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Cover Picture

Brooch set with pink Argyle diamonds, maximum width approx 7cm; 1068 pink diamonds and 160 white diamonds weighing a total of 16.31 ct and 3.45 ct respectively. See 'Gemmological properties of Type Ia diamonds with an unusually high hydrogen content' pp.451-60.

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Gemmological properties of Type Ia diamonds with an unusually high hydrogen content

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Abstract

One hundred and thirty-nine Type Ia diamonds that showed unusually intense hydrogen-related absorptions in the infrared range were studied; they are referred to as 'H-rich diamonds' for brevity. We demonstrate that the various kinds of H-rich diamonds often have a number of gemmological and physical properties in common, for example a yellow luminescence, certains types of colour zoning and clouds of sub-microscopic inclusions. We also report the discovery of several new hydrogen-related absorptions in the infrared and the visible ranges, some giving rise to a violet colour never described before in coloured diamonds.

Key words: Diamond, Hydrogen, Infrared, Colour centre.

Introduction

In recent years hydrogen has been recognized as a common impurity in natural Type Ia diamonds (Woods and Collins, 1983), in addition to the well-known nitrogen (and possibly boron) impurities. Little is known, however, of the influence that this hydrogen impurity may have on the optical properties of such diamonds, in particular their colour. In the course of the coloured diamond project, undertaken at GIA Research since 1986 in order to better understand the properties of natural and treated coloured diamonds, we have studied a number of diamonds with unusual characteristics. For example, we recently reported on a greyish-blue coloration in diamond believed to be caused by hydrogen-related colour centres (Fritsch and Scarratt, 1992). The presence of hydrogen in diamond can be detected by a series of sharp absorptions in the infrared region, especially at 1405 and 3107 cm^{-1}, which have been known since 1961 and attributed by Charette to C-H bonds (Charette, 1961). These two frequencies are also known as $h_{\omega}b$ (1405 cm^{-1}), the elementary frequency for the bending motion of the C-H bond, and $h_{\omega}s$ (3107 cm^{-1}) the elementary frequency for the stretching motion of the C-H bond.

Over the last five years, a number of gem-quality diamonds exhibiting strong C-H bands at 3107 cm^{-1} have become available. For convenience, these diamonds are hereafter called 'H-rich diamonds' but, strictly speaking, they only are diamonds with unusually intense hydrogen-related infrared absorptions. These diamonds, although they may have different appearances, present a number of gemmological properties in common. The large number of samples we

Fig. 1. Four typical H-rich diamonds, ranging in colour from greyish-yellow (0.28 ct, left), to light brownish-yellow (1.02 ct, centre) to light grey (0.09 and 0.15 ct, right). Stones courtesy Davenport Jewelry Company, Dallas, Texas. *Photo by Robert Weldon*

Fig. 2. Greyish-violet 0.88 ct pear-shaped diamond and brown-yellow 1.20 ct round brilliant-cut, both from the Argyle mine in western Australia. They represent typical examples of H-rich diamonds described in detail in this paper. Stones courtesy of Argyle Diamonds. *Photo by Robert Weldon*

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Fig. 3. The vast majority of 'white' or 'opalescent' diamonds, such as these three round brilliant-cuts from the Panna mine in India ranging from 0.30 to 0.33 ct, are also H-rich diamonds. Stones courtesy Malhotra Inc., New York. *Photo by R. Weldon*

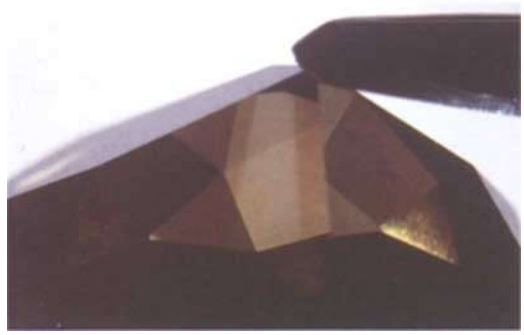


Fig. 5. Brownish colour zones limited by planar borders in a greyish-green chameleon diamond. Magnification 10×. *Photomicrograph J.I. Koivula*

studied (over one hundred) has enabled us to document a number of absorptions in the infrared and visible ranges related to the presence of the hydrogen impurity, some of which had never been described before. In particular, some rare hydrogen-rich diamonds from Argyle in western Australia exhibit a violetish-grey to greyish-violet colour never described before in coloured diamonds.

Materials and methods

The 139 samples examined in this study were all faceted gem-quality diamonds, on loan from private parties. They represent a wide range of colour with essentially yellow, grey (Figure 1) or brown as the main component (for 78 of them), but also bluish-grey to greyish-violet (for 6 of them), white (also called 'opalescent diamonds' in the trade; 8 samples) and blue and green (47 samples). Their geographical origin is generally unknown, as is unfortunately the case with most diamonds. However, the bluish-grey to greyish-violet stones are all from Argyle, as well as one brown-yellow (Figure 2) and one greenish-yellow stone. A series of three white diamonds is from the Panna mine, India (Figure 3).

This sampling includes 31 stones either known to be treated, or established to be so based on criteria explained elsewhere (Fritsch and Shigley, 1989 and 1991). Although most of these treated, hydrogen-rich stones were essentially green or blue (sample 8; Fritsch and Shigley, 1989), we documented also some that were essentially yellow (sample 2; ibid.).

All data collection was done at GIA Research. Ultraviolet-visible absorption spectroscopy was performed on a Pye Unicam 8800 spectrophotometer, using a band-width of 0.5 to 1 nm. The sample is cooled to 80 K using a pour-fill dewar cooling unit. Infrared absorption was recorded on a Nicolet 60SX FTIR spectrometer at a resolution of 4 cm^{-1} in the range 400-25000 cm^{-1}. Use of a microbeam chamber allowed for maximum energy output.

All samples were selected because they exhibit an absorption band at 3107 cm^{-1} that is particularly intense, generally comparable or superior in intensity to the intrinsic two-phonon diamond absorption around 2450 cm^{-1} (Figure 4. We indicate on this figure a position of 3105 cm^{-1}, not 3107, because our spectra are done at a resolution of 4 cm^{-1} only).

For this report, we have tentatively distinguished four types of H-rich diamonds on the basis of their properties: the 'brown to greyish-yellow family' (66 samples), the 'grey to violet family' (14), white diamonds (8) and finally 'chameleon diamonds' (36). 15 samples could not be classified because the necessary data were not available for various reasons. We call 'chameleon diamonds' those that typically change reversibly from a grey-green to a brighter yellow colour when heated in the flame of an alcohol lamp. Such photochromic behaviour was formerly described by Raal and Robinson (1982) in treated Type Ia diamonds and in some natural green diamonds from the South African gold mines (Raal, 1969). Brief gemmological reports on chameleon diamond behaviour can be found in Crowningshield (1975) and Fryer (1981, 1982).

Gemmological properties

Microscopic examination

Sixty-four of the 131 H-rich diamonds that are not white show colour zoning under low magnification. Generally, one or more distinct sectors having a brown or grey component to their colour are visible, limited by clearly defined, often planar, and sometimes smoothly curved surfaces (Figure 5). Some greyish-yellow diamonds show a grey-to-

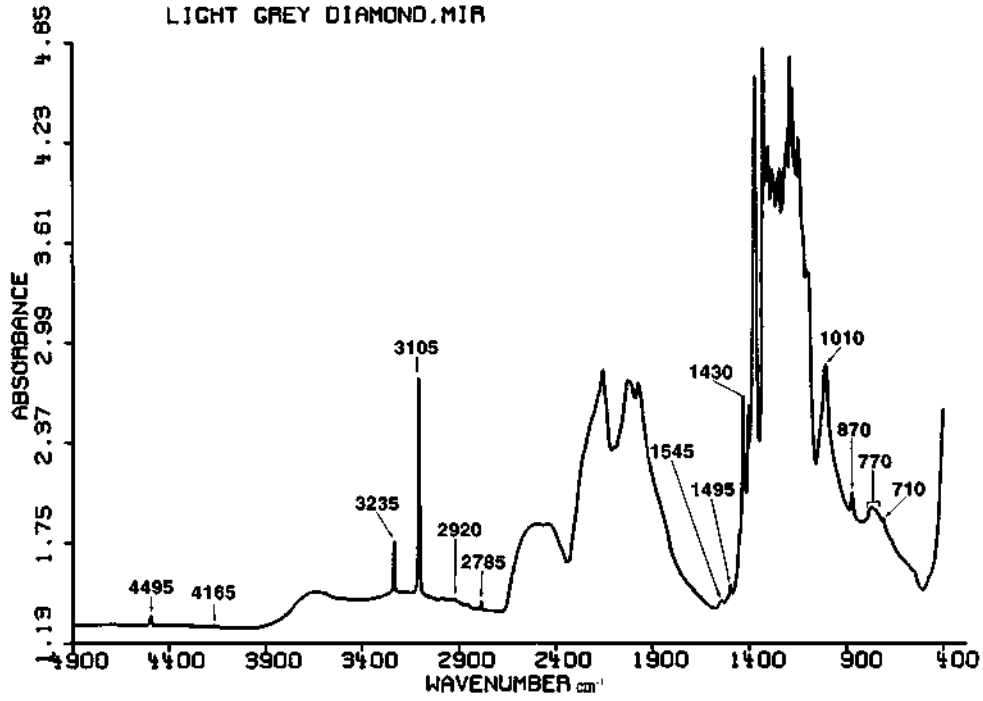


Fig. 4. Mid-infrared absorption of a light grey 'H-rich' diamond showing the intense H-related absorption at about 3105 and 3235 cm^{-1}

yellow colour zoning, also clearly limited by planar boundaries (Figure 6a). In some instances, a thin colourless layer can be observed between the two coloured zones (Figure 6b).

These brown or grey sectors contain clouds of sub-microscopic inclusions of unknown nature (Figure 6c). These clouds often occupy the entire colour zone. Sometimes, they form a petal-like pattern in certain directions (Figure 7), with more or less convoluted contours. Clouds of similar light-scattering inclusions are observed throughout the eight white diamonds, to which they impart their white colour. Rarely, white diamonds show some hint of sectorial growth as well.

There is generally no prominent graining in H-rich diamonds. When present, it is visible at the limit of the various colour zones.

Between crossed polarizers, H-rich diamonds show typically little anomalous birefringence ('strain'), usually producing interference colours of the first order and beginning of the second order. The pattern follows that of the colour zoning and is referred to as 'sectorial strain' (Figure 8).

Ultraviolet luminescence

With the exception of white diamonds, which tend to fluoresce blue to green, untreated, H-rich diamonds typically fluoresce yellow, more strongly in long-wave ultraviolet light than in short-wave. The luminescence colour might show a nuance of green or orange, but this nuance in colour description might simply be due to different colour perceptions by different observers. This ultraviolet luminescence is often followed by a yellow phosphorescence, which varies in intensity and duration from sample to sample. We have observed this phosphorescence in 70 per cent of the non-white samples. It is extremely strong and long-lasting (longer than one minute, in some cases longer than five minutes) for chameleon diamonds; this unusual luminescence behaviour is actually one of the most efficient ways to recognize chameleon diamonds.

Forty of our H-rich diamonds show a zonation of their luminescence. This zonation can take two different appearances. First, the luminescence zonation may follow the sectorial colour zoning. The most spectacular pattern is observed in some diamonds zoned yellow and grey: the grey areas fluoresce and phosphoresce yellow, while the yellow areas fluoresce blue (Figure 9a). Secondly, the luminescence may follow the clouds and the cloud area will fluoresce a strong yellow, in contrast with the rest of the stone (Figure 9b).

Gemmological spectroscopy

In most cases, the spectrum observed with the hand-held spectroscope at room temperature or

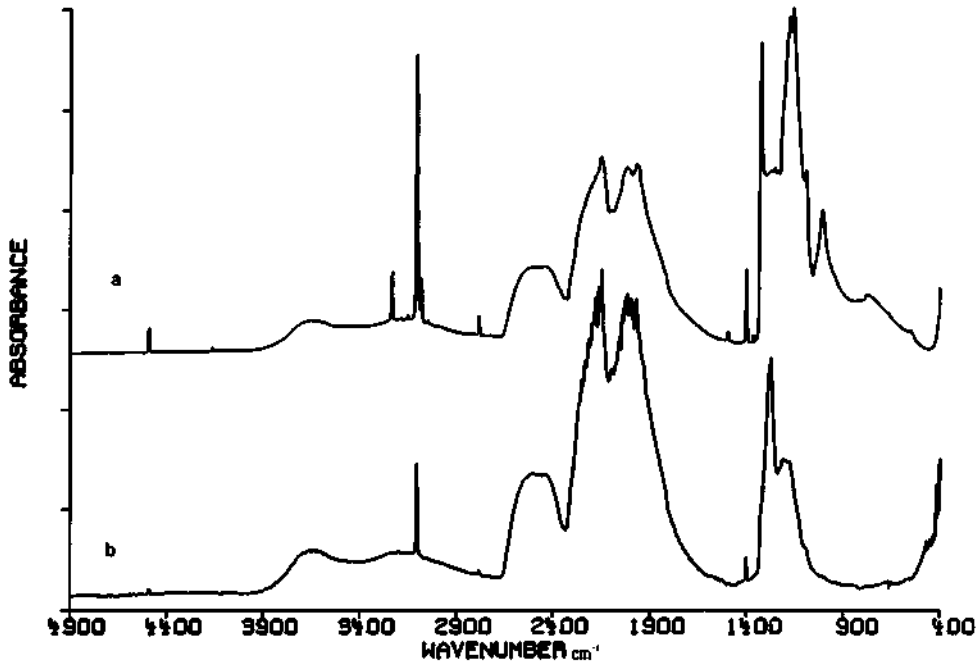


Fig. 10. Typical mid-infrared absorption spectra of (a) white and (b) chameleon diamonds. White diamonds are generally pure Type IaB, while 'chameleon diamonds' are pure Type IaA.

with cryogenic cooling is not helpful in identifying the diamond as containing large amounts of hydrogen, since it generally shows Cape lines at about 415 and 478 nm, common in all Type Ia diamonds. Crowningshield (1969) reported a 4.28 ct dark bluish-grey diamond with a sharp absorption at about 548 nm and a zoned blue and yellow luminescence, which might very well have been an H-rich diamond. We have observed on three stones (out of 97) an absorption line at about 545 nm of medium width (which may correspond to Crowningshield's observation) and in two stones a sharp line slightly above 560 nm. Only in these rare instances can gemmological spectroscopy help recognize an H-rich diamond.

Infrared absorption spectroscopy

Infrared absorption results show that all H-rich diamonds examined in this study are Type Ia, that is they contain aggregated nitrogen (for a detailed discussion of diamond types, see Fritsch and Scarratt, 1992). All chameleon diamonds we examined were pure Type IaA stones, whereas all of our white diamonds were pure Type IaB diamonds (Figure 10). It should be noted that we have encountered on occasions chameleon and white diamonds that did not show quite intense enough a 3107 cm^{-1} band to satisfy our criterion, although they were always close.

In correlation with the presence of intense H-related absorptions at 3107 cm^{-1} and 1405 cm^{-1} (the latter often masked by nitrogen-related absorptions) and their overtones, combinations and companion lines described previously (Davies *et al.*, 1984), we have also observed:

(1) three sharp bands around 6070, 5880 and 5555 cm^{-1} (Figure 11a);
(2) up to four bands of decreasing intensity centered around 7500, 7850, 8255 and 8615 cm^{-1}, forming possibly a vibronic structure (again, see Figure 11a); and
(3) a number of strong, broad absorptions of complex shape between 9000 and 11000 cm^{-1} (roughly 900 to 1100 nm; Figure 11b).

The newly discovered sharp bands at 6070, 5880 and 5555 cm^{-1} are believed to be, respectively, an overtone (2 $h_{\omega}s$), a new combination ($h_{\omega}s + 2h_{\omega}b$) and another overtone (4 $h_{\omega}b$) of the fundamental 'C-H' vibrations at 1405 ($h_{\omega}b$) and 3107 cm^{-1} ($h_{\omega}s$). It appears that Woods and others reported at the 1987 De Beers Diamond Research Conference the discovery of a new line at 6072 cm^{-1}, which they attributed to the first overtone of the 3107 cm^{-1} line, however these results were never formally published.

The well-known H-related absorption at 3235 cm^{-1} seems to be systematically more intense for diamonds belonging to the grey to violet family. In

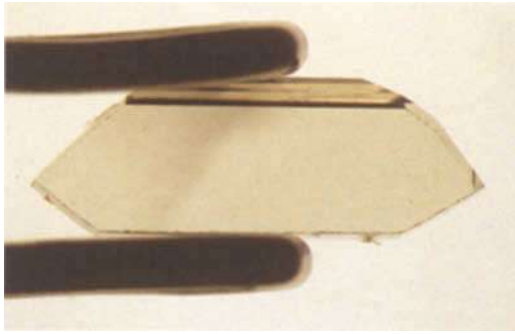


Fig. 6. (a) Yellow-and-grey planar colour zoning is seen using diffused light in a slab cut from the 0.28 ct greyish-yellow H-rich diamond illustrated in Figure 1. Magnification 4x.

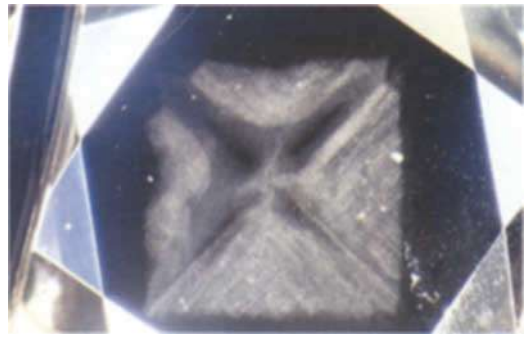


Fig. 7. The square cloud observed in a slab of the 1.02 ct light brownish-yellow diamond shown in Figure 1 exhibits four less-included lobes forming a pattern reminiscent of a flower. Magnification 7x. *Photomicrograph Emmanuel Fritsch*

Fig. 6. (b) Observation at higher magnification demonstrates that a thin colourless layer exists between the yellow and grey colour zones seen in (a). Magnification 10x.

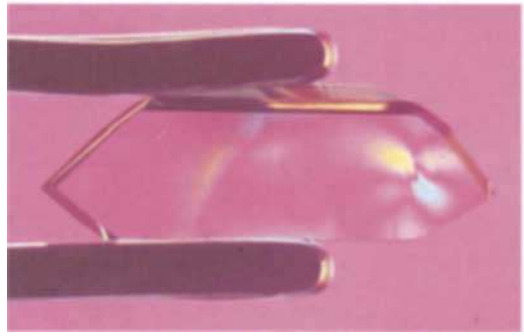


Fig. 8. The 'strain' observed between crossed polarizers in H-rich diamonds is generally weak. It also follows the pattern of colour zoning, as seen in this slab cut from the 0.28 ct greyish-yellow diamond shown in Figure 1 (compare also with Figure 6 a, b and c). The contrast of interference colours has been enhanced using a first order red compensator. A small, atypical strain centre is also present in this stone. Magnification 4x. *Photomicrograph Emmanuel Fritsch*

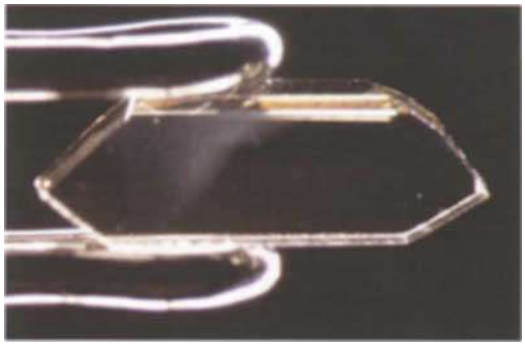


Fig. 6. (c) Observation in dark-field show that the grey colour zone seen in (a) corresponds to a cloud. Magnification 4x. *Photomicrographs Emmanuel Fritsch*

the very few cases when the shape of the faceted stone permitted, it was possible to demonstrate that H-related infrared absorptions in general are more intense in the grey or brown sectors of the stones (which also correspond to the clouds).

Using vacuum fusion analysis, Chrenko and Strong measured in a stone with 'very strong' hydrogen absorptions a hydrogen concentration of 400 at. ppm (Chrenko and Strong, 1975). One can therefore speculate that the hydrogen concentration in 'H-rich' diamonds would be of the order of 100 to 1000 ppm. Attempts to quantify the amount of hydrogen present in 'H-rich' stones studied in this report have so far been unsuccessful. This is because most non-destructive experimental techniques available today to

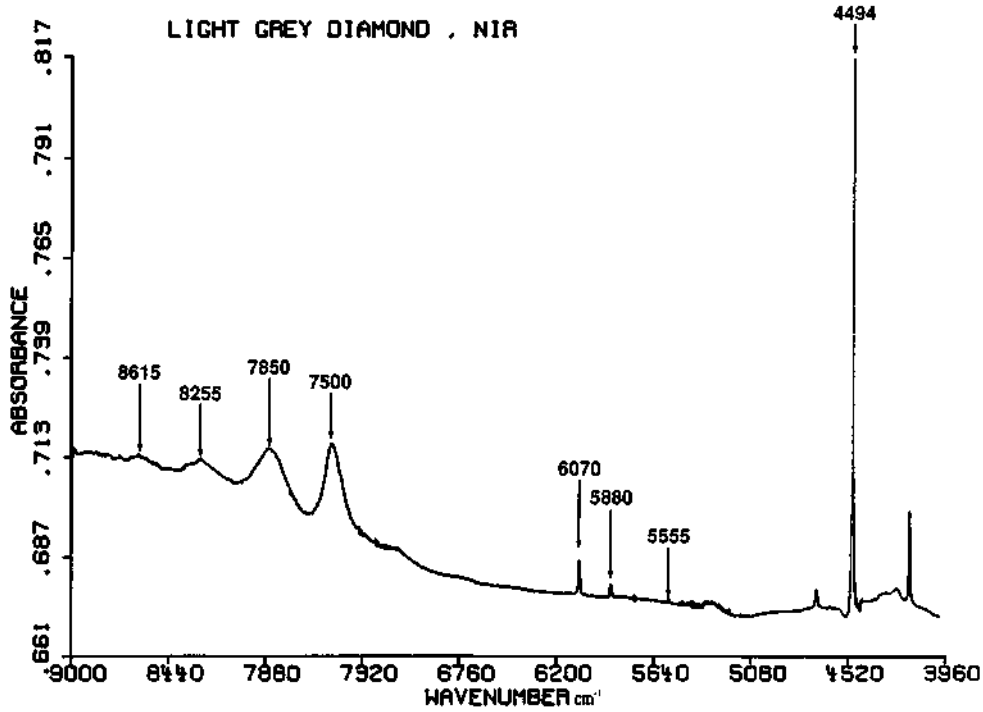


Fig. 11a

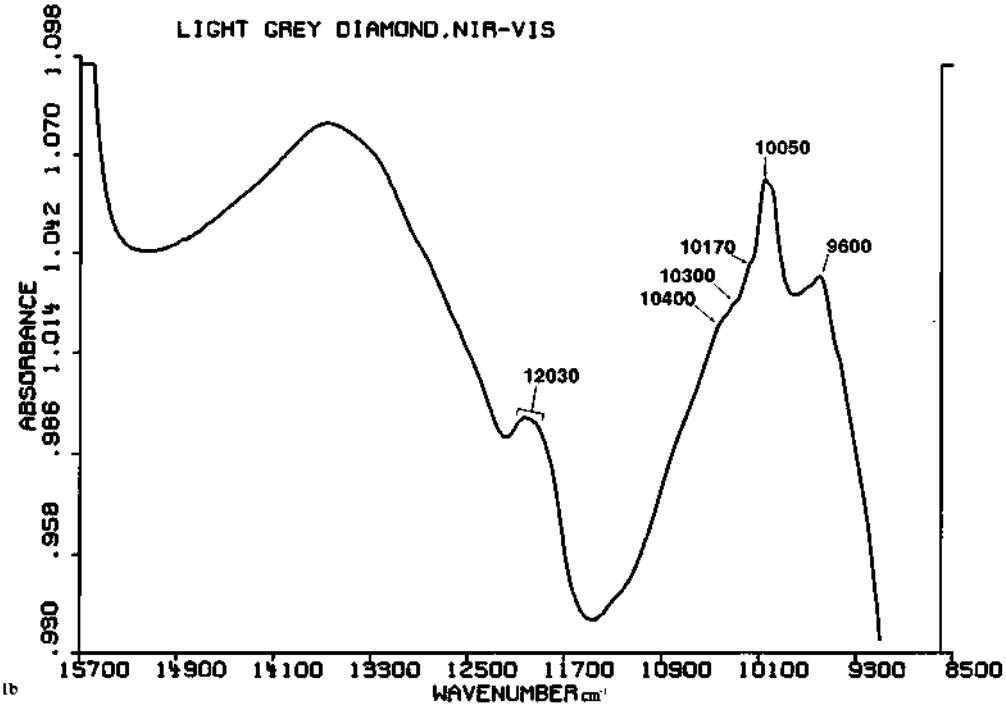


Fig. 11b

Fig. 11. Near-infrared (a) and near-infrared-visible (b) absorption spectra of a light grey H-rich diamond showing some of the newly discovered hydrogen-related bands, for example at 6070, 5880 and 5555 cm^{-1}.

