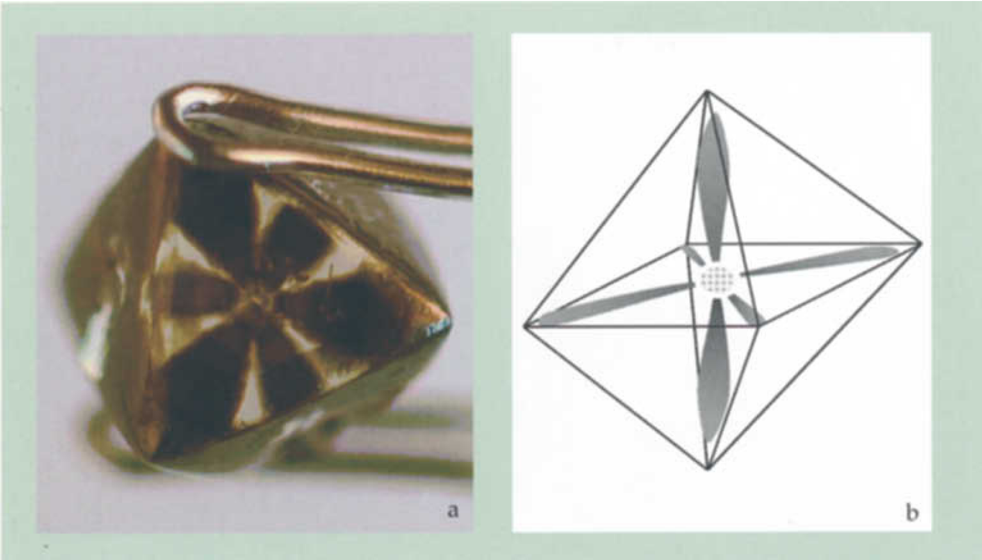

***Figure 2:** (a) The six-petalled flower cloud (micro-inclusions) in sample B, an octahedral diamond of 3.40 ct, viewed through a (111) face. (b) The sketch map shows the spatial arrangement of the cloud inclusions and their crystallographic relationship with the host octahedral diamond. Note that the sketch map and the real diamond are shown in slightly different orientations. The cloud is dark brown with grey fringes and originates from the centre of the crystal. The six petals perfectly follow along the <100> direction to all six corners of the crystal. This is good evidence for crystallographically controlled growth of the cloud. Photograph by Elizabeth Schrader.*

stone has an extra large culet facet parallel to and only slightly smaller than the table facet. The table measures approximately 3.92 mm. Because the axis of the flower-shaped cloud is almost perpendicular to the table and culet, this arrangement not only allows for an excellent view of the cloud, but it also provides an ideal 'window' for spectroscopic measurement.

Sample B

A 3.40 ct octahedral diamond crystal measuring approximately 9.36 × 9.27 × 8.67 mm (*Figure 2a*). Known in the trade as a 'glassy', this extremely well formed crystal has fairly smooth crystal faces and good transparency which allow very clear views of the cloud and its crystallographic orientation.

Both diamonds were examined with a binocular gemmological microscope, a Leica research microscope with magnification capability up to 500×, and a GIA GEM viewing cabinet and UV lamp set. Visible-range spectra were observed at room temperature and at liquid nitrogen temperature, with a desk-model Beck prism spectroscope.

Infrared spectra were recorded at room temperature with a Nexus 670 Fourier-transform infrared (FTIR) spectrometer over the range of 400 to 10500 cm^{-1}, fitted with a microbeam chamber that allows for maximum energy output. Resolution is 4.0 cm^{-1}. Spectra with good signal/noise ratios were obtained by averaging 1024 scans for both mid- and near-infrared ranges. Ultraviolet-visible (UV-VIS) absorption spectra were recorded over the range of 360 to 760 nm using a Hitachi U-4000 spectrophotometer with a resolution of 0.1 nm and a slit width of 0.5 nm. For this measurement, the sample was held in a cryostatic cell cooled by liquid nitrogen. Metal disks with holes of various diameters were employed as masks to analyse selected regions of the diamond.

Figure 3: A close-up of the flower-shaped cloud in sample A taken at 70× magnification. Note: the small dark needle-like crystalline inclusion in the centre of the cloud appears white due to reflections in this photomicrograph. Photomicrograph by Wendi Mayerson.

Results

Magnification

Examination of sample A with magnification up to 60× revealed that the brownish symmetrical cloud was actually composed of numerous tiny inclusions. At 100× magnification, these inclusions appeared as short, randomly scattered needles.

The transparency of the diamond varied from the centre of the stone to the rim, depending on the density of the cloud. The whole cloud (*Figure 3*) is centred around a small black crystalline inclusion from which it radiates outward in the shape of a six-rayed star, approximately 1.5 mm in diameter. All six rays are well developed in one plane. This star is bordered by a hexagonal cloud with each of the six rays meeting their end at the midpoint of a side of this cloud's denser border creating a right angle. Further from the centre, beginning at the edge of the hexagon, the shape of the cloud changes from rays (straight lines) to petals (pseudo-elliptical forms), which appear mainly two-dimensional and extend through a large part of the crystal. It is at the end of each ray that the corners of each petal begin, and this specific orientation truly enhances the 'flower' image. The six petals are arranged in two groups. Relative to the central plane, three petals radiate upward, and the other three downward (*Figure 1b*). This implies that the axis of the flower cloud coincides with the <111> crystal direction – the only direction along which diamond has three-fold symmetry.

This alignment is more easily seen in sample B because the crystal form remains for reference. Sample B (*Figure 2b*) illustrates that the petals of the flower cloud point to the six corners of the octahedron, i.e., in the <100> directions, thereby aligning themselves with the a, b and c cubic crystallographic axes of the diamond. The clouds in sample B are also brown, but are outlined by a grey border.

Fluorescence

In sample A, the flower cloud showed weak-medium orangy-yellow fluorescence to long-wave and weak yellow fluorescence to short-wave UV (*Figure 4*). In sample B, the grey border surrounding the flower cloud showed very weak yellow fluorescence to both long- and short-wave UV.

Spectra

With the desk-model spectroscope and transmitted light, we observed strong 415 nm lines in both samples A and B. Sample B also contained a weak line at 478 nm. Both of these lines are nitrogen related. Cooling the diamonds to liquid nitrogen temperature and using transmitted light, we resolved a line at 563 nm in both stones. This line, along with one at 545 nm that was not observed in either sample, has been associated with hydrogen by Fritsch and Scarratt (1993).

Four areas of sample A were analysed by both infrared and visible spectrometers, and their positions are shown in *Figure 5*. These spots sampled different densities of micro-inclusions within the flower cloud. Spot 1 is

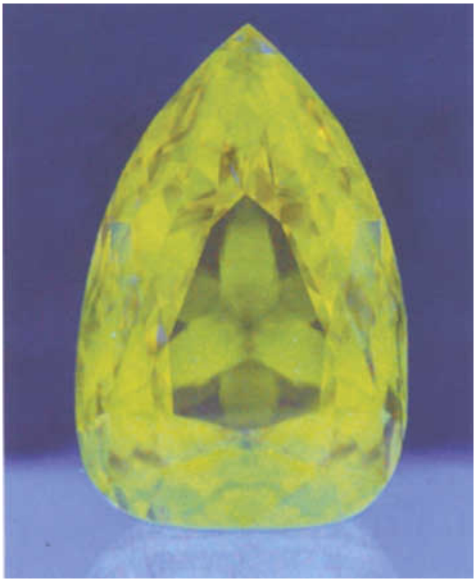

***Figure 4:** The flower-shaped cloud in sample A, the 3.02 ct pear-shaped modified brilliant, fluoresced weak-medium orangy yellow in long-wave UV. Photograph by Elizabeth Schrader.*

at the centre of the flower cloud, and has the highest density of micro-inclusions. In contrast, spot 4 is smaller in size, and located at a clean part between two petals, it has the lowest density of micro-inclusions. Densities at spots 2 and 3 are intermediate. Because there were no polished parallel faces on sample B, light entering the sample would have been scattered to some extent, therefore test spots could not be located with certainty.

UV-visible absorption spectra of spots 1 and 2 from sample A are shown in *Figure 6*. Both spots show almost identical spectra, with a moderately strong N3 absorption at 415.1 nm, its side band at about 404 nm, and a weak peak at 563 nm. The same features of UV-visible absorption were observed from sample B, but with much stronger intensity.

Infrared spectra for sample A are summarized in *Figure 7*. Absorption at the one-phonon range of 1350-1000 cm^{-1} is saturated (off-scale), as is normal for the high concentration of nitrogen in type Ia diamonds. Existence of a peak around 480 cm^{-1} indicates that a substantial concentration of nitrogen is present in the coupled aggregation state ('A' form nitrogen). An outstanding feature is the high but varying concentration of hydrogen. Multiple hydrogen-related peaks consistently appear throughout different regions of the stone. For all four spots, strong and sharp peaks at 3107 and 1405 cm^{-1} reveal that this diamond is hydrogen-rich. In addition to the above two fundamentals, many other H-related absorptions as reported by Fritsch and Scarratt (1993) have also been observed (2785, 2813, 3050, 3080, 3153, 3170, 3188, 3236, 3255, 4167, 4495, 4704, 5888, 6070 cm^{-1}).

Quantitatively, the concentration of hydrogen can be described in comparison with intensity of the intrinsic two-phonon diamond absorption around 2450 cm^{-1}, because the intensity of this absorption per unit path-length is the same for all

***Figure 5:** The four locations in sample A analysed using infrared and VIS/UV spectrometers to check the distribution of impurities and defects. Spot 1 has the highest cloud density, and spot 4 has the lowest. The two large parallel facets make this diamond an excellent specimen for spectroscopic measurement. The diameters of spots 1–3 are 2.0 mm and that of spot 4 is approximately 0.6 mm. Photograph by Elizabeth Schrader.*

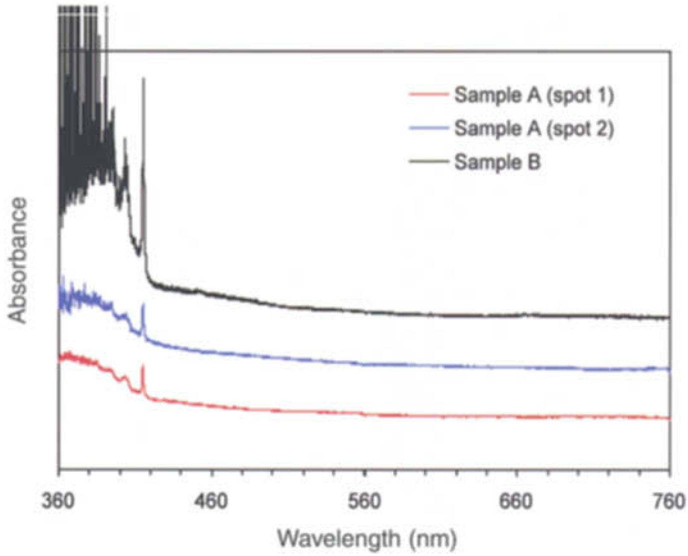

Figure 6: *Visible/ultraviolet absorption spectra. In sample A, both spots 1 and 2 show a moderately strong N3 (415.1 nm) absorption line and its side band at ~ 404 nm. No evident difference was detected between these two spots, consistent with the homogeneous distribution of body colour. In sample B, the same features were observed, but with stronger absorption.*

diamonds. Peak heights in absorption coefficient are used for the comparison in this study. The greater the ratio of the 3107 cm^{-1} peak relative to the two-phonon peak, the more abundant the hydrogen concentration. At spot 1, which has the highest cloud density (i.e. greatest number of micro-inclusions for a given area), the ratio is 1.14. It decreases to 0.40 at spot 4, which has the lowest density of micro-inclusions. In a consistent way, spots 2 and 3 show moderate ratios from 0.60 to 0.70. Such a strong correlation between hydrogen concentration and the cloud density has an important implication in the discussion of the physical location of hydrogen in diamond. Techniques are currently not available to measure structurally bonded hydrogen quantitatively in diamond (which would allow a basis of comparison), so absolute concentrations of hydrogen in the studied diamonds could not be calculated. The infrared absorption spectrum of the octahedral rough diamond (B) is shown in *Figure 8*. Generally, it shows the same features as sample A, and weaker absorption lines due to hydrogen can also be detected in the range 4000-6000 cm^{-1}.

Discussion

The fact that diamonds with cloud inclusions usually contain substantial amounts of hydrogen has been known for a long time. It was postulated that the bonding sites for hydrogen in diamond would be at internal surfaces such as inclusion-matrix interfaces (Melton and Giardini, 1974, 1975; Woods and Collins, 1983). In a very recent study of clouds and the micro-inclusions in diamonds from southern Africa, Izraeli *et al.* (2001) found that the clouds were composed of silicate, carbonate and brine inclusions. The silicates belong to either the eclogitic or the peridotitic paragenesis, but both are associated with carbonates and brine. We attempted to identify the micro-inclusions in our samples by Raman analysis but failed to get any discernible signal, probably due to the tiny grain size of the micro-inclusions. Since neither carbonate phases nor a CO_2 component were detected in the studied diamonds, micro-inclusions as clouds in

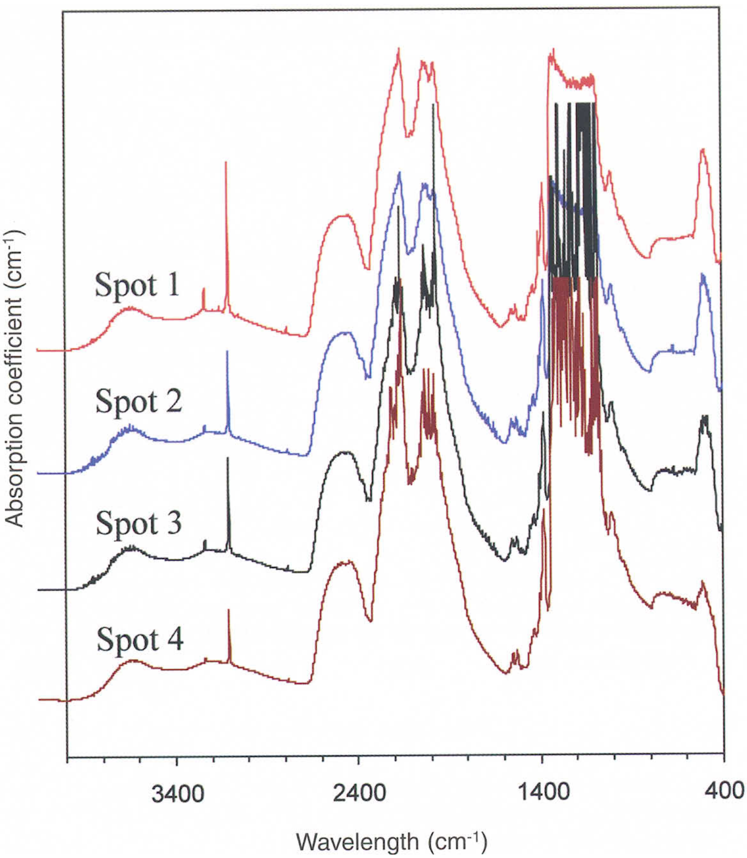

Figure 7: *Infrared spectra of spots 1–4 in sample A. An outstanding feature is the high but varying concentration of hydrogen. Positive correlation between the intensity of the 3107 cm^{-1} peak and the density of the cloud (micro-inclusions) strongly suggests that hydrogen is bonded at the interface of the host diamond and the micro-inclusions.*

diamond could have a wide range of chemical composition.

