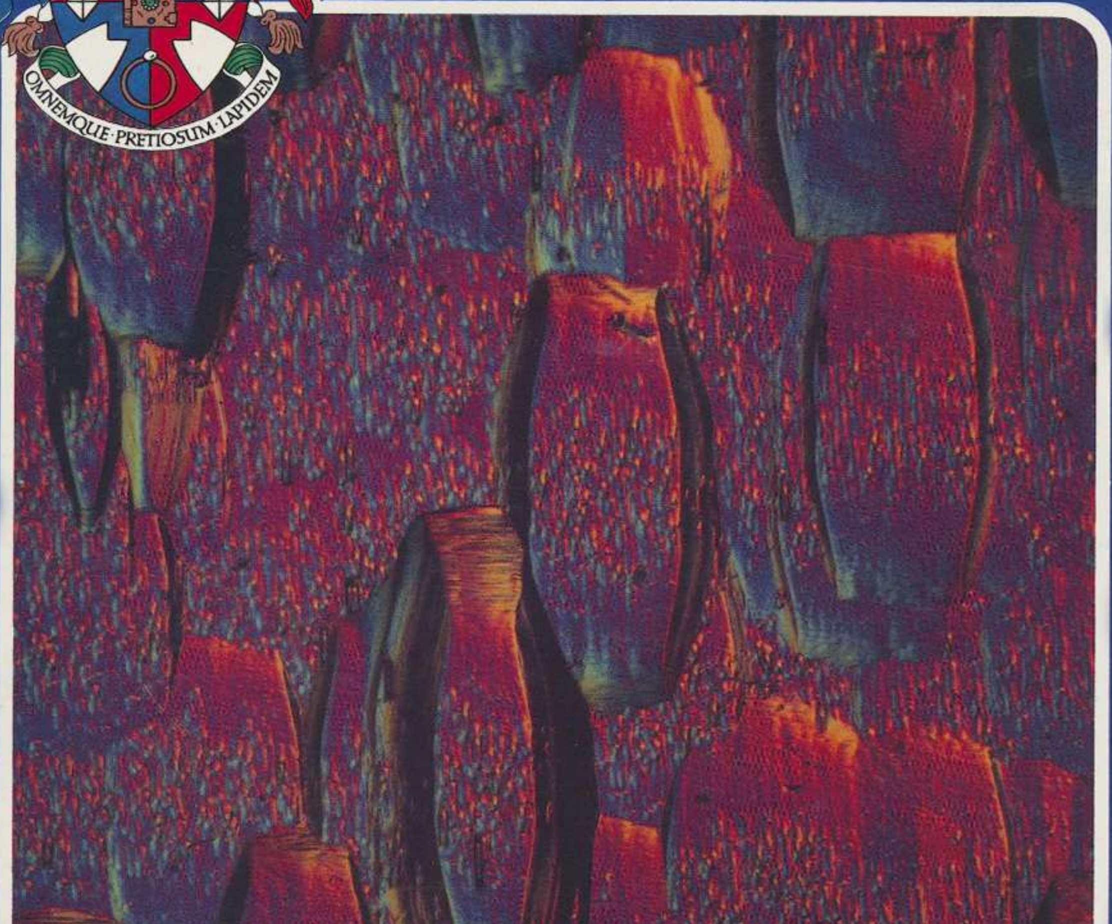
Volume 21 No.3

July 1988

The Journal of Gemmology



GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

OFFICERS AND COUNCIL

President: *Sir Frank Claringbull, Ph.D., F.Inst.P., FGS
Vice-President: R. K. Mitchell, FGA
Chairman: *D. J. Callaghan, FGA
Vice-Chairman: *N. W. Deeks, FGA
Honorary Treasurer: *N. B. Israel, FGA

Members elected to Council:

*A. J. Allnutt, M.Sc., Ph.D., FGA
*E. M. Bruton, FGA
*C. R. Cavey, FGA
P. J. E. Daly, B.Sc., FGA
*A. E. Farn, FGA
A. J. French, FGA
G. Green, FGA
*R. R. Harding, B.Sc., D. Phil, FGA
J. W. Harris, B.Sc., M.Sc., Ph.D.
J. A. W. Hodgkinson, FGA
D. Inkersole, FGA
B. Jackson, FGA
*E. A. Jobbins, B.Sc., C.Eng., FIMM, FGA
*G. H. Jones, B.Sc., Ph.D., FGA
D. G. Kent, FGA
D. M. Larcher, FGA
A. D. Morgan, FIBF, FGA
*J. B. Nelson, Ph.D., FRMS, F.Inst.P., FGA
W. Nowak, C.Eng., F.R.Ae.S., FGA
M. J. O'Donoghue, MA, FGS, FGA
*P. G. Read, C.Eng., MIEE, MIERE, FGA
*K. Scarratt, FGA
E. Stern, FGA
*C. H. Winter, FGA

*Members of the Executive Committee

Branch Chairmen:
Midlands Branch: J. Leek, FGA
North-West Branch: R. Perrett, FGA
South Yorkshire & District Branch: G. A. Massie, FGA

Examiners:

A. J. Allnutt, M.Sc., Ph.D., FGA
E. M. Bruton, FGA
A. E. Farn, FGA
R. R. Harding, B.Sc., D.Phil., FGA
E. A. Jobbins, B.Sc., C.Eng., FIMM, FGA
G. H. Jones, B.Sc., Ph.D., FGA
D. G. Kent, FGA
P. Sadler, B.Sc., FGS, FGA
K. Scarratt, FGA
M. Virkkunen, M.Phil., FGA
C. Woodward, B.Sc., FGA

Editor: E. A. Jobbins, B.Sc., C.Eng., FIMM, FGA
Editorial Assistant: Mary A. Burland
Curator: C. R. Cavey, FGA
Secretary: Jonathan P. Brown, FGA, Barrister

Saint Dunstan's House, Carey Lane, London EC2V 8AB
(By Goldsmith's Hall) ***Telephone:* 01-726 4374**

The Journal of Gemmology

VOLUME 21

NUMBER THREE JULY 1988

Cover Picture

Boat-shaped etch figures on a first order prism face of a green beryl crystal from the Soviet Union. The c-axis runs in the long direction. Nomarski Differential Interference Contrast. 80x. (See 'Etch figures on beryl', p.142.)
Photograph by John I. Koivula.

ISSN: 0022-1252

Douglas Wheeler

It is with deep regret that we report the death on Saturday 7 May 1988 of Douglas Wheeler, former Assistant Secretary of the Gemmological Association of Great Britain and Deputy Secretary of the National Association of Goldsmiths.

Douglas was born on 15 May 1922 in East Ham, London, and joined the staff of the GA and NAG in 1936 at the age of 14. He served both associations continuously except for a period of five years in HM Forces. On his 19th birthday he volunteered for the RAF and after flying training in Canada saw active service in Europe. He was commissioned at 21. Douglas returned to civilian life in 1946 and rejoined the Associations, working alongside the late Gordon Andrews and his brother, the late Harry Wheeler, both of whom had also returned from the services.

He studied at Chelsea Polytechnic as an evening class student and became an FGA in 1948. He was appointed Assistant Secretary for the GA in 1973 and Deputy Secretary of the NAG in 1976.

Douglas retired from business in November 1983. He said at that time that he had greatly enjoyed his years with the two Associations and had been lucky in the people he had met and worked with. He looked forward to a new life of retirement in Norfolk.

He leaves his wife, Kathleen, two sons, Michael and Stephen and grandchildren.

ISSN: 0022-1252

Notes from the Laboratory – 12

Kenneth Scarratt, FGA

The Gem Testing Laboratory of Great Britain, 27 Greville Street, London, EC1N 8SU

The Lennix synthetic emerald, an update

Farn first described the Lennix synthetic emerald in 1980 (Farn, 1980) following a gift in 1979 of a number of sample crystals to the Laboratory. Little has been seen of this synthetic in the market since Farn's first report, however, last year a further gift of three crystals was made to the Laboratory by Szemes Attila of *Enterprise Française de Fabrication D'emeraude de Culture* (Figure 1) and another description (Graziani, *et al.*, 1987) was published in *Gems & Gemology.*

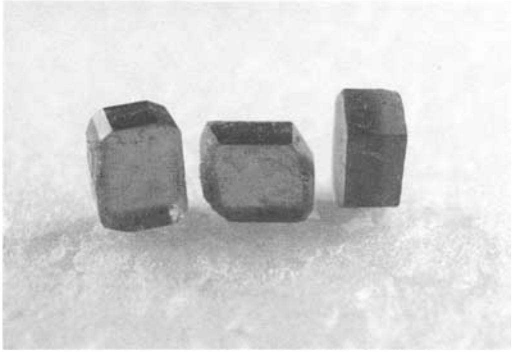


Fig. 1. Lennix synthetic emerald crystals.

The three crystals recently donated weigh 0.81, 0.71, and 0.82 ct, the 0.81 ct stone measuring 4.34 – 5.66 x 2.84 mm. All fluoresce red when irradiated with either long-wave or short-wave ultraviolet rays and also X-rays (diffraction tube, Mo target at 40 kV and 15 mA). Following the slicing and polishing of the 0.81 ct specimen refractive index measurements of 1.561-1.565 were made and these are both consistent with flux grown synthetic emeralds in general and similar to those reported by Farn (1.562-1.566) and Graziani, *et al.* (1.559-1.562).

It is often difficult to obtain accurate results when determining the SGs of stones in the size range of these crystals if the hydrostatic method is used. To determine the SGs of these crystals a liquid was mixed in which an inclusion free and colourless quartz was suspended at room temperature. When the Lennix crystals were placed into the same liquid with the quartz 'marker' each behaved in the same way as the quartz, i.e. at room temperature they were suspended in the same position, as the temperature was gradually raised they slowly sank at the same rate as and with the quartz marker, and as the temperature was lowered they slowly floated to the surface at the same rate and with the quartz marker. This indicates an SG of 2.65 (somewhat below the value that is normally expected of a natural emerald) which is also consistent with the findings of both Farn (2.65) and Graziani, *et al.* (2.65-2.66).