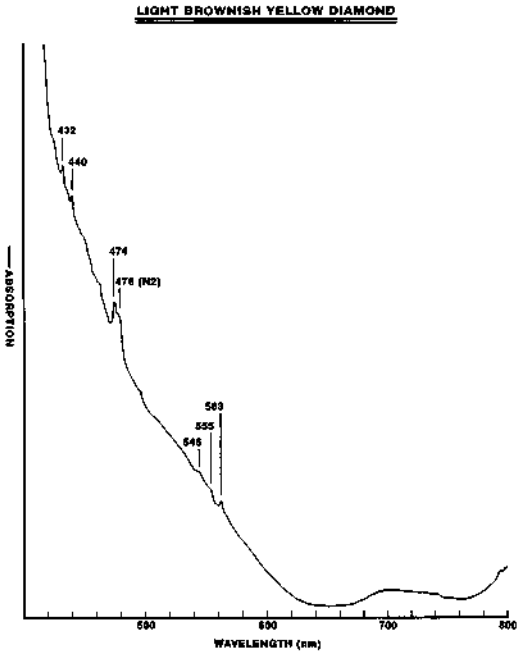


Fig. 12. Ultraviolet-visible absorption spectrum taken at liquid-nitrogen temperature of a 1.02 ct light brownish-yellow diamond illustrated in Figure 1, typical of the 'brown to greyish-yellow family' of H-rich diamond, shows a sharp absorption band at 563 nm and other associated bands (see text) believed to be due to hydrogen-related defects.

measure the concentration of hydrogen in diamonds are not suited to measure concentrations of the order of magnitude expected in our samples.

Ultraviolet-visible absorption spectroscopy

Since all these stones are Type Ia diamonds, the N2 and N3 centres (with major absorptions at 478 and 415 nm respectively), corresponding to nitrogen aggregates, have often been found associated with the features described below.

A typical spectrum of diamonds belonging to the 'brown to greyish yellow family', first described by Scarratt (1986) and illustrated in Figure 12, is characterized by a regular increase of the absorption from the red toward the violet, which is responsible for the dominant brown to greyish-yellow coloration. On this major absorption feature are superimposed a very broad band centred around 700 nm, a weak but sharp band at about 563 nm accompanied by wider bands (possibly phonon side bands) at 555 and especially 545 nm, a moderate to strong band at 474 nm and two sharp bands at 440 and 432 nm. On one occasion, the broad 700 nm band, which absorbs mostly the red end of the visible spectrum, was strong enough compared to the other features to give rise to a primarily green coloration (with yellow and grey overtones).

The 'grey to violet family' of H-rich diamonds shows a typical spectrum (Figure 13) containing a broad band centred around 700 to 730 nm, a broad, composite absorption feature located between 500 and 600 nm, and weak, sharp bands at 448, 444, 425, 415, 404 and 380 nm. In bluish-grey stones (see Fritsch and Scarratt, 1992), a broad maximum around 550 nm is always well individualized and a band at about 590 nm is present in greyish-violet stones.

The two categories of absorption features described above have been observed to our knowledge exclusively in H-rich diamonds, and not in other kinds of diamond. Therefore we suggest that H-related defects are responsible for such absorptions in the visible range, which affect the colour of diamonds. The exact nature of these defects is still unknown.

Chameleon diamonds display a typical spectrum (Figure 14) with a weak, broad feature centred around 700 nm, a broad band centred around 480 nm and a sharp band at 425 nm, which from our experience is a companion line to the 480 nm band. The 480 nm band is also known as the 2.6 eV band, and is commonly accompanied by a bright yellow luminescence and phosphorescence (Collins, 1982), as is the case for chameleon diamonds. The differences in absorption in one chameleon diamond between room and low temperature has been reported by Scarratt (1984) and demonstrates the importance of the reduction in the absorption of a very broad band centred in the near-infrared at about 800 nm to obtain the yellow colour. The difference in absorption between the stable, greener colour at room temperature and the yellow colour immediately after heating has not yet been recorded because of technical problems.

White diamonds show an apparent absorption increasing regularly toward the ultraviolet. This feature is not a true absorption and is actually the result of light scattering due to the 'cloud' of microscopic inclusions observed in such stones.

Discussion

There is no doubt that hydrogen-rich diamonds have been mined occasionally over the years. For example, we documented a hydrogen-rich diamond of unknown origin from the British Museum coloured green (by natural irradiation) that had been catalogued in 1934 (Shigley and Fritsch, 1990). We also report here on three H-rich stones from India, the major

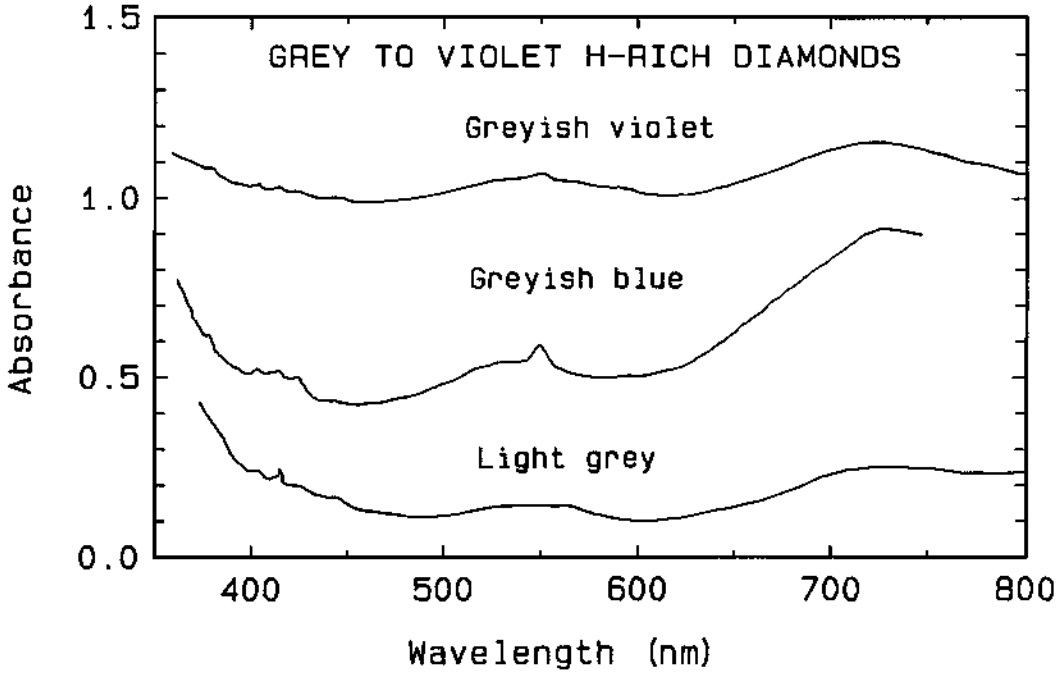


Fig. 13. Ultraviolet-visible absorption spectra taken at liquid-nitrogen temperature of three H-rich diamonds from the 'grey to violet family', all exhibit a broad band at about 550 nm.

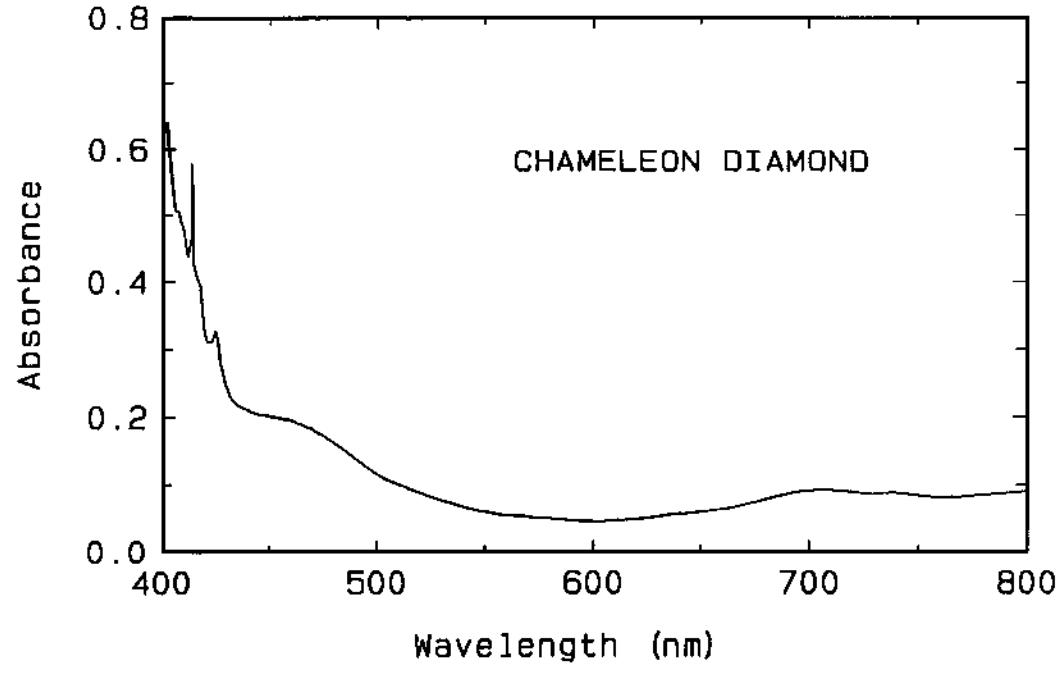


Fig. 14. Typical ultraviolet-visible absorption spectrum taken at liquid-nitrogen temperature of a chameleon diamond, showing the typical broad band centred around 480 nm and its sharper companion band at about 425 nm.

diamond-producing country until the eighteenth century. Thus, there is a strong likelihood that this locality produced more such diamonds over the centuries.

However, the number of hydrogen-rich diamonds present in the gem market has greatly increased, starting in the mid-1980s. One wonders what might be the cause of this sudden abundance. A number of our samples are known to come from the Argyle mine in north-west Australia. This mine became fully operational only in 1985. In addition, hydrogen-rich diamonds have been reported from the Jwaneng mine in Botswana, where commercial recovery of diamonds started in 1982 (Welbourn *et al.*, 1989). Therefore, these two relatively recent mines could be the source of these suddenly common H-rich diamonds.

The pattern of colour zones and clouds observed in H-rich diamonds, as well as their luminescence behaviour and infrared absorption spectra, is similar to that of cuboid internal growth sectors observed in rough diamonds of cube or cube-related shape from the Jwaneng mine in Botswana (Welbourn *et al.*, 1989). Cuboid growth in diamond is a nonfaceted growth along non-crystallographic surfaces of mean {100} orientation (Lang, 1974). It is interesting to note also that the luminescence and colour zonation described above have a symmetry consistent with the grey to brown sectors being cuboid growth sectors. The greenish-yellow luminescence of Jwaneng diamonds is attributed, at least in part, to the S1 and S3 centres (Welbourn *et al.*, 1989) and the same centres could be the source of the yellow luminescence observed in our samples. Welbourn and his co-workers also observed in some cases the zoned yellow and blue luminescence we described above. The clouds in their samples were formed by light-scattering defects in the form of thin discs, about one micrometre in diameter, lying on the {111} planes (Walmsley *et al.*, 1987). These defects could be the physical location of the hydrogen impurity.

The singular fact that none of our samples was a Type II diamond merits comment. To date, no natural Type II diamond has been documented as showing any H-related absorption. One pragmatic explanation is that the presence of nitrogen is necessary for the incorporation of hydrogen in diamond (Fritsch and Scarratt, 1989). But the hydrogen-related absorptions we observe have been proved conclusively by isotopic studies to be due to C-H vibrations (Woods and Collins, 1983) and the same authors identified N-H-related absorptions at different energies between 3300 and 3400 cm^{-1}. In addition, one should note that the $\delta^{13}C$ of Type IIa diamonds in several localities tends to be on average much lower than that of Type I diamonds (Harris, 1989). This difference in carbon isotope ratio suggests that Type II diamonds may have a somewhat different geological origin from Type Ia diamonds. Consequently, hydrogen might be found only in the environment in which Type I diamonds grow.

Conclusion

We have demonstrated that in natural diamonds, hydrogen induces absorptions in both the infrared and the visible range, some of which had never been described before. Some of those absorptions result in a fairly intense coloration, to include a greyish-blue colour formerly thought typical of Type IIb diamonds and a violet colour never before encountered in natural diamonds. In addition, broad, prominent H-related absorptions are found in the near-infrared, a spectral region in

Fig. 9a. Zoning of the ultraviolet luminescence has been observed in a number of H-rich diamonds, and can take two different appearances: (a) in H-rich diamonds showing a yellow and grey planar colour zoning, the yellow zone fluoresces blue and the grey zone yellow, as in this slab from a 0.28 ct greyish-yellow diamond already illustrated in Figures 1, 6 and 8.

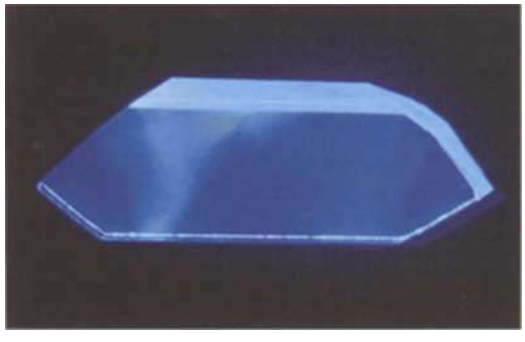
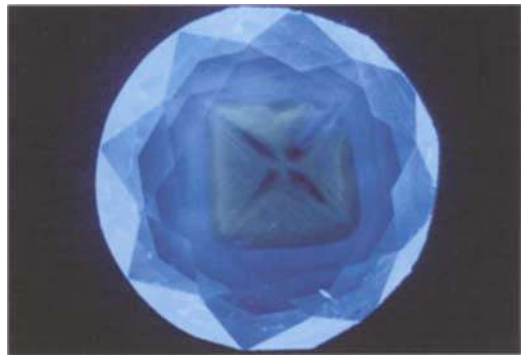


Fig. 9b. The cloud in this slab from a brownish-yellow 1.02 ct diamond – already illustrated in Figures 1 and 7 – fluoresces a strong yellow in long-wave, in contrast with the rest of the stone, which in this case fluoresces blue. *Photomicrographs John Koivula*



which diamonds are generally considered perfectly transparent. Our observations suggest that these diamonds result from mixed growth, with both octahedral and cuboid growth sectors.

In many cases, H-rich diamonds can be easily identified by classical gemmological observations on the basis of their colour appearance, combined with their internal zonation, type of inclusions and typical ultraviolet luminescence. Rarely hand-held absorption spectroscopy can help. Because those H-rich diamonds belonging to the 'brown to greyish-yellow' and 'grey to violet' families present body colours generally judged unattractive, they have commonly been treated to produce green and yellow colours deemed more attractive.

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The glass filling of diamonds
Part 1: an explanation of the colour flashes

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Abstract

An explanation is given for the appearance of bright colour flashes associated with regions bordering the fissure-fillings of diamonds and other gemstones. A procedure is outlined for determining the exact spectral wavelength at which the infilling glass and the diamond possess the same refractive index.

The diamond colour flashes

As with emeralds, brilliant colour flashes are associated with diamond fissure filling. Compared with Opticon-filled emeralds, the situation is different for diamonds. Apart from the coloured fancies, those of the Cape series increase in value as they approach the entirely colourless state. Any mechanism contributing to an enhanced body colour would lower their commercial attractiveness. The colour-flashing is such a mechanism. An understanding of the mechanism responsible for this optical phenomenon is the first step towards its management.

The cause of the flashes

Some months before this paper was submitted for publication, the writer had attended a slide-illustrated lecture by E.A. Jobbins[1] on the microscopical observations on fissure-filled diamonds. It was during this lecture that the writer immediately recognized the cause of this hitherto unexplained effect. It was clear to him that its mechanism was identical to that of an optical effect of which he had made regular use for the past twenty-five years! He has to confess that while he had read the seminal paper published in 1989[2] by members of the laboratories of the Gemological Institute of America, he had totally failed to appreciate the connection at that time.

This laboratory procedure was one which allowed the positive identification of small particles or fibres of different substances which had been immersed in suitable microscopical slide preparations. Its analytical principle was derived from a monochromatizing light filter invented by Christiansen in 1884[3]. The principle was first transformed into a polarized light microscope unit by Crossmon in 1948[4]. Further improvements were made later by Cherkasov in 1957[5] and by Schmidt in 1958[6]. It was finally worked up into a commercially-available system by Brown and McCrone in 1963[7], who named it *'optical dispersion staining'* for the systematic identification of all transparent substances, whether crystalline or not. It has since been a much-used technique and is employed world-wide, now mainly in the identification of all asbestos minerals and their substitutes.

The dispersion staining analytical system

Without doubt, the least painful way to explain the cause of the diamond colour flashes is to describe the workings of the dispersion staining system. There is no uncertainty whatever that the optical mechanisms involved are identical.

The system comprises four elements. The first is a polarized light microscope on to the nosepiece of which can be coupled the Brown-McCrone *dispersion staining objective*. The second is a set of calibrated high refractive index immersion liquids, and the third a data bank of refractive index and dispersion data on many hundreds of the commoner minerals and chemical compounds. The fourth element consists of a graphical procedure for converting the observed dispersion staining colours into numerical statements on the refractive index and dispersion of the unknown particle or fibre.

Dispersion staining colours

To produce the brightest colour effects, the particle and immersion liquid must have different dispersion curves which should have as disparate slopes as possible in the visible region. Referring to Figure 1, two hypothetical curves are shown as linear plots of refractive index (n) against wavelength (λ). It is seen that only at a single wavelength (termed λ_0), does the solid particle and the immersion liquid have the same refractive index. At λ_0, a clear, colourless, inclusion-free, solid particle, of whatever shape, will be perfectly

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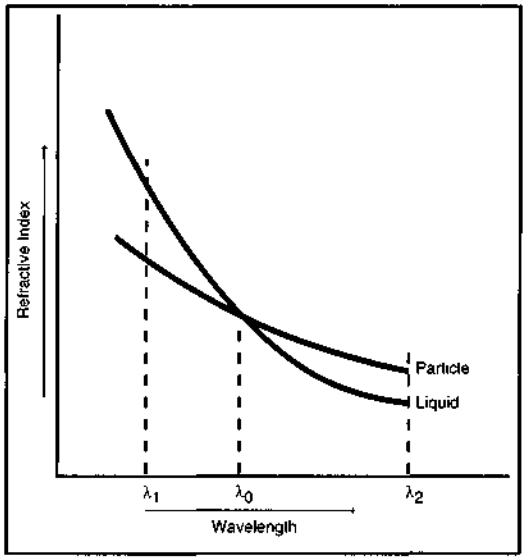

Fig. 1. Hypothetical dispersion curves for particle and liquid showing a match in refractive index at λ_0.

invisible in a colourless liquid. However, on either side of λ_0, say at λ_1 and λ_2, optical discontinuities will exist and the particle's boundaries will be clearly visible.

The microscopy of dispersion staining

Consider the situation illustrated in Figure 2. This is a representation of the microscopical dispersion staining of a lens-shaped colourless particle or small crystal immersed in a thin layer of liquid enclosed between a microscope slide and a cover slip.

A parallel beam of white light from the microscope's condenser-and-iris illuminator (not shown) is directed upwards to the slide preparation. The liquid has been chosen so that it has the same refractive index as the particle at a wavelength of 580 nanometres. This wavelength corresponds approximately to a yellow light. While all visible spectral wavelengths are present in the white light beam, for the purpose of clarifying the dispersion colour-staining mechanism, only three are considered, namely red (650nm), yellow (580nm) and blue (470nm).

In Figure 2A, a small annular diaphragm or stop is shown lying in the back focal plane of the microscope's objective. Its purpose is to allow the yellow unrefracted rays to pass through to the imaging plane. Because of the wavelength dispersing behaviour of the prism-like structure of the particle, the mismatching blue and red rays are bent away in opposite directions from the undeviated yellow rays. The annular stop prevents them from reaching the imaging plane. *As a consequence, the particle is perceived as a white image having a yellow boundary and is seen against a white background.*

In Figure 2B, a central stop diaphragm is placed in the back focal plane. Its effect is to stop the unrefracted yellow rays from the particle and the unscattered white light from the source from passing into the image space. Instead, the mismatching red and blue rays are allowed to pass through. *Thus when a central stop is used, the particle appears as a dark image with purple (i.e. a mixture*

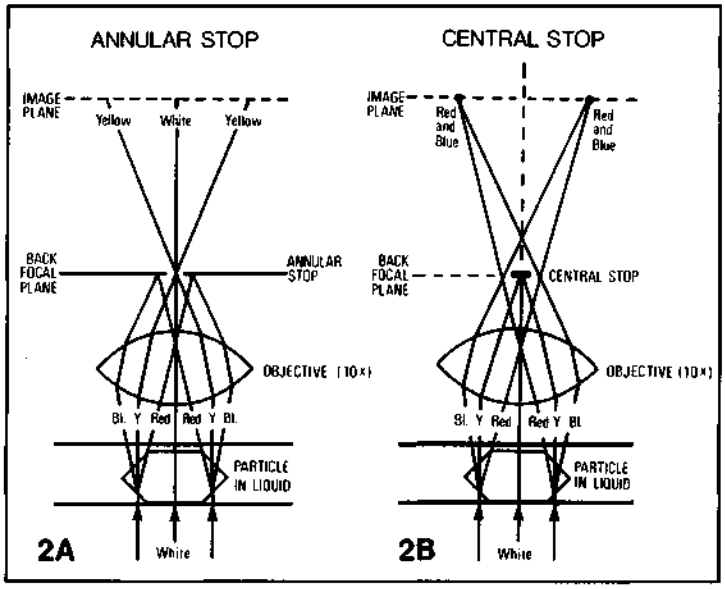

Fig. 2. Schematic representation of dispersion staining for three colours, red (λ = 650nm), yellow (λ = 580nm) and blue (λ = 470nm).

Fig. 3. The McCrone dispersion staining microscope objective.

of red and blue rays) borders, seen against a dark background.

The dispersion staining microscope objective (Figure 3) is equipped with a 10 times magnification objective lens and a rotating-disc which permits the insertion into the objective's back focal plane of either an *annular stop* or a *central stop*. A third click- stop setting allows both to be moved aside so that the full aperture of the back focal plane can be inspected for alignment purposes. Thus the colours seen at the borders of the uncoloured body of the particle are quite different for the two kinds of stops.