Although the mineralogy and chemistry of the micro-inclusions in the studied diamonds is unclear, there is no doubt that the observed hydrogen-related absorptions in the mid-infrared range are not from the micro-inclusions themselves. This conclusion is based on the fact that the stretching vibration of H-O in both silicate and oxide phases, some of the most likely candidates as inclusions in diamonds, would appear in the range of 3450-3700 cm^{-1}. This is at a much higher wavenumber than the persistent 3107 cm^{-1} feature observed here and in numerous other analyses by Woods and Collins (1983) and our own unpublished data. Some minerals, like amphibole, could contain significant amounts of constituent hydrogen, but these minerals are not stable within the diamond stability region and thus are rather unlikely to occur as inclusions in diamond. In addition, although sulphides are common inclusions in diamond (Meyer, 1987), no hydroxy-sulphide has ever been reported as an inclusion in diamond.

The positive relationship between the hydrogen concentration and the density of micro-inclusions in diamond, as observed in this study, strongly indicates that micro-

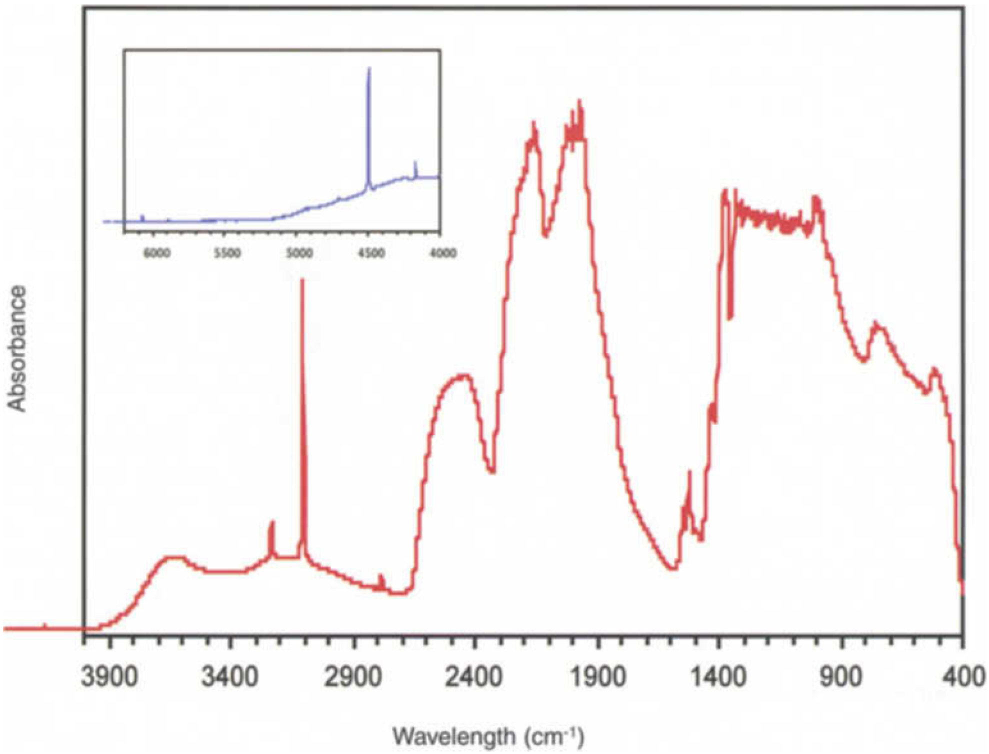

Figure 8: *Infrared spectrum of sample B. It shows strong absorptions of hydrogen at both middle infrared and near infrared (inset) regions. Absorption in the range of 1350 -1000 cm^{-1} is saturated, due to the high concentration of nitrogen (see also sample A, Figure 7).*

inclusions could be an important factor in controlling the incorporation of hydrogen in diamond. Ten diamonds studied by Melton and Giardini (1975) contained mineral inclusions with some evidence of irregular opaque regions at the interface between inclusion and host diamond. They found that the volume of gas (H_2O, H_2, CO_2, CH_4) released from crushing the diamond specimens appeared to be directly related to the number and sizes of the inclusions. They speculated that the gas was released from the interface zone between the inclusions and the host diamond. Similar observations were also indicated in Woods and Collins (1983). The results obtained in the present study more clearly demonstrate the relationship between the intensity of the hydrogen absorption and the density of clouds of micro-inclusions, and thus supports the suspicion that hydrogen is most likely bonded at the interfaces between the diamond matrix and its micro-inclusions (Melton and Giardini, 1974, 1975; Woods and Collins, 1983).

Hydrogen-rich diamonds commonly exhibit greyish or brownish colours (Fritsch and Scarratt, 1993; Fritsch, 1998), and in many cases they exhibit less transparency than those that are H-poor. A possible reason could be the scattering of light by the numerous micro-inclusions. Some of these micro-inclusions are visible under a conventional gemmological microscope, but many are not, due to their extremely small size. Hence, even diamonds that might be graded as flawless may contain some micro-inclusions. It should be noted that not all diamonds with cloud inclusions are necessarily rich in hydrogen. For instance, a diamond described by Mayerson and Reinitz (2000) showed a flower-shaped cloud, but no absorptions related to hydrogen were detected.

A diamond with a 'star/flower' patterned cloud was first reported by Alfred Descloizeaux in 1845, but the formation of this regular pattern was not well understood. As shown in sample B (see *Figure 2a*), the six-petalled cloud originates from the centre of the octahedral crystal. The petals precisely follow the <100> directions, and extend to each of the six corners of the crystal. This spatial orientation is consistent with the flower pattern seen in sample A (see *Figure 1a*). All of the observations of the morphology of the diamonds in this study demonstrate that the growth of clouds (micro-inclusions) in such regular patterns is controlled by the growth of the {100} sector of diamond.

Surface energy, originating from the uncoupled electrons of the outermost layer of carbon atoms at the surface, plays an important role in controlling diamond nucleation. Among all the materials, diamond has the highest surface energy – the property that governs how efficiently new material is added to the surface during crystal growth. The calculated surface energies for a freshly cleaved plane are 5.3 Jm^{-2} for the (111) plane, 6.5 Jm^{-2} for the (110) plane, and as high as 9.2 Jm^{-2} for the (100) plane (Pierson, 1993). This high surface energy allows it to absorb and capture adjacent materials (impurity elements or tiny crystals) efficiently. Originating from a defect such as the inclusion observed in each of the two diamonds in this study, growth of the cloud preferentially follows the <100> direction of diamond due to the extremely high surface energy of the {100} faces. The uncoupled electrons of the carbon atoms at the interface of the diamond with the micro-inclusions could be balanced by absorbing hydrogen atoms and forming a carbon-hydrogen bond, when hydrogen is available. This process may help to explain why hydrogen in diamond is bonded at the interface of the micro-inclusions. A cloud formed in this way will appear as a six-rayed star or flower, when viewed through a (111) face. Since the (111) plane of diamond is extremely difficult to cut and polish, and the polish of both the table facet and the parallel culet of sample A are near-perfect, we believe that these facets are not exactly parallelto the (111) plane, but probably offset by a few degrees.

Diamonds with similarly shaped clouds having the same orientation with the host diamonds have been reported by Humble (1982) and Mitchell (1982). More recently, Koivula (1999) reported on a diamond with a hexagonal cloud of micro-inclusions, which exhibited the shape of a six-rayed star. From the crystal growth viewpoint, these types of patterns may reflect a stable growth environment and/or relatively rapid growth rate. In different conditions, the micro-inclusions would perhaps have aggregated and formed the larger crystal inclusions more commonly observed.

Conclusion

In the two diamonds studied, the hydrogen-related absorption is strongest in regions where the cloud appears to be optically most dense. This supports previous proposals that hydrogen in diamond is physically bonded at internal surfaces such as inclusion-matrix interfaces. Regular and symmetrical patterns of clouds form through crystallographic control of the {100} sector of the host diamond, in which trace hydrogen impurities combined with the high surface energy, may have played a significant role. To form these regular patterns, relatively rapid growth rate of the diamond and a stable mantle environment are necessary.

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Gem mining and sustainable environmental management in Sri Lanka

P.G.R. Dharmaratne

National Gem and Jewellery Authority, Colombo 3, Sri Lanka

ABSTRACT: Various methods of accessing alluvial gem gravels (known as *illama*) in Sri Lanka for the extraction of gemstones, such as open pits, shafts and tunnels, and dredging, are briefly summarized. The methods adopted to minimize environmental damage caused by mining include: introduction of legislation, restriction on types of mining methods permitted, awareness programmes and restoration of mined-out lands. The lessons learned by the Sri Lankan gem industry, with centuries of experience, can be applied to other gem-producing countries.

Introduction

Mining of minerals for the consumption by human beings started many centuries ago and if it were not for minerals and their products, the world would be without many of the material comforts for its population today. For example, life can not be imagined without having metal for machinery and motor vehicles, cement for construction, fuel and minerals for energy production, all of which are products of mining. Gems, though not an essential commodity, on the other hand make life more beautiful and attractive. So it can be said that minerals bring comforts for the body while gems give comfort for the senses and the eye in particular. Since minerals play such an important role in the lives of people, it is the duty of all of us to extract them with the least possible damage to the environment in which we live.

Gem mining

Introduction

Sri Lanka has been identified as one of the earliest sources of gems in the world (Hughes, 1999), and is still a leading producer. Mining activities were not properly organised until the early 1970s; before 1970, gem mining was done haphazardly and different regulations were in force in different districts. With the establishment of the State Gem Corporation, predecessor to the National Gem and Jewellery Authority (NGJA), in 1972 all the activities were brought under one institution and many regional offices were established to issue licences for mining and thereby supervise and minimise the impact on the environment. One of the main objectives of the State Gem Corporation was the development, regulation and control of the gem industry (SGC Act No. 13, 1971).

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Mining increased rapidly with provision of many facilities to gem exporters. While legalised mining reduced the damage to the environment, illicit mining also continued and unlike licensed mining, this caused more extensive damage to the environment.

Mining by means of open pits

A gem-bearing gravel bed occurring on or near the surface is exploited using mammoties and crowbars to excavate open pits most of which are without any support on their side walls. The miner fills bamboo baskets with gravel, and throws them upward to the waiting hands of another man at the pit-head. The method used for bailing out water from the pit depends on the rate of water seepage. It can be done by hand with buckets or by using mechanised water pumps. When the gem-bearing gravel is reached, it is collected separately at the pit-head, and washed in running water in closely woven conical bamboo baskets (*Figure 1*). If there is a shortage of water, material from surface digging can be dry sieved after removing the larger rocks by hand. Only the remaining material needs to be washed to remove dust and clay. With the correct techniques of washing, gemstones can be concentrated at the bottom of the sieve.

The use of bulldozers and scrapers has been allowed in special circumstances such as where very thin gem gravel beds occur, or in areas which have been mined-out by open pits or shafts and tunnels. This machinery is used to remove the overburden, since open-pit mining is no longer economical in such situations.

Mining by shafts and tunnels

The placer deposits of gems (*illama*) and in situ deposits occurring below a certain depth are mined by sinking shafts and excavating tunnels. In Sri Lanka, only placer deposits are mined by sinking pits, but for deeper deposits, recovery of the *illama* by successively deeper pits becomes uneconomical. In such situations, it is

***Figure 1**: Washing of gem gravel using bamboo baskets.*

Figure 2: Typical gem pit, showing timbering and lagging of walls.

common practice to excavate horizontal tunnels at the level of the gem-bearing gravel layer in order to recover gemstones. In small operations through hard ground, the shafts are either round (2 m diameter) or square (2 m sides), but in soft ground (e.g. beneath paddy fields), they are rectangular in section, measuring about 2 × 4 m (*Figure 2*).

The shaft is reinforced with timber crossbeams (from rubber trees) while fern foliage is pushed between the sides of the shaft and vertical struts (arecanut trunks) are driven behind the crossbeams, to prevent the damp sidewalls from caving in. When shafts are 3 – 4 m deep, clay and sand shovelled into small bamboo baskets are manually lifted up to the shaft head. Deeper shafts utilise manually operated winches to lift excavated material and water. As the rate of water flow increases, traditional methods of removing water are replaced by water pumps.

The *illama* is collected separately near the shaft at a place where the ground is specially levelled. The *illama* can be up to a few metres thick, and generally rests directly on decomposed rock (*malawa*) or unweathered rock (*parugala*). Washing the *illama* is done in a nearby stream or in a pond specially constructed for the purpose. The miners stand waist deep in the pond and move the baskets in a circular motion to remove all the lighter materials (*Figure 1*). Washing is continued for about half an hour with more *illama* being intermittently fed into the baskets. During the washing, lighter material collects at the top of the basket and is hand sorted and thrown out of the pond, while the heavy gem-bearing material settles at the bottom of the basket. After washing, the baskets are stacked. Later, an experienced miner collects the gems while sweeping the gravel back and forth by hand.

When the *illama* is at a fairly deep level (>8 m) horizontal tunnels, 1 – 2 m high, are excavated from the bottom of the shaft so that the floor of the tunnel follows or lies on the rock layer underlying the *illama*. As the tunnels are excavated deeper into the

Figure 3: *River dredging by manual methods (courtesy of* Gemstones and their origins *by Peter C. Keller).*

surrounding area, an adequate supply of fresh air and oxygen for breathing as well as for lighting candles, becomes more difficult. In such situations, air pumps are installed to provide fresh air into the mine. The tunnels are supported with timber and crossbeams similar to those of the main shaft. In Sri Lanka, over 60 percent of the mining is done by shafts and tunnels.