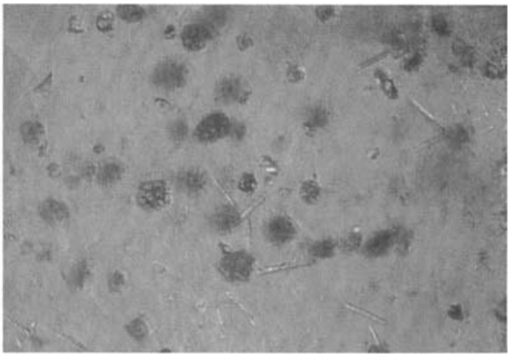


Fig. 2. Crystal aggregates and needle-like inclusions in the Lennix synthetic emerald.

The inclusions and growth features are similar to those of the original 1979 samples, in that the Lennix synthetic emerald is both heavily included and zoned. As one has come to expect a synthetic emerald to be of a high quality (at least in terms of clarity) the faceted Lennix synthetic emerald poses a threat to the over-confident. When examined in the direction along the *c* axis (Figure 2) a multitude of small crystal aggregates are seen which are similar to those described by Farn (Farn, 1980. Figures 5

ISSN: 0022-1252

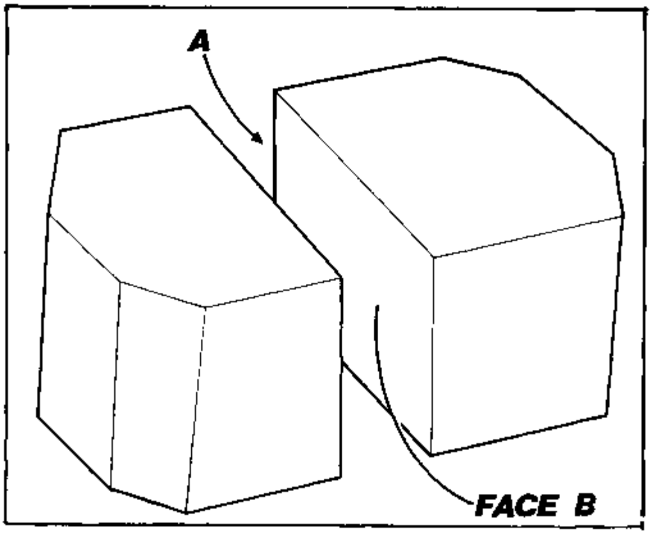


Fig. 4. Line drawing showing the direction in which the 0.81 ct Lennix synthetic emerald was sawn (A) and polished.

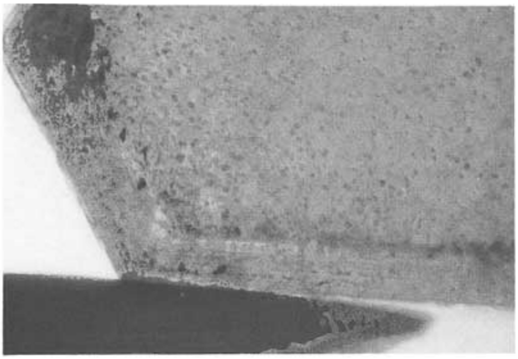


Fig. 3. Crystal aggregates and zoning in the Lennix synthetic emerald.

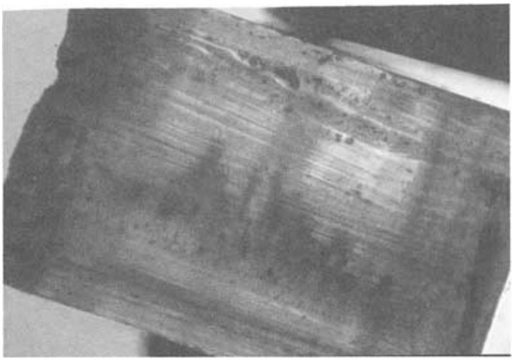


Fig. 5. Zoning in the Lennix synthetic emerald.

Fig. 6. 'Two phase' inclusions in the Lennix synthetic emerald.

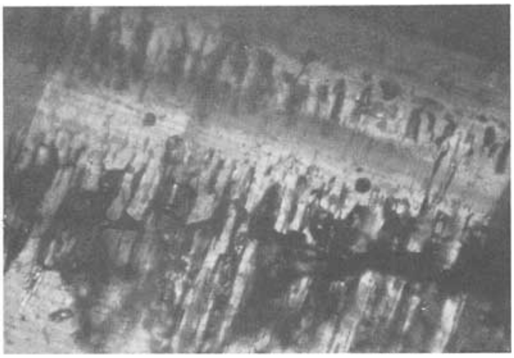


Fig. 7. 'Two phase' and other needle-like inclusions in the Lennix synthetic emerald.

and 6) and a clearly visible zoned structure can be observed within a limited area close to the edge of the crystal. This zoning running 'parallel' with the outer shape of the crystal can be seen in Figure 3.

Upon looking into these crystals one gains the impression that a large 'seed' is contained within. In order that this might be further investigated the 0.81 ct specimen was sliced and polished in the direction indicated by Figure 4. Figure 5 is taken through face 'B' of Figure 4, and this clearly reveals two distinct growth periods. The first characterized by a layered colourless or near-colourless and green area which forms the greater part of the crystal and the second by an outer skin which is layered roughly parallel with the four sides of the crystal. As observed with the crystals reported on in 1980, these later crystals contain large two- and sometimes three-phase inclusions (some of which show a distinct red colour), Figure 6. However, also contained within the more recent crystals are multitudes of small needle-like inclusions, Figures 2 and 7.