The purpose of both stops is to generate the 'staining' colours at the particle's boundaries. From the kind of colours seen, an estimate can be made of the matching wavelength (λ_o) when the n values of the particle and that of a chosen immersion liquid are identical. The liquids most often used in routine particle identifications are available in a convenient set of 31 Cargille Certified High Refractive Index Liquids ranging in n_D values from 1.500 to 1.800 in 0.010 steps.

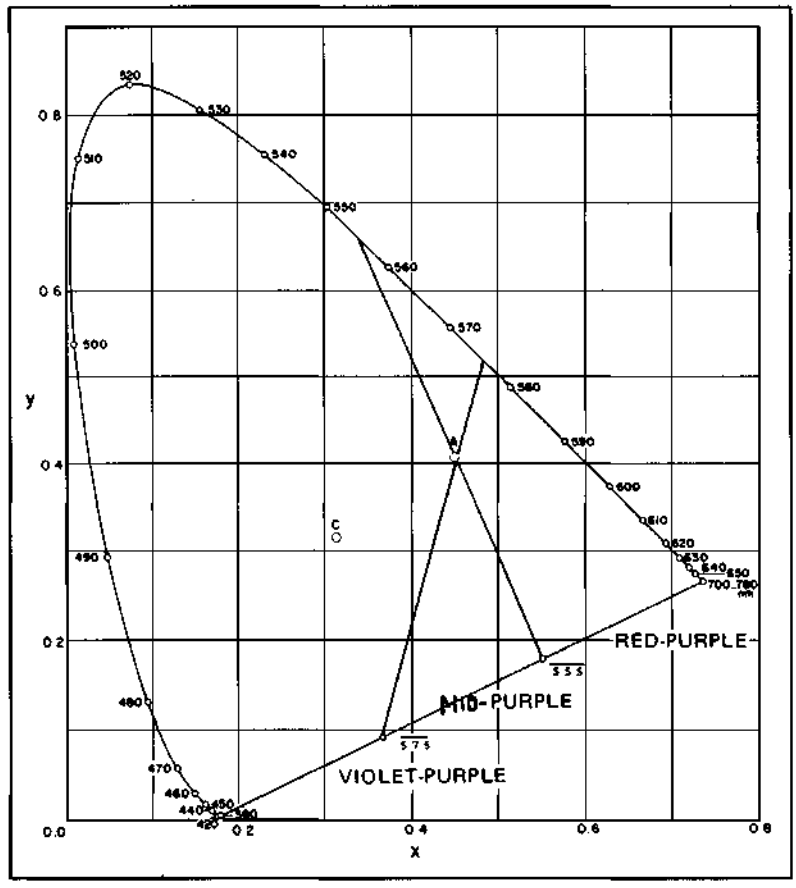

Fig. 4. The CIE (1931) Chromaticity Diagram.

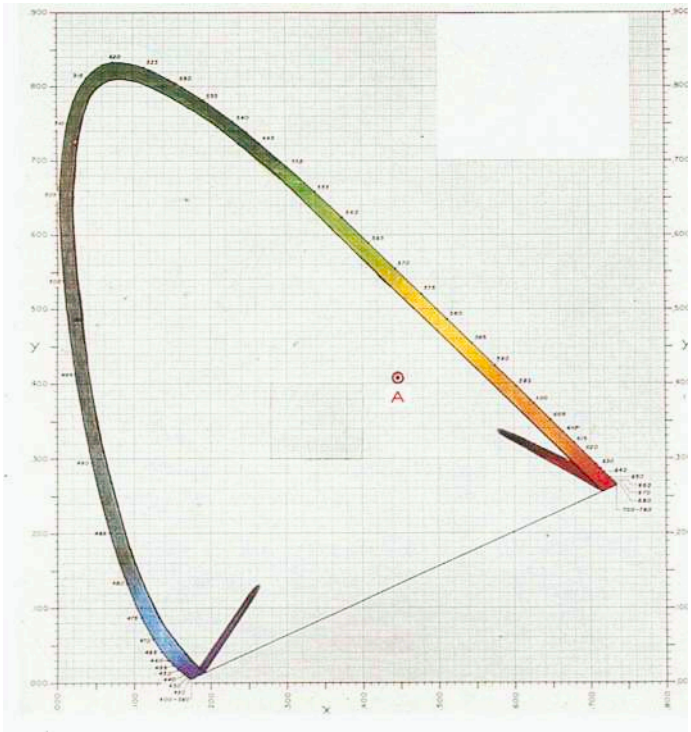

Fig. 5. The CIE Chromaticity Diagram showing the idealized dispersion staining colours for the annular stop mode. CIE Illuminant 'A'.

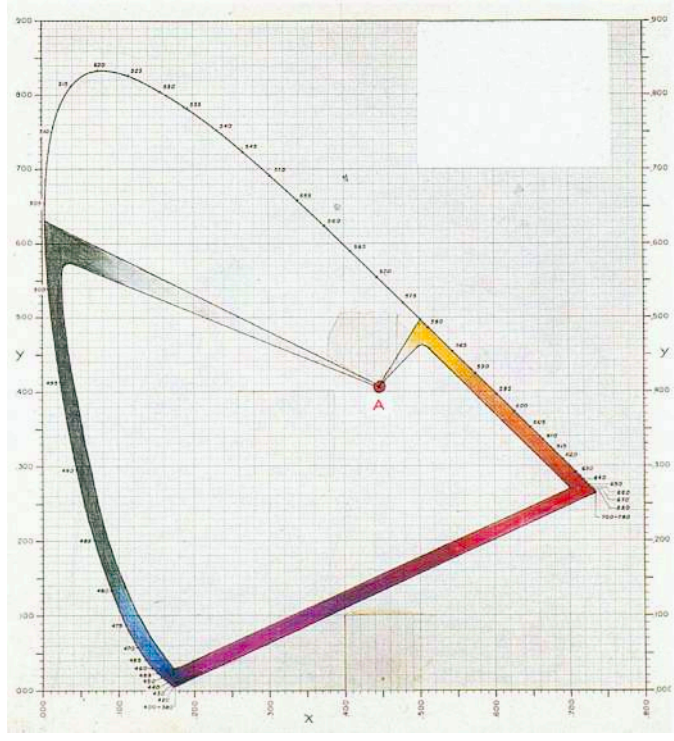

Fig. 6. The CIE Chromaticity Diagram showing the idealized dispersion staining colours for the central stop mode. CIE Illuminant 'A'.

They are stable liquids whose n values have been accurately calibrated at three wavelengths (the C, D and F lines of the solar spectrum).

The kind of microscope illumination used is important, as reproducible dispersion colours depend on the colour temperature of the light source. A 20 watt condensed tungsten filament lamp is preferred. It is operated slightly above the normal rated voltage. Such a white light source corresponds closely to the C.I.E. Standard Illuminant 'A', having a colour temperature of 2855K. [8,9] The central stop is the one most frequently used. However, inspection of the annular stop colours can yield a second judgement of the λ_o value of the particle or fibre. The dispersion staining colours observed for both annular and central stops are shown in Table 1.

The CIE Chromaticity Diagram

The CIE (1931) Chromaticity Diagram[8,9] is a helpful way of visualizing dispersion staining colours and in assigning λ_o values to them. The diagram shown in Figure 4 represents the spectral colours as a curved distorted triangle with their wavelengths marked around it. Spectral mixtures of violet and red are known as the spectral purples and these all fall on the straight line joining the violet and red end-members. The purples are arbitrarily divided into three sections, namely the violet-purples, the mid-purples and the red-purples. The divisions are made at values of λ at $\overline{575}$and $\overline{555}$. The 'purple bar' placed over the numbers indicate that these colours are complementary to the spectral colours at 575 (yellow) and 555 (green-yellow) respectively. They are linked through the white point, here taken as the CIE Illuminant 'A'. A particular advantage of this diagram is its ability to show corresponding annular and central stop colours, i.e. complementary colours at opposite spectral ends of a straight line passing through the chosen white source.

A Chromaticity Diagram showing the idealized dispersion staining colours for the annular stop mode is shown in Figure 5. It can be seen that all the spectral colours are represented except the spectral purples.

The corresponding diagram for the central stop mode is shown in Figure 6. All the purples are present, but the spectral colours in the continuous region between the blue-green at λ = 504nm and the yellow at λ = 579 are absent (see Table 1).

Dispersion Staining Charts

The most convenient way of presenting and using dispersion colour information is not by plotting the usual direct *dispersion curves* (Figure 7A, left-hand graph), but as *dispersion staining curves* (Figure 7B, right-hand graph). In the latter graph, the refractive index for the sodium D line of the matching Cargille liquid (n_D^{25}) is plotted against a function of the matching wavelength (λ_o).

Table 1: Dispersion staining colours using a CIE Standard Illuminant 'A' (colour temperature of 2855K)

Spectral Colours*			Annular Stop Colours		Central Stop Colours	
Colour	λ *range in nm*	λ *(mean) in nm*	*Colour*	λ *in nm*	*Colour*	λ *in nm*
Violet	400-450	440	Dark violet to violet	440	Pale yellow†	579
Blue	450-480	470	Blue	470	Yellow	581
Blue-green	480-510	495	Blue-green	495	Orange	$\overline{594}$
Green	510-550	530	Green	530	Red-purple	$\overline{530}$
Green-yellow	550-570	560	Green-yellow	560	Mid-purple	$\overline{560}$
Yellow	570-590	580	Yellow	580	Blue	460
Orange	590-630	605	Orange	605	Blue-green	500
Red	630-700	650	Red to dark red	650	Pale blue- green†	504

* These are the spectral colours according to Wright[9]. The boundaries between the colours are arbitrary since no sharp upper or lower limits can be assigned in the continuous white spectrum.

† The dispersion colours are virtually pure spectral colours in the annular stop mode. This is also so for the central stop mode, except for the λ values above about 485nm and below 595nm when desaturation begins to increase gradually. No dispersion colours will be seen in either mode if the n values of the particle and liquid are too far apart to match at any wavelength in the visible region. Also, in principle of course, no dispersion colours would ever be seen if the n values and dispersions of the particle and liquid were identical. This would be an unlikely occurrence.

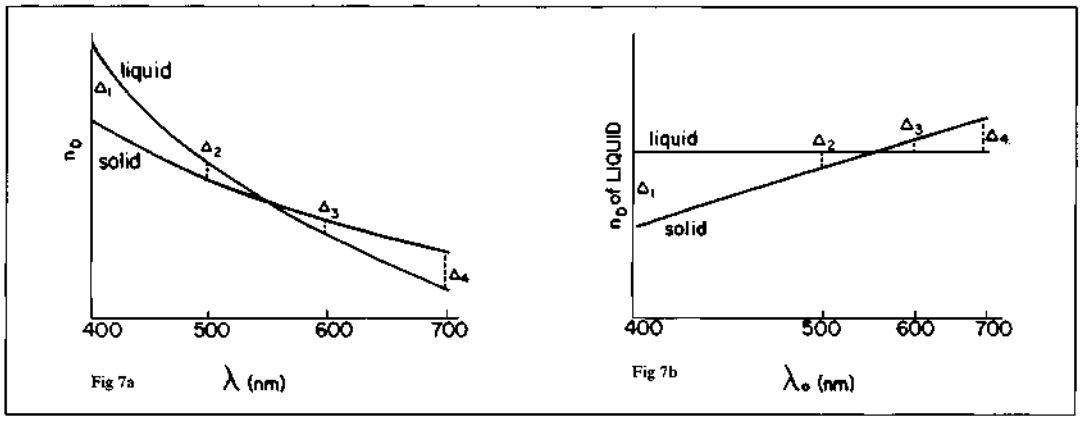

Fig. 7. The derivation of the analytical dispersion staining graphs of (7B) from the conventional dispersion graphs of (7A).

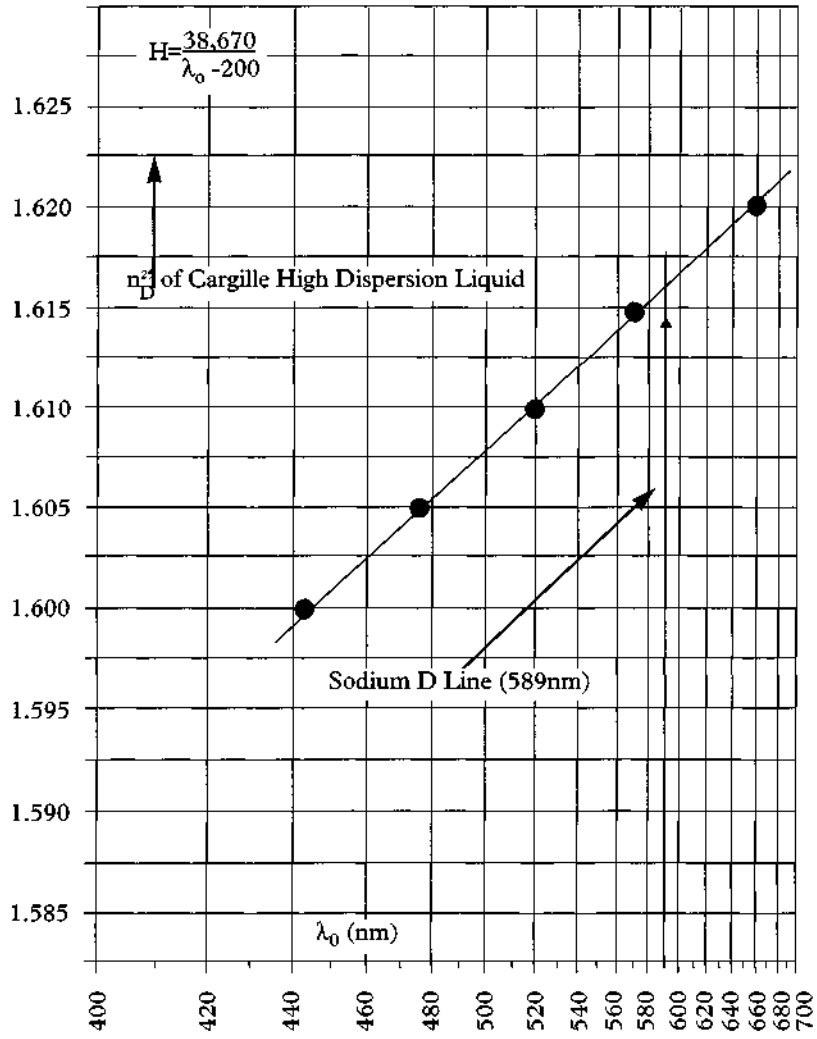

Fig. 8. The dispersion staining chart for an unknown crystal, showing the smoothed graph of estimated λ_o plots. Central stop. CIE Illuminant 'A'. The n_D value for the crystal is seen to be 1.616.

The wavelength scale adopted is that used in the Hartmann dispersion relationship:†

$$H = \frac{K}{\lambda - 200}$$

where λ = wavelength (nm),
K = a constant,
and H = distance (mm) along the scale corresponding to a given value of λ.

[For a λ range from 400 to 700nm, corresponding to a scale length of 180 mm, K has a value of 60 000.]

In this way, the dispersion staining curves of materials plot almost invariably as straight inclined lines, with the Cargille liquids plotting as horizontal straight lines. Thus the dispersion staining curve gives directly the matching wavelength (λ_o) in each liquid (identified by its n_D^{25} as ordinate). The prefix '25' is the calibration temperature in °C of the Cargille liquid.

An example is given here of the dispersion staining analysis of an unknown white crystalline powder. The central stop mode and Illuminant 'A' were used. The dispersion staining colours were noted for microscope slide preparations in which the powder was immersed in five different Cargille High Dispersion Liquids. The matching wavelength, λ_o, was estimated from the observed dispersion staining colours using the relationships listed in Table 1. The immersion liquids used were the Cargille (n_D^{25}) liquids 1.600, 1.605, 1.610, 1.615 and 1.620.

The estimated λ_o values were plotted on a Hartmann chart and the best straight line drawn through the plots. In this way, the n_D for the crystals was determined by interpolation at the point where the inclined dispersion staining graph intersected the vertical line corresponding to λ_o = 589nm. A value of n_D = 1.616 was found. A quick search through the comprehensive dispersion staining data tables[10] showed the crystals to be sodium bromate ($NaBrO_3$). The plot is shown in Figure 8.

As well as obtaining the actual n value at λ = 589nm for the crystals, it is possible from the same chart to find their n values for any of the other visible wavelengths. The procedure takes a little longer [11], but the results are just as accurate as for λ = 589nm. Thus the n values found for the standard (i.e. Cargille calibrations) solar spectrum lines 'C', 'D' and 'F' were n_{656} = 1.613; n_{589} = 1.616 and n_{486} = 1.624, respectively.

†This relationship provides a simple means of approximating the conventional optical dispersion curves (i.e., change in n with λ) from two points only. A straight line connecting the two points permits interpolation, and perhaps even extrapolation, with considerable accuracy.

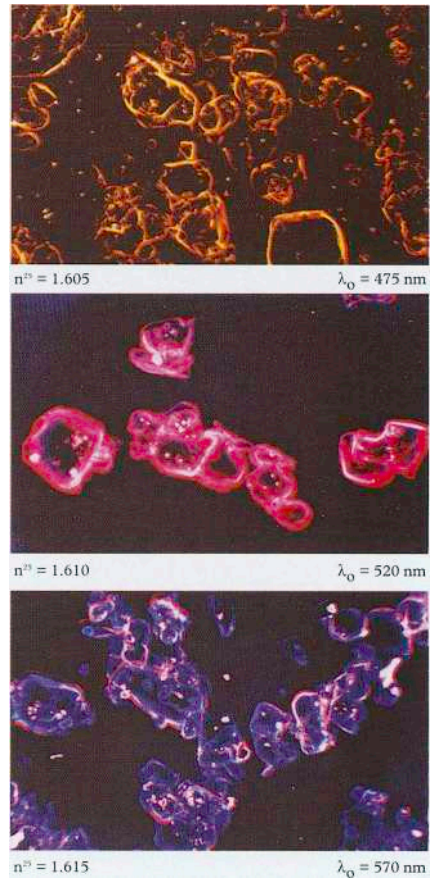

Fig. 9. Photomicrographs of unknown crystals mounted in High Dispersion Cargille Liquids of n_D = 1.605, 1.610 and 1.615. Central stop. CIE Illuminant 'A'. Magnification X80.

Three of the preparations were photographed and the results are shown in Figure 9.

The dispersion staining colours of diamond fillings

By now it is apparent that the spectral colour flashes seen by *darkfield examination in a gemmological microscope* are indeed identical to those seen in the central stop mode of the dispersion staining objective of a polarized light microscope. They are the colours listed in Table 1 and shown in the chromaticity diagram of Figure 6.

As to be expected from a consideration of Figure 2B, the most intense colours will be seen in the extreme angular darkfield mode of a gemmological microscope and *only at a particular orientation* of the infilled diamond. This is the reason for the sudden brilliant flashes. These will occur when the planes of the cleavage infillings bisect the small angle formed by the narrow beam

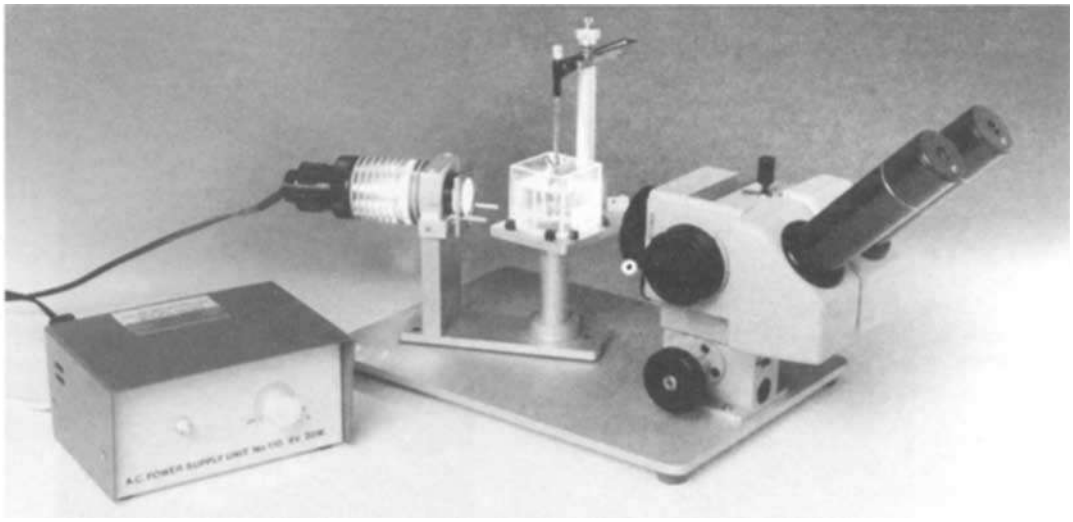

Fig. 10. A horizontal gemstone immersion microscope suitable for the determination of the λ_o value of the glass phase in filled diamonds.

of the light source and the optic axis of the microscope.

On the other hand, the examination of the infillings by the *brightfield (transmission) mode with a gemmological microscope*, the most intense spectral colours will be seen when the plane of the cleavage infillings lie parallel to the common direction of the light beam and the optic axis of the microscope's objective. As with the annular stop mode of the dispersion staining objective, the spectral purples are never seen. Instead, as shown in Table I and Figure 5, only the unmixed spectral colours are observed, and of these, the predominant colour flashes will be green and greenish-yellow.

In both darkfield and brightfield microscope images, the spectral colours will be rendered more monochromatic (i.e. unmixed with neighbouring wavelengths) if a nearly parallel beam of light from the illuminating source is employed. This is the equivalent of using a narrow slit in gemmological spectroscopes, whether prism or diffraction grating.

The optimum conditions for λ_o estimations

To specify these conditions, it is necessary to consider first the geometry and optics of a faceted diamond. This stone, like other gemstones, is designed to be an efficient retroreflector. It is similar to a motorway 'cat's-eye'. Direct transmission viewing of its interior is virtually impossible, either with unaided or magnified vision. In fact, the direct viewing in air of a stone using a single parallel beam of light in a back-reflection mode (darkfield) is not too simple a matter. Constant changing of the orientation of the stone in its holder is needed to inspect its whole interior. One convefitional American gemmological microscope overcomes this need for excessive stone manipulation by using an extended diffuse light source. Such an illuminant is not suitable for the detection of faint or narrow colour flashes.

Moreover, this light source invariably consists of a tubular fluorescent lamp having a colour temperature approaching and often exceeding that of the CIE daylight simulant Source 'C' (6775K). A glance at Figure 4 demonstrates the importance of the choice of illuminant. For a λ_o = 495nm, the darkfield colour with Source 'A' (2855K) is orange (λ = 593nm). With Source 'C', it is red-purple (λ = 495). Indeed, there are only two matching wavelengths where the 'A' and 'C' darkfield colours are identical. It can be seen that these occur at λ_o = 583nm and λ_o = 482nm.

It is the multiple total internal reflections which makes gemstone microscopy so different and troublesome. However, it is quite simple to frustrate or nearly eliminate these reflections by immersing the stone in a colourless liquid of even a moderate refractive index. The evident attractiveness of also using a single *directed*, rather than a strongly *diffused* light source, is testified by the rising popularity of horizontal immersion microscopes. With these, much more of a stone's interior can be seen at a single chosen orientation.

The ideal design requirement for a microscope suited to the present purpose is now clear. The desiderata are:

1. A condensed filament tungsten (non-halogen) lamp operated only at a colour temperature corresponding to Source 'A'. [A Source 'C' illumination yields no greater colour discrimination than Source 'A'. It is

more costly to ensure that it is indeed an accurate Source 'C'.]