River dredging

When the gem-bearing placer deposits occur at the bottom of a shallow river, long-handled mammoties (a type of manual scraper with the blade perpendicular to the handle so that material can be scooped up towards the user) are used to scoop up the gravel (*Figure 3*). To prepare for this process, a brushwood dam is erected at a place where the river slows down naturally, and the water is allowed to escape from one side of the dam. Using long-handled mammoties, the overlying sand and gravel are scooped over the place where water passes through. This procedure is continued until the *illama* is reached. The *illama* is then loosened by using long pointed steel rods and is also scooped into the moving water which removes the lighter and finer minerals, leaving heavy gem minerals behind. Good gemstones can be easily seen and hand picked and the rest of the gravel is washed in the same manner as discussed earlier (*Figure 1*).

In the past, gravel pumps and dredgers could be used to extract the overburden and gem gravel, but they are banned at present because of the damage they cause to river banks.

Environmental management

Causes of environmental damage

Damage to the environment due to gem mining has been discussed by de Silva (1989), Rupasinghe and Cooray (1993) and Dharmaratne (1994).

1. *Damage to land and vegetation cover*

Most damage to land caused by mining activities is due to open-pit methods. In particular, mining for topaz involves moving large volumes of earth to recover gemstones. Illicit miners leave behind large craters and pits, particularly in the forests, which fill with water and become breeding grounds for mosquitoes; this in turn endangers the lives of people and animals.

Tree trunks are used to support the walls and roofs of shafts and tunnels and the flow of earth into the workings is prevented by lagging with a variety of fern (*kekilla*). This fern has strong roots which bind the soil and prevent erosion. Large areas of fern cover are harvested annually to support many thousands of gem pits, and consequently, during the monsoon rains heavy erosion occurs in these areas.

2. *Damage to plantations*

   When near-surface gem deposits are discovered in plantations of tea, rubber, coconut or pepper, mining is carried out without any consideration or respect for the trees. Valuable trees are either removed deliberately or fall down due to excavation. The loss of good plantations, damages the national economy.

3. *Damage to rivers and river banks*

   Gem mining in rivers and streams is allowed by the NGJA only because of the uncontrollable nature of illicit mining. Illicit miners not only dredge the river bottom but also damage river banks by undercutting. Their operations may take place by day and by night. During dredging, fine clay particles can be released into suspension in the water and cause the death of river species; they can also prevent use of the water for bathing and drinking. Furthermore, the sedimentation of waterways and dams reduces the efficiency of hydroelectric power plants.

4. *Damage to buildings and properties*

   Tunnelling under roads, buildings, canals, culverts and other structures can cause untold damage. There are many instances of land owners literally undermining their own properties, because it is sometimes worth the risk of forgoing a property in the hope of recovering high-value gemstones.

Legislature

The State Gem Corporation Act No. 13 of 1971 was repealed in 1993 and the National Gem and Jewellery Authority Act No. 50 of 1993 came into effect with regard to the gem and jewellery industry. The Act states (p. 48) that:

> 'No person shall carry-on the gem industry except under the authority of a licence issued by the Authority and every person who commits an offence under this Act shall on conviction after a trial before a magistrate, be liable to a fine not exceeding one million rupees or to imprisonment for a period not exceeding five years or to both such fine and imprisonment.'

The NGJA can, with the consent of the relevant parties, having regard to the circumstances in which any offence under this act was committed, compound such offence for a sum of not exceeding one-third the maximum fine imposable.

The regulations in respect of the gem and jewellery industry were gazetted in 1972. Accordingly a licence for mining for gems is issued under the following conditions:

1. The land owner/co-owners should give consent in writing to the prospective licensee.

2. If the land in question is cultivated; the consent of the cultivator too should be obtained if he is not the owner of the land.

3. In the case of cultivated land the consent of the regional office of the Agrarian Services Department (ASD) should be obtained and the ASD takes a security deposit for each pit to ensure that the licensee restores the land after mining. The NGJA also takes a security deposit for each pit to ensure that the pits are closed, as it is the responsibility of the NGJA to

restore lands after mining. In the case of river dredging, substantial security deposits are required by the NGJA for the possible work involved is much larger than that for restoration of mining damage on high ground.

4. In mining cultivated land and rivers, water pumps are the only machinery allowed. Backhoes are permitted only in special circumstances and only with a very large security deposit since the excavations created are much larger than in normal pit mining.

Control of illicit gem mining

Raids are conducted with the assistance of the police to enforce the regulations and to apprehend offenders, because sometimes illicit gem miners attack unarmed field officers. There have been occasions in the past when even armed police have been the victims of illicit gem miners who sometimes flock in their thousands to new gem deposits discovered near the surface. The police have the authority to conduct their own raids and on such occasions, offenders are brought before a court of justice and due punishments are given.

Illicit mining in State lands, rivers and roads, or their reservations, is treated very seriously and the punishments are high compared with those for illicit mining on private land. Roads, rivers and their reservations, which comprise about 10 metres on each side of the road or river, belong to the government, and construction or excavation is not allowed in the reservations in order to safeguard these routes. If, for example, a water pump is seized on private land, it may be released with a fine of Rs 2500 (about US$25), whereas if the same pump were seized in one of the above-mentioned locations, the fine may be a third of the value of the pump if it is a first offence, two-thirds of the value if the offence is repeated and on a third offence the pump is forfeited to the State. Water pumps are the most common machines used in gem

Figure 4: *Conducting awareness programmes to reduce the environmental damage caused by improper mining practices.*

Figure 5: Restoration of river banks by planting trees after the damage caused by river dredging (the river is on the left).

mining, and although gravel pumps, bulldozers and scrapers are rarely used, they too can be seized if used illicitly. This practice has been in operation for many years. However it has now been found that it is not a sufficient deterrent and therefore action has been taken to increase the severity of the punishment and to seize the machinery on the first offence. This is done particularly to discourage the use of gravel pumps in rivers and bulldozers and scrapers in large scale excavations in illicit mines.

Restoration of mined-out lands

The security deposits kept at the NGJA are released only if the pits are closed and the lands are restored in a fit state for cultivation. Most often, when the value of gemstones found is very high, miners ignore the need to close pits and reclaim the land. The NGJA has established a rehabilitation fund with the money from those unclaimed deposits. During the recent past this fund has financed the following activities:

1. Conducting seminars for the gem mining community to educate them in environmentally friendly mining methods and restoration of lands (*Figure 4*).
2. Restoration of river banks by erecting brushwood dams along the original river boundary and filling the excavated area behind it; also planting suitable trees along the river banks (*Figure 5*).
3. Restoration of mined-out land by using bulldozers and scrapers and planting trees (*Figure 6*).

Conclusions

Mining by any method and for any mineral causes environmental damage and the only action that can be taken is to ensure that the damage is minimized. In the case of gem mining in Sri Lanka, many hundreds of thousands of people are engaged in gem mining, with or without a licence from the NGJA. While the damage to the environment

***Figure 6**: Restoration of mined-out land by (a) filling pits and (b) planting coconut and mango trees.*

by legalised mining is minimal, the greatest harm comes from illicit mining and results in unfilled pits, soil heaps and pollution of waterways.

Illicit gem mining is not a problem specific to Sri Lanka, but one faced by all gem-producing countries. The discoveries of near surface deposits have caused gem rushes involving thousands of people in Sri Lanka, Madagascar, Tanzania, Brazil and in many other countries. Licensed mining can be supervised and strict rules can be enforced to reduce the environmental degradation. The field officers of the NGJA with the assistance of police make every effort to stop illicit mining, but the nature of such operations and the number of people involved prevent its complete eradication. The damage that illicit mining causes is offset to some extent by a rehabilitation fund established by the NGJA which is used to restore mined-out lands.

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Gem-quality chondrodite from Balangoda, Sri Lanka

J.C. (Hanco) Zwaan[1] and G. Zoysa[2]

1. *National Museum of Natural History, Leiden, the Netherlands*

2. *Mount Lavinia, Sri Lanka*

ABSTRACT: Chondrodite, a humite group mineral, has only rarely been described before as a gemstone. It has been found as small orange-brown crystal fragments in dolomitic limestone, near Balangoda, in Sri Lanka. Until now, only a few stones have been cut, in sizes up to 3 ct. The properties of this mineral are very close to the properties of clinohumite, which is rare and a collector's stone, known since the mid-1980s.

Keywords: Balangoda, chondrodite, gemmological properties, Sri Lanka

Introduction

Chondrodite is a member of the humite group, together with norbergite, humite and clinohumite. The general chemical formula of the group is $nM_2SiO_4.M(OH,F)_2$, where n = 1, 2, 3, 4 for norbergite, chondrodite, humite and clinohumite respectively. M is Mg, Fe^{2+}, Mn, Ti, Zn, etc. (Deer *et al.*, 1982). The chemical formula of monoclinic chondrodite is $2Mg_2SiO_4.\ Mg(OH,F)_2$.

The hardness is 6.5 on the Mohs' scale, which is slightly higher than the hardness of clinohumite. {100} cleavage is poor, sometimes distinct, and {100} twinning is common. According to Deer *et al.* (1982) the refractive indices are n_α = 1.592–1.617, n_β = 1.602–1.635, n_γ = 1.621–1.646. The birefringence varies between 0.028 and 0.034. Specific gravity ranges from 3.16 to 3.26. Known colours are yellow, brown, red and grey.

Until now, among the humite group minerals, only clinohumite has seriously been described as a gemstone (see e.g. Fryer, 1986; Hurwit, 1988; Henn *et al.*, 2001; Hyrsl, 2001). Known localities are Mahenge in Tanzania, the Pamir mountains of Tajikistan, and the Taymyr region, northern Siberia.

Only Webster (1962), Pough (1965) and O'Donoghue (1988) mentioned chondrodite as gemmy material from the Tilly Foster Mine, near Brewster, New York. The red-brown crystals contain gemmy parts, though dark in colour, and are suitable only for the cutting of rather small stones. Webster (1962) also mentioned Pargas and Kafveltorp in Sweden, as potential sources, but Pough (1965) disregarded these localities, because the crystals are a greyish and rather unattractive brown, with only 'a suggestion of clarity'.

The chondrodite fragments that were discovered in Balangoda (6° 40' N, 80° 44' E), about 20 miles E of Ratnapura, Sri Lanka, are orange-brown, and look very similar to the described clinohumite from other sources. It may therefore not come as a surprise that at first, these crystal fragments were presented to us as 'clinohumite' from a new occurrence in Sri Lanka. They are found in a quarry, in which dolomite is the main rock type. Chondrodite crystal fragments are found in

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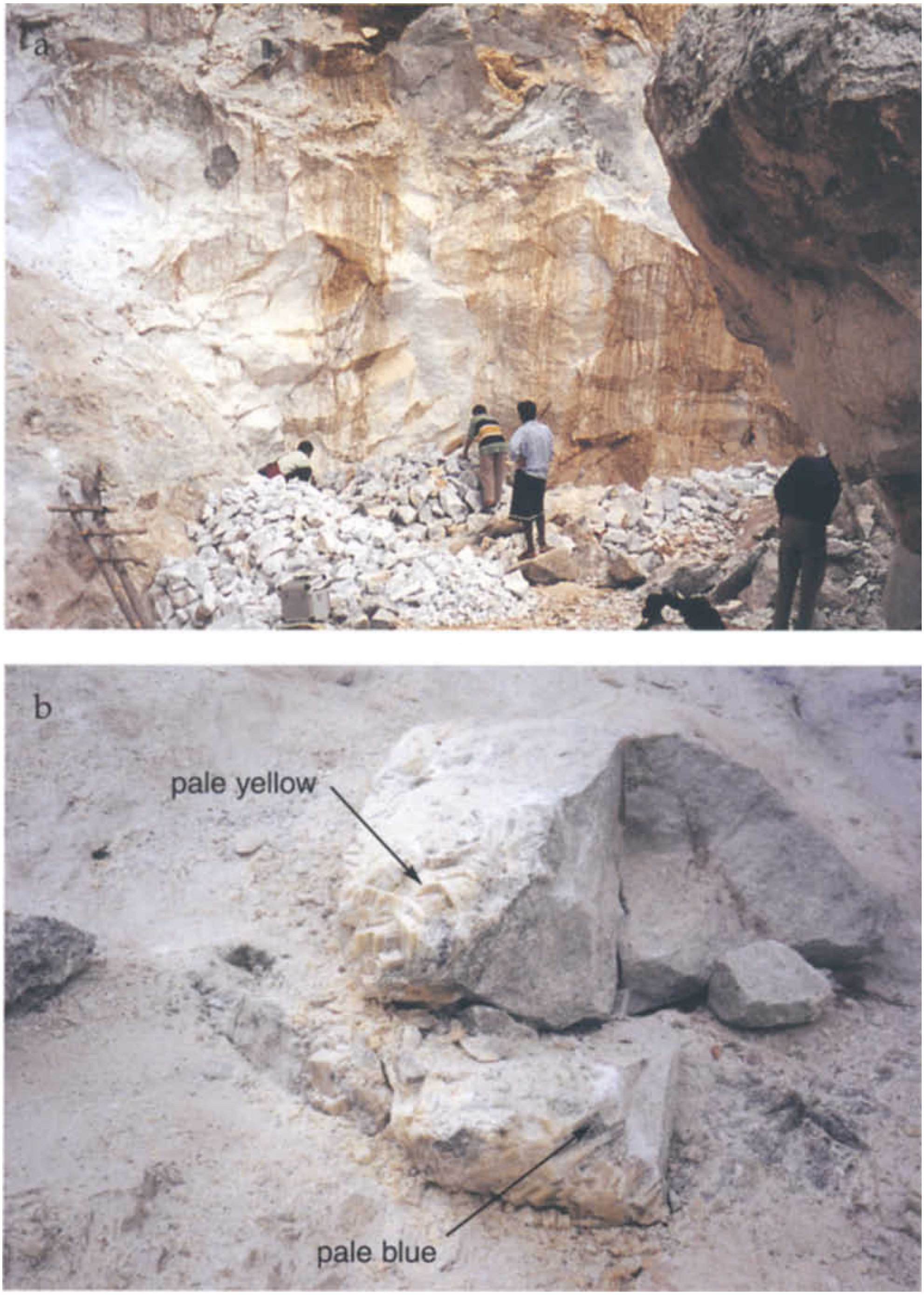

Figure 1: *(a) Dolomite quarry, near Balangoda, Sri Lanka, produces gem-quality chondrodite. (b) Chondrodite fragments are found in pale blue and pale yellow calcite veins, which are present in dolomite.*

pale blue and pale yellow calcite veins, which are present in the dolomite (*Figure 1*).