The absorption spectrum is typical of that to be expected from 'emerald'. As can be seen in Figure 8, the Lennix synthetic emerald transmits ultraviolet down to 275 nm.

The filling of cavities and feathers in ruby

Rubies in which cavities have been filled with glass are no longer an uncommon sight in the Laboratory. However, upon sorting through a parcel of rubies recently we came across two interesting forms of filling. The first was a plastic filling and was observed in several cabochon-cut rubies (Figure 9) and the second was a fracture that had been filled (at least partially) with glass (Figures 10 and 11). This latter type of infilling could be somewhat more difficult to detect than the 'normal' cavity infilling as the finished product looks, at first glance, to be similar to a 'normal' feather.

Inclusions in heat treated corundum

A heat treated sapphire recently submitted for examination displayed, in transmitted light, the not uncommon sight of an altered guest mineral and associated tension halo (Figure 12). In reflected light though, this inclusion revealed its 'hi-tech' origins by bearing a close resemblance to a 'compact disc' (Figure 13).

The two penny pieces test

An interesting book was loaned to us recently by R. J. Bridges, its title being, *Familiar Lessons on Mineralogy and Geology.* It is the 'twelfth edition'

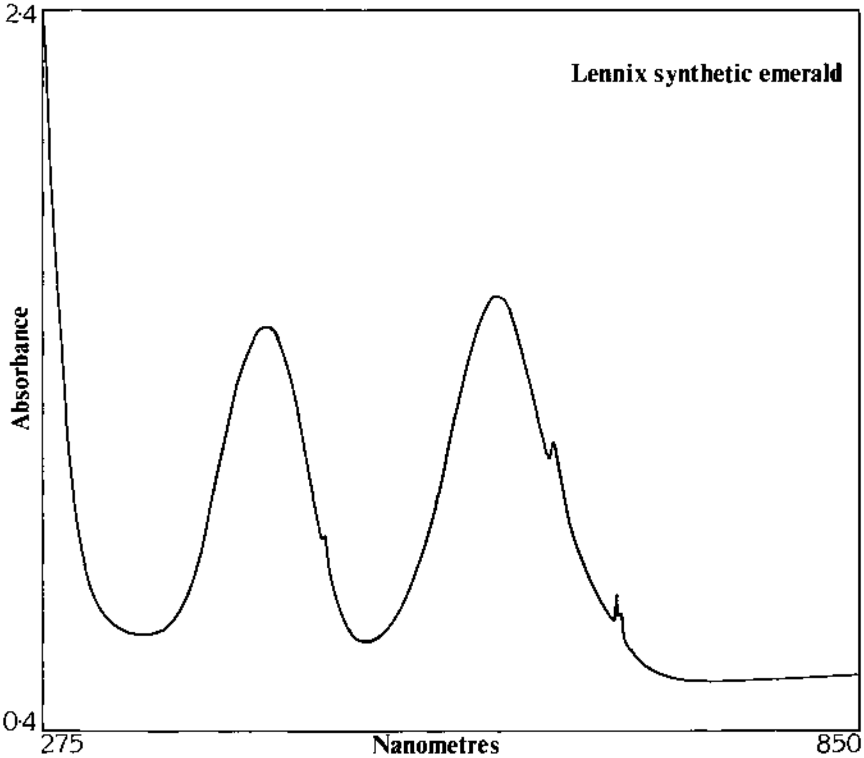


Fig. 8. Absorption spectrum of Lennix synthetic emerald. The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 2.54 mm.

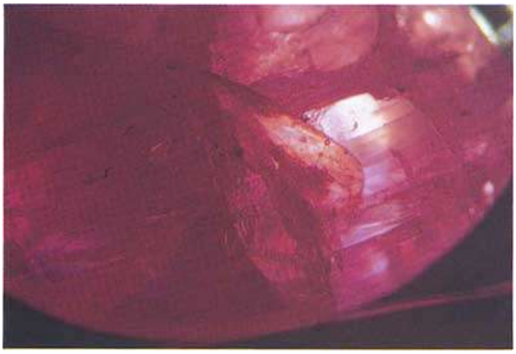


Fig. 9. Plastic infill in a cabochon-cut ruby.

Fig. 10. Partially glass-filled feather in a natural ruby.

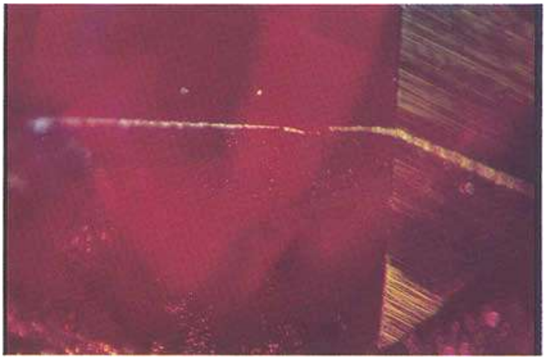


Fig. 11. Partially glass-filled feather in a natural ruby.

Fig. 12. Altered inclusion and tension halo in a heat treated sapphire, transmitted light.