2. The lamp to be coupled to a condenser lens so as to be capable of producing a broad parallel, or near-parallel beam of white light (i.e. without filters of any kind).
3. This source-assembly to be capable of being swung around an angle from a direct transmission (brightfield) mode to a back-reflection (darkfield) mode with the gemstone as the centre of rotation.
4. The stone in its holder to be capable of being easily manipulated and viewed in either air or in a square, parallel-sided, glass cell containing a suitable colourless immersion liquid.

It so happens that a microscope meeting these ideal requirements will also perform all or more of the tasks needed for routine and research gemmological microscopy.

It should be stated here that all compound gemmological microscopes can detect strong colour flashes, but for accurate quantitative results, a parallel or near-parallel light beam and a standard illuminant are essential. Even a simple 10x loupe can be used to see the colour of the flashes, but it must be remembered that examinations in daylight will result in wrong estimates of λ_o.

The darkfield mode is the one preferred by the writer. Here, the colour flashes are seen against a black background. With the brightfield mode, the flashes are seen against a white background and therefore appear to be less contrasty and more desaturated than they really are. Nevertheless, a note of the brightfield dispersion staining colours serves as a useful check on the λ_o estimation made by the darkfield mode.

The darkfield mode has also a surprising and valuable feature. It was discovered when trying to detect minute fibres of asbestos found in air samples using the central stop mode. With the 10x microscope objective in use, it was found to be almost impossible to see the true, resolved images of chrysotile-asbestos fibres less than about one micrometre in diameter. Despite this, the true dispersion staining colours of chrysotile fibres of down to 0.1 micrometre diameter were vividly seen in their full strength and saturation.

This behaviour seems to be a universal phenomenon. For example, although the true images of stars can never be resolved in even the largest telescopes, stars still show their own characteristic colours. For this reason, while not yet in a position to test this experimentally with the glass infillings, it is quite likely to hold good. If so, it means that if the molten glass manages to penetrate to the root of the thinnest fissure, colour flashes will reveal it. Here again, brightfield will not be nearly so sensitive.

Experimental Observations

Two Yehuda-filled diamonds of 0.37 and 0.39 carats were examined with a horizontal immersion microscope of the kind shown in Figure 10. Colourless benzyl benzoate ($n_D = 1.57$) was used as the immersion liquid, and the four optimum viewing conditions were followed.

Both stones displayed the same dispersion colours. The darkfield mode colours gave a λ_o value of about 560nm (mid-purple). This was confirmed by the brightfield mode, which showed a green-yellow flash. This meant that the glass and the diamond possessed the same n value at 560nm. A glance at the Hartmann dispersion chart of diamond (in Figure 11) shows diamond, and therefore the glass, to have an n value of 2.421_5 at $\lambda = 560$nm. Of course, no conclusion could be reached as to the magnitude of the dispersion of the n values of the glass. This could only be determined by the methods described in Part 2 (to be published in a future issue of the *Journal*). It is, of course, much greater than that of diamond.

When the stones were examined in air in the darkfield mode, the results were found to be identical to those of the immersed stones. However, still using this mode, but now in air, when the stones were slowly turned, sudden green-yellow colour flashes were seen against a bright background. This was indeed a puzzling behaviour, but the reason for this 'forbidden' colour flash was not difficult to uncover.

With the immersion cell, the diamond's total internal reflections were eliminated, but in air they played their normal, intended role in returning the light to the viewer. In this way, and at certain angles, they converted the back-reflection (darkfield mode) light beam into a transmission (brightfield) beam. As will be recalled, this green-yellow colour is the A-Source complementary colour to mid-purple.

These observations with the two Yehuda-filled diamonds confirmed all the experimental observations already reported[2]. In this Reference, the complementary colours seen however, were not those found during the present observations. The difference could well have arisen from the use by the six authors of the daylight fluorescent tube illumination. This explanation is entirely consistent with the facts as shown in Figure 4. It is also supported by a later note in 'Gem News' by two of the authors[12] who reported colours identical to those seen by the writer. Here they made use of a

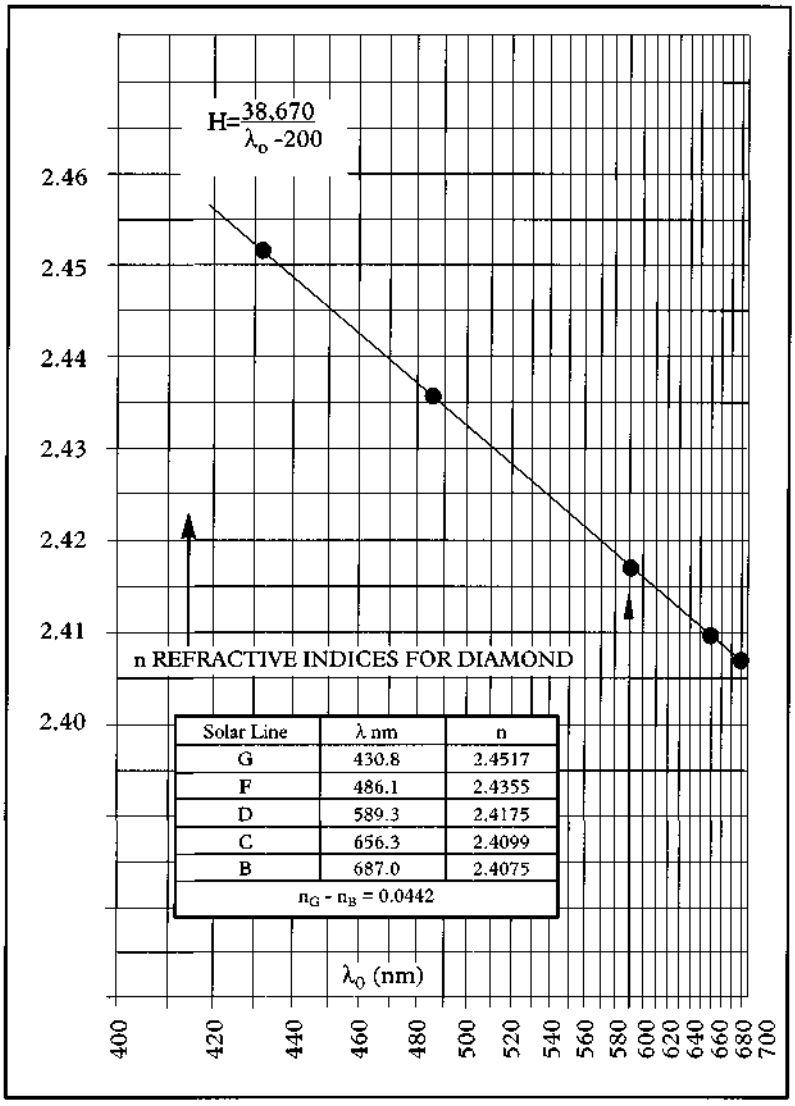

Fig. 11. The Hartmann dispersion chart for diamond.

fibre-optics 'light wand', which has a colour temperature very close to that of Source A.

In References 2 and 13, the authors state that the complementary colour flashes are interference colours. This is not so. The writer demonstrated this by inserting single and crossed polarizing filters into the illuminating and viewing light paths. The colour flashes were identical to those seen without polars.

With some stones, when the fissure roots are narrow and unfilled, the use of crossed polars allows one to distinguish with certainty between dispersion staining colours and the classical Newtonian interference colours. Interference colours are quite different from those of the fully saturated colours arising from dispersion staining.

The CIE Chromaticity Diagram of Figure 12 shows the locus of three orders of interference colours. It can be seen that the petrologist's *first order sensitive tint plate*[14] (having an optical retardation of 550nm) shows a mid-purple colour of considerable desaturation. A petrologist's quartz wedge inserted at 45° between crossed polars shows these progressively desaturating orders perfectly.

Dispersion colours (the 'fire' of diamonds [15]) pose no problem even with immersion viewing. These do not 'flash' and they display the entire spectral range of colours at the same orientation. This is why it is always necessary to state clearly in any discussion of this subject whether it is a *dispersion colour* or a *dispersion staining colour*. With

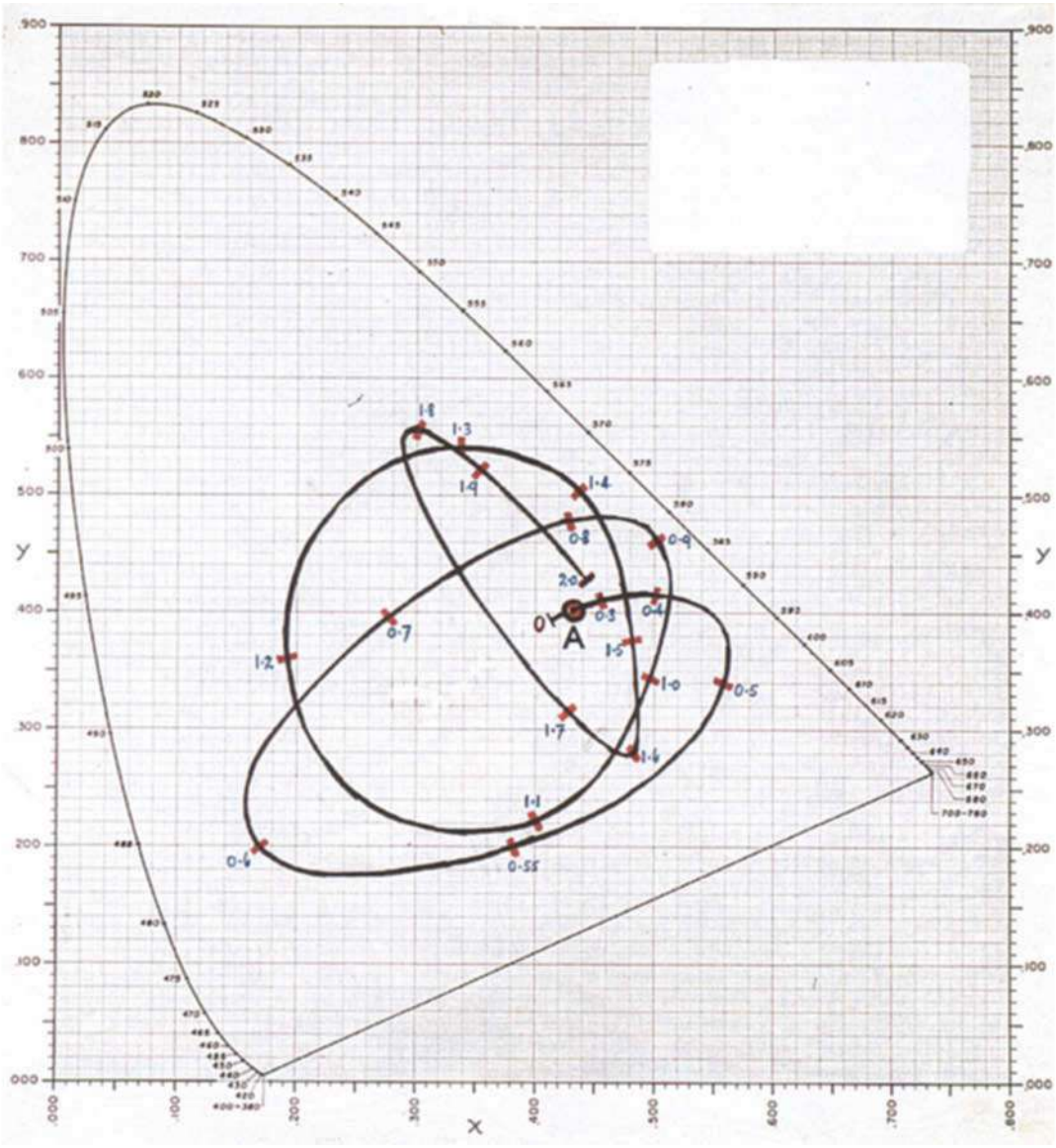

Fig. 12. The CIE Chromaticity Diagram showing the locus of three orders of the Newton Series interference colours. CIE Illuminant 'A'.

experience, optimum viewing conditions and a good reference table of λ_o colours, the writer has found it possible to estimate λ_o values to within ±6nm.

Concluding Remarks

From the preceding discussion, it is clear that if the dispersions of the host gemstone and that of its inclusion become farther apart, then the dispersion staining colours become more intense. If both coincide, the colours vanish and perhaps the inclusion boundary images as well. Remembering that λ_o is the wavelength at which the glass and diamond have the same refractive index, it is also clear that with λ_o values lying just beyond either end of the visible range (400nm to 700nm), no spectral colour flashes will be seen. It follows that if it were decided to eliminate the colour flashes, then the price to be paid for this change would be an increased visibility of the glass-diamond inter-

faces. Just how much will not be known until it is tried.

The thought may also have occurred that a λ_0 glass showing a darkfield blue dispersion staining colour would be an improvement over the Yehuda mid-purple one. The intention would be to help cancel out the yellow body colour of the less valuable of the Cape series stones. This is not a viable stratagem as the brightfield colour for such a glass is yellow. Perhaps this idea may have been tried out in a more recent Israeli enhancement attempt by Koss [16]. It would be of interest to examine these stones in the future.

It is impossible to imagine that a 'runny', wettable, low melting-point glass would ever be discovered which would possess an identical dispersion to diamond. Only a monocrystalline diamond filling will do. The only conceivable process would involve enclosing a batch of the fissured stones in the high-temperature, high-pressure cell of that used in diamond synthesis. Even this exotic repair scenario could only result in yellow fissure fillings. In any case, costs would certainly rule it out.

There is only one small improvement which the writer can think of. It is to incorporate pure, colourless particles of diamond (say less than 10 000 grit size) into the batch of glass used for infilling, hoping that an effective de-gassing stage will help to entice a substantial amount of them into the larger fissures.

Acknowledgements

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Opalite triplets - new imitations of opal

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Abstract

Significant quantities of a reportedly new production of the imitation opal known as 'Opalite' or 'Opal Essence' which was on display at the 1993 Tucson Gem Shows, is described. The refractive index and SG were found to be 1.50 and 1.17 respectively. Also on display at the shows were triplets and mosaic triplets made with central layers of Opalite under a clear dome and a wax-like base. A key non-destructive method of identification for the unassembled Opalite is the recognition of the clear plastic coating, whilst observations made on a microscopic level, both in terms of internal structures and phosphorescence effects are important in the identification of the triplets and mosaic triplets.

Key words: Mosaic, Opal, Opal Essence, Opalite, Plastic, Triplet

Introduction

In the late 1970s and early 80s reports were published (Horiuchi, 1978 and 1982) concerning the introduction of a new opal simulant. This simulant, which has in latter years been marketed as 'Opalite' (Koivula and Kammerling, 1989), may be described as a plastic imitation of opal in which the play-of-colour is caused by the same mechanism as that which causes the visual effect in natural opal (*see for example* Nassau, 1980).

The 1993 AGTA Tucson Gem Show saw the introduction of a new production of 'Opalite' made in Japan (Koivula and Kammerling, 1989, report a US marketing effort at that time and state that it was also being promoted as 'Opal Essence'). Further, the company displaying the new production, Universal Canal Jewelry, also produced doublets, triplets and mosaic triplets made by making use of thin layers of the same material.

Whilst there are no difficulties in terms of differentiating between the 'Opalite triplet' (or indeed any other triplet) and natural solid opal, problems are forecast for the separation of the new composite with plastic imitation opal from the natural opal triplets. The following report outlines in a brief format (for comparison with the triplet material) the properties of two samples of the new Opalite production obtained at the 1993 AGTA show and in a more detailed format, the properties of six Opalite triplets and four Opalite mosaic triplets provided for research by Universal Canal Jewelry.

Working methods

During the examination of the new production of 'Opalite', as well as the triplets and mosaic triplets assembled from this material, priority was given to basic gemmological testing techniques that might produce simple identification criteria. The instrumentation used was limited to the GemoLite microscope, standard refractometer, ultraviolet lamps, plus sectility and thermal reaction testing equipment.

Standard microscopic observations were made using a GemoLite microscope at magnifications of between 10 and 60x. A variety of illumination techniques were used including darkfield, brightfield (diffused and transmitted) and variable incident lighting through an optical fibre.

A GIA GEM Instruments Duplex II refractometer was used to obtain both 'distant vision' refractive indices (from curved surfaces) and normal flat surface readings from the bases of cabochons. The GIA GEM Instruments Thermal Reaction Tester was used on setting '90' and the reactions observed under magnification with the microscope.

A non-standard variation in the use of the equipment was employed in the observation of the *'detail'* of the luminescence effects. A GIA GEM dual long-wave/short-wave ultraviolet lamp was placed in the position normally occupied on the GemoLite by the standard double tube overhead fluorescent light. Observations were made in a 'darkroom' at magnifications of between 10 to 30x, after the observers eyes had become dark adapted (1 to 2 minutes). The effects were otherwise observed in the standard 1:1 at approximately 12 inches distance, but again in a darkroom with dark adapted eyes.

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Fig. 1. Two Opalite samples, illustrating the different sizes/appearances the colour patches may show. *Photo by Maha DeMaggio.*

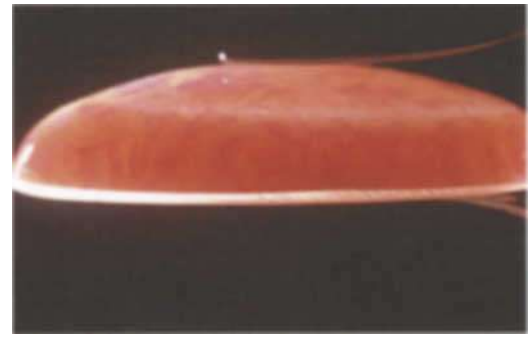


Fig. 2. This edge-on view of a solid Opalite cabochon in transmitted light clearly reveals the transparent colourless coating on the base. Note also the material's salmon pink body coloration when so illuminated with islands of deeper colour. 7x. *Photo by John I. Koivula.*

Opalite

Since the CSIRO concluded their investigations in 1964 (Jones *et al.*, 1964) and the true cause of the play-of-colour in opal became known, several attempts have been made to synthesize or imitate the 'opal effect'. By the mid 1970s Pierre Gilson had produced his 'synthetic opal' (Liddicoat, 1974; Jobbins *et al.*, 1976; Scarratt, 1986) and by the end of the decade an all-plastic 'play-of-colour' material, 'Opalite', had been produced (Horiuchi, 1978).

The two examples of the latest production of Opalite obtained at the 1993 Tucson Gem Show, and described here, are similar in their characteristic features to those described for the 1988 production by Koivula and Kammerling (1989).

The two samples, which closely resemble natural white opal, or more particularly the Gilson synthetic white opal, in general appearance, are of similar size, 3.70ct (19.22 x 14.12 x 3.93mm) and 3.84ct (19.2 x 14.35 x 4.21mm),but were chosen for their slightly differing structural appearance. The 3.70ct example displays mostly small pinpoint colour segments whilst the 3.84ct example displays broader colour segments (Figure 1).

Both samples are perfectly oval with good proportions and, contrary to the appearance of natural opal which is cut with weight as an important consideration, the backs are flat and free from any indentations, cavities, etc.

Both display irregular columnar structures when viewed in profile (Figure 2) and, as previously reported, show what appears to be a clear layer 0.4mm in depth on their bases (see also Figure 2). Upon closer examination the clear coating on the 'base' is revealed to be one that covers the entire surface of the 'opal effect' layer. Figure 3 shows that when the examples are viewed 'base on' a clear rim, similar in proportions to the layer seen across the base in profile, is seen (cf Figure 2). Also, when viewed from the top,there appears to be a significant clear portion which has to be 'focused through' before the play-of-colour portion is reached.

Under magnification and in reflected light (directly overhead and at approximately 90° to the

Fig. 3. When viewed base-on and illuminated with horizontal fibre-optic illumination, this Opalite cabochon reveals the thickness of the clear coating covering its upper surface. 7x *Photo by John I. Koivula.*

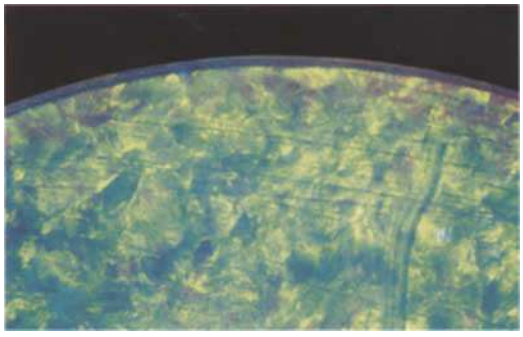


Fig. 4. The cracked or 'dried mud' structure - also referred to as the 'honeycomb' appearance - of the Opalite is seen here when examined in transmitted light down the length of the columnar structure. 20x. *Photo by John I. Koivula.*

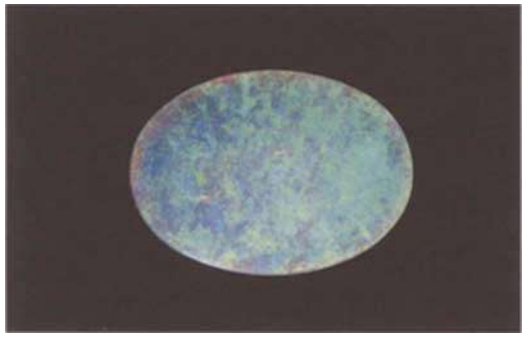


Fig. 5. A brightly reflecting, green metallic 'foil-like' effect is noted here when viewing the flat base of this Opalite cabochon using overhead illumination. *Photo by Maha DeMaggio.*

Fig. 6. The six Opalite triplets examined in this investigation. *Photo by Maha DeMaggio.*

surface of the specimen), the colour segments appear to change through blue, green and orange. The blue and green colours have a dull two-dimensional appearance whilst the orange, which may be mixed with yellow, has a bright three-dimensional appearance. In brightfield illumination and viewing directly through the top of the cabochon, the basic overall colour is an orange-yellow with islands of pink contained within structures that may be described alternatively as having the appearance of 'cracked and dried mud' or a 'honeycomb structure' (Figure 4). When viewed through the side, again in transmitted light, the overall colour is of a salmon pink that contains deeper pink islands.

An unusual feature is seen principally when the flat back of the cabochon is viewed. As the cabochon is moved slowly in reflected light, a brightly reflecting green layer with a metallic foil-like appearance becomes evident (Figure 5). To some extent, this 'foil-like' effect may be observed in the top of the cabochon as a stripe moving across the top as the specimen is rocked.

Whilst the overall face-up colour-effect in these plastic imitations is blue in either incandescent or fluorescent overhead light, when the cabochons are rocked so that the view becomes close to 'edge-on', the colour effect is predominately orange. Thus far, the authors have not noted a similar effect in natural white opal.

The refractive index, determined both by the distant vision and flat contact techniques, was found to be 1.50. The SG was determined by hydrostatic weighing as 1.17 . Under long-wave ultraviolet light the specimens fluoresced a strong bluish-white, with the acrylic on the base (where it is most distinctive) reacting more strongly than the remainder of the cabochon. No phosphorescence was observed. The specimens were also found to be easily sectile and melted in contact with a 'hot point'.

In order to make the comparison with previous productions complete, the infrared spectrum of the latest production was taken. The resulting curve was found to be similar to those previously published (see Koivula and Kammerling, 1989, Figure 5).

Fig. 7. Examined with horizontal fibre-optic illumination, the bright edges of bubbles both above and below the Opalite layer are noted. 10x. *Photo by John I. Koivula.*

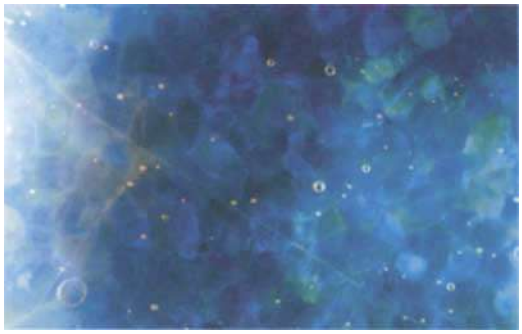


Fig. 8. The three-dimensional pinpoint (or pinfire) colour segments of the Opalite layer in this triplet display a characteristic 'brush stroke' or 'ploughed field' effect. 10x. *Photo by John I. Koivula.*

Opalite triplets

Six Opalite triplets (Figure 6) were examined for general appearance, microscopic clues to identification, refractive index, UV fluorescence, hot point reaction and sectility. The specimens ranged from 1.77 to 2.03 ct.