The dolomitic marble in which chondrodite has been found is part of the Highland Complex: an intimate association of interbanded ortho- and paragniesses including pelitic gneiss, metaquartzite, marble and charnockitic gneiss, which forms the broad belt of rocks extending from northeast to southwest through the central highlands of the island. Limestones and dolomites (among other sediments) are thought to be deposited 2.0 Ga ago (Cooray, 1994). Intrusion of granitoids in the area took place at 1.8 to 1.9 Ga ago, after which high grade regional metamorphism turned the dolomites into dolomitic marble, between 550 and 610 Ma ago.

So far, only a small number of stones have been polished. Cleaner stones up to 0.5 carats are faceted, while stones up to 3 ct are cut 'en cabochon'.

Table I: *Physical properties of gem-quality chondrodite from Balangoda, Sri Lanka.*

Colour:	orange-brown
Transparency:	transparent to translucent
Cleavage:	distinct
Refractive indices:	1. 1.609 – 1.636 2. 1.610 – 1.638 3. 1.612 – 1.639
Birefringence:	0.027 – 0.028
Specific gravity:	3.17 – 3.22
Dominant pleochroic colours:	orange-brown and yellow-brown
Fluorescence:	Inert to long- and short-wave ultraviolet radiation.

Figure 2: *One of the investigated gem-quality chondrodite crystal fragments from Balangoda, Sri Lanka, weighing 1.24 ct.*

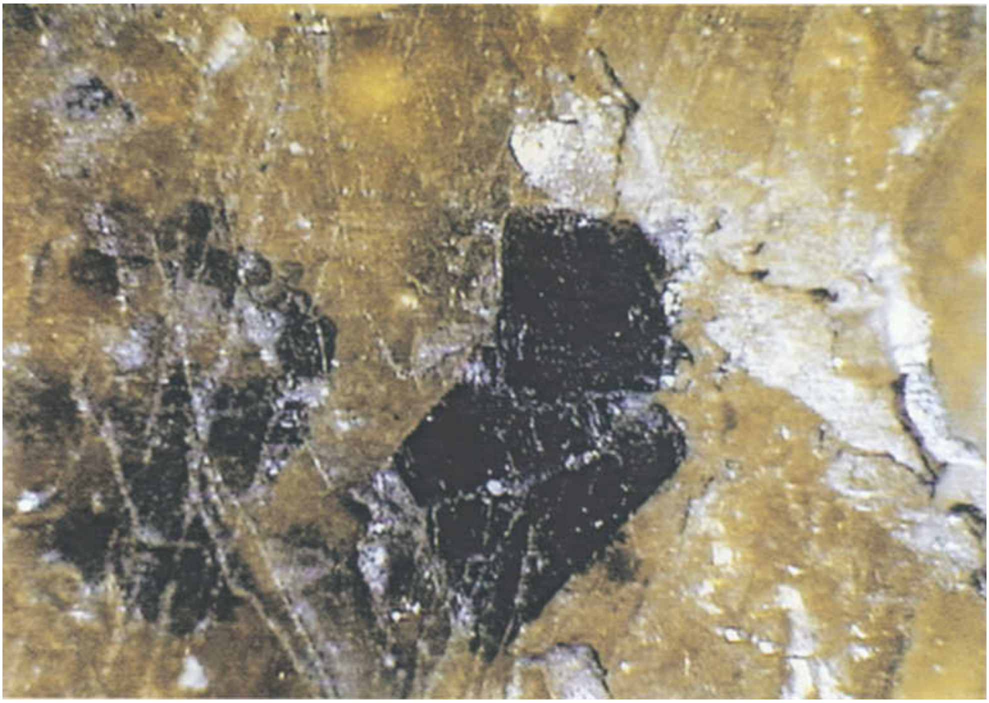

Figure 3: Spinel octahedra (dark) at the surface of chondrodite. Spinel crystals are common inclusions in chondrodite from Balangoda, Sri Lanka. Width of view: 4 mm.

Materials and methods

Three crystal fragments (*Figure 2*) were studied; the gemmological properties were measured, using standard gemmological equipment. After preliminary investigations using Energy Dispersive X-ray Fluorescence (EDXRF), chemical analyses were carried out with EPMA (Electron Probe Micro Analysis, JEOL model JXA-8800M). EPMA analyses were performed at the Faculty of Earth Sciences, Vrije Universiteit, Amsterdam.

Physical properties

The measured physical properties are presented in *Table I*. As the fragments were presented to us as 'clinohumite', it is immediately apparent that the refractive indices are much too low for that mineral (cf. the range of 1.63–1.67 reported by Henn *et al.*, 2001).

Chemical analysis

After preliminary investigation of each crystal fragment with micro-EDXRF, it became clear that this method poses some problems in obtaining satisfactory analyses. EDXRF can be considered as a standard instrumental technique that is used by many gemmological laboratories to get (semi-) quantitative analyses of gemstones, but in this case, the technique is not suitable for two reasons: the fluorine content is significant but cannot be measured, and an unusual content of copper (more than 0.05 wt%) was found. It could not be decided from the EDXRF analyses whether this copper is due to contamination or really is within the lattice of the analysed mineral. In order to find more reliable answers it was necessary to do further and detailed EPMA analysis on one crystal fragment.

The electron microprobe analyses are presented in *Table II*.

Table II: Electron probe spot analyses of chondrodite from Balangoda, Sri Lanka.

Oxides (wt.%)	1	2	3	4	5	Average
SiO_2	34.2	34.8	34.3	34.6	34.5	34.5
TiO_2	0.43	0.42	0.49	0.44	0.44	0.45
Al_2O_3	0.03	0.02	0.02	0.02	0.02	0.02
FeO	0.90	0.85	0.93	0.88	0.89	0.89
MnO	-	-	-	0.02	0.02	0.01
MgO	56.0	56.3	55.8	55.9	55.9	56.0
CaO	0.04	0.03	0.02	0.03	0.02	0.03
Na_2O	0.02	0.02	0.01	0.01	0.03	0.02
K_2O	0.02	0.02	0.02	0.03	0.02	0.02
F (a)	5.47	5.61	5.37	5.31	5.38	5.43
Cl	-	-	-	-	-	-
	97.11	98.07	96.96	97.24	97.22	97.37
-O = F	2.30	2.36	2.26	2.24	2.27	2.29
Total (a)	94.81	95.71	94.70	95.00	94.95	95.08
H_2O (b)	2.52	2.51	2.56	2.60	2.57	2.55
Numbers of ions on the basis of 10 (O, OH, F)						
Si^{4+}	2.008	2.021	2.012	2.023	2.018	2.017
Ti^{4+}	0.019	0.018	0.022	0.019	0.019	0.020
Al^{3+}	0.002	0.001	0.001	0.001	0.001	0.001
Fe^{2+}	0.044	0.041	0.046	0.043	0.044	0.044
Mn^{2+}	0.000	0.000	0.000	0.001	0.001	0.000
Mg^{2+}	4.894	4.875	4.881	4.867	4.875	4.878
Ca^{2+}	0.002	0.002	0.001	0.002	0.001	0.002
Na^+	0.003	0.002	0.002	0.001	0.003	0.002
K^+	0.002	0.002	0.002	0.002	0.001	0.002
Number of cations	6.974	6.962	6.967	6.959	6.963	6.966
F^-	1.015	1.029	0.996	0.981	0.997	1.003
OH^-	0.985	0.971	1.004	1.019	1.003	0.997

- not detected
(a) low totals are due to conductivity which was not optimal
(b) calculated

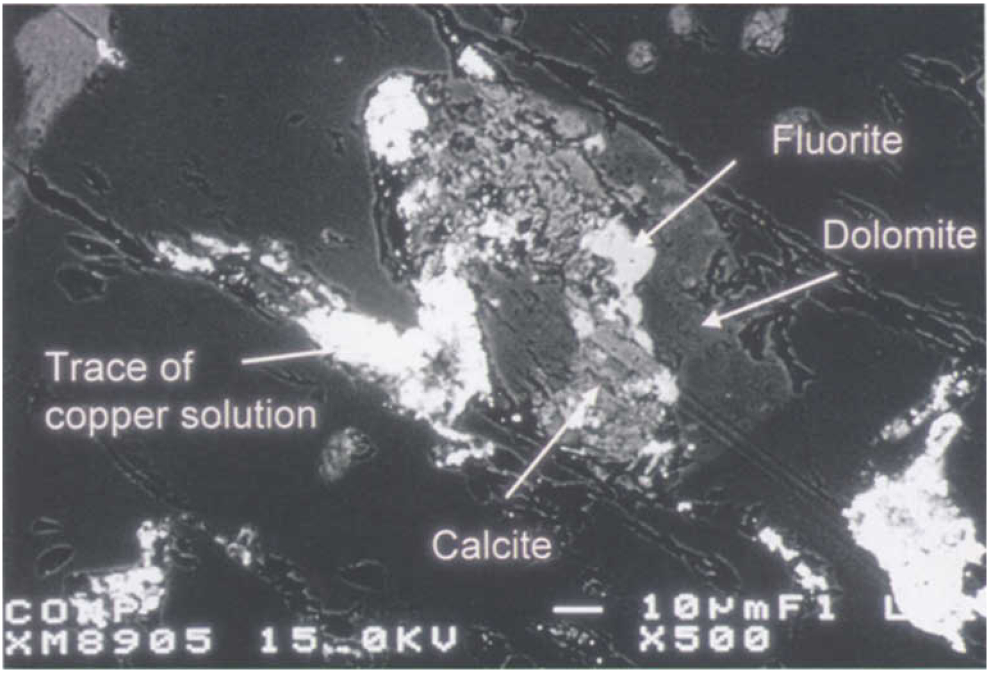

Figure 4: *Electronphotomicrograph, showing the presence of small fluorite, calcite and dolomite inclusions in chondrodite, indicating the dolomitic marble environment, in which chondrodite was found. Traces of a dried-up copper iodide/iodate and/or sulphate solution are present on the surface and in cracks.*

Internal features

The crystal fragments that were investigated contain many dark grey to grey-green crystal inclusions, octahedral shapes, as well as rounded crystals (*Figure 3*). Qualitative analyses of a few crystal inclusions at the surface confirmed that this cubic mineral is spinel ($MgAl_2O_4$), which only shows a trace of iron. Other relatively small inclusions that were identified are fluorite, Mg-bearing calcite and dolomite (*Figure 4*).

Discussion

It is difficult to distinguish the humite group minerals optically. Although the refractive indices (and specific gravities) increase progressively from norbergite to clinohumite, they show considerable overlap.

However, the refractive indices of the crystal fragments (*Table I*) are clearly within the field of either chondrodite or humite and substantially lower than the values known for clinohumite (Deer *et al.*, 1982, report RIs between 1.628 and 1.674, birefringence 0.028-0.041, and SGs between 3.17 and 3.35, for clinohumite). The SGs are in line with chondrodite, but appear too low for humite. Distinct cleavage can only occur in chondrodite. Humite and clinohumite both show poor cleavage. The presence of twinning is common in chondrodite, whereas it is absent in humite. In the crystal fragments, twinning was difficult to recognize, because the material could not properly be observed in the right direction. However, in thin sections made of one crystal, the presence of twinning was confirmed. Chondrodite from Balangoda can be distinguished from the described gem quality clinohumite from other sources by short-wave ultraviolet radiation. Chondrodite is inert under SW-UV, whereas clinohumite shows a moderate to strong orangey-yellow fluorescence (compare Fryer, 1986; Hurwit, 1988; Henn *et al.*, 2001; Hyrsl, 2001).

The chemistry indicates Mg/Si ratios of 2.43 to 2.46 (average 2.44), which indicates chondrodite. Theoretically chondrodite has a Mg/Si ratio of 5/2 = 2.50, whereas clinohumite has Mg/Si = 2.25 and humite Mg/Si = 2.33. The chondrodite analysed, contains little iron (0.89 wt%), at the lower end of the range 0.4–7.3 wt% FeO reported by Jones *et al.* (1969). The fluorine content is substantial, which is normal for chondrodite. It always shows a great degree of fluorine replacement of hydroxyl. The average F/(F+ Cl + OH) ratio is slightly above 0.50, which is near-average compared to the ratios of 0.34–0.94 in chondrodites from other occurrences (Kearns *et al.*, 1980). The high fluorine content is consistent with the low iron content: in general, the replacement of (OH) by F decreases, when the replacement of Mg by Fe increases (Deer *et al.*, 1982).

The indicated presence of copper by EDXRF turned out to be a contamination problem. With EPMA, it was discovered that traces of a dried-up copper iodide/iodate and/ or sulphate solution are present on the surface and in cracks (*Figure 4*). Thus copper was not found in the chondrodite itself. This is consistent with the results of Jones *et al.* (1969), who found that Al, as well as P, Cl, Cr, Co, Ni, Cu and Pb, were not individually detected at the 0.05 wt.% level, in humite group minerals.

Conclusions

Until now, chondrodite has only rarely been described as a possible gemstone. Gem-quality chondrodite from Balangoda, Sri Lanka, is extremely rare, and as at mid-2002 only a few stones have been polished. Compared to clinohumite, another mineral of the humite group, which has been cut and polished as a gemstone, chondrodite is characterised by low refractive indices, birefringence and specific gravity. It also is inert under short-wave UV, whereas gem-quality clinohumite shows an orangey-yellow fluorescence. Typical inclusions of chondrodite from Balangoda, are grey green spinel crystals. The chondrodite shows a low iron content and contains a substantial amount of fluorine.

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Light emitting diodes as light sources in portable gemmological instruments

Claude Lamarre

Lasalle, Quebec, Canada. lamart@hotmail.com

ABSTRACT: Light emitting diodes (LEDs) can be used as light sources substituting for incandescent light bulbs in portable battery-operated gemmological instruments. They are small, have an average life span in excess of 100 000 hours, are bright and are cold as they produce light by luminescence. This article reviews a 590 nm (yellow) and a white LED used as sources in a polariscope and refractometer and a blue 472 nm light source used with a red filter (cross-filter apparatus) to observe red fluorescence in a Cr-bearing gem material.

Keywords: Battery-operated, colour change, cross-filter apparatus, light emitting diode, polariscope

Introduction

What are light emitting diodes (LEDs)?

LEDs essentially consist of a PN junction specifically designed to emit light when forward biased. They are solid state lamps and various types are available that can emit light ranging from ultraviolet (370 nm) to infrared (950 nm). Although LEDs have been around commercially since the late 1960s, it is only during this past decade that blue, white and UV light emitting diodes have made their appearance. Over the years the brightness of these devices has improved to a level that allows their use as traffic lights and other full colour displays that can be seen in broad daylight.