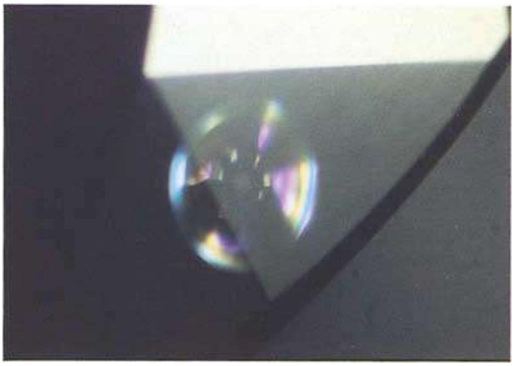


Fig. 13. Altered inclusion and tension halo in a heat treated sapphire, reflected light.

and is dated 1830. There are a number of interesting 'tests' described (many of which cannot be recommended today), one of which is described as follows '*. . . if the substance be small, place it betwixt two penny pieces, and strongly press them with the thumb and finger, when, if it is not a diamond, it will break and be reduced to powder;. . .*' Apart from its intended use as currency, we have heard of many uses for the humble penny and now we have yet another.

ANICS, synthetically grown beryl

During the International Gemmological Conference held in Brazil in September/October 1987, the author was given a group of four synthetic beryl crystals. They were given via Dr Miyata of the Institute of Gem & Jewellery Art, Kofu, Japan, by Naosuke Adachi of the manufacturing company, Adachi New Industrial Co. Ltd, of Osaka, Japan. The method of growth is by chemical vapour deposition and the following types of material are said to be produced: emerald, reddish beryl, sky blue beryl, pink beryl, violet beryl, yellowish-green beryl, colourless beryl and watermelon beryl. It is reported (Yagi and Adachi, 1979) that the doping agents involved in producing these colours are: Co, Mn, Ni, Cu, Nd, Ag, Ti, Fe, Ce, Cr and their combinations.

The four stones given are red, violet/mauve, sky blue, and 'watermelon' with a mauvish centre and green skin (Figure 14). The latter weighs 0.64 ct and its dimensions are 7.7 x 3.5 x 2.8 mm. The 'watermelon' type, which closely resembles tourmaline, has been described by Koivula (1986) as having a specific gravity of 2.66 and refractive indices of 1.559 and 1.564. The company give the mean refractive indices and specific gravity for each type as: emerald 1.57 and 2.63-2.70, reddish 1.568 and 2.66, sky blue 1.575 and 2.67, pink 1.569 and 2.66, and violet 1.573 and 2.67 respectively. These figures largely agree with those obtained on the specimens in Figure 14, although the SG obtained on the violet/mauve sample was a little less, at approximately 2.64, than that quoted by the manufacturer of 2.67, and the refractive indices of the 'watermelon' specimen differed fractionally, at 1.560-1.563, to those obtained by Koivula. The colour in three of the specimens is clearly zoned and the most common inclusions are twisted 'veil-like' feathers and diffuse clouds.

Fig. 14. ANICS synthetic beryl group.

'Fluorolith'

Every now and then peculiar 'fashion stones' appear on the market such as the 'mood stones' of about a decade ago. A short time ago we were given the two stones in Figure 15 and were told that they were being marketed as 'fluorolith'. They are interesting in that they phosphoresce quite strongly and for a considerable length of time, after exposure to light. Figure 16 shows this green phosphorescence after exposure to an optical fibre light.

Fig. 15. Two cabochons of 'Fluorolith'.

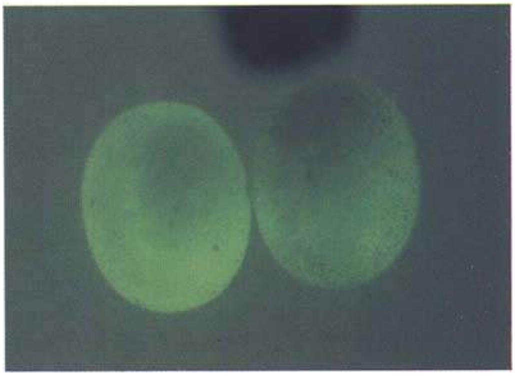


Fig. 16. The two cabochons of Figure 15 phosphorescing after exposure to light.

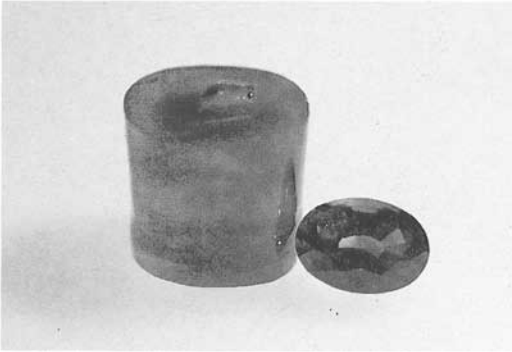


Fig. 17. Kyocera synthetic blue sapphire.

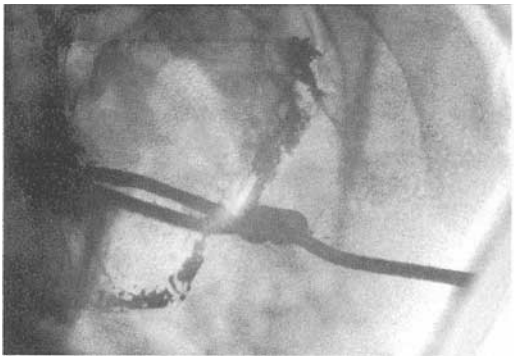


Fig. 21. Platinum wire and seed in the Kyocera synthetic emerald crystal of Figure 19.