Appearance

When viewed from the top and without magnification the Opalite triplets have a similar appearance to natural or synthetic opal triplets in that one appears to be looking through a 'lens' at the 'opal' layer below. The phenomenal colours seen are mainly blue to green and these change as the stone is moved ('roll over') as might be expected for natural or synthetic opal. A side view reveals an unusually thick (compared with what might be expected for a natural opal triplet) layer of Opalite (0.40 to 0.80mm) under a colourless dome of a slightly greater circumference and above a black base of lesser proportions. It should be noted that not all the Opalite layers were of a uniform thickness; rather, in several specimens these were wedge shaped.

Microscope

The specimens were chosen for their variation in colour segment size and type (see Figure 6). Observed under low magnification (15x) and in reflected light, the basic appearance is again similar to that which is expected for a natural or synthetic opal triplet. However, because of the high nature (2.4 to 2.5mm) and lens-like rounding of the dome as well as its somewhat greater circumference than the Opalite layer, the play-of-colour towards the edges appears 'blurred' by internal reflections (see Figure 6). Bubbles are clearly visible in the junction layers and these stand out with 'bright' edges in horizontal fibre-optic illumination (Figure 7).

As with the whole Opalite specimens, the colour of each segment changes through blue, green and orange, but unlike the whole Opalite each of the colours and segments in the 'pinpoint segment' type have a three dimensional appearance. Some colour segments in the 'pinpoint' type revealed the 'ploughed field' or 'brush stroke' effect (Figure 8) seen in some natural opal, but this was not generally the case. On the other hand this effect was very evident in the Opalite triplets with the larger colour segments.

Upon focusing through the Opalite layer to the junction below, a metallic 'foil effect' similar to that described for the whole Opalite, seemed to be present in small areas, but with generally a mauve colour. The base, whilst appearing black, is translucent and grey with a multitude of included black spots. As with the whole Opalite the slice present in the triplet appears as an overall 'salmon pink' with deeper pink islands when viewed side-on in transmitted light (Figure 9). The junction adhesive layers above and below the Opalite layer have a similar appearance to each other and are probably the same substance.

Refractive Index

Distant vision readings for the dome of the triplet produced a reading in the region of 1.50, which is the same as that recorded for the Opalite itself, whilst the readings from the flat backs revealed readings of 1.49. In the authors' experience these are within the ranges of the glass and plastic substances sometimes used to produce colourless caps and black backs for natural opal triplets. However, conclusive identification of these materials was not carried out.

UV Fluorescence

The six triplets were examined under both long-wave and short-wave ultraviolet light for possible fluorescence and phosphorescence reactions. Under long-wave, the only part of the triplet that could be said to fluoresce is the adhesive in the upper and lower junctions. Here the adhesive layers have a bright blue fluorescence which is followed by a distinctive mottled yellow-green phosphorescence when the ultraviolet light is turned off. This effect is best seen under magnification as misinterpretation may result from 1:1 observation (i.e. when viewed through the dome, as will be the case when the stone is set), the same bright blue fluorescence will be seen as well as the continuing mottled phosphorescence, as appearing (incorrectly) to come from the 'opal' or 'Opalite' layer. Note: to obtain the phosphorescence reaction, this material must be held close to the UV lamp (25-50mm) for a minimum of 30 seconds.

Under short-wave ultraviolet light the adhesive layers fluoresce similarly to the long-wave effect, but of a lesser intensity. Under this wavelength there is no perceptible phosphorescence. The colourless dome fluoresced with a yellow/chalky effect of a moderate strength under this wavelength.

Thermal reaction/sectility

With the prior knowledge that we were dealing with a plastic opal-like material, it was decided to carry out two potentially destructive testing procedures under controlled conditions. These were the point reaction to heat of the various compo-

nents of the triplets and also the ability of the various parts to 'peel' when a sharp blade is applied.

Both the base and the Opalite layers were found to be easily sectile - the base slightly more so. When the probe of the thermal reaction tester was placed lightly on a small portion of the exposed area of the Opalite layer, the part touched was found to melt very quickly. The same test on the black base layer revealed that this portion of the triplet melted extremely quickly and on a par with what might be expected if the material were a wax candle. The transparent colourless dome was found to be neither sectile nor did it react to the thermal reaction tester.

Opalite Mosaic Triplets

Two oval Opalite mosaic triplets (Figure 10) were examined and compared with a single natural opal mosaic triplet also obtained at the 1993 Tucson Gem Show. The sizes of all three samples were similar: the natural mosaic measuring 17.99 x 13.05 x 3.8mm and weighing 6.63ct, and the Opalite mosaics measuring 16.5 x 12.49 x 5.15 and 16.45 x 12.3 x 4.91mm and weighing 6.79 and 6.13ct respectively. Each specimen was examined for general appearance, microscopic clues to identification, refractive index, UV fluorescence, hot point reaction and sectility.

Appearance

When viewed from the top and without magnification the Opalite mosaic triplets were similar in appearance to the natural opal mosaic triplet. The sectional nature of the opal or Opalite mosaics can be seen clearly, and without magnification, through the transparent colourless domes. Also clearly visible without magnification are the shapes of the various sections of the mosaics. In the case of the Opalite these could be seen as being triangular whilst in the case of the natural opal the shapes are more irregular, i.e. truncated triangular and trapezoid generally with chipped and rounded points.

As with the Opalite triplets discussed earlier, the colours seen in the Opalite mosaics are mostly blue to green and the 'roll-over' effect is similar to that which occurs in the natural opal mosaic specimen. However, the colours of the natural specimen, whilst tending to have a greater presence of orange/red, were a little duller in appearance.

When viewed side-on the Opalite mosaics revealed a somewhat thinner section of Opalite than is used in the Opalite triplet and the thickness is also variable as the cabochon is turned (from 0.3 to 0.4mm), but is of a similar thickness to the opal used in the natural opal mosaic triplet (the latter varying from 0.3 to 0.4mm). However, the curvature of the clear dome on the natural mosaic triplet begins more closely to the opal layer than it does for the Opalite mosaic triplet, which has a steep rise before the curvature begins (Figure 11). Both the natural opal and the Opalite mosaic triplets have black material bases but the base of the natural is somewhat thinner than in the Opalite assemblage.

Microscope

Observed under low power (15x) magnification, and in reflected light, both the natural opal and the Opalite versions of the mosaic triplets reveal substantial gaps between the mosaic sections in which can be seen the clear adhesive and bubbles therein. It is also confirmed that the mosaic sections in the natural version vary more in their shape than do those in the Opalite version, all of which are triangular with truncation only occurring at the edges of the triplet.

The mosaic sections used in the Opalite version appear to have been selected from the type of Opalite in which the colour segments are wide rather than the pinpoint type and, as a result, the 'ploughed field' or 'brush stroke' effect is evident in most of the sections (Figure 12).

The blurring of the edges observed in the Opalite triplets does not seem to be as great a factor in the Opalite mosaic version. This is probably due to the differing profiles of the domes of each type. The triplet being more rounded and having a greater 'overhang' beyond the outer edge of the Opalite layer, in comparison with the mosaic version.

The sections in the natural opal mosaic, as might be expected, are made from a variety of types (from the pinpoint play-of-colour to wider colour patch versions (Figure 13)), and many individual sections may also contain included matrix material.

In transmitted light the natural opal version loses virtually all of its play-of-colour effect and the near transparent and grey (rather than black) nature of the base is revealed (Figure 14). In this situation the bubbles in the adhesive layers stand out with black rims. Due to the greater opacity of the backing, in contrast the Opalite version appears much darker and still exhibits much of its play-of-colour.

Refractive Index

Distant vision refractive index measurements were recorded for the domes and direct refractive

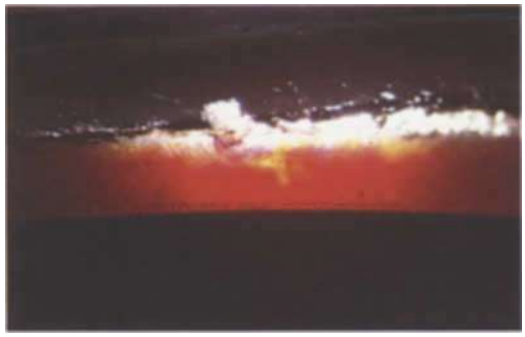


Fig. 9. The salmon pink transmitted-light appearance of Opalite is clearly seen in the triplets as well when viewed side-on. 7x. *Photo by John I. Koivula.*

Fig. 10. The two Opalite mosaic triplets examined in this investigation. *Photo by Maha DeMaggio.*

index readings were taken from the bases of both the natural opal and Opalite versions of the mosaic triplets. For the Opalite version the RI of the dome was found to be 1.51 and the base 1.49, whilst for the opal version the dome was found to have a refractive index of 1.52 and the base 1.53.

Fluorescence

The two Opalite mosaic triplets and the natural opal mosaic triplet were all examined for their reactions to ultraviolet light.

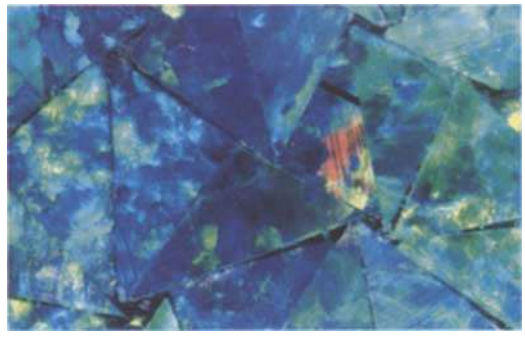
In common with the Opalite triplets, under long-wave ultraviolet light the adhesive layers of the Opalite mosaic triplets were found to have a bright blue fluorescence which was followed by a distinct phosphorescence. This effect is best seen under magnification when the true nature of the fluorescence and the phosphorescence, i.e. coming from the adhesive rather than the Opalite, can be seen. When viewed through the clear dome with the unaided eye (1:1), the fluorescence effect of one of the Opalite versions appeared to be coming from between the Opalite mosaic sections, i.e. from the adhesive, but the other sample appeared to show an overall effect, probably due to the fact that its upper adhesive layer is thicker.

Under short-wave ultraviolet light the transparent domes of the Opalite versions fluoresced with a 'chalky' appearance which interfered with any effect the adhesive or Opalite might have. However, the sample with the thicker upper adhesive layer phosphoresced (from the adhesive) whilst for the sample with the thinner layer no phosphorescence was seen.

The reaction of the natural opal mosaic triplet was as could be expected from a material made with a natural 'white' opal component (see Jobbins *et al.*, 1976). Under long-wave ultraviolet light, viewed from the side, the upper adhesive layer fluoresced as with the Opalite version. This was also confirmed when the triplet was viewed through the clear dome, when the fluorescence of the adhesive could be seen in between the opal sections (Figure 15). However, and as can be

Fig. 11. When examined from the side, the two Opalite mosaic triplets on the right are seen to have thicker colourless caps than does the typical natural opal mosaic triplet, as illustrated by the one assemblage on the left. *Photo by Maha DeMaggio.*

Fig. 12. As seen here, magnification reveals the typical 'brush stroke' or 'ploughed field' appearance of some of the chips in this Opalite mosaic triplet. Note also the very sharp edges of the individual chips as compared with those of the natural opal mosaic triplet shown in Figure 13. 7x. *Photo by John I. Koivula.*



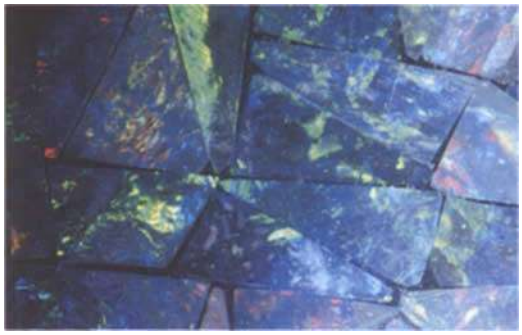


Fig. 13. Careful observation reveals the varying phenomenal colour types in the opal typically used to produce natural opal mosaics. Note also the blunted and other irregular terminations to the individual opal fragments. 7x. *Photo by John I. Koivula.*

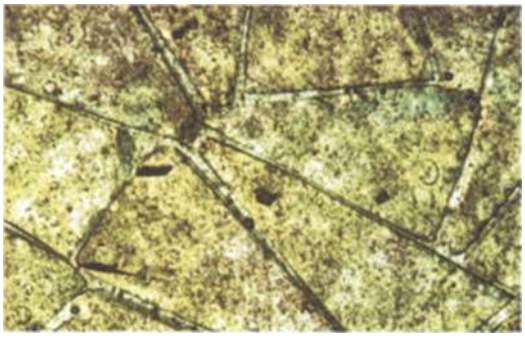
expected with white opal, it was noted that the opal sections also fluoresced and when examined under magnification the distinct phosphorescence effect, which could be seen at 1:1, was found to come from the opal sections rather than the adhesive between them.

Thermal reaction/sectility

Only the adhesive layer of the natural opal mosaic triplet reacted to the thermal reaction tester in that it melted at the point of contact. In the case of the Opalite assemblage, however, both the base and the Opalite layer melted at the point of contact - the base extremely fast and on a par with a wax-like substance.

The transparent domes of the Opalite assemblages were found to have no reaction to the thermal reaction tester and nor were they sectile. However, both the Opalite layer and the base were found to be sectile, the base more so that the Opalite. The natural opal version was found to be non-sectile apart from the adhesive layer.

Fig. 14. The same natural opal mosaic triplet illustrated in Figure 13, seen here in transmitted light. 10x. *Photo by John I. Koivula.*



Discussion

The authors hope that the foregoing report assists, first in warning gemmologists of the presence of Opalite triplets and mosaic triplets on the market and, secondly, in giving some basis for their identification. However, in the discussion below it should be remembered that it is the nature of 'composite' stones and particularly those composed of natural opal, that the components may and do vary (differing types of opal, adhesive, backing and domes) from those discussed here (see Anderson/Jobbins, 1990; Nassau, 1980).

The reportedly new production of Opalite is similar to, if not the same as, previous productions and reference should be made to Koivula and Kammerling (1989) for useful identification features. However, the observation of the clear plastic/acrylic layer which covers the entire surface of the Opalite cabochon, together with the refractive index of 1.50 (cf. natural opal - at 1.44) and lack of phosphorescence (white opal usually phosphoreses strongly) should be sufficient to identify the material, particularly when set in jewellery. If the flat back of the Opalite is visible through a setting, observation of the green foil-like flash should also indicate that the substance is not natural opal, although similar effects have been noted with synthetic opal. Any damage marks on a suspect stone, such as chips and sharp edged scratches, would tend to indicate a natural or synthetic stone rather than the plastic imitation, where damage would have a much softer or smoother appearance.

The Opalite triplets and mosaic triplets create a number of problems for the unwary. The clear domes are made of a material (most likely clear glass) sometimes used for natural opal triplets and the Opalite structures seen through the dome are

Fig. 15. A natural opal mosaic triplet under long-wave ultraviolet radiation. Note the fluorescence of the adhesive between the opal sections. Under this magnification phosphorescence is seen to come from the opal sections and not the adhesive - the reverse was the case for the Opalite mosaic triplets. *Photo by John I. Koivula.*

similar to those observed in natural opal. However, such natural opal layers may contain matrix material which should not be present in Opalite or mosaic Opalite layers. The Opalite layers in the Opalite triplets were also noted to be somewhat thicker than might be expected for the opal in a natural opal triplet, an observation that would be particularly useful when examining loose stones.

The natural opal mosaic triplet examined for comparison purposes was produced from irregularly-shaped pieces of opal whilst the Opalite version was made from essentially all triangular pieces. A useful identification technique is the observation of fluorescence and phosphorescence effects under magnification. During this investigation it was found that the adhesive used in the Opalite mosaic type phosphoresced whilst the Opalite did not, whereas in the natural opal version the opal phosphoresced whilst the adhesive did not or was not perceptible positioned next to the opal sections. This observation would also apply in the case of the triplets if white opal were used in the natural version.

Whilst destructive testing is not recommended, the observation of the surface area of the wax-like base of the Opalite triplets as a 'hot point' is brought close, will undoubtedly reveal a movement of the surface even before contact is made.

Undoubtedly, gemmologists must now be far more critical in their examination of assembled stones which appear to include opal as one of their components. Those which are set in closed back/bezel settings will be particularly difficult to identify.

Acknowledgements

The authors wish to thank Mr Yung Sang Kim of Universal Canal Jewellery for providing the Opalite triplets and Opalite mosaic triplets, that are the basis of this report; to Tom Moses, of GIA Gem Trade Laboratory (GIA GTL), New York, for useful discussions; to Dino DeGhionno of the GIA GTL, Santa Monica, who assisted in the testing of the specimens and provided many useful comments on the manuscript; and to Maha DeMaggio of the Gemological Institute of America for providing the macrophotography used herein.

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The first occurrence of musgravite as a faceted gemstone

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Abstract

Two pale greyish-mauve faceted stones (weighing 0.30 and 0.37 ct), described as 'taaffeite', very probably from Sri Lanka, show X-ray diffraction data which are in entire agreement with musgravite, a rare beryllium-magnesium-aluminium oxide related to taaffeite but not identical with it, and which has never been found previously in nature in gem quality. Apart from the colour, which seems to be paler than for most taaffeite specimens, and with a greenish cast, the physical properties of musgravite are not sufficiently different from those of taaffeite to permit distinction between the two species using traditional gemmological equipment; here X-ray diffraction seems to be essential for reliable identification.

Introduction

Taaffeite and related minerals were considered as extremely rare stones until about a decade ago, when the number of positively identified specimens in public and private collections was of the order of twenty (Anderson *et al.*, 1951; Kampf, 1991).

In the 1950s one of the authors (C.M.G.) was little more than a boy and on visiting London he had the opportunity of seeing one of these stones exhibited in the 'new acquisition' glasscase of the British Museum (Natural History), together with sinhalite. Needless to say, having a taaffeite specimen was considered as a very remote (and rewarding) possibility by a private collector and in particular it has been a kind of 'youth dream' for some of us.

Around 1980, a bright red stone of about 1 carat in weight was sold as 'red taaffeite' to Dr E. Gübelin by a gem dealer in Sri Lanka; the physical properties of this stone were almost identical with those of taaffeite, but the colour was quite unusual. A detailed investigation on this stone was carried out by Moor, Oberholzer and Gübelin (1981); mainly on the grounds of chemical analysis and crystal-structure determination, these authors ascribed the stone to a new mineral species, 'taprobanite'. However, the supposed differences between taaffeite and 'taprobanite' were shown not to be real, mainly because of an error in the chemical formula originally proposed for taaffeite (Schmetzer, 1983a; Nuber and Schmetzer, 1983); therefore, in spite of its better characterization, 'taprobanite' was discredited by the Commission on New Minerals and Mineral Names of the International Mineralogical Association in favour of taaffeite, because of priority (Schmetzer, 1983b).

In the last few years (McDowell, 1984; Kampf, 1991; Jarry *et al.*, 1992; Gunawardene, 1984a,b) taaffeite gem specimens have been found in considerable number (exceeding 1000) in several localities in Sri Lanka, and also from at least one locality in Burma (Spengler, 1983). In Sri Lanka a zincian variety with relatively high refractive indices and density has also been discovered (Schmetzer and Bank, 1985), and a second specimen of the very rare red variety has been found quite recently (Koivula and Kammerling, 1991).

Some taaffeite crystals have been preserved in their natural state, as waterworn hexagonal prisms with different terminations at each end of the sixfold axis, in agreement with their crystallographic symmetry (polar point group 6mm): in at least one case goniometric measurements could be carried out (Saul and Poirot, 1984; Kampf, 1991).

In May 1992, Dr Domenico Nicita, a friend of the authors and a gem dealer, showed us a brilliant-cut stone which had been identified as 'taaffeite' and whose origin was thought to be Sri Lanka. This stone is rather small (0.30ct in weight) and its colour is a pale greyish-mauve with faint but definite change to light mauve on passing from daylight to artificial light, similar to what happens in some taaffeite specimens (Bank and Henn, 1989); the colour is however definitely paler than for most taaffeite specimens.

Following our interest in rare stones and beryllium minerals, and in particular for taaffeite, one of the authors (C.M.G.) bought it for his collection, planning to check it adequately, as for all unusual stones in general.

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Experimental results

The physical properties of the first stone studied by us are reported in the first column of Table 1: they show close analogy with those of taaffeite, to the point that using ordinary gemmological equipment the stone could indeed be classified as 'taaffeite'. However, because of the peculiar colour, we wanted to complete our investigation using X-ray diffraction. For this purpose a four-circle single-crystal X-ray diffractometer was employed without difficulty, in spite of the large size of the specimen (Pilati *et al.*, 1988).

The unit-cell data obtained using a Enraf-Nonius CAD4 diffractometer are reported in

Table 1: Physical data for taaffeite-group minerals

	Musgravite[1] *first stone*	*Musgravite*[1] *second stone*	*Musgravite Australia*[2]	*Musgravite Antarctica*[3]	*Musgravite Greenland*[4]	*Pehrmanite-18R Finland*[5]
Weight (ct)	0.30	0.37				
Lattice	Hexagonal-R	Hexagonal-R	Hexagonal-R	Hexagonal-R	Hexagonal-R	Hexagonal-R
a (Å)	5.665(3)	5.670(1)	5.675(2)	5.6804(2)	5.687(2)	5.70
c (Å)	41.07(3)	41.019(7)	41.096(5)	41.104(2)	41.16(2)	**41.16**
Extinction rule:	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n
ω	1.726(1)	1.725(1)	1.739(2)			mean index 1.79
ε	1.720(1)	1.719(1)	1.735(2)			
Optical charact.	uniax.(-)	uniax.(-)	uniax.(-)		uniax.(-)	uniax.(-)
Density (g/cm³)	3.64	3.62	3.68			4.07

	Taaffeite-8H Sri Lanka	*Taaffeite*[1]	*Taaffeite*[1]	*Taaffeite*[1]	*Taaffeite*[1]
Colour		mauve	pink	mauve	mauve
Weight (ct)		0.39	0.45	0.63	0.84
Lattice	Hexagonal-P	Hexagonal-P	Hexagonal-P	Hexagonal-P	Hexagonal-P
a (Å)	5.684(1)[6]	5.685(3)	5.685(2)	5.686(3)	5.687(1)
c (Å)	18.332(7)[6]	18.332(7)	18.314(4)	18.313(4)	18.325(5)
Extinct-ion rule:	hhl: l=2n	hhl: l=2n	hhl: l=2n	hhl: l=2n	hhl: l=2n
ω	1.721-1.724(2)[7] zincian 1.730(1)[8]	1.725(2)	1.722(2)	1.726(2)	1.726(2)
ε	1.717-1.720(2)[7] zincian 1.726(1)[8]	1.719(2)	1.718(2)	1.720(2)	1.721(2)
Optical charact.	uniax.(-)	uniax.(-)	uniax.(-)	uniax.(-)	uniax.(-)
Density (g/cm³)	3.59-3.62[7] zincian 3.71(2)[8]	3.63	3.62	3.65	3.63

Sources: 1. Present work 2. Hudson *et al.*, 1967 3. Grew., 1981 4. Chadwick *et al.*, 1993 5. Burke and Lustenhouwer, 1981 6. Moor *et al.*,1981 7. Range of values reported in the literature 8. Schmetzer and Bank, 1985. For our samples the refractive indices have been measured using a total refractometer with sodium light (569 nm); the density has been determined using a hydrostatic balance.