LEDs emit light by luminescence and a schematic diagram of an LED is shown in *Figure 1*. When the charge carriers within the semiconductor PN junction – the electrons and holes – recombine with one another, electrons are transferred from the conduction band to the valency levels with consequent release of energy. This release of energy and its wavelength(s) depend on the materials forming the semiconductor. The outside energy source is the electric current applied to forward bias the device.

LEDs are current-operated devices in contrast to incandescent light bulbs which are voltage-operated. Electric current is a flow of electrons in a circuit while voltage is a potential difference applied to an electrical circuit to produce a current flow. In the average current-regulated LED system, the electronic control circuit supplies a constant current (of about 20 milliampere) to the LED over a wide range of voltage. A basic

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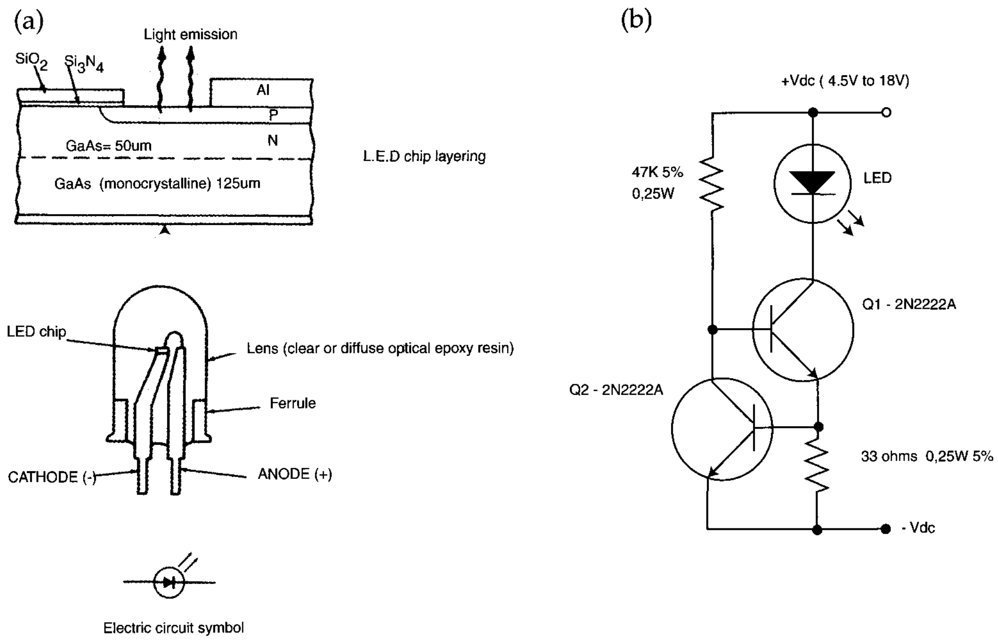

Figure 1: *(a) Schematic diagram of an LED and its chip construction; the ferrule is not present in all LEDs. (b) Basic constant current source (18 ma) appropriate for LEDs.*

constant current source (18 ma) appropriate for LEDs is shown in *Figure 1b*. Therefore, current-regulated LEDs with an electronic control circuit can be run by a range of portable batteries and will provide optimum brightness over the whole life span of the battery.

LEDs provide non-coherent ordinary light sources and are near monochromatic in nature. Visible colour LEDs available are red, orange, yellow, green, blue-green and blue. There are also LEDs that produce white light in a way similar to that produced by a fluorescent tube. These are blue LEDs with their junction coated with YAG which is fluorescent: the blue emission stimulates the YAG coating to produce fluorescent white light.

Most LEDs have a spectral bandwidth of about 35 nm. The colours most useful to the gemmologist are the 590 nm yellow, the 472 nm blue and the white LED. The 370 nm UV LED produces no visible light and can be used as a LWUV source. LEDs have many advantages over incandescent light sources: they are rugged, do not possess a filament that can break under shock and produce no noticeable heat under normal conditions. Their life span of over 100 000 hours far exceeds that of any incandescent bulb, and their low current consumption compared with incandescent bulbs make them a natural choice for portable battery-operated equipment. LEDs can also be pulsed, their rise and fall time being measured in nanoseconds. They are encapsulated in clear or diffuse optical epoxy resin terminated by a lens with two electrodes protruding for electrical connection. A typical diameter is 5 mm.

An instrument performing the functions of a portable polariscope, refractometer light sources and a cross-filter apparatus using LEDs has been designed by the author and the configurations are shown in *Figures 2, 3* and *4*. Power is supplied by battery or by the mains via an AC/DC transformer. Suitable LEDs are supplied by Agilent Technology Inc. (www.agilent.com). UV LEDs are supplied by Roithner Lasertechnik of Austria (www.roithner-laser.com).

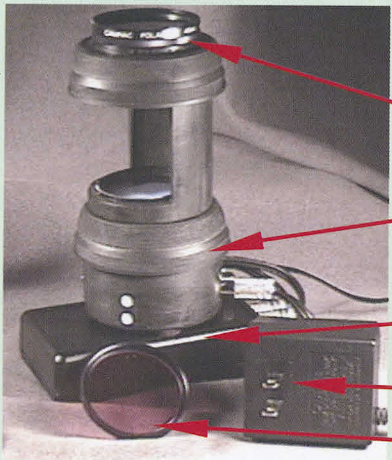

Figure 2: Portable polariscope with LED illuminator unit.

Analyser

Polariser / diffuser / illuminator module

Electronic control module

AC / DC transformer

Photographic red filter R2

Figure 3: Refractometer illuminator with white and yellow sources.

Polariser / diffuser / illuminator module

White LED source

Yellow 590nm LED source

Figure 4: Apparatus set up for cross-filter work with blue LED illuminator and red filter.

Red photographic filter

Specimen chamber (50mm diameter x 75mm height) (Will accomodate a standard immersion cell)

Blue LED illuminator

Electronic control circuit

Use of white and yellow light emitting diodes

The white light produced by fluorescence in LEDs has a general spectral distribution somewhat similar to that of fluorescent tubes but without the sharp emission lines that the tubes produce. Through an OPL spectroscope the LEDs show a broad peak in the blue and a rather smooth continuous spectrum from red to violet. They are very useful for the detection of colour-change gems such as alexandrite or colour-change garnets. Used as a light source in the polariscope unit (see *Figure 2*) they are also useful in parallel filter configuration, to observe pleochroic colours. Compared to a standard incandescent light in a bench polariscope, the colours displayed are easier to distinguish and truer. In addition, the polariser does not heat up during use so the unit can be left on for extended periods without risk of damaging the filter or the lamp – a major advantage for use in the classroom.

The yellow LED with a peak at 590 nm constitutes an excellent near-monochromatic light source for the refractometer (see *Figure 3*). This application of an LED was first reported by Read (1980, p. 82-4) and was the first ever application of LEDs to gemmological instruments.

The white LED can also be used with the refractometer for distant vision readings or for locating the colour fringe prior to using the yellow source.

Use of blue light emitting diodes

Owing to their near monochromatic emission, coloured light emitting diodes can be used instead of colour filters in the observation of internal growth features. One example is the use of a blue LED to examine polysynthetic twinning in yellow chrysoberyl. Other colours of LEDs may show useful effects and are currently being investigated.

Another use of the blue LED is in combination with a red filter as a crossed filter configuration to observe fluorescence (see *Figure 4*). When a chromium-bearing gem is placed between the blue source and the red filter, a red fluorescence can generally be observed. A yellow filter can be substituted for observation of apricot-yellow fluorescence in natural unheated yellow sapphire from Sri Lanka. However, the main reason for building such an apparatus was for a classroom demonstration to investigate the reddish fluorescence of natural-colour black pearls. Over 200 specimens of Tahitian black cultured pearls were tested for fluorescence but none was observed; however, further investigation will be needed as it is possible that the intensity of the LED is insufficient to have produced any noticeable effect.

An interesting effect is observed when chromium-bearing pyrope, which is non-fluorescent, is illuminated by the blue LED against a white background: its colour changes to blue-green, while most other red gems that do not contain chromium show a darker red (*Figure 5d*). The reason for this phenomenon is simple: chromium-bearing gems all have a broad absorption band in the yellow area of the spectrum and absorption of the violet up to the blue region of the spectrum. They transmit freely the red and green wavelengths. The blue LEDs emit light at peak intensity around 472 nm. Emission diminishes rapidly on each side of the 472 nm peak (*Figure 5b*). The human eye is most sensitive to the green portion of the spectrum (*Figure 5a*). So in red chromium-bearing non-fluorescent gems illuminated with a blue LED, too little red is being emitted by the LED and since all the yellow is absorbed by the gem this leaves only the blue and green wavelengths from the source to be freely transmitted from the gem to the eye and brain of the observer; the gem therefore appears blue-green (*Figure 5c*).

Conclusions

Modern light emitting diodes are very useful as a source of illumination in gemmological instruments. Their advantages over incandescent light bulbs

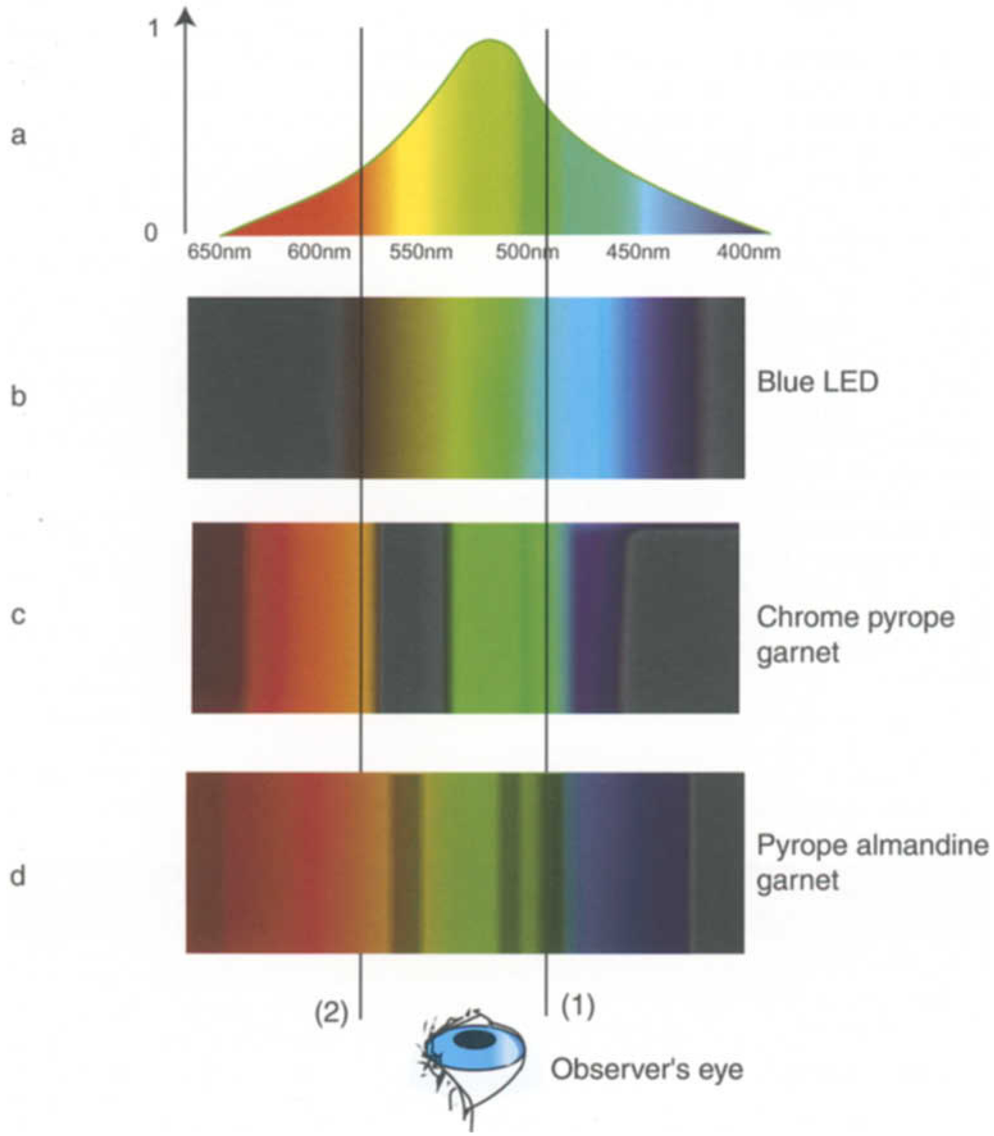

Figure 5: *(a) Spectral sensitivity of the average human eye.*

(b) Diffraction grating spectrum of blue LED with maximum emission at 472 nm.

(c) Chrome pyrope garnet spectrum (diffraction grating); the garnet is seen as blue-green in the blue LED illumination (1).

(d) Pyrope almandine garnet spectrum (diffraction grating); the garnet is seen as darker red in the blue LED illumination (2).

include their small size and cold operation, and their brightness and low power consumption make them ideal for portable battery operation and classroom / laboratory instruments. Many instruments can be combined in one compact unit that can be operated in the field as well as in the laboratory giving more flexibility to the gemmologist.

LEDs with a peak wavelength of 370 nm and no emission of visible light are potentially useful as a portable LWUV source and their use is being explored.

Acknowledgements

The author is grateful to Odile Civitello GG FGA of Montreal, Canada, Director of Ecole de Gemmologie de Montréal, for access to gem testing facilities and loan of specimens, to Maureen DeCelles of Montreal, Canada, for the loan of specimens and to François Longère F.C.gma of Montreal, Canada, for the loan of black natural-colour Tahitian cultured pearls.

Reference

Read, P.G., 1980. Two reports: (1) Alternative refractometer light sources: (2) Thermal diamond probes. *Journal of Gemmology* **17**(2), 82-94

Abstracts

Diamonds | Instruments and Techniques | Gems and Minerals

Diamonds

Diamanten im Amazonasgebiet.

M.L. Da Costa and H. Höhn. *Aufschluss*, **53**, 2002, 6-18.

The geology and mineralogy of diamond deposits in the Brazilian state of Amazonas are discussed with notes on mining methods and on the crystals recovered.

M.O'D

Characteristics of nitrogen and other impurities in diamond, as revealed by infrared absorption data.

F.V. Kaminsky and G.K. Khachatryan. *Can. Min.* **39**(6), 2001, 1733-45.