Kyocera synthetics

The Laboratory has obtained through the UK offices of the Kyocera Corporation an up-to-date range of their synthetic stones. This includes: blue sapphire, white and black 'opal', emerald, star ruby, alexandrite and alexandrite cat's-eye (Figures 17, 18, 19, and 20).

The emerald crystal seen in Figure 19 weighs 22.15 ct and measures 13.19 x 16.37 x 10.05 mm. The seed is clearly visible in the crystal and a platinum wire can be seen looped through it (Figure 21). Twisted and veil-like feathers, typical of synthetic emeralds in general, are present within the crystal, however, little in terms of the 'usual' inclusions are present in one of the faceted stones. This is a 1.22 ct emerald-cut stone measuring 7.01 x 6.04 x 4.35 mm and those inclusions present consist of many needles (Figure 22) running parallel to the optic axis – which is perpendicular to the table facet. The refractive indices for this emerald-cut stone are 1.560-1.565 but another brilliant-cut stone weighing 1.20 ct, had indices of 1.562-1.565. The SG for the emerald-cut stone was found to be 2.64 and that of the crystal 2.66. Using a prism-type hand-held spectroscope, in all cases a strong chromium spectrum was seen. Under long-wave ultraviolet light the stone's fluorescence is a very weak orange-red or it is inert and under short-wave ultraviolet the fluorescence is a dull or weak orange-red. When viewed through a Chelsea colour filter the stones appear a strong red and under an intense light, such as that provided by the optical fibre type, they glow a bright red (Figure 23).

The star ruby (Figure 20) is a nicely proportioned oval cabochon of 1.42 ct which when observed with a prism-type hand-held spectroscope displays the normal chromium spectrum for ruby. Its SG and RI (distant vision) are also within the range for corundum. The star is formed from a mass of silk-like inclusions (Figure 24) which in themselves could prove deceptive but the 'smoky' or 'flame-like' structures so often seen in the surface areas of

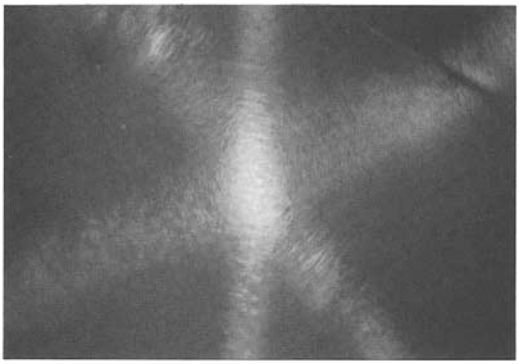


Fig. 24. The silk-like inclusions responsible for the star effect in the Kyocera synthetic star ruby.

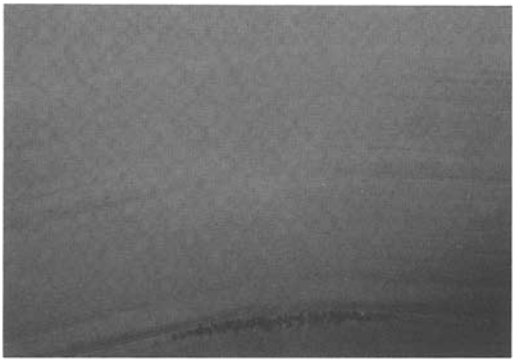


Fig. 26. Zoning in a Kyocera synthetic alexandrite.