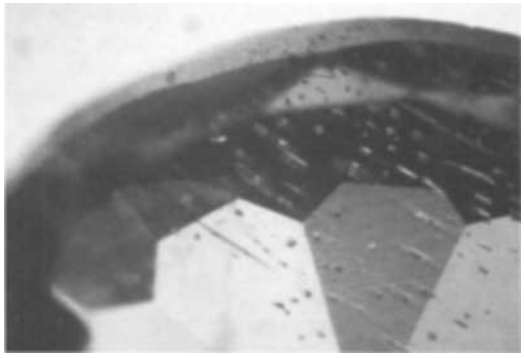

Fig. 1. Inclusions in musgravite, first stone, reflected light (50x).

Table 1, together with the corresponding results obtained by other authors for minerals of the taaffeite group. On comparing our crystallographic data with those of the other minerals, it is clear that the gem is not taaffeite, but it should be ascribed instead to musgravite, a closely related but distinct species.

Musgravite is indeed very similar to taaffeite, although it has never been found in gem quality specimens previously. It was first discovered in the Musgrave Range, Australia (Hudson *et al.*, 1967) and it was considered to be only a polytype of taaffeite ('taaffeite-9R'); later a second occurrence was found in Antarctica (Grew, 1981) and using material from both these localities the crystal structure of musgravite was established with good accuracy and compared with that of taaffeite (Nuber and Schmetzer, 1983). From this study, the chemical formula of these two phases were shown to be different ($BeMg_2Al_6O_{12}$ and $BeMg_3Al_8O_{16}$, respectively); therefore, the two minerals are not polytypes in the strict sense but are polytypoids, and the distinct name of musgravite could be assigned to the rhombohedral

Fig. 2. Inclusions in musgravite, first stone, transmitted polarized light (50x).

modification. Meanwhile, pehrmanite, the iron equivalent of musgravite, was discovered in Finland (Burke *et al.*, 1981), but the crystals are very small and of no gemmological interest. A very recent discovery of musgravite has been made in Greenland (Chadwick *et al.*, 1993).

Consequently, it seems that some of the supposed 'taaffeites' on the gem market which in all probability come from Sri Lanka are actually musgravite. Following our discovery, five additional stones were obtained by courtesy of Dr Nicita: four show unit-cell data virtually identical with those of taaffeite and one is musgravite. These data and their physical properties are also reported in Table 1.

On account of these results, musgravite seems therefore to be rarer than taaffeite. As we have said, the colour of the 'true' taaffeite stones we have examined is in all cases deeper than that of musgravite, ranging from a decided rose to mauve, sometimes with a distinct colour change on passing from daylight to artificial light, whereas musgravite is paler with a more decided greenish cast; however, two stones only are not very significant statistically, and on this basis the existence of darker musgravite cannot be excluded. In his works on taaffeite (1984a,b), Gunawardene lists a number of occurrences in Sri Lanka, and only one locality (Balangoda) seems to provide nearly colourless stones; this might be an interesting point to follow up.

Since the point-group symmetry of musgravite is $\bar{3}$m and that of taaffeite is 6mm, the crystal habit should be appreciably different in the two cases. For instance, most of the pictures and the drawing published by Kampf (1991) of crystals from Sri Lanka clearly show polar symmetry, since they are clearly pyramidal; on the other hand, musgravite is centrosymmetric and its crystals should be equally terminated at both extremities, like corundum. This is confirmed by the crystal shape of the musgravite found in Greenland, which is clearly rhombohedral (see Figure 2 in Chadwick *et al.*, 1993)

On examining the stone with the immersion microscope, the pavilion shows swarms of polyhedral birefringent inclusions (see Figures 1-2), which are in association with disc-shaped groups of smaller, possibly two-phase inclusions. The crystalline inclusions, which are protogenetic in nature, are grouped along parallel planes and can be ascribed to alternation of two different minerals: the former appears as brown tabular crystals and is with all probability identical with phlogopite, which has been already identified with certainty in taaffeite inclusions by Gunawardene

(1984); the latter mineral forms bipyramidal crystals with high interference colours between crossed polarizers. Like the original taaffeite specimens, the mineral is neither fluorescent under shortwave (254nm) nor longwave (365nm) ultraviolet radiation.

The optical absorption spectrum, examined through a direct-vision prism spectroscope, shows a weak absorption band centred at 475nm.

Conclusions

Our observations show that some of the gemstones sold as 'taaffeite' may be of a much rarer mineral, musgravite, the presence of which has never been noticed so far in the gem fields. It would be interesting to have some material of absolutely certain origin, not only to confirm the country of origin, but also to know whether these stones are actually found together with taaffeite (as seems quite probable), or they come instead from another locality.

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Diamond replicas - possible but just

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Abstract
The author describes some of the problems encountered when making models or replicas of famous diamonds.

This paper is about replicas of some of the world's most important diamonds and the problems of making them, so perhaps I should start off by saying what a replica is and what it is not. For this we have to make a distinction between a replica and a model.

When a cutter gets a very large diamond rough, one of the first things he does is make models of it. Nowadays this modelling can be done on a computer but when, for example, in 1935 Lazare Kaplan received the 726 ct diamond rough called the Jonker he made real models of the stone. The models were then cut in various ways to decide the best way in which to saw and cleave the diamond. The result was an amazingly accurate prediction of what he would get out of the actual cutting (see Balfour, 1992).

In such cases, of course, the absolute accuracy of the model is of paramount importance. They can be made of many materials. A model of the rough for the Regent diamond in the Natural History Museum in London, for example, is made of lead.

Sometimes, however, we are concerned with the appearance of a cut stone and while ideally we would like to have the same exactness as a 'model', generally this is not possible. Very few diamonds have been studied with the exactness necessary and, as we shall see, even when a certificate from a testing laboratory has been issued it is woefully inadequate for the real model maker. One can only concentrate on making the stone *look* as much like the original as possible. These I call 'replicas'.

One of the earliest models/replicas of a cut diamond to which I have found a reference was that presented to the Natural History Museum in London by the famous (infamous?) British mineralogist, James Gregory. (Gregory had reported that no diamonds would ever be found in South Africa and any that were had obviously been dropped there by ostriches!)

The 'replica' that Gregory presented at the turn of the century was of a stone called the Pigot, which has now disappeared. George Pigot had brought the rough back to England in about 1770 and after his death his heirs continued to try to sell it. At some 48 ct it was one of the largest - and hence most expensive - diamonds in Europe at the time. No buyer could be found and in 1800 the British Parliament gave permission for the family to dispose of it by lottery. The diamond finally got into the hands of Rundell and Bridges, the Crown Jewellers, who did not find a buyer until 1822.

When trying to sell a large diamond it was the custom to make 'models' of the stone to show potential customers and it was one of these 'models' that Gregory had presented to the Natural History Museum. In the best traditions of modern advertising 'hype', the more desperate Rundell and Bridges became to sell, the bigger these 'models' became. Anyone taking measurements from Gregory's 'model' would have assumed the diamond weighed 93.30 ct!

The sad end to this story was that, when the purchaser of the Pigot, Ali Pasha, realized that he was dying, he ordered that the two things he loved most in the world - his wife and his diamond - should not out-last him. The diamond was destroyed, but fortunately his wife was spared!

Much more in the nature of a replica is a glass copy of the diamond named the Dresden Green from the collection of Sir Hans Sloane, acquired by the Natural History Museum in 1753. The diamond had probably been cut in London and sold to Frederick Augustus II, Elector of Saxony and King of Poland, in 1741, but was almost certainly available for study when the replica was made.

Therefore the history of replicas of cut diamonds goes back at least 250 years. The earliest material was, of course, glass - hardly what one

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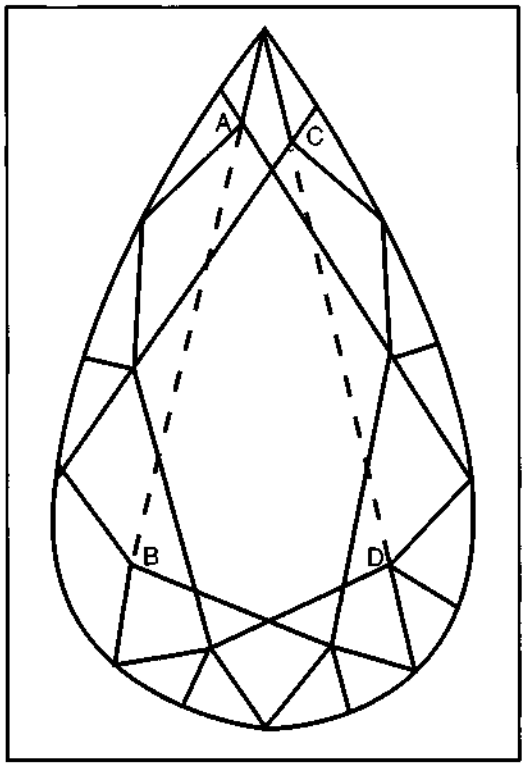


Fig. 2. The crown of a pear-shaped diamond; by making AB and CD straight the eye is carried to the point and the diamond made to appear slimmer and more elegant

would call a satisfactory diamond simulant. However, it was good enough at the time for the collection of diamond replicas made of glass on show at the Great Exhibition of 1851 to cause a considerable stir. Other materials that are still used are quartz, synthetic spinel and synthetic sapphire (also not exactly satisfactory simulants) and, further 'up market', yttrium aluminium garnet (YAG) and cubic zirconia (CZ), the most realistic of all and unlikely to be improved upon. If the material used for the replica does not have a sufficiently high refractive index, instead of light being bounced around the stone by total internal reflection and coming out of the crown, it will pass straight through the stone and out of the back. The stone will look dead, particularly in the centre, where it is acting like a window. This is why quartz (RI 1.55) can never be cut as a satisfactory diamond simulant. YAG (RI 1.83) and CZ (RI 2.15) are both much nearer to diamond (RI 2.41).

The replica of the Dresden Green referred to above was almost certainly made under the ideal conditions of having the original available to refer to. But so often one reads in the descriptions of large diamonds 'present whereabouts unknown' or 'stolen without trace', that for a replica maker like myself these ideal conditions remain only a dream. I do not expect anybody to send me their 80 ct diamond to study, even if I knew who to ask. For many reasons including security, insurance, tax and currency, most of these owners do not advertise their possessions.

The extremely high prices being paid recently for large diamonds have caused many of the old and famous diamonds, such as the Agra and the Tereschenko, to appear in the sales-rooms of Sotheby's and Christie's. The diamonds are then normally submitted to one of the major testing laboratories* for a certificate. Unfortunately these certificates are not always published in the sale catalogue and the laboratories take the view that these are confidential papers available only to the owner, even for historically important stones. Figure 1 shows what is missing for people such as myself, even when the certificate is published.

Fortunately the sale catalogues do provide life-size photographs of such diamonds which help to fill in much of the information missing from the certificate. They also help to supply what I call the 'design factors' of the cut - the ways in which the cutter has adapted the standard brilliant-cut to emphasize features he considers to be of importance.

Figure 2 illustrates this point better than words. Although this may look like a normal pear-shape crown, by making AB and CD straight the eye is carried to the point and the diamond is made to appear slimmer and more elegant. Bent lines would emphasize the 'roundness' rather than the length.

There are, of course, sources other than sales catalogues, and one which I cannot recommend highly enough for its illustrations and information is Lord Balfour's book *Famous diamonds*, a new edition of which has just appeared (1992). Unfortunately this book gives the dimensions of very few of the stones. For this information, there is no alternative to 'scattergun' research - it is buried in old books and journals and only weeks in museum libraries will find it. There is no bibliography or central source of information available.

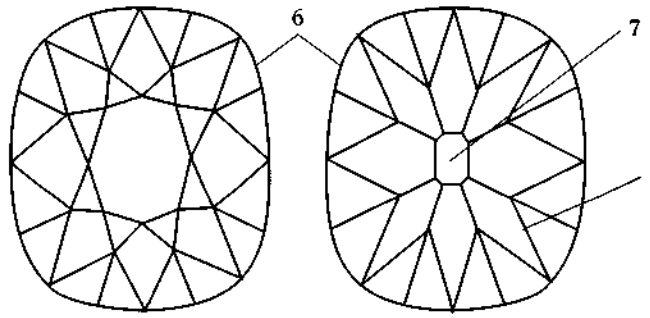
Some famous stones have been studied, particularly by Herbert Tillander from Finland, and this information can quickly be found by a search through the indexes of the major gemmological publications.

However, the great time for writing about large diamonds was in the late 1800s when so many were being found in South Africa. (Sadly, a major

* in New York, Antwerp, Lucerne or London

Information given on a typical diamond grading report

SHAPE AND CUT	Cushion antique mod. brill.
Measurements	21.10 x 19.94 x 11.59 mm[1]
Weight	32.24 ct
PROPORTIONS	
Depth	58.1%[1]
Table	53%[2]
Girdle	Extremely thin to medium[3] faceted
Culet	Slightly large[4]
FINISH	
Polish	Good
Symmetry	Good
CLARITY GRADE	VS1
COLOUR GRADE	Fancy light pink[5], natural colour, whitish graining is present



Explanation

1. This gives the total depth but not how much is above or how much is below the girdle.
2. This is a percentage of the width. The length of the table is not given.
3. How thick is 'medium' ? Slight extra thickness in the girdle can make a big difference to the weight.
4. Given how enormous some of the old culets were, this is hardly an exact description!
5. Colouring in diamonds can be very subtle and light colours can need a lot of imagination to see. No comparison stones exist. 'Fancy' here means only that the stone is a definite colour and not just 'off white'. (Although reports may grade yellow stones from K to Z, nowhere have I seen comparison stones for colours in this range. Also, this type of scale exists only for yellow diamonds and not for other fancy colours.)
6. This shape is indicative only. All pear-shapes, for example, would look the same in this section of a report. This is a standard stamp, not the shape of the stone.
7. In reality there may or may not be a culet and it may or may not be this shape.
8. This indicates only that there are girdle facets, not how long they are or if they are visible through the table.

Fig. 1. Information given on a typical diamond grading report with comments by the author.

find no longer generates the same excitement - perhaps there have been too many.)

An interesting area of what, perhaps, should be called reconstructions rather than replicas is the old French Crown Jewels. When the inventory was made the stones were pressed into wax. These impressions still exist and, thanks to Bernard Morel, many have been published. This information, combined with a knowledge of cutting of the time, has allowed a 'reconstruction' of the eighteen diamonds known as The Mazarins. They might not be up to the accuracy demanded of other replicas but for the first time people can have an idea of what these stones looked like.

Let us look at some of the situations that can arise:

(1) *All information available*
This is undoubtedly the rarest situation and I can think of only one instance when this almost applies. Kane *et al.* (1990) in their paper on the Dresden Green quote a different paper which gave the inclination and azimuth angle of most facets. (Some of the lower girdle facets could not be measured because of the setting.) Here one can obviously expect a high level of accuracy - a model rather than a replica.

(2) *Some angles available*
Typical are the Regent and the Wittelsbach, for both of which Tillander measured the angles of the mains. By making a replica with these angles correct and the facet diagram fitting the photograph, one can expect a very high degree of accuracy.

(3) *Photograph and certificate available*
This will give sufficient information to enable a replica to be made which is very realistic from the top but, as the certificate (see for example Figure 1) does not indicate how the depth is divided between the crown, girdle and pavilion, one cannot be totally sure about angles. There are various hints in the photograph and if the depth is unusual this can be built into the replica as, for example, the exceptional depth of the Premier Rose.

(4) *Photograph only available from a sales catalogue*
As many people buy on the strength of photographs in catalogues such as those produced by Christie's and Sotheby's, the auctioneers go to tremendous pains to make sure that they show the stones at the exact size. One can, therefore, measure their height and width. Calculations based on these dimensions and the weight give a fairly accurate value for the depth. As in (3) above, one can get a good 'face-up' replica (i.e. as when viewed through the table). What one sees should be very close to the original.

(5) *Line diagrams of correct size or dimensions given*
For stones not recently put up for sale or historical stones which have disappeared, replicas can be made from these details but one cannot have as much reliance on the accuracy of the dimensions. Typical of these is the Florentine, which was stolen from the Emperor of Austria after he went into exile in 1918 and has never been heard of since. This jewel is of great historical importance and had been recorded by that extraordinary diamond dealer/traveller, Jean Baptiste Tavernier, in 1657. A replica which might be at maximum 10 per cent out in size is surely better than no replica at all for such a stone. Often one comes across a line diagram and the dimensions, then one has to trust only the accuracy of the line diagram, especially on such features as lower girdle length. Again a sound knowledge of the history of cutting provides a useful check.

I give below some other factors or considerations which affect the making of a replica or model:

Shape:

Either from photographs or from line diagrams, mostly published at the turn of the century. *Not* from certificates. Beware - some diamonds have been deliberately photographed not face on (see for example the Premier Rose in *Famous diamonds* (Balfour, 1992)).

Dimensions:

From certificates when available, but many of the big South African stones were written about at the time of their first cutting. Also from photographs in sales catalogues. At some point in cutting the replica, a decision based on one's own knowledge must be made about where the girdle comes so one can calculate mains angles.

Facet arrangements:

For the crown these can be taken from a photograph if available. The biggest problem on the pavilion is the girdle facets when they do not appear through the table. Here a knowledge of the history of faceting helps one to make an educated guess.

Colour:

Perhaps the single biggest problem. Few important diamonds are on display and descriptions of colour are at best vague and colour balance will

vary from one published photograph to another. An additional factor is the availability of material - coloured CZ is made to be attractive in its own right and not to imitate the often very subtle tones of coloured diamonds. A run of a special colour from one of the CZ manufacturers must usually be for a minimum of 50 kg costing perhaps $5000 and hence out of the question for just one replica. Sometimes one is forced to use material the colour of which is a little more intense than the original diamond.

Sometimes one searches hard to find the information one wants but fails. And sometimes one gets too much! I hope one day to make a replica of a stone called the Cumberland which is usually described as a *round* stone. However, Lord Twining, expert on European crown jewels and writer of heavy tomes, identified it as a *triangular* stone which came up for sale at Christie's in London in 1953. On a carousel of diamond replicas originally presented to Queen Victoria by the East India Company, probably for her Diamond Jubilee, now in the store rooms of the Natural History Museum in London, sits a 'replica' of the Cumberland - it is *cushion-shaped*!

Given the problems outlined here and on the certificate, are replicas possible? If one demands one hundred per cent accuracy in every factor, what I call a model, then the answer is almost invariably 'No'. If one wants something that face-up looks like the real thing even to the owner, and would be indistinguishable to most of us if put side by side with the real thing, the answer is definitely 'Yes'. And if any more justification is necessary, they give a lot of pleasure to a lot of people. What more can one ask?

References

Balfour, I., 1992. *Famous diamonds*. Second edn. NAG Press, Colchester.

Kane, R.E., McClure, S.F., Menzhausen, J., 1990. The legendary Dresden Green diamond. *Gems & Gemology*, **26**, 4, 248-66.

[*Manuscript received 18 May 1993*]

Gemmological Abstracts

BANK, H., HENN, U., 1993. Gemmologische Kurzinformationen. (Short gemmological notes.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 1-6, 10 photographs, bibl.

An article composed of the following short notes. A green zoisite from Tanzania; the authors feel that this material should be called green zoisite not green tanzanite or chrome tanzanite. A 5-7cm, 3mm thick tourmaline 'melon' from Madagascar was identified as a tourmaline-glass doublet. Also from Tanzania a ruby-quartz doublet. A yellow-brown star corundum was found to be a synthetic/natural doublet with good asterism. Rubies with cracks were treated either with oil/paraffin or resin or, in faceted stones, a glass-like substance was used as a filler. Many more diffusion-treated sapphires were noticed on the market. Other examples included a dyed star-sapphire of 12.5ct from Sri Lanka; various filled cracks in emeralds; dyed quartzes imitating fire opals; and the name 'aqualite' used in the trade (Thailand) for apatite. A synthetic emerald from Russia (produced by hydrothermal synthesis and sold under the trade name 'Vasar') showing unusually strong pleochroism and a definite blue colour at right angles to the optic axis: physical values as for synthetic emeralds. E.S.

BRANDSTÄTTER F., NIEDERMAYR, G., 1993. Einschlüsse von gediegen Kupfer in Cu-Elbait von Sâo José da Batalha in Paraíba, Brasilien. (Inclusions of native copper in elbaite of Sâo José da Batalha in Paraiba, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 37-41. 1 photograph, 1 photomicrograph, 1 X-ray picture, 1 table, bibl.

The native copper inclusions were found in grey-green tourmalines of Sâo José da Batalha. They form typical dendritic platelets (80-100μm in size, 1μm thick), orientated parallel to the *c*-axis of the host crystal. Electron probe analysis showed the tourmaline to be cuprian elbaite with significant iron and magnesium content. E.S.

BROWN, G., 1993. Paraiba tourmaline. *South African Gemmologist*, **7**, 1, 4-6.

Bright blue tourmalines from Mina da Batalha, Paraiba, Brazil, contains up to 2.38% CuO and/or 2.88% MnO. Blue colour is ascribed to the presence of up to 1.4% Cu^{2+}: a green colour is ascribed to intervalence charge transfer between adjacent Mn^{2+} and Ti^{4+} sites. Cut stones are very expensive. M.O'D.

CUIF, J-P., DAUPHIN, Y., STOPPA, C., BEECK, S., 1993. Forme, structure et couleurs des perles de Polynésie. *Revue de Gemmologie*, **114**, 3-6, 10 photos (3 in colour).

The colour, shape and structure of Polynesian pearls are described in this first part of a general survey paper. M.O'D.

DA CUNHA, C., 1993. Gemmes en lumière. *Revue de gemmologie*, **114**, 11-14, 2 photos (2 in colour), 1 fig.

Quartz with blue inclusions, rhodochrosite, green chrome chalcedony, chrysoprase and green dyed quartz are highlighted. M.O'D.

DELÉ-DUBOIS, M-L., FOURNIER, J., PERETTI, A., 1993. Rubis du Vietnam. *Revue de Gemmologie*, **114**, 7-10, 5 photos (4 in colour), 2 figs.

Ruby from various Vietnam sources are compared with those from Myanmar and other classic locations. Inclusions reported in the Vietnam stones are apatite, quartz, amphibole and rutile. M.O'D.

DHARMARATNE, P.G.R., 1993. Gemmological examination of a colour changing cobalt spinel. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 47-50. 1 graph, bibl.

The author examined a 41.65ct mixed-cut blue stone from the Nilani Gem Museum in Ratnapura, Sri Lanka, which showed a colour-change from blue in daylight to violet in tungsten light. The stone was identified as spinel with cobalt as trace element. E.S.

 ISSN: 0022-1252

DUCHI, D., FRANZINI, M., GIAMELLO, M., ORLANDI, P., RICCOBONO, F., 1993. The iron-rich beryls of Alpi Apuane. Mineralogy, chemistry and fluid inclusions. *Neues Jahrbuch für Mineralogie. Monatshefte*, **5**, 193-207, 3 photos, 5 figs.

Beryls from the Alpi Apuane show unusually high Fe^{2+} content and include emerald and aquamarine. Fluid inclusions are found in both green and blue varieties and three-phase inclusions are illustrated. Crystals show a low *c/a* ratio and are characterized by elongated prism and pinacoid, the largest examples reaching about 1cm in length. Blue beryl comes from the Calcaferro and Buca della Vena mines, emerald from the latter. All come from late-Alpine veins and seem to have avoided any appreciable strain event. At Buca della Vena aquamarine samples occur in quartz veins associated with microcrystalline hematite and magnetite. Emerald occurs in dolomite veins with pyrite, in a dolomitic limestone. M.O'D.

GEBHARD, G., SCHLÜTER, J., 1993. Natrolith von St. Hilaire, Quebec, Kanada. (Natrolite from St Hilaire, Quebec, Canada.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 43-5, 1 photograph, 1 table, bibl.