Diamond crystals from Siberian, Arkhangelsk, South African, Canadian and South American deposits were analysed for structurally bound nitrogen, hydrogen and 'platelet' defects using IR absorption spectroscopy. Wide variations in total nitrogen and hydrogen contents and in the state of nitrogen aggregation were established from different areas and deposits. On this basis, three groups were distinguished: (1) low-nitrogen, highly aggregated-nitrogen diamond, (2) intermediate diamond crystals and (3) high-nitrogen, poorly-aggregated-nitrogen diamond (occasionally with high contents of hydrogen and 'platelets'). These represent, in general terms, three major stages of diamond formation: (1) the initial stage at high *P–T* conditions, which occasionally occur in super-deep areas (e.g. lower mantle and transition zone, (2) the main stage and (3) the final stage, which represents the latest episodes of magmatic evolution and is characterized by high oversaturation of the crystallization medium and high internal *T*-gradients. These data may be used for 'fingerprinting' diamonds, in prospecting for new deposits in diamondiferous areas and in the evaluation of diamond crystals from newly discovered deposits.

R.A.H.

Post-eruptive processes in kimberlites – implications for diamond exploration.

K. Leahy. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, **110**(1), 2001, 1-4.

Deposits of primary diamond ore (kimberlite and less commonly, lamproite volcanic and intrusive rocks) are rare, and even in highly prospective terrains geochemical and geophysical techniques are required to help locate these tiny volcanic targets. The environmentduring eruption and more importantly, the environments to which the diamond-bearing volcanic material has been subjected since eruption, determine the response of the targets to these techniques. Post-eruptionprocesses within (serpentinization) and beyond (erosion) the crater are outlined, and the Fort à la Corne kimberlite field in western Canada is used as an example. The consequences for exploration of groundwater and sea-water levels, and uplift and climate are presented.

J.F.

Abundance and composition of mineral inclusions in large diamonds from Yakutia.

N.V. Sobolev, E.S. Efimova, A.M. Logvinova, O.V. Sukhodol'skaya and Yu.P. Solodova. *Doklady Earth Sciences*, **376**(1), 2001, 34-8 (English translation).

The abundance of inclusions in 2334 diamonds from the Mir, Udachnaya and Aikhal kimberlite pipes is presented. Chromite, garnet and olivine inclusions are abundant and EPMA results for garnet and chromite are given. The results indicate that the inclusion assemblages are similar in diamonds of varying size from the same pipe. Sulphide inclusions are predominant only in large diamonds from the Mir pipe.

A.M.C.

Gems and Minerals

The Barra de Salinas pegmatites, Minas Gerais, Brazil.

F.M. Bastos. *Mineralogical Record*, **33**, 2002, 209-16.

Fine gem-quality crystals of tourmaline are among the minerals to be found at the Barra de Salinas pegmatite, Minas Gerais, Brazil. The pegmatites have been worked since the 16th century. Maps and a mining history are included as well as colour photographs.

M.O'D.

Abstractors

A.M.Clark	A.M.C.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
J. Flinders	J.F.	M. O'Donoghue	M.O'D.	E. Stern	E.S.

For further information on many of the topics referred to, consult Mineralogical Abstracts

 ISSN: 1355-4565

Rare Australian gemstones - The Springsure deposit of precious opal.

R. BEATTIE. *Australian Gemmologist*, **21**(5), 2002, 207-10.

While the Springsure deposit of precious opal represents Queensland's first discovered source of volcanic opal, and is capable of producing occasional gem quality specimens, this opal's tendency to dehydrate and crack after mining and exposure to ambient atmospheric conditions limits its commercial potential. P.G.R.

North Queensland mabé pearls.

G. BROWN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001, 193-108. 1 map, 5 photographs, bibl.

Bead nucleated half pearls are being cultivated in the bivalve *Pteria* (*penguin* or blackwing) shell in the tropical reef waters off Orpheus Island, North Queensland. The valves of these molluscs are lined with silver aragonitic nacre from its hinge outward towards an intermediary arc of gold to brown aragonite nacre and a rim of calcite nacre. Polymer hemispheres of various sizes are glued to the inner surfaces of the valves of one year old *P. penguin* shells. Eighteen months later the molluscs are harvested and the half pearls cut away. These true mabé pearls show very attractive colours ranging from gold to brown, silver and also grey hues with strong iridescence. E.S.

Rutilquartz vom Oberon Parnuk im Polar-Ural.

J.V. BURLAKOV AND J.A. POLENOV. *Lapis*, **27**(2), 2002, 35-40.

Rutilated quartz of ornamental quality is described from Verchny Parnuk in the Polar Urals of Russia. Details of crystal forms and of the inclusions are given.

M.O'D.

Sri Lanka gem industry: past, present and future.

P.G.R. DHARMARATNE. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001. 199-206, 1 map, 3 tables, bibl.

Sri Lanka has been known for gem mining for many centuries. It was first mentioned in literature in 250 BC and there are many early legends. The alluvial deposits are now dwindling and there is a move towards primary deposit mining. The author discusses how legislation with regard to mining, trading, cutting and polishing exports and imports has changed over the years. There have been big fluctuations in the number of licences issued for the various aspects of the industry over the years. E.S.

Corundum/spinel reaction textures in carbonate-origin rocks, Sri Lanka.

M.D.P.L. FRANCIS AND P.G.R. DHARMARATNE. *Australian Gemmologist*, **21**(5), 2002, 211-14.

Carbonate-source rocks containing corundum and spinel are ubiquitous as thin bands in almost all gem producing areas in Sri Lanka. Marble, composed mainly of calcite and dolomite with phlogopite mica, is the dominant lithology within some of the major gem fields. Where both corundum and spinel are present within the marble rock, reaction textures are visible. These textures indicate sequential reactions during corundum and spinel formation. One reaction is balanced, where corundum and phlogopite react to produce rims of spinel and K-feldspar around the corundum. Another reaction involves corundum and spinel replacement, but this reaction is unbalanced and requires more detailed analyses of the phases for its specification. P.G.R.

Les nouvelles mines d'émeraude de La Pita (Colombie). 2e partie.

E. FRITSCH, B. RONDEAU, F. NOTARI, J-C. MICHELOU, B. DEVOUARD, J-J. PEUCAT, J-P. CHALAIN, Y. LULZAC, D. DE NARVAEZ AND C. ARBOLEDA. *Revue de gemmologie*, **144**, 2002, 13-21.

Up to 33 claims are established in the La Pita mining district between Muzo and Coscuez, Colombia. Typical RI and SG of the emeralds found are ε 1.570– 1.571, ω 1.578–1.581: 2.69-2.70. Stones show distinct colour zoning and notably strong pleochroism. Inclusions are characteristic of Colombian emeralds in general. La Pita emeralds can be distinguished from all others by a predominance of V over Cr, a low concentration of Rb and characteristic Mg values. Stones are Fe-poor. M.O'D.

Gem kaleidoscope from Asahi.

Industrial Diamond Review, **62**, 2002, 11, 2 photographs.

The idea was triggered by a previous collector's piece – the De Beers hourglass. The gems used in the kaleidoscope are emerald, tsovorite and paraiba tourmaline for green, amethyst for purple, spinel and ruby for red, sapphire for pink, sapphire, iolite and topaz for blue, sapphire and citrine for yellow, and diamond and topaz for white, and altogether 21 ct of gems are used in each kaleidoscope. Each gem is a little different in size. The body is 24 carat gold plated. Since each instrument is hand-made, only 40-50 can be produced per month and the total production is planned to be 2000 kaleidoscopes. The price is 1 million yen per piece. E.S.

Rubis trapiches de Mong Hsu, Myanmar.

V. GARNIER, D. OHNENSTETTER, G. GIULIANI AND D. SCHWARZ. *Revue de gemmologie*, **144**, 2002, 5-12.

Describes the trapiche ruby crystals found at Mong Hsu, Myanmar with notes on the local geology and on the formation of the crystals. Cathodoluminescence tests are noted and there is a table of included minerals in which the trapiche rubies are compared with non-trapiche Mong Hsu material. M.O'D.

Imperialtopase aus Ouro Preto, Minas Gerais, Brasilien.

A.L. GANDINI, R.M.S. BELLO, H.M.P. ROESER AND J. CESAR-MENDES. *Aufschluss*, **53**, 2002, 154-8.

Topaz of the highest quality and near-red in colour is mined at different locations in the Brazilian state of Minas Gerais. Details of the geology and mineralization of the topaz-producing areas are given. M.O'D.

Gemmologische Kurzinformationen. Rote Turmaline aus Nigeria.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001, 225-8. 7 photographs, 1 graph, bibl.

Since 1998, Nigeria has produced large amounts of red tourmalines from an occurrence near Ibadan in the western province of Oyo. The tourmalines have a good red to pink colour in contrast to other Nigerian localities which produce stones of a browner tint. The physical characteristics are those of elbaite and the red colour is due to trivalent manganese; fluid inclusions as well as crystal inclusions and growth zoning were observed. E.S.

Edelsteine der Feldspatgruppe.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001. 179-92, 12 photographs, 4 diagrams, 3 tables, bibl.

Feldspars are the most common minerals on the earth, but good gem quality varieties are rare. Optical effects can be seen in a large spectrum of commercially available moonstones, amazonites, and labradorites. Other feldspars are being cut, but are of interest only to collectors. The author discusses occurrence and physical properties of sanidine, orthoclase, microcline, larvikite, albite, oligoclase, andesine, labradorite, bytownite and anorthite amongst others. E.S.

Die Achate vom Finkenberg in Idar.

R. HOFFMANN ROTHE, *Lapis*, **27**(2), 2002, 13-17.

Agate of exceptional quality is described from the Finkenberg area near Idar-Oberstein, Germany. Red predominates in the patterning and the material has been used to good effect in the fashioning of cameos. M.O'D.

John Jago Trelawney.

A.R. KAMPF. *Mineralogical Record*, **33**, 2002, 217-24.

Biography of a collector [born John Jago] who gave a gemstone collection to the Natural History Museum of Los Angeles County and a mineral collection to the Smithsonian Institution. M.O'D.

Flashstones – Zeugen 'versteinerter' Blitze.

J. KARFUNKEL AND B. PEREGOVICH. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 207-16, 2001. 4 photographs, 1 map, 2 graphs, bibl.

Deformed quartz crystals struck by lightning which were found in deep channel-forming elongated pits in colluvial deposits in the 'Sierra do Espinhaco', a narrow mountain range in Central Eastern Brazil. The artisan miners call these 'pedra de raio' – flashstones. They are single quartz crystals struck by lightning which were macroscopically deformed by shock energy. Special environmental and atmospheric conditions explain their genesis. Such crystals become collectors' pieces. E.S.

Gem News International.

B.M. LAURS (Ed.). *Gems & Gemology*, **37**(4), 2001, 326-43.

Notes are given of distinct colour changes observed in cut stones of spodumene, zircon and sapphire after subjection to ionizing radiation from a synchrotron similar to the technique used by the U.S. Postal Service on a small portion of the mail to eliminate a potential threat from anthrax spores. Descriptions are given of cut iolites (0.36–1.33 ct) and pink sapphires from quartzofeldspathic gneiss in the Palmer Canyon area of Wyoming, a 3.54 ct green kyanite from Bahia, Brazil, and of large crystals of pink tourmaline from the Cryo-Genie mine in Warner Springs, California. R.A.H.

Spessartine garnet from Ramona, San Diego County, California.

B.M. LAURS AND K. KNOX. *Gems & Gemology*, **37**(4), 2001, 278-95.

Two pegmatites in the area around the Little Three mine near Ramona, the Hercules-Spessartine and the Spaulding dykes, yielded most of the estimated 40 000– 50 000 ct of facet grade rough mined from 1956 to 1994. Details are given of the history and mining of these pegmatites and electron microprobe results are given for four spessartines (ranging from light orange-yellow to yellow-orange) with composition $Sp_{94.8-88.8}Alm_{4.7-11.0}Gro_{0.5-0.2}$, with *n* 1.799–1.802; the absorption spectra of all samples show strong peaks for Mn^{2+} and subordinate Fe^{2+} bands. Typical internal features are wavy two-phase partially healed fractures, negative crystals, needles and/or tubes, growth patterns and anomalous birefringence; mineral inclusions are rare. R.A.H.

Korund in Brasilien.

A. LICCARDO AND H. JORDT-EVANGELISTA. *Aufschluss* **53**, 2001, 121-5.

Both ruby and blue sapphire are found in Brazil and over 20 locations are listed and shown on a map. Some stones are colour-enhanced. M.O'D.

Formation of the Denchai gem sapphires, northern Thailand: evidence from mineral chemistry and fluid/melt inclusion characteristics.

P. LIMTRAKUN, K. ZHAW, C.G. RYAN AND T.P. MERNAGH. *Mineralogical Magazine*, **65**(6), 2001, 725-35.

The Denchai gem sapphire deposits in Phrae Province, N Thailand, are closely associated with late Cainozoic alkaline basaltic rocks. The sapphires occur in placer deposits in palaeo-channels at shallow depths. EPMA gave Fe_2O_3 0.32–1.98, TiO_2 0.01–0.23, Cr_2O_3 <0.01, Ga_2O_3 0.01–0.03 and V_2O_5 <0.03 wt.%. Three types of primary fluid/melt inclusions could be recognised: type I are CO_2-rich inclusions with three phases (LH_2O, LCO_2 and V) with the vapour phase comprising 10–15 vol.%; type II are polyphase inclusions (vapour + liquid + solid) with a fluid bubble (20 –30 vol.%), an aqueous phase (10-15 vol. %) and several solid phases; type III are silicate-melt inclusions of vapour bubbles, silicate glass and solid phases. PIXE analyses reveal high K (~ 4 wt.%) as well as Ca (~ 0.5 wt. %), Ti (~ 1 wt.%), Fe (~ 2 wt.%), Mn (0.1 wt.%), V (< 0.03 wt.%), Rb (~70 ppm) and Zr (~ 200 ppm) in the silicate glass. The Ga_2O_3 contents and Cr_2O_3/Ga_2O_3 values (< 1) of the sapphires favour their formation by magmatic processes. The presence of CO_2-rich fluids and high K in the silicate melt inclusions link the origin of these sapphires to CO_2-rich alkaline magmatism. R.A.H.

Gemmologische Kurzinformationen. Padparadscha und/oder Padmaraja.

U.W. LIPPELT. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001. 228-30.

There is a need in the trade for a definition of the colour of padparadscha, as various fancy-coloured corundums have been given this name. The name refers to the colour of the lotus flower and in southern Asia the name padmaraja has always been given to a corundum with the colour of a lotus flower; however, padparadscha was the name given to an orange coloured corundum. The author suggests there is only one variety and that the golden yellow sapphire should be called by its proper Sanskrit name of padparadscha. E.S.