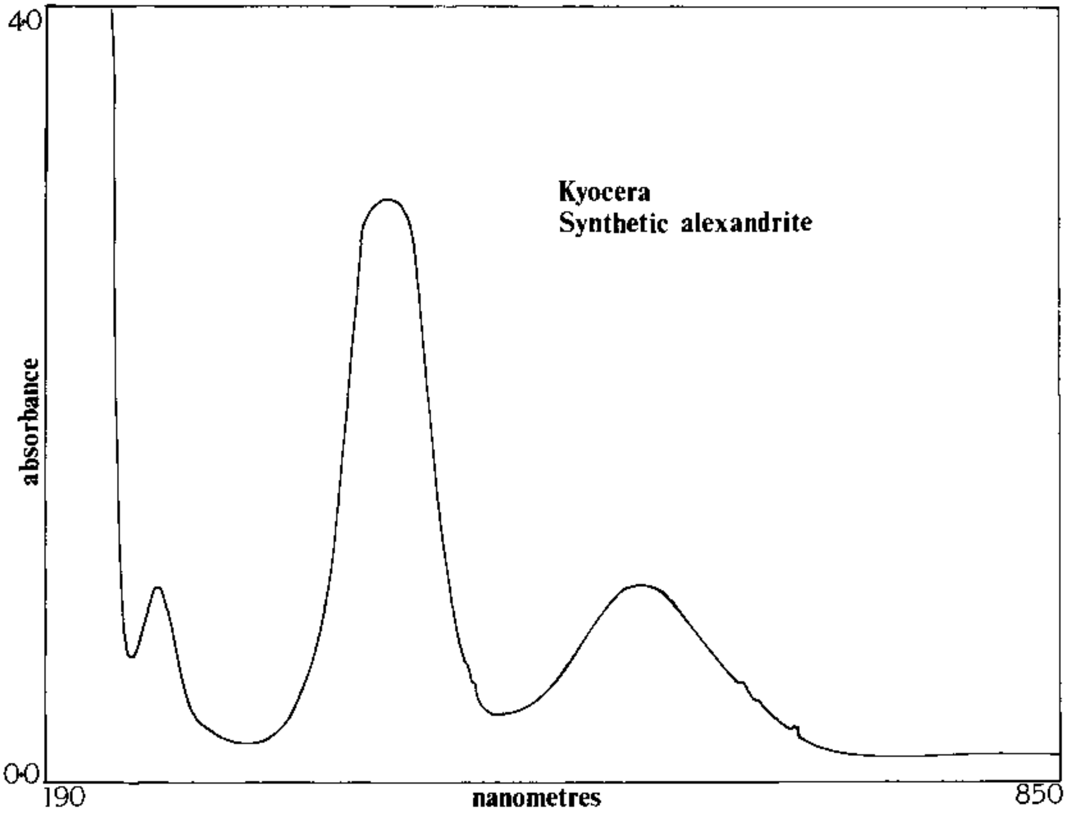


Fig. 25. Absorption spectrum of the synthetic alexandrite crystal. The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Andersom model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 6.5 mm.

synthetic star corundum give away the origin of this material.

Figure 18 shows the synthetic alexandrite and synthetic alexandrite cat's-eye produced by Kyocera. The uncut alexandrite specimen weighs 18.13 ct and measures 17.02 x 13.30 x 6.53 mm and the cabochon-cut cat's-eye weighs 0.97 ct. The refractive indices obtained from the round faceted stone are 1.740-1.748, and the absorption spectrum of the crystal is reproduced in Figure 25. The uncut synthetic alexandrite has easily visible growth structures which at first glance may appear to be 'curved lines'. However, as the angle of view is changed slightly, it can be seen that they are in fact angular (Figure 26), and similar growth features can be seen in the round faceted stone. The cat's-eye cabochon has a clear 'fibrous' structure (Figure 27) which is dissimilar to that seen in the natural material (see Kane 1987). The uncut cat's-eye material has similar structures but many bubbles are present close to the surface.

The faceted synthetic blue sapphire in Figure 17 has refractive indices of 1.760-1.768, but the colour distribution of the uncut material is most distinctive (Figures 28 and 29). Bubbles are also present.

The Kyocera opal product is similar in its structural characteristics to the Gilson material, i.e. a chicken wire or mesh-like structure is clearly visible in both the black and white material (see Schmetzer and Henn, 1987).

Acknowledgements

It is with pleasure that the author acknowledges the assistance of all the members of staff at the Gem Testing Laboratory of Great Britain in compiling these 'Notes'. In particular, S. J. Kennedy, I. Shenker and N. Sturman, provided much information concerning the Kyocera synthetics. The fluorolith was shown to us by E. A. Thomson Gems, who continue, as always, to provide the Laboratory with

Fig. 18. Kyocera synthetic alexandrite and synthetic alexandrite cat's eye.

Fig. 19. Kyocera synthetic emerald crystal.

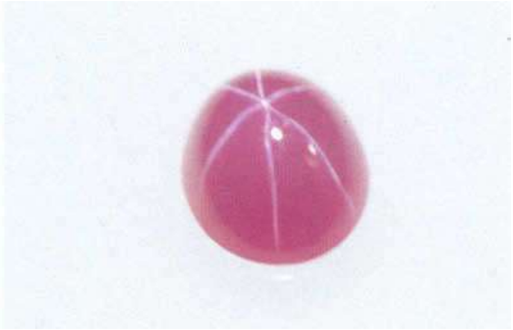


Fig. 20. Kyocera synthetic star ruby.

Fig. 22. Needle-like inclusions in the Kyocera synthetic emerald.

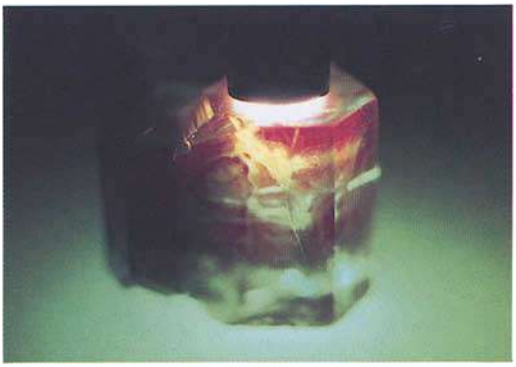


Fig. 23. Kyocera synthetic emerald glowing red in the light produced from an optical fibre light unit.

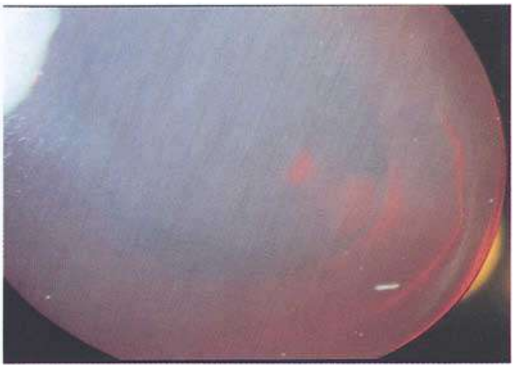


Fig. 27. 'Fibrous-type' structure in a Kyocera synthetic alexandrite cat's-eye.