Cut, clear transparent, colourless natrolite from St Hilaire, Quebec, shows fine orientated cracks, moss-like inclusions of brown to bright-yellow as well as fine needle-like inclusions parallel to the *c*-axis. SG 2.26, RI 1.477-1.490, DR 0.013. E.S.

HARDER, H., 1993. Prähistorische Gläser aus Sri Lanka. (Pre-historic glasses from Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 27-36, 1 map, 2 tables, 4 photographs, bibl.

Multi-coloured glasses are found in Sri Lanka in varying geological environments, at the surface (ground glass), in river gravels, in gem pits (called pit glass). The chemical composition is different from tektites - they have a high sodium and lead content - so it could be that they are man-made, possibly in pre-historic times. After the finish of any mining activity the pit is generally filled with overburden and other waste. The waste is rediscovered during modern mining and can consist of bricks, pottery, gem gravel from other mines and waste from glass production. Glass was an important trade article on the maritime silk road. E.S.

KAMMERLING, R.C., KOIVULA, J.I., 1993. Examination of an interesting assembled imitation of emerald. *South African Gemmologist*, **7**, 1, 20-5, 6 photos in colour.

An imitation emerald crystal purchased in Colombia contained a green fluid which escaped on cutting. The specimen, in the form of a 6.59ct hollowed-out hexagonal prism, appeared a medium-dark green and consisted of a 'water-worn' core fitted inside a hollow crystal of poor quality emerald or pale beryl. The internal cored surfaces were the chief source of the colour which concentrated in patches and was apparently a dyestuff. The core, though displaying a water-worn appearance, seemed to be some form of plastic as it had a very low heft and was very soft. The two pieces, when fitted together, were capped by a grey metal plug covered with a mixture of what might have been a mixture of ground-up mineral matter in a polymer. The grey metal may have been lead and the groundmass melted at the gentle touch of the thermal reaction tester. M.O'D.

KARFUNKEL, J., WEGNER, R., 1993. Das Alexandritvorkommen von Esmeraldas de Ferros, Minas Gerais, Brasilien. (The alexandrite occurrence of Esmeraldas de Ferros, Minas Gerais, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 7-15, 1 map, 2 photographs, bibl.

The alexandrite occurrence of Esmeraldas de Ferros is compared to the neighbouring occurrence at Hematita. The physical properties of both are similar but the geological and tectonic settings are different. The alexandrites of Esmeraldas de Ferros have been affected by tectonic movements and are strongly fractured. The quality is good but they are rarely more than 0.10ct when cut. The colour change is distinct to good. E.S.

KONEV, A.A., VOROBJOV, E.I., BULACH, A., 1993. Charoit- der Schmuckstein aus Sibirien und seine seltenen Begleitminerale. *Lapis*, **18**, 4, 13-20, 14 in colour, 2 maps.

Charoite and its accompanying minerals tinaksite, tausonite (strontium titanate) and others is described from its type location in Siberia. M.O'D.

LEES, B., 1993. Die Wahrheit Åber die neuen Rhodochrosite von der Sweet Home Mine, Alma, Colorado. *Lapis*, **18**, 2, 30-5, 16 photos in colour, 1 map.

Fresh discoveries of gem-quality rhodochrosite have been made at the Sweet Home mine, Alma, Colorado, USA. Details of

some of the more spectacular discoveries are given. M.O'D.

LIEBER, W., 1993. Frabzonen in Fluorit-Kristallen. *Lapis*, **18**, 6, 39-48. 15 photos in colour.

Reworked paper from Lapis 1/93 discussing and describing colour zoning in fluorite. A revised list of references is provided. M.O'D.

LURIE, J., 1993. Polyhedra and gemmology. *South African Gemmologist*, 7, 1, 7-19, 12 figs (5 in colour).

A survey of equidimensional symmetrical polyhedra is presented with remarks on space-filling in solids. M.O'D.

LYCKBERG, P., 1993. Eine Reise zu den Smaragd-Vorkommen im Bereich von Takovaja im Ural. *Mineralien Welt*, 4, 3, 53-9, 21 photos (16 in colour).

The emerald-bearing area of Takovaja in the Urals is described with notes on the history, geology and mining of the area, as well as on emerald, phenakite, tourmaline, garnet, alexandrite and topaz, with other minerals. M.O'D.

MAY, M., MAITRALLET, P., 1993. Etude d'un spinelle synthétique rouge par dissolution anhydre, de fabrication russe. *Revue de gemmologie*, **114**, 15, 2 photos (1 in colour), 2 figs.

A flux-grown red spinel octahedron weighing 4.01 ct and manufactured in Russia had SG 3.56 and RI 1.718. A black fingerprint inclusion was observed. M.O'D.

NIEDERMAYR, G., 1993. Das Einschlussbild synthetischer, nach dem Verneuil- Verfahren hergestellter Korunde. *Mineralien Welt*, **4**, 3, 14, 2 photos in colour.

Well-illustrated short piece on the growth and characterization of flame-fusion corundum. M.O'D.

REDMANN, M., HENN, U., 1993. Smaragde mit künstlich behandelten Rissen und deren Erkennung. (Emeralds with treated cracks and their identification.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 17-25, 1 table, 3 graphs, 2 photographs, 4 photomicrographs, bibl.

Emeralds with cracks can be enhanced in transparency by colourless oiling. According to CIBJO (1991) this is an established trade practice and need not be declared. Cracks filled with artificial resin must be declared. The article gives a survey of today's processes in emerald crack-filling and their identification and distinction between different filling substances. A table gives the various colours and RIs of oils used for these purposes. There are three main methods of identification: (a) with the help of a microscope, especially when the stone is immersed, (resin often shows small bubbles, and is frequently iridescent); (b) examination under UV; however, some resins fluoresce only slightly and, in cases where the cracks have been sealed at the surface, not at all; (c) by infrared spectroscopy which allows a definite identification of the filling substance. E.S.

RYKART, R., 1993. Quarze mit inhomogen verteilten Rauchquarzfarbzentren aus dem Rheinischen Schiefergebirge. *Aufschluss*, **44**, 151-7, 8 photos in colour.

The paper discusses the colour of smoky quartz and its cause with particular reference to fine crystals from the Schiefergebirge in the German Rhineland. M.O'D.

SCOVIL, J., 1993. Neues aus den USA: Die Tucson Gem & Mineral Show 1993. *Lapis*, **18**, 28-32, 8 photos in colour.

Among the gem-quality minerals on show at the 1993 Tucson Gem & Mineral show were orange spessartine from the Kunene river, Namibia; brazilianite from Baixo, Minas Gerais, Brazil; transparent orange clinohumite from Kukh-i-Lal in the Pamirs; demantoid from the Bobrovka river in the Urals; chrysoberyl trillings from Medeiros Neto, Bahia, Brazil; aquamarine from the north-east of Minas Gerais, Brazil; tourmaline from Krasny-Chikoy in the Baikal area of Siberia and amethyst from a number of places. M.O'D.

STALDER, H.A., 199?. Edel- und Schmucksteine aus der Schweiz. Teil 3:Undurchsichtige-Mineralien. *Schweizer Strahler*, **9**, 10, 473-524. 29 photos (15 in colour). Includes German and French versions.

Opaque gem and ornamental materials are covered in the third part of a survey of Swiss gemstones. Species included are jadeite, nephrite, andalusite, kyanite, lazulite, vesuvianite, rhodonite, rhodochrosite and uvarovite. M.O'D.

Book Reviews

ARIYARATNA, D.H., 1993. *Gems of Sri Lanka.* Fifth revised edition. D.H. Ariyaratna, London. pp 109. Illus. in black-and-white and in colour. £9.99.

The gem minerals of Sri Lanka deserve better than this muddled book whose best feature is the coloured photograph depicting faceted stones from the Natural History Museum on the front cover. The naïveté of the text would be hard to beat though the mixture of science, astrology and folk-lore has its own charm. The text cannot be relied on for scientific accuracy and this is a pity since no comparable book on the subject exists in English. This reviewer is not equipped to say whether or not the accounts of gem mining and trading in Sri Lanka are soundly based although they are interesting to read. The whole book is disordered, unconsciously whimsical and at the same time echoes the ponderous didacticism of the British gem textbooks of not so long ago. In no sense can the book be regarded as even moderately worthy of its subject. With revision under the careful eye of a serious scientist the text could one day approach a moderate usefulness but the lack of such supervision is sadly obvious this time. M.O'D.

FAIRBAIRN, R.A., 1993. *The mines of Alston Moor.* Northern Mine Research Society, Keighley. pp 191. Illus. in black-and-white (British mining. no 47).

Though primarily a monograph of the mines and mining of this famous district of the northern Pennines of England this should be required reading for those interested in fluorite deposits (on the mineral side) and in the development and decline of a mining area (on the socio-historical side). M.O'D.

FEDERMAN, D., 1992. *Modern Jeweler's Gem profile/2: the second 60.* Modern Jeweler, Shawnee Mission, KS. pp. 143, illus. in colour. US$ 39.95.

The second (131) tome of gem photographs by Tino Hammid and descriptions aimed at the readers of *Modern Jeweler* and at modern jewellers, this is an attractive book describing a variety of gemstones which include sugilite, blue Paraiba tourmaline and the 'Hancock' red diamond. Notes on history and provenance are interesting, as are the speculations on values. Readers completing a close study of the book (in which the standard of colour photography varies from the very good to the not-so-good) may like to work out how 60 becomes 131, but all will welcome the larger number! M.O'D.

FIELD, J.E. (ed.), 1992. *The properties of natural and synthetic diamond.* Academic Press, London. pp xiv. 710. Illus. in black-and-white and in colour. £90.00.

Though not described as a third edition, the recent work really began with Berman's *Physical properties of diamond* (1965) and Field's *The properties of diamond* (1979), both being, as the present work, multi-author exhaustive studies of diamond. In the preface the reader is warned that further studies will be necessary before very long. While covering all the areas dealt with by the previous books, advances in investigative techniques have compelled the enlargement of the text and in addition some knotty points have come at least closer to resolution; these recent thoughts can be found in the sections on nitrogen aggregation and geology. Diamond growth is strongly covered but the platelet story, even with the new conception of voidites, is still not settled.

It can be seen, therefore, that this is a very wide-ranging text and a look at the extensive lists of references provided in each section shows that it is also up-to-date. A small colour-plate section is devoted to synthetic diamonds which are described in a lengthy section of text. The book also deals with the many applications of diamond, many of which have some relevance to the properties which make diamond unique as a gemstone. Although expensive, gemmologists with a special interest in diamond should at least endeavour to see the text in a major library, since so much current thinking is included and little of this shows up in gemmological texts, for space, relevance and cost reasons. M.O'D.

FIELD, L., 1992. *The jewels of Queen Elizabeth II: her personal collection.* Thames & Hudson, London. pp 120. Illus. in black-and-white and in colour. £12.95.

This well-designed and easily readable book is a revised and shortened paperback version of the author's *The Queen's jewels*, Harry N. Abrams Inc, New York, 1987. Based on a selection of photographs, the main items in the Queen's personal jewellery collection are described with some general historical notes. Some stones shown are important and have rarely been illustrated before. The book is highly recommended. M.O'D.

KELLER, P.C., 1992. *Gemstones of East Africa.* Arizona. Geoscience Press, Phoenix, pp. xiv, 144, illus. in black-and-white and in colour. Price on application.

The gemstone deposits of Kenya and Tanzania are described from the point of view of the geologist and gem prospector. Chapters, each with lists of references and accompanied by some previously unpublished maps, deal with Kenya and Tanzania only: they cover diamond deposits of Tanzania; ruby and sapphire of East Africa; emerald and alexandrite from Tanzania; tanzanite from Merelani, Tanzania; garnets of East Africa; tourmaline of East Africa and prase opal from Haneti Hill, Tanzania. A prefatory chapter discusses East African geology and appendices deal with noteworthy localities of East African gemstones, East African gemstones in the Los Angeles County Museum of Natural History. The matter is very readable and well-presented; the colour photographs are nearly outstanding but show some slight blurring in my copy at least. A most welcome book and one of the forerunners of a new generation of gemmological studies departing from the over-trodden and repetitive path of gem testing. M.O'D.

POINAR, G.O., Jr, 1992. *Life in amber.* Stanford University Press, Stanford, CA. pp. xiii, 350, illus. in black-and-white and in colour. £40.00.

With 30 citations in the field of amber inclusions, a full-length study from this author is particularly welcome since very few gemmologists will have access to the mostly biological sources covered. Leaving the often vexed arena of taxonomy aside, this survey of plant and animal inclusions in amber will provide an invaluable source of information on the types most likely to occur in natural amber.

The opening chapter gives an excellent summary of the formation and occurrence of amber and this is followed by an account of world amber deposits with maps, charts and tables. The next chapter describes the world's major collections of fossiliferous amber and precedes the descriptions, by kingdom, of the major inclusions. This account begins with bacteria, moulds and fungi, going on to bryophyta (mosses and liverworts) and the higher plants gymnosperms and angiosperms. The next section (approximately 200 pages) covers the various animal kingdoms and most readers will be astonished at the variety of creatures that have been found in amber. With so exhaustive a listing, it is clear that many more species remain to be discovered. The descriptions and taxonomic arrangement make this section of the book useful for biologists working in these fields.

The next section of the book gives a reasoned study of the importance of amber inclusions for biological research. This is especially useful when we consider that many of the species found as inclusions are now extinct so that evolution studies are aided as well as work on biogeography. The chapter ends with a speculation that DNA might be cloned from amber inclusions; the implications here are enormous.

Appendices give useful regional summaries: one lists arthropod classes, orders and families reported from Mexican amber and the other covers the same area for the Dominican Republic. There is a 30-page bibliography and a well-constructed index. The price is very reasonable for so original a book which will be found essential for many biologists as well as the wide public interested in amber. M.O'D.

SCHIFFER, N.N., 1993. *Rhinestones.* Schiffer Publishing Co., Atglen, PA. pp. 156. Illus. in colour. £16.95.

This is good value for money as there is a price guide to the items illustrated. The text describes the history of rhinestones (named from Rheinkiesel - Rhine pebbles) a term describing coloured glass moulded in Bohemia and sold at shops on the banks of the Rhine early in this century. The stones and the artefacts made from them are described in order of colour; there are a few references and the price guide at the end of the book. The colour photographs are quite good and the range of objects illustrated very wide. Publication date is 1993 and the ISBN 0 88740 457 X. M.O'D.

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

GIFTS TO THE GAGTL

The Association is most grateful for gifts of gems and gem material for research and teaching purposes from the following:

Mrs Ameena Kaleel, FGA, Mt Lavinia, Sri Lanka, for smoky quartz, garnets, zircons (with very good spectra), corundum crystals, rutilated quartz and kornerupine cat's-eyes.

He Ok Chang, FGA, Brazil, for new decorative stones from Brazil.

Mr H. Stern, Rio de Janeiro, Brazil, for a parcel of emeralds from Brazil.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 14 July 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship
Fitzmaurice, Karl M., Castlerea, Ireland. 1990.

Ordinary Membership
Cadby, John H.V., Trowbridge.
Finlayson, James C., Stoke-on-Trent.
Jayarajah, Aravandy P., Colombo, Sri Lanka.
MacArthur, Iain, Barnes, London.
Sison-Jones, Maria D., London.
Torenvlied, Pieter, Stonehaven.

Gold Laboratory Membership
Cry for the Moon, 31 High Street, Godalming, Surrey GU7 1AU.

At a meeting of the Council of Management held on 11 August 1993 also at 27 Greville Street the business transacted included the election of the following:

Transfer to Diamond Membership
Kassam, Salim S., London. 1993.
Papadopoylos-Fatalos, Costas, Athens, Greece. 1993.

Transfer to Fellowship and Diamond Membership
Beckett, Shona-Maria Ferguson, London. 1993.
Cooper, Carolyn, Hong Kong. 1993.
De Silva, Gamini, London. 1993.
Garrod, Douglas J., Torquay. 1993.
Gellini, Delio, Harrogate. 1993.
Harper, Jonathan, London. 1993.
Mallett, Gillian E., Cambridge. 1993.
Spencer, Riitta M., Helsinki, Finland. 1993.
Strachan, Elizabeth, London. 1993.
Triantaphyllides, Zoe M., Athens, Greece. 1993.
Wates, Peter J., Coulsdon. 1993.
Wu, Chao-Ming, Taipei, Taiwan. 1993.

Fellowship
Chen, Kesheng, Guangxi, China. 1992.
Harris, Richard J., Carlisle. 1993.
Lewis, Rob, Dunstable. 1993.
Maharaj, Rajendra K., Toronto, Ont., Canada. 1988.
Moyersoen, Jean-Francois, Monaco. 1978.
Muigai, Mumbi, Nairobi, Kenya. 1973.
O'Connell, Helen M., Chessington. 1993.
Thomson, Joanna L., Peebles. 1993.

Transfer to Fellowship
Campbell-Pedersen, Maggie, London. 1993.
Daniels, Razia, Chester. 1993.
Day, James P.M., Royal Tunbridge Wells. 1993.
Embleton, Michelle L., Basildon. 1993.
Finlayson, James C., Alsager, Stoke-on-Trent. 1993.
Hue-Williams, Sarah, London. 1993.
Humphrey, Mary S., London, 1993.
Lu, Jei-Chih, London. 1993.
Massow, Kenneth J., Rochford. 1993.
McCormack, Susan L., Liverpool. 1993.
Preece, Susanne L., Bath. 1993.
Proudlove, David, Lochgilphead. 1993.
Robinson, Zoe L., London. 1993.
Ruhmer, Fiona J., London. 1993.
Sandum, Mark A., Ramsgate. 1993.
Saxton, Carol A.L., Alton. 1993.

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FORTHCOMING MEETINGS

London

Meetings will be held on the second floor at 27 Greville Street. Refreshments will be available from 6.00 p.m. and lectures will start at 6.30 p.m.; these will be followed by discussion and closing about 7.45 p.m. The charge for a member will be £3.50 and, as places are limited to 55, entry will be by ticket only, obtainable from GAGTL.

8 November	'Thai evening'	Amanda Good FGA and Martin Issacharoff
22 November	'CIBJO matters' - the gem trade in Europe	Harry Levy FGA
7 December	'Pearls in the Laboratory'	Stephen Kennedy FGA, DGA, and Ana I. Castro FGA
24 January 1994	'Overview of world diamond producer sources'	Robin Walker
7 February	'The independent gemmologist's workshop'	Patrick Daly, FGA
23 February	'Decorative and collectors' minerals from southwest England'	Dr Robert Symes
7 March	'The history of Garrards, the Crown Jewellers'	William Summers
30 March	'Jewellery at auction'	David Lancaster, FGA

The GAGTL Annual Conference is to be held on 24 October 1993 at the Great Western Royal Hotel, Paddington. This will be followed on 25 October by a GAGTL Open Day and the Presentation of Awards.

Midlands Branch

29 October	'Rescued from the scrap box'	David Wilkins
26 November	A practical demonstration of light behaviour in gemstones	Dr Jamie Nelson
11 December	41st Anniversary Dinner	
28 January 1994	'The Cheapside Hoard'	James Gosling
25 February	'Jewellery through the ages'	Nigel Dunn
25 March	'Platinum - design and technology in the workshop'	Dr John Wright
29 April	Annual General Meeting followed by 'The gems of Sri Lanka'	C. & N. Gems

The meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-445 5359.

North West Branch

17 November	Annual General Meeting	
16 February 1994	'A contemporary use of pearls'	Jane Sarginson
16 March	'Current trends in gem testing'	Dr Roger Harding

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270-628251.

Scott, Damian T.F.C., London. 1993.
Slater, Richard M., Bath. 1993.
Sondack, Julia, London. 1993.
Vuillet À. Ciles, Pierre, London. 1993.
Walker, Averil S., London. 1993.
Withers, Justine M., Redhill. 1993.

Ordinary Membership
Jefferson, Gareth, London.
Johnston, Dale R., Dundonald, Belfast.
Kent, Tricia, Princes Risborough.
Sadow, Tanja M., Singapore.
Simpson, David C., Devizes.
Van Der Kemp, Francina M., The Hague, The Netherlands.
Wilson, Deborah T., Boston.

Ordinary Laboratory Membership
Mallory & Son Ltd, 1-4 Bridge Street, Bath, Avon BA2 4HP.

GAGTL LONDON LECTURES 1994

The following lectures will be held in the GAGTL Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU, entry by ticket only. For further details see Forthcoming Meetings on p. 497.

Monday 24 January
'Overview of world diamond producer sources'
Robin Walker

Robin Walker is the only member of staff of the De Beers Central Selling Organization in London who has had experience in the field as a prospector. He spent fourteen years in West Africa, rising to General Manager of the Sierra Leone operation. Altogether, he has been with the CSO for thirty-four years and is now a Manager with the Marketing Liaison Department.

Monday 7 February
'The Independent Gemmologist's Workshop'
Patrick Daly, FGA

Pat Daly entered the jewellery trade in 1970, working in retail and manufacturing before becoming independent in 1984. He has taught gemmology since 1982 with Alan Hodgkinson, at Sir John Cass College, at the GA and at Regents College, taking a particular interest in the ways in which jewellers and gemmologists of

slender means may make the best possible use of the instruments they have and also make their own instruments. He is now working as a freelance jewellery valuer and teacher of gemmology and geology.

Wednesday 23 February
'Decorative and Collectors' Minerals from Southwest England'
Dr Robert Symes

Dr Bob Symes is currently Deputy Keeper in the Department of Mineralogy, Natural History Museum. He has written and co-authored many books on minerals, specializing in British occurrences and is a recent President of the Russell Society. He is currently writing Minerals of Northern England.

Monday 7 March
'The History of Garrards, the Crown Jewellers'
William Summers

William H. Summers, LVO, retired recently from Garrard & Co Ltd, the Crown Jewellers, which he joined in 1950. During the last thirty years he represented them as Crown Jeweller and as a director. He has travelled extensively throughout the world, particularly in the USA, the Far East and Australia to promote the company and British jewellery and silver.

Wednesday 30 March
'Jewellery at Auction'
David Lancaster, FGA

David Lancaster joined the Garrards - Mappin and Webb group in 1970 and spent nine years in South Africa at their Johannesburg branch. On his return to the UK he joined Christie's and has since specialized in period jewellery at Christie's South Kensington. He is also a keen collector of minerals.

Wednesday 13 April
'Ancient Gems and Jewellery'
Dr Jack Ogden, FGA

Dr Jack Ogden is a specialist in the history of the materials and technology of jewellery. He has written and lectured widely on the subject and is editor of *Jewellery Studies*, the Journal of the Society of Jewellery Historians, which he helped found in 1977, and a co-editor of *Gem and Jewellery News*. As a director of the Cambridge Centre for Precious Metal Research, he undertakes consultancy work for museums, dealers and collectors.

Tuesday 26 April
'Cutting it Fine'
Dr George Harrison Jones, FGA

Dr George Harrison Jones has been an Examiner for the GA and GAGTL since 1975 and is on the Members' Council. He specializes in cutting unusual gem species to make the best of their inherent properties and has many examples of his work on display in the Earth Galleries of the Natural History Museum.

Wednesday 11 May
'Spreading Gem Knowledge'
Ian Mercer, FGA

Ian Mercer is Director of Education in GAGTL. He joined the staff of the Association after more than twenty years with the Geological Museum at South Kensington working as a geologist in the Earth science exhibitions team. He headed the team for the 'Treasures of the Earth' exhibition, pioneered videodisc technology in London museums and investigated educational aspects of exhibit use. With a particular interest in gem crystallization, Ian wrote the highly successful Museum book *Crystals*.