Kupferhaltige Turmaline aus Nigeria.

C.C. Milisenda and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001, 217-23, 4 photographs, 1 map, 2 graphs, bibl.

The Oyo State in western Nigeria produces gem quality tourmalines which owe their colour to trace amounts of manganese and/or copper, similar to tourmalines from Paraiba in north-eastern Brazil. Most of these stones show an amethyst colour and can be heated to an attractive aquamarine blue. Chemical analysis shows that these stones are typical elbaites with traces of Ti, Fe, Cu, Mn, Bi, Pb and occasionally Zn. They are sold under the trade name 'Indigo tourmalines' and also 'Paraiba Africana' however, the very vivid neon blue of the Paraiba stones is hardly seen in the Nigerian specimens. E.S.

Five centuries of Mexican pearls.

D.M. Moreno and E.A. Castillo, *Australian Gemmologist*, **21**(5), 2002, 190-201.

This review covers the history of the Mexican pearling industry in the Gulf of California (also known as the 'Sea of Cortez') from the pre-Columbian Period, through the pervading influence of the Japanese pearl culturing industry which created the Sea of Cortez™ bead nucleated cultured pearl, and of the innovative Mexican methods used to produce loose (whole) cultured pearls from the indigenous pearl oyster (*Pteria sterna*). P.G.R.

Gem Trade Lab Notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds). *Gems & Gemology*, **37**(4), 2001, 318-25.

Notes are given of a 292 ct charoite host to a large X-shaped spray of tinaksite, a 4.54 ct cat's-eye chrysoberyl cabochon with α 1.780, γ 1.793 and SG 3.81 which was found to be unusually rich in Fe (9–10 wt.% Fe_2O_3 as total Fe), faceted quartz with a large almost spherical inclusion of rhodochrosite, and semi-translucent dark blue star sapphires in which only the stars had been diffusion-induced. R.A.H.

Observation des émeraudes traitées en luminescence U–VISIO

F. Notari, C. Grobon and E. Fritsch. *Revue de gemmologie*, **144**, 2002, 27-31.

Emeralds previously treated with synthetic resins have the resins replaced by cedar wood oil when they come to be cleaned. IR spectrometry and Raman techniques are able to detect the resins but do not precisely establish how much resin remains after the cleaning process: the resins need to be completely removed before replacement with the oil. Luminescence aging is found to be the best method of establishing the complete removal of resin material. M.O'D.

Amethyst und Achat aus S-Brasilien

H. Pöllmann, M.L. Da Costa and R. Wegner. *Aufschluss*, **53**, 2002, 167-80.

Amethyst and agate-producing sites in southern Brazil are identified, shown on a map and discussed with reference to local geology and mineralization. M.O'D.

Zur Geschichte des Smaragds in Brasilien.

H.M.P. Roeser, J. Cesar-Mendes and A.L. Gandini. *Aufschluss*, **53**, 2002, 135-50.

History of emerald mining in Brazil with notes on the different locations which are shown on a map. Chemical compositions of specimens from different mining areas are given. All contain different amounts of Cr, Fe and V. There is an extensive bibliography. M.O'D.

Pink to pinkish orange malaya garnets from Bekily, Madagascar.

K. Schmetzer, T. Hainschwang, L. Kiefert and H.-J. Bernhardt. *Gems & Gemology*, **37**(4), 2001, 296-308.

Garnets from Bekily, SE Madagascar, are predominantly pink to pinkish-orange, with some stones orange to red; electron microprobe results for 11 cut stones and 12 garnets from rock samples show the majority to be intermediate members of the pyrope-spessartine series with variable contents of almandine and minor grossular. The refractive index, specific gravity and colour of these garnets are related to their Fe and Mn contents; in general, they contain less Mn than most malaya garnets from East Africa. Inclusions identified by Raman spectroscopy are platelets and needles of rutile, as well as graphite, quartz, apatite, zircon and sillimanite. R.A.H.

Sterngranate aus Madagaskar.

K. Schmetzer, M. Glas, and H-J. Bernhardt. *Lapis*, **27**(2), 2002, 20-27.

Fine quality asteriated dark red almandine is described from the area of Ambatondrazaka, Madagascar and compared to star garnet from India. Similar material from Ilakaka, Madagascar is also described. Specimens from both places show four rays and a description of the mechanism causing the effect is given. M.O'D.

Star garnets from Ilakaka, Madagascar.

K. Schmetzer and H.-J. Bernhardt. *Australian Gemmologist*, **21**(5), 2002, 202-6.

The three star garnets examined were found in mixed parcels of gem materials originating from the Ilakaka area and are intermediate members of the pyrope-almandine series. Microscopic examination showed that the four and six rayed stars are caused by dense networks of needle-like inclusions orientated parallel to the two-fold axes or parallel to the three-fold axes of the host garnets. P.G.R.

An update on "Paraíba" tourmaline from Brazil.

J. E. Shigley, B.C. Cook, B.M. Laurs and M.O. Bernardes. *Gems & Gemology*, **37**(4), 2001, 260-76.

Vivid blue, green and purple-to-violet elbaites continue to be recovered in small amounts in NE Brazil. Mining is currently taking place at Mina de Batalha and adjacent workings in Paraíba State, and at least two pegmatite localities (the Mulungu and Alto dos Quintos mines) in neighbouring Rio Grande do Norte State. All these pegmatites occur within late Proterozoic metamorphic rocks of the Equador formation; the source of the Cu is unknown. Electron microprobe optical and specific gravity data are given for six cuprian elbaites (Cu 0.40–0.69 wt. %) from the Mulungu mine; these six specimens were 'oiled' to minimize the visibility of surface-reaching fractures. The bright blue tourmaline exhibits minimal pleochroism, so faceting can be done in any orientation. R.A.H.

"Voices of the Earth": transcending the traditional in lapidary arts.

S.E. Thompson. *Gems & Gemology*, **37**(4), 2001, 310-7.

An account is given of work and techniques used by gemstone artists, including the production of convex facets and the use of diamond grits for polishing. Colour photographs are given of some of the pieces by nine leading designers. R.A.H.

Compositions and formation conditions of fluid inclusions in emerald from the Maria deposit (Mozambique).

Y. Vapnik and I. Moroz, *Mineralogical Magazine*, **66**(1), 2002, 201-13.

Fluid inclusions in emerald and quartz from the Maria hydrothermal vein deposit cutting Precambrian ultrabasic rocks were studied using microthermometric and Raman microprobe techniques. In the emeralds, inclusions contain fluids within the Na–Ca–Mg–$(HCO_3)^-$–$(CO_3)^-$–C1–H_2O system saturated in carbonic acid brines. Nahcolite is a main daughter solid phase, the mean nahcolite and NaCl contents being 25 and 5 wt.% respectively. Mg-calcite, magnesite, calcite and aragonite also occur as daughter phases in the fluid inclusions. Groups of nahcolite crystals may amount to ~ 50 vol. % of necked-down inclusions. Zones of fluid inclusions with numerous birefringent solid phases are typical of the Maria emerald deposit. The probable conditions of emerald growth are 400–500°C at 3–5 kbar. R.A.H.

What's new in minerals.

Various Authors. *Mineralogical Record*, **33**, 2002, 255-75.

Among the specimens on display at the Munich show of 2001 were transparent green pargasite from Burma, amethyst from Ambatondrazaka, Toamasina, Madagascar, an octahedral diamond crystal of 2.6 cm from Mbuji-mayi, Congo, fine single crystals of jeremejeevite from Namibia as well as aquamarine from the Erongo mountains in the same country.

At the Pasadena show 2001, were fine transparent tsavorlite crystals of 1.5 and 2 cm, from Arusha, Tanzania. These are unusually large sizes for this material. Specimens at the Tucson show 2002 included some rare hiddenite and emerald from North Carolina, multi-coloured tourmaline crystals from the Baixo mine, Taquaral, Minas Gerais, Brazil, fine rose quartz crystals on quartz from Paroon, Afghanistan and dark purple crystals of fluorite from Yiwu, Zhejiang, China. M.O'D.

Instruments and Techniques

Gemchecker™ professional valuation and appraisal module.

T. Linton and K. Frazer. *Australian Gemmologist*, **21**(5), 2002, 215-8.

This report, by the G.A.A. Instrument Evaluation Committee, concentrates on the professional valuation and appraisal module which is part of the Gemchecker™ computer based system. The complete system has provision for the entry of company and customer records, and gemstone identification data, and contains gemstone image scanning procedures, a comprehensive database of gemstone properties for identification purposes, current price lists for diamonds and coloured stones, and valuation (appraisal) protocols. Familiarity with the modules and operational use is the key to rapid and efficient use of this system. The programme could appear daunting to valuers due to both its size and facilities. However, as it is a modular system, only those parts necessary for operational use need to be purchased. P.G.R.

Jewels of the Nizams.

V.R. Bala Krishnan, 2001. Department of Culture, Government of India, New Delhi. Distributed by Antique Collectors' Club, Woodbridge, IP12 4SD, UK. Illus. in colour. Hardcover ISBN 81 7508 306 9. £50.00.

The jewel collections of the Nizams of Hyderabad were offered for sale to the Indian Government in 1972. It took 23 years for the negotiations to be concluded: tax issues were involved. At last in 1991, the Supreme Court of India ruled that the Government would pay the trusts set up to handle the effects of the Nizam more than 2 billion rupees for 173 items of jewellery. Modifications to the ruling with a diminution of the sum and the incorporation of the whole of the jewellery collections were made subsequently in 1993. This was not the end of the story since the final settlement was not made until 12 January 1995 when the collections finally became the property of the people of India.

The wealth of the Asaf Jah dynasty is recorded as far back as the 14th century and the book summarizes the history of the dynasty before describing the ways in which the collections were formed and augmented by astute purchasing, often from dealers in Europe and the United States.

The book then becomes a 159 page *catalogue raisonné* in which all the pieces are illustrated in colour with full descriptions, including measurements, stone and metal details. Former owners are identified where possible.

The book continues with a list of references and a glossary of Indian jewellery terms, a bibliography and an index. The standard of reproduction is high and the price most reasonable for a book of this kind. M.O'D.

Geschönte Steine.

B. Bruder, 1998. Neue Erde, Saarbrücken [Rotehbergstr 33, D-66111 Saarbrücken]. pp 109, illus. in colour, softcover. ISBN 3 89060 025 5. Price on application.

After a brief introduction to gem testing methods, the text examines treated stones in alphabetical order and includes a number of photographs of quite pleasing quality. The text is quite well organized but an adequate bibliography should have been provided. Nonetheless, this is a useful introduction to an ever-changing subject, though serious study would require a much greater depth of coverage. M.O'D.

Handbook of near-infrared analysis. (2nd edn, revised and expanded.)

D.A. Buns and E.W. Ciurczak, 2001. Marcel Dekker Inc., New York. pp xv, 814. Hardcover, ISBN 0 8247 0534 3. US$225.00.

This is a very large general survey of the many uses of near-IR analysis, covering such varied topics as history and development of techniques, calibration and applications. Those with an interest in gem materials will note the section dealing with the detection of counterfeit turquoise. Here the problem was the use of coloured plastic to imitate the natural material and consequent unfavourable media attention given to the problem in the south-western areas of the United States where turquoise was traditionally produced. Near-IR analysis quickly identified plastic substitutes for natural turquoise showing peaks in the spectrum in the areas where natural turquoise is usually flat. Notes on the use of organic fillers in other gem minerals are given and there are short notes on how they may be detected. Readers browsing in this area of the book will also find good coverage of the detection of counterfeit currency! Each section has its own list of references and the diagrams and tables are easy to read. M.O'D.

Diamond: the story of a cold-blooded love affair.

M. Hart, 2001. Fourth Estate, London. pp 287. Hardcover ISBN 1 84115 279 X. £15.99.

An account of the work of the De Beers organization with a number of sketches illustrating diamond recovery and sales in different parts of the world. The entry of the company into the polished goods market is described as well as the effects of the Canadian diamond rushes of recent years. Among the stories is a step-by-step account of the polishing of the Centenary diamond by Gabi Tolkowsky in 1998. The style is clear and concise – the book can be read at a single sitting. There is a useful bibliography and an index. The book is recommended to gemmologists and diamond specialists who will enjoy the politico/ commercial issues raised. M.O'D.

Tektites in the geological record: showers of glass from the sky.

G.J.H. MacCall, 2001. The Geological Society, London. pp vii, 256, illus. in black-and-white. Softcover, ISBN 1 86239 085 1. £65.00 (£25 to Fellows of the Geological Society).

Tektites, some of which have been used ornamentally and more as collectors' prizes, are found on Earth only in four *strewn fields* which are described in this excellent, easily-understood and timely survey. Tektites are mostly formed from projected melt from terrestrial rocks at a site of impact, a process still not fully understood. The velocities and trajectories of the melt projected from these sites are still being studied and some details of the work being carried out accompany descriptions of the major impact sites.

Discussion of glasses related to tektites includes some of the latest thinking on Darwin Glass and Libyan Desert Glass, this being familiar to gemmologists. There appears to be no close connection between Libyan Desert Glass and tektites though there is almost certainly a meteoritic relationship. The glass (which is almost pure silica) has never been found in any form other than dispersed lumps and these may have originally formed part of a melt sheet. An impact source is at least probable.

There is a glossary and a first-rate bibliography, and discussions of topics other than the two I have selected are equally well written and interesting. The Society is to be congratulated on accepting this monograph for publication. M.O'D.

Black opal. A comprehensive guide to cutting and orientating.

GREG PARDY, 1999. GP Creations, PO Box 340, Urangan, QLD 4655, Australia. pp 203. Hardback and videotape. ISBN 0 646 37266 1. Price on application.

This is a very well produced book dealing with the whole process of cutting black opal from the rough material to the finished gemstone. The writing is somewhat 'homespun' in a conversational manner but this does not detract from the quality of information contained in its pages, and it is obviously written by a master of this branch of lapidary work. The book opens with a detailed account of the occurrence of opal in Australia and the types of opal to be found in various mining regions of Queensland, but is primarily concerned with black opal found in the Lightning Ridge, Sheepyards, Grawin-Glengarry Fields and Coocoran opal fields.

The various types of opal 'nobbies' (rough opal as mined) and their local names are illustrated with excellent photographs. This is followed by an account of the latest mining methods also accompanied by clear illustrations of the equipment. The main body of the book then deals with orientation, lapidary equipment and Greg Pardy's technique for producing solid, doublet and triplet opal gems. This is clearly written and easy to follow, with clear illustrations accompanying the various stages of the processes.

The photographs of finished black opal gems by Len Cram and Pasquale Giorgio are superb, particularly those of the 17 ct Eye of Destiny, the 100 ct green on black gem, and the triplet mosaic oval cabochon.

The book is accompanied by a video cassette running for 1 hour 52 minutes produced and filmed by Pasquale Giorgio, and edited by Megan Turner. This shows the processes described in the book in clear detail with a running commentary by Greg Pardy as the opal is gradually converted from a rough nobby to a beautiful black opal gemstone. There is no hurrying, in fact the only criticism that might be made is that the film seems rather slow, but this is only because the cutting process is followed faithfully with no omission of practical details. There are no unnecessary comments or detracting background music, and the video would serve well as a basic teaching method for producing gem cabochons applicable not only to black opal but to most materials. The book and video should be in every gem cutter's library and can be recommended. A.D.M.

Royal treasures: a Golden Jubilee Celebration.

J. ROBERTS (Ed.), 2002. Royal Collection Enterprises Ltd., London. pp 496, illus in colour. Softcover ISBN 1 902163 52 4. £27.00.

The Royal collections contain all forms of fine art, including jewellery, and a selection of the finest items has been placed on display in a new purpose-built gallery at Buckingham Palace. While the present arrangement commemorates the Golden Jubilee of The Queen, no doubt the exhibits will be regularly changed. The catalogue is very well produced, lies flat when opened and is reasonably priced.

Readers will first look for the items of jewellery which are described in pages 219-235. There are 18 pieces, including several cameos, the Darnley Jewel (attributed to Scotland), the Diamond Diadem made in 1820 for the coronation of George IV, the Cullinan Brooch of 1908-10 made by Joseph Asscher & Co. and containing Cullinan diamonds 3 and 4 of 94.4 and 63.6 ct, Queen Victoria's diamond necklace and drop earrings of 1858, the necklace supporting a pendant diamond of 22.48 ct. The Great and Lesser Georges, Garter collar and sash badges respectively, are of considerable historical interest: both are set with diamonds.

Hardstone flowers and plants form a separate section of the catalogue, some of the examples making use of diamonds and rubies as well as hardstones and enamels. Specimens of Fabergé work are included in this section.

Indian works of art include jewelled daggers and the emerald belt of Maharajah Sher Singh, made around 1840. This formed part of the exhibition of Mughal jewels held at the British Museum in 1999. Foremost among the items in this section is the Timur Ruby necklace in which the red stones are spinels, the centre stone with an engraved inscription.

This is a selection only and the exhibition should be visited at least once. Those readers interested in coronations will be pleased to see John Whittaker's *Ceremonial of the Coronation of His Most Sacred Majesty King George the Fourth*, 1823 and printed in gold throughout. Tortoiseshell at its finest can be seen as the binding material for *Holy Bible*, 1776, which is accompanied by the *Prayer Book* of 1815. *Corals, fossils and mineral specimens* is the title of a watercolour by Vincenzo Leonardi, dated between 1630-40. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Photographic Competition

The 2002 Photographic Competition on the theme of ***Out of the Ordinary*** drew a record number of unusual and interesting stones or unusual cuts of the better-known gem species.

First Prize

Bob Maurer FGA DGA, London

Amethyst 34.52 ct by Bernd Munsteiner from the collection of Thomson Gems (also illustrated on front cover).

 ISSN: 1355–4565

Second Prize

Michele White, FGA, DGA, RBSA, Moseley, Birmingham, West Midlands

Landscape agate mounted in an 18ct gold hand-made brooch by Michele Wight.

Third Prize

John Harris FGA, Durdar, Carlisle, Cumbria

Feathers applied to a mother-of-pearl background gold brooch, mid-19th century.

We are pleased to announce that the prizes were sponsored by Harley UK, and the Association is most grateful to them for their generosity. The prizes will be presented and the winning entries exhibited at the Annual General Meeting to be held on 25 September.

OBITUARY

John Sinkankas, the finest gem cutter of his time, the most lucid of writers in English on mineral and gem topics and the kindest and most approachable of men, died after a short illness on 17 May 2002.

John was born to Lithuanian immigrant parents on 15 May 1915, and grew up close to the traprocks of New Jersey in which he soon took an interest during boyhood. The proximity of New York City with its museums and the existence of mineral collecting groups inspired an interest that was never to leave him. It was not the only one however, since he developed a considerable skill in water-colour painting which is well shown in his *Gemstones of North America and Emerald and other beryls.*

At the same time, John came to love flying and in fact spent many years as an aviator with the United States Navy, concluding his active career there in 1961. He had been through the Second World War and the Korean War.

After the war John was able to pursue his mineral and gem interests more fully and became a celebrated lapidary, combining practical skill with a gift for teaching which comes out in all his books. He found ways to facet crystals which were previously thought too fragile to fashion, and at the same time he owned interests in a number of celebrated gem mines in the United States.

John built up a superb library of gem books which are now part of the collections of the Gemological Institute of America: with Marge his wife he operated Peri Lithon Books which was an eye-opener to me when I first visited it – even after curating the British Museum's earth science books for years.

What I have written is a very small part of one of the most active lives I have known, but it does not quite show how nice a man he was. He had great times looking for and finding fine tourmalines in southern California some years ago: I remember best his frequent use of "y'know" and "y'see" which I have made, quite inadequately, my own. A fine way to access John is to listen to his commentary on part of the video *Gemstones of North America.*

John included a brief autobiography to pages 1163-6 of the second volume of *Gemology: an annotated bibliography* (1993) and I have drawn on this for John's earlier years. This major work is as good as it could be, like all John's productions.

We offer our sympathy to Marge who is just as much a distinctive character as her husband and who ran Peri Lithon Books with great skill and kindness. Michael O'Donoghue

* * *

Maurice M. Whitehead FGA (D.1950), East Horsley, Surrey, died recently.

MEMBERS MEETINGS

London

On 3 May at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Joseph Tenhagaen of Miami, Florida, gave a talk on 'New aspects of cut in round brilliant-cut diamonds'. A report was published in the June issue of *Gem & Jewellery News*, **11**(3), 2002), p. 56.

On 21 May there was a private viewing and tour of the Tiaras exhibition at the Victoria and Albert Museum, South Kensington, with exhibition curator, Geoffrey Munn.

On 26 June at the Gem Tutorial Centre, Richard W. Hughes of Fallbrook, California, gave a talk on Burma ruby and new corundum treatments. A report will be published in the September issue of *Gem & Jewellery News*.

Midlands Branch

On 26 April at the Earth Sciences Building, University of Birmingham, Edgbaston, Dr Jamie Nelson gave a fascinating insight into the behaviour of light in gemstones and the idiosyncrasies of gemstone cuts. The meeting also included the Branch AGM when David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected, President, Chairman, Secretary and Treasurer respectively.

On 19 June a Gem Club was held at Barnt Green when Doug Morgan and David Larcher ran a practical session on photomicroscopy.

The annual Summer Supper Party was held on 22 June at Barnt Green.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Stuart Dennis of Asprey & Garrard, London, for cut gemstones and diamonds.

Robert B.R. Gau, FGA, Taipei, Taiwan, for the donation of free time in helping to run examinations in Taipei.

John Greatwood, FGA, Mitcham, Surrey, for six square cabochon sunstones.

David Halperin of Val D'Or Ltd, London, for a piece of dyed alabaster imitating coral.

Joseph Tenhagen, FGA, Miami, Florida, U.S.A., for a large collection of cut gemstones.

The Worshipful Company of Goldsmiths, London, for a donation of £50,000.

North West Branch

On 17 April at Church House, Hanover Street, Liverpool 1, Dr Roger Harding gave a talk entitled 'Gems in the collection of the Natural History Museum, London'.

On 15 May at Church House Rosamond Clayton gave a talk entitled 'Diamonds – the fourth dimension (cut)'.

A Bring and Buy was held on 19 June at Church House.

Scottish Branch

The Annual Scottish Branch Conference was held in Perth from 3 to 6 May, keynote speaker Ted Themelis. A report was published in the June issue of *Gem & Jewellery News*, 11(3), pp. 52-54.

On 30 June at the National Museum of Scotland, the George Lindley & Co. Lecture was given by Richard Hughes entitled 'Crossing gemmological frontiers'.

South West Branch

On 19 May at the Bath Royal Literary and Scientific Institution, 16-18 Queen Square, Bath, Michael Norman, Chairman of the Guild of Independent Valuers, gave a talk entitled 'The colour of money'.

The talk was followed by a practical session on red stones with Richard Slater, Keri Slater and Bronwen Harman.

Gem-A BRANCH LAUNCHED IN USA

In response to a demand by members in America, a new branch of Gem-A has been launched – Gem-A USA.

Internationally-renowned diamantaire Gabi Tolkowsky spoke at the Gem-A USA launch in Las Vegas held on Sunday 2 June, reminding us that "Education generates the future for thousands of people around the world", adding 'Education is eternal like the diamond – it starts and never stops'.

Anne Ferrara Dale FGA GG, has been appointed Director of Gem-A USA. She is the owner of a retail jewellery store in Louisiana and is a federal expert witness for the Internal Revenue Service. Anne is a Fellow of Gem-A having qualified in the Gemmology Diploma Examination in 1987, and is also a graduate of the Columbia School of Gemology and the GIA.

In her work as Gem-A USA Director, Anne will concentrate on promotion of Gem-A Education and Membership, coordinating with trade organizations and aiming at unified and supportive relationships with the trade through Gem-A Education.

Gabi Tolkowsky speaking at the launch of Gem-A USA.

Anne Ferrara Dale, Gabi Tolkowsky and Terry Davidson at the JCK Show, Las Vegas.

MEMBERSHIP

Between 1 April and 30 June the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Kwok Hei, Tsing Yi, New Territories, Hong Kong, 2002/2002

Fellowship (FGA)

Beck, Cyril Anthony, Sale, Cheshire, 1967
Chaudhari, Ruchi, West Lafayette, Indiana, U.S.A., 1997
de Vries, The Hague, The Netherlands, 2002
Dimmick, Helen Margaret, London, 2001
Douthwaite, Elaine, Shipley, West Yorkshire, 1982
Francis, Melanie, Toronto, Ontario, Canada, 2002
Green, James E.W., Pelsall, Walsall, 1979
Ho, Feony P.C., Kwun Tong, Kowloon, Hong Kong, 2002
Hsieh, Ming-Tsung, Feng-Yuan City, Taichung, Taiwan, R.O.C., 2002
Knight, James Harry, London, 1988
Lwin, Mon Mon Myat, Kamayut Township, Yangon, Myanmar, 2002
Mitch, Alexandra F., Galveston, Texas, U.S.A., 2002
Roberts, Justin John, Wembley, Middlesex, 2002
Roy, Maryse, Montreal, Quebec, Canada, 2002
Schraq, Catharina Neeltje, Gaes, The Netherlands, 2002
Segal, Neil Conrad, Umhlanga Rocks, South Africa, 1979
Tangsubkul, Hiranya, Bangkok, Thailand, 2002
Toullic, Nathalie, Brentford, Middlesex, 2002
van Dam, Anita Johanna, Maasland, The Netherlands, 2000
van der Made, Barbara Claudia, Ermela, The Netherlands, 2002

Diamond Membership (DGA)

Leeks, David, Semarang, Indonesia, 2002
Ma Mei Chuan, Sai Kung, New Territories, Hong Kong, 2002
Petrozello, Ryan, Randolph, New Jersey, U.S.A., 2002
Zhang, Xiao Ling, Kowloon, Hong Kong, 2002

Ordinary Membership

Burrowes, Bruce, Twickenham, Middlesex
Clayton, Harriet, Edinburgh, Scotland
Craven, Lea Alison, Wyke, Bradford
Dunn, Andrew Charles, Caversham Park, Berkshire
Gouveia-Lima, Isabel, London
Langlands, John, Edinburgh, Scotland
Liem, Deborah Alexandra, Singapore
Lunn, Ruth Hannah, Las Lagunas, Mijas Costa, Malaga, Spain
Martayan, Gerard, Saint-Antoine, Paris, France
Myint, Eddie Aung, London
Ndiekeno, Dikenga, Manor Park, London
Sylvester, Sheila, Brussels, Belgium
Wesley, Ian, London
Wreford, David, London
Yokokawa, Naomi, East Sheen , London


F.M. JEWELLERY

FORTHCOMING EVENTS

4 September	**Scottish Branch.** *Colourful corundum – a view from 'down-under'.* *Lin Sutherland. The Portuguese Crown Jewels. Rui Galopim De Carvalho.*
18 September	**North West Branch**. *Chasing rainbows. John Harris.*
25 September.	**London**. Annual General Meeting and lecture (free of charge – Gem-A members only).
27 September.	**Midlands Branch**. *Diamonds, certification, appraisal and valuation. Richard Taylor.*
16 October	**North West Branch.** *Jewels for a Royal occasion. Rosemary I. McIver.*
25 October	**Midlands Branch.** *Tucson surprises – the highlights of Tucson 2002. Alan Hodgkinson.*

Gem-A Conference 2002

To be held on
Sunday 3 November
at Kempton Park Racecourse, Sunbury on Thames, Middx.
In conjunction with the Rock 'n' Gem Show
Speakers:
Professor Dr Edward J. Gübelin
Professor Andy Rankin
Dr Bob Symes OBE
Stephen Webster

4 November	**Presentation of Awards and Reunion of Members.** Goldsmiths' Hall, Foster Lane, London EC2.
19 November	**Scottish Branch.** The Crown Jewels. *E. Alan Jobbins.*
20 November	**North West Branch.** AGM and social evening.
29 November	**Midlands Branch.** *Fabulous Fabergé expert, auctioneer and buyer. Stephen Dale.*
7 December	**Midlands Branch.** Celebration 50th Anniversary Dinner.

Contact details

(when using e-mail, please give Gem-A as the subject):

London:	Mary Burland on 020 7404 3334; e-mail gagtl@btinternet.com
Midlands Branch:	Gwyn Green on 0121 445 5359; e-mail gwyn.green@usa.net
North West Branch:	Deanna Brady 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South West Branch:	Bronwen Harman on 01225 482188; e-mail bharman@harmanb.freeserve.uk

Gem-A Website

For up-to-the-minute information on Gem-A events visit our website on www.gagtl.ac.uk

Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are centred on a separate line.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

Volume 28 No. 3 July 2002

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Cover Picture

Amethyst 34.52 ct.
Photograph by Bob Maurer
First Prize in the Photographic Competition, see p. 183

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