Monday 13 June
AGM and Reunion of members

GEM DIAMOND EXAMINATIONS 1993

In 1993 5 candidates sat in January and 45 in June for the Gem Diamond Diploma Examination. Of these 30 passed including one with Distinction. The names of the successful candidates are as follows:

Qualified with Distinction
Papadopoylos-Fatalas, Costas, Athens, Greece.

Qualified - January Examination
Bakayianni-Sabou, Aristea, Athens, Greece.
Gofa, Sophia, Athens, Greece.
Hare, Rebecca M.A., Fleet.
Prior, Louise C., London.
Scott, Kenneth MacDonald, Carluke.

Qualified - June Examination
Beal, Michael R., London.
Beckett, Shona-Maria Ferguson, London.

Burgess, Timothy R., London.
Cooke, Eva-Maria, London.
Cooper, Carolyn, London.
De Silva, Gamini, London.
Duncan, Andrew, Liverpool.
Garrod, Douglas J., Torquay.
Gellini, Delio, Harrogate.
Godfrey, Irmfried A., Glasgow.
Harper, Jonathan, London.
Jackson, Coralyn D., Rosyth.
Jeffrey, Vivian, London.
Kassam, Salim S., London.
Mallett, Gillian E., Cambridge.
Norman, Andrew J., London.
Orr, Caroline, London.
Spencer, Riitta M., Helsinki, Finland.
Strachan, Elizabeth, London.
Triantaphyllides, Zoe M., Athens, Greece.
Turner, Gaynor J., Edinburgh.
Turner, Stephen J., Edinburgh.
Wates, Peter J., London.
Wu, Chao-Ming, Taipei, Taiwan.

EXAMINATIONS IN GEMMOLOGY 1993

In the 1993 Examinations in Gemmology 485 candidates sat the Preliminary examination (65 in January and 420 in June) 321 of whom qualified, and 425 sat the Diploma examination and 201 qualified, 18 with Distinction.

The **Tully Medal** for the candidate who submits the best set of answers in the Diploma examination, which in the opinion of the Examiners are of sufficiently high standard, was awarded to Mrs Guo Tao of Wuhan, P.R. China.

The **Anderson Bank Price** for the best non-trade candidate of the year in the Diploma examination was awarded to Mr Pierre Vuillet à Ciles of Villards d'Heria, France.

The **Diploma Trade Prize** for the best candidate of the year who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Guo Xiaoming of Wuhan, P.R. China.

The **Anderson Medal** for the best candidate of the year in the Preliminary examination was awarded to Mrs Guo Tao of Wuhan, P.R. China.

The **Preliminary Trade Prize** for the best candidate under the age of 21 years on 1 June 1993 who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Yip Ngai of Kowloon, Hong Kong.

DIPLOMA

Qualified with Distinction

Astrom, Mikko, Helsinki, Finland.
Bertorelli, Andrea E.L., London.
Chellew, Ross, London.
Forrest, Jacqueline, Glasgow.
Guo, Tao, Wuhan, P.R. China.
Guo, Xiaoming, Wuhan, P.R. China.
Hue Williams, Sarah, London.
Ibanez de Aldecoa, M. Angeles, Madrid, Spain.
Jegge, Erich P., Zurich, Switzerland.
Kitawaki, Hiroshi, Saitama Pref., Japan.
Leong, Margaret, Bandar Seri Begawan, Brunei.
Mani, Heida, Mississauga, Ont., Canada.
Proudlove, David, Lochgilphead.
Saxton, Carol A.L., Alton.
Scott, Damian T.F.C., London.
Vuillet À Ciles, Pierre, London.
Walker, Averil S., London.
Wang, Shengzhong, Wuhan, P.R. China.

Qualified

Alexanders, David, Toronto, Ont., Canada.
Alonso Florentino, Jose Maria, Madrid, Spain.
Balducci, Annette, Neston.
Berreux, Cedric, La Chaux-de-Fonds, Switzerland.
Bombeke, S., Schoonhoven, The Netherlands.
Buxani Naina Mahesh, Hong Kong.
Campbell Pedersen, Maggie, London.
Cavelti, Christian G., Vancouver, BC, Canada.
Chan Mei Wah, Carol, Hong Kong.
Chan Seung Yuen, Samuel, Hong Kong.
Chedta-Thaiyawong, Kanitha, Bangkok, Thailand.
Chen, Meihua, Wuhan, P.R. China.
Chenevix-Trench, Susannah, London.
Cheung Shuk Mei, Hong Kong.
Choi Dong-Geun, Seoul, Korea.
Choi Pui Ho, Eddie, Hong Kong.
Chow Wing Yuen, William, Hong Kong.
Chown, Philip, Sevenoaks.
Crabbe, Jeremy P., Hong Kong.
Daniels, Razia, Chester.
Dansereau, Eva M., Winnipeg, Man., Canada.
Day, James P.M., Royal Tunbridge Wells.
de Chamerlat, Marie, Paris, France.
de Granville, Francesca, Oklahoma City, Okla., USA.
Del Barrio Lazaro, Pedro A., Valencia, Spain.
Donkin, Jeffrey J., London.
Duigan, Ingeborg, Hong Kong.
Earnshaw, Alison, Tonbridge.
Embleton, Michelle L.E., Basildon.
Ettila, Annamari, Helsinki, Finland.
Farrimond, Thomas, Cambridge, New Zealand.

MEMBERSHIP '94

Members, Fellows and Diamond Members receive an annual membership card, *The Journal of Gemmology* and the *Gem and Jewellery News* quarterly. Fellows (members who hold our Diploma in Gemmology) may use FGA after their name and Diamond Members (members who hold the Gem Diamond Diploma) the title DGA, and both may also apply for the use of the Coat of Arms on their stationery.

Laboratory Members receive a membership certificate for display, *The Journal of Gemmology* and *Gem and Jewellery News* quarterly, and may apply for use of the Laboratory logo on their business stationery. Gold Laboratory Members may enjoy the benefits of Laboratory Members together with lower fees for diamond reports, assistance with temporary import of stones for testing, and special facilities on pearl and coloured stone reports.

All members are eligible for a 10% discount on the retail price of instruments and specimens, and a 5% discount on books purchased from Gemmological Instruments Limited and Overseas Members benefit from arrangements to pay by credit card and all their journals will be sent by airmail.

Subscription Rates 1994

	UK	Overseas
Ordinary Member Fellow Diamond Member	£45.00	£69.00
Laboratory Member	£225.00 +VAT	-----
Gold Laboratory Member	£525.00 + VAT	£525.00

Ferguson, Neil, Balloch.
Finlayson, J.C., Alsager.
Fowle, Michael J., Nairobi, Kenya.
Fry, Suzy, London.
Fung Lai Yi, Hong Kong.
Gibson, William M., Highland, Md., USA.
Gillies, Bronwyn, London.
Gisbert Garcia, Ana M., Madrid, Spain.
Godfrey, Irmfried A., Glasgow.
Goyal, Hariprasad, Jaipur, India.
Graham, Jennifer J., Glasgow.
Granlund Jarvinen, Ingalill, Kasnas, Finland.
Green, Janette F., Leamington Spa.
Guo, Shouguo, Wuhan, P.R. China.
Gutierrez Martinez, Jose A., Madrid, Spain.
Haddock, Brendan, Edinburgh.
Hamp-Gopsill, David, Burton-on-Trent.
Hanna, Margaret A., London.
Harada, Kayoko, Kanagawa Pref., Japan.
Harris, Richard J., Carlisle.
Hawes, Rona M., Redhill.
Hui Wing Chiu, Ernest, Hong Kong.
Humphrey, Mary S., London.
Hung Ching Ting, Hong Kong.
Hung Suet Fung, Hong Kong.
Indiano Iglesias, Natividad, Madrid, Spain.
James, Cary S., Woodstock, Ont., Canada.
Jeong, Seok-Ran, Busan, Korea.
Jones, Amanda, Birmingham.
Joshi, Vikas, Jaipur, India.
Jun, Huang, Wuhan, P.R. China.
Kang, Joo-Youn, Seoul, Korea.
Keating, Martina, London.
Kelloniemi, Katri, Helsinki, Finland.
Kennedy, Lisa, London.
Kiji, Michio, Osaka, Japan.
Kim, Gye Hong, Taejon, Korea.
Kim, In-Kyu, Seoul, Korea.
Kim, Jee-Eun, London.
Kim, So Won, Kyungido Kuri, Korea.
Kinda, Yumiko, Osaka, Japan.
Kitawaki, Jyunko, Osaka, Japan.
Kiviluoto, Raija, Helsinki, Finland.
Kohn, Peter A., Oxford.
Krommenhoek, Celine, Amsterdam, The Netherlands.
Kruise, B.J., Schoonhoven, The Netherlands.
Kuosmanen, Jussi, Helsinki, Finland.
Lai Yi Oi, Hong Kong.
Lanko, Jantine, Amsterdam, The Netherlands.
Lasry, Veronique, Madrid, Spain.
Lau, Paul, Hong Kong.
Lau Heung Ping, Linda, Hong Kong.
Lau Hok Keung, Hong Kong.
Law Yiu Sing, Hong Kong.
Lee, Han Yun, Seoul, Korea.
Lee, Heui-Yeol, Seoul, Korea.
Lee, Jin Young, London.
Lee, Myoung-Hee, Seoul, Korea.
Lee, Sang Yen, Taejon, Korea.
Lee, Sook Jin, Taejon, Korea.
Lee Choi Kan, Franky, Hong Kong.
Lee Fung Kiu, Hong Kong.
Leinonen, Ossi, Kemi, Finland.
Lewis, Robert, Totternhoe.
Li, Jingzhi, Wuhan, P.R. China.
Lin, Songshan, Wuhan, P.R. China.
Linde, Pamela A., Crewe.
Lu, Jei-Chih, London.
Luke Ting Cho Lin, Arlene, Hong Kong.
McCormack, Susan L., Liverpool.
McLean, Grace L., Dundee.
Ma Siu Lam, Hong Kong.
Margolis, Paul H., Vancouver, BC, Canada.
Martin, Jennifer F., Bristol.
Massow, Kenneth J., Rochford.
Mathiopoulou, Regina, Athens, Greece.
Molloy, Theresa A., Vancouver, BC, Canada.
Moon, Sang Rok, Seoul, Korea.
Morris, Patricia E.J., Crewe.
Nam, Song-Ja, Daejun, Korea.
Nicholson, Charles J.R., London.
Nicoll, Douglas J., Haddington.
O'Connell, Helen M., Kingston-upon-Thames.
Odawara, Hiroko, Osaka, Japan.
Oele, Kees, Schoonhoven, The Netherlands.
Okuta, Etsuko, Osaka, Japan.
Ortega Marin, Antonio J., Murcia, Spain.
Paakkari, Petri William, Lahti, Finland.
Preece, Susanne L., Bath.
Rijkelijkhuizen, C.J., Schoonhoven, The Netherlands.
Roberts, Keri J., Bath.
Robinson, Zoe L., London.
Romero Paya, Oscar, Valencia, Spain.
Roskin, Gary A., Marion, Indiana, USA.
Roubin, Ernest, Athens, Greece.
Rouleau, Jocelyne, Quebec, Canada.
Ruhmer, Fiona J., London.
Sagir, Yoram, Israel.
Sandum, Mark A., Ramsgate.
Saorin Penalva, Jose A., Murcia, Spain.
Sapalski Rosello, Cristina, Madrid, Spain.
Sarma, Sunil, Jaipur, India.
Schuivens, C., Geleen, The Netherlands.
Seo, Joung Hee, Taejon, Korea.
Shibata, Hitoshi, Osaka, Jana.
Silvonen, Nanna K., Vantaa, Finland.
Slater, Richard M., Bath.
So Chak Tong, Anthony, Hong Kong.
Sondack, Julia, London.
Stahl, Elone, Lannavaara, Sweden.

Stamatiadis, Nick B., Athens, Greece.
Suh, Young-Hye, Kyeongnam-Do, Korea.
Summanen, Sari, Helsinki, Finland.
Ta'eed, Amelia, Apeldoorn, The Netherlands.
Tanaka, Kazuhide, Osaka, Japan.
Tang, Yuanjun, Wuhan, P.R. China.
Tarkkanen, Mika Olavi, Helsinki, Finland.
Thompson, Jane D., Woodbridge.
Thomson, Joanna, Peebles.
Tonn, Heleen A., Rotterdam, The Netherlands.
Trifaud, Guillaume N., Bangkok, Thailand.
Tripathi, Rajesh, Jaipur, India.
Tuovinen, Annikki, Aanekoski, Finland.
Turner, David B., Newcastle-Upon-Tyne.
Turner, Stephen J., Edinburgh.
van Opstal, Wilma, Tilburg, The Netherlands.
Vinkka-Keskinen, Susanna, Hameenlinna, Finland.
Welsh, Alexis L., Bangkok, Thailand.
Whang, Kyu-Young, Seoul, Korea.
White, Isabel H., Tunbridge Wells.
Wilcox, Kimberly A., London.
Williams, Jason F., Cobham.
Withers, Justine M., Redhill.
Wong Chi Wing, Hong Kong.
Wong Lai Fun, Alice, Hong Kong.
Wong Man Yee, Bess, Hong Kong.
Wong Ming Kin, Hong Kong.
Wu, Chao-Ming, Taipei, Taiwan.
Yamasuga, Ryoji, Hyogo Pref, Japan.
Yan, Gao, Wuhan, P.R. China.
Yang, Hye Keong, Pusan, Korea.
Yasuda, Kiyotaka, Osaka, Japan.
Yi, Young Mee, Taejon, Korea.
Yokote, Hideki, Fukuoka Pref, Japan.
Yu, Peter K.N., Hong Kong.
Yun, Sun-Whoa, Seoul, Korea.
Zanettin Barbin, Fabrizia, Geneva, Switzerland.
Zhang, Beili, Wuhan, P.R. China.
Zhang, Congsen, Wuhan, P.R. China.
Zhang, Xianfeng, Wuhan, P.R. China.
Zhang, Xiang Dong, Hong Kóng.
Zhi, Zhan, Wuhan, P.R. China.

PRELIMINARY

Qualified - January Examination

Baik Bong Jun, Yaesu, Korea.
Bok Hee Ahn, Seoul, Korea.
Chen, Meihua, Wuhan, P.R. China.
Ettema, Johan A., Barendrecht, The Netherlands.
Guo, Tao, Wuhan, P.R. China.
Guo, Xiaoming, Wuhan, P.R. China.
Jung, Gwang Gyo, Daejon, Korea.
Kang, Han Yong, Chungnam-Do, Korea.
Kang, Seung Ho, Pusan, Korea.
Kim, Hee Kyung, Seoul, Korea,
Kim, In-Kyu, Seoul, Korea.
Ko, Hyo-Chong, Seoul, Korea.
Kuiphuis, H.H., Schoonhoven, The Netherlands.
Lee, Chang-Hun, Kyung B K-Do, Korea.
Lee, Han Yun, Seoul, Korea.
Lee, Jae-Yeol, Daejon, Korea.
Li, Zhaocong, Wuhan, P.R. China.
Lin, Songshan, Wuhan, P.R. China.
Moon, Sang Rok, Seoul, Korea.
Shim, Hoo Joung, Daejon, Korea.
Sin, Tea Sun, Seoul, Korea.
Sung, Hee Jin, Chung Nam-Do, Korea.
Tang, Yuanjun, Wuhan, P.R. China.
Verhoef, L., Gouda, The Netherlands.
Wang, Shengzhong, Wuhan, P.R. China.
Yang, Sung-Ja, Seoul, Korea.
Yun, Young Harn, Pusan, Korea.
Zhang, Congsen, Wuhan, P.R. China.

Qualified - June Examination

Ahamed, Omar Faiz, Gillingham.
Alexanders, David, Toronto, Ont., Canada.
Allum, Jason P., Shaftesbury.
Andrews, Peter W., Reading.
Au Ming Cheung, Hong Kong.
Au Yang So-Wah, Natasha, Hong Kong.
Ayles, Catherine R., Edinburgh.
Bae, Eun Jeung, Taegu, Korea.
Bao, Deqing, Wuhan, P.R. China.
Barnes, Matthew J., Rochester.
Benes, Alexandra, London.
Bishop, Heather M., Ipswich.
Blaauw, Pauline P., Rotterdam, The Netherlands.
Bosma, Elizabeth J.A., Amsterdam, The Netherlands.
Bossenbroek, Anna E.H., Doorn, The Netherlands.
Brady Moloney, Zoe D., Camberley.
Bronger, Kimberly K., Sheppey.
Bruce, Rachel M., Edinburgh.
Bryan, William L., Surrey.
Butcher, Anna R., London.
Cai, Cuihua, Wuhan, P.R. China.
Campbell, Robert D., Surrey.
Carr, Rachel J., Blackburn.
Carr, Simon D.P., Garstang.
Carroll Marshall, Anne E., Hong Kong.
Carvalho, Roberta Melo De, London.
Cavelti, Christian G., Vancouver, BC, Canada.
Chan, Kin-Chung J., Hong Kong.
Chan Kwok Keung, Hong Kong.
Chan Shiu Fai, Hong Kong.
Chan Yuk Victoria, Hong Kong.

Chan Zen Iu, Hong Kong.
Chau Kit Yee, Fion, Hong Kong.
Chellew, Ross, London.
Chen, Pauline Lian Bee, Hong Kong.
Cheng Fung Kei, Hong Kong.
Cheng Yuen Yi, Hong Kong.
Cheung, Hoi Ying, Kowloon, Hong Kong.
Cheung, Kit Ching, Kowloon, Hong Kong.
Chew Lee Lee, Hong Kong.
Choi, Jae Hee, Inchon, Korea.
Choi, Lai Na, Lina, Hong Kong.
Choi Pui Ho, Eddie, Hong Kong.
Chow Chun Wai, Hong Kong.
Chua, Virna Ngo, Taikoo Shing, Hong Kong.
Chui Yee Hung, Hong Kong.
Chung Yam Ming, Daly, Kowloon, Hong Kong.
Cliff, Graham O., London.
Cookson, Ian P., Sheffield.
Cooper, Shaun P., Wickhambreaux.
Corbett, Heather R., Bury St Edmunds.
Crook, Gary A.G., London.
Cunningham, Ruth, Edinburgh.
Curtis, Mary E., Auckland, New Zealand.
Cyriac, Joseph J., Worksop.
Dalla Libera, Natalie A., London.
Davis, Shelagh M., Andover.
Deba Kiladi Wa Deba, Manchester.
de Chamerlat, Marie, Paris, France.
Devon, Jill V., Felsted.
Dickinson, Barry E., Blackburn.
Dragland, Frode R., Sortland, Norway.
Drummond, Michelen, Toronto, Ont., Canada.
Egginton, Roy, Bournemouth.
Eggleston, Avrina, London.
Elstgeest, Audrey C., Schoonhoven, The Netherlands.
Evans, Sara J., Somerset.
Farion, Jean-Christopher, Shepton Mallet.
Feingold, Lorna M., London.
Feng, Jiansen, Wuhan, P.R. China.
Ferraro, Benedicta, London.
Fok, Paulyanna, Kowloon, Hong Kong.
Freyer, Nina, Hong Kong.
Fung Yuk Fung, Hong Kong.
Gamst, Terje, Breivikbotn, Norway.
Garvik, Beate K., Oslo, Norway.
Gerrits, Marioes A.A.J., The Netherlands.
Ghurahoo, Julien M.B., Utrecht, The Netherlands.
Gibson, William M., Highland, Md., USA.
Gillies, Bronwyn, London.
Goldschmidt-Husein, Asli, Bangkok, Thailand.
Goss, Sanya L., Aldershot.
Graff, Elliott M., London.
Guillotel, Corinne, London.
Gulliani, Narinder, West Midlands.
Gunell, Carola Merete, Kirjala, Finland.
Hajimihail, Michael, Athens, Greece.
Hamidulla, Suzan, Helsinki, Finland.
Hammer, Sharon, Ont., Canada.
Harootouniun, Katrina, London.
Hartford, Katrina D., Maple Ridge, BC, Canada.
Hellenbrand, Chagay M., Willowdale, Ont., Canada.
Henderson, Stephen M., West Ferry, Dundee.
Hindley, Stuart W., Worksop.
Hindmarsh, Andrew, London.
Ho Tung Tak, Hong Kong.
Hoefsloot, Marlou M.L.J., The Netherlands.
Hong, Ji Hyun, Choongbuk-do, Korea.
How, Sarah J., Shaftesbury.
Hui Sze Wai, Hong Kong.
Hui Wai Yee, Wendy, Hong Kong.
Human, Tracey D., Toronto, Ont., Canada.
Ikuta, Miwa, Kyoto, Japan.
Ispan, Karlo, London.
Jack, Johanne C., Montreal, Que., Canada.
Jansen, Edwin T.D.M.L., Schoonhoven, The Netherlands.
Janssen, Maurice, Schoonhoven, The Netherlands.
Je, Soung Soo, Inchon, Korea.
Johansson, Ingvor, Stockholm, Sweden.
Joshi, Vikas, Jaipur, India.
Kan, Wing Lok, Kowloon, Hong Kong.
Karppijarvi, Karina Pirjatta, Raisio, Finland.
Karunarathne (Buddadasa), K.A., Colombo, Sri Lanka.
Kashi, Kenya, Osaka, Japan.
Keating, Martina, London.
Kennedy, Karen Fiona, Berks.
Ketomaki, Tapio, Jokela, Finland.
KienHuis, Anne-Marie A.M., Wierden, The Netherlands.
Kilby, Linda E., Lancashire.
Kilger, Flavia L.M., Schoonhoven, The Netherlands.
Kim, Eun-Joo, Busan, Korea.
Kim, Jee-Eun, London.
Kim, Kyoung Jin, Chungnam, Korea.
Kim, So Won, Kyungido Kuri, Korea.
Kim, Sung Ju, Pusan, Korea.
Kim, Sung-Mo, Seoul, Korea.
Kim, Young-Suk, Seoul, Korea.
Kim, Sung-Mo, Seoul, Korea.
Kimani, Marjory Nyakiago, Nairobi, Kenya.
King, Andrew, Northants.
Kit Ching Cynthia, Lai, Hong Kong.
Ko Kwai Chun, Hong Kong.
Kobayashi, Masahide, Osaka, Japan.
Kodama, Aki, Osaka, Japan.

Kon Kiang Fung, Hong Kong.
Konst-Kurstjens, Monique A.M., The Netherlands.
Ku Chun Lan, Hong Kong.
Lai, Suet Ling, Hong Kong.
Lake, Richard J., Gorey, Jersey.
Lam, Christina, Ont., Canada.
Lam, Francine, Hong Kong.
Lam, Siu Wing, Hong Kong.
Lam Lai Ping, N.T., Hong Kong.
Lambert, Wendy C., Glasgow.
Lau Heung Ping, Linda, Hong Kong.
Law Yiu Sing, Hong Kong.
Lee, Hyeon-Joo, Seoul, Korea.
Lee, Jin Young, London.
Lee, Mi-Suk, Chonbuk-do, Korea.
Lee Choi Kan, Franky, Hong Kong.
Lee Fung Kiu, Hong Kong.
Legrand Cox, Veronique, Hong Kong.
Leong, Margaret, Bandar Seri Begawan, Brunei.
Leung Yuet Shim, Stella, Hong Kong.
Liang, Tao, Wuhan, P.R. China.
Lo Poi Man, Polly, Kowloon, Hong Kong.
Louis, Eugene, Athens, Greece.
Luo, Weixing, Wuhan, P.R. China.
Macdonald, Louise C., Suffolk.
Ma Cho Pan, N.T., Hong Kong.
McIntosh, Robert P., Penicuik.
McKay, Euan S., Fife.
Mackenzie, Nicola-Jane, Hong Kong.
McKeown, Nicola, Plymouth.
Mak, Judy, Hong Kong.
Mak, So Yi, Hong Kong.
Mann, William M., Gloucester.
Marshall, Michael R., West Midlands.
Mathon-Clark, M.V.J., London.
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