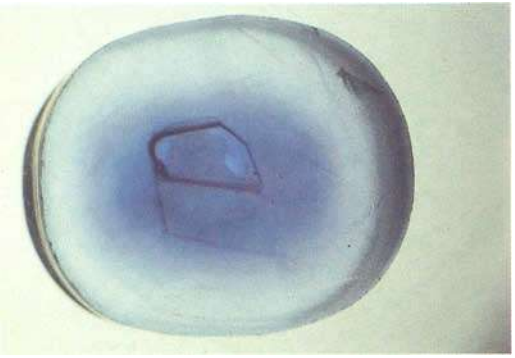


Fig. 28. Colour distribution in a Kyocera synthetic blue sapphire crystal.

valuable information for which we are most grateful. We owe a debt of thanks to Szemes Attila of *Enterprise Française de Fabrication D'emeraude de Culture*, for the Lennix synthetic emerald specimens and to Naosuke Adachi of Adachi New Industrial Co. Ltd, of Osaka, Japan for the ANICS synthetic beryl specimens and state further, that we wish some other manufacturers of synthetic gem materials could find their way to being as generous. Our thanks also go to R. J. Bridges for the loan of *Familiar Lessons on Mineralogy and Geology.*

Fig. 29. Colour distribution in a Kyocera synthetic blue sapphire crystal.

References

Farn, A. E., 1980. Notes from the Laboratory, *Journal of Gemmology*, **XVII**, 2, 73-80.

Graziani, G., Gübelin, E., Martini, M., 1987. The Lennix synthetic emerald, *Gems & Gemology*, **23**, 3, 140-7.

Kane, R. E., 1987. Inamori synthetic cat's-eye alexandrite, *Gems & Gemology*, **23**, 3, 158-62.

Koivula, J. 1986. Gem News, *Gems & Gemology*, **22**, 1, 55.

Schmetzer, K., Henn, U., 1987. Synthetic or imitation? An investigation of the products of the Kyocera Corporation that show a Play of Colour, *Gems & Gemology*, **23**, 3, 148-51.

Yagi, I., Adachi, N., 1979. Syntheses of emerald and other colour varieties of beryl minerals. *Journal of the Gemological Society of Japan*, **6**, 3, 3 (67).

[*Manuscript received 10 May 1988*]

The 10x lens

A.E. Farn, FGA

Seaford, East Sussex, BN25 3HP

It was not entirely inappropriate that the July/October *Journal* arrived on Remembrance Day, 11 November 1988. I was encouraged by the editorial which indicated that there was room for some lighter material other than the 'meat' of the *Journal's* highly scientific content which it quotes as 'tackling gemmological education at the frontiers'. I noted and was particularly warmed by the nostalgia expressed in the Editorial for the Louis Kornitzer style of writing. Kornitzer certainly holds a special place in the dealer/traveller world of gemstones. His style reveals a deep appreciation and love of gemstones. He was, however, a man who earned his living by buying and selling gems. Without this commercial appreciation and profit motive our world of gemmology would be less well provided for.

Fortunately for students of gemmology stones which are heavily included or indeed flawed are relatively cheap and provide ideal material upon which to practise.

In these retirement days there is time for reflection, retrospection and a reading of papers previously published, plus periodicals to peruse. Having moved house and home several times recently in fairly rapid succession I am somewhat geared to clearing out and generally reducing the accumulation of old papers, periodicals and the like.

When these occasions occur I start with determination and enthusiasm to discard some of the papers and books, but they all suddenly acquire interest and importance. Very few are jettisoned, at worst they are 'relegated'. My industry soon grinds to a halt, held up by my immersion in an absorbing article by Basil Anderson, or one of his informative yet entertaining letters. These 'pearls of wisdom', evoke memories of the old days, the old lab and old friends. The *Journal* editorial, in like manner, directed my thoughts to one of the most delightful writers of the gemmological scene. Someone who revels in the structures of gemstones and who has over many years explored the interiors of gemstones with a poetic eye.

In the old days our opposite number was the Service Public du Controle des Diamants, Perles Fines, et Pierres Précieuses de la Chambre de Commerce et d'Industrie de Paris. We of course were The Laboratory of the Diamond, Pearl and Precious Stone Trade Section of The London Chamber of Commerce. Mademoiselle Dina Level is possibly one of the longest serving members of the Paris Laboratory. She started in 1929 and retired in July 1969 completing 40 years of service for which she received the Médaille d'or du Travail, the gold medal of industry. She is also Présidente d'Honneur Association Française de Gemmologie and an Honorary Fellow of The Gemmological Association of Great Britain. She is now retired from the Paris Laboratory but not from the world of gemmology. In her earlier days she was a welcome visitor to our laboratory. We enjoyed her enthusiastic and truly gallic reactions to the luminescent effects in the X-ray viewing chamber and other optical phenomena.

At one time not many gemmologists had seen adequately displayed the fluted or 'organ pipe' group of bright red lines in the spectrum of natural red spinel. When we demonstrated this effect to Dina Level many years ago we used a small colourless glass bottle packed tight with hundreds of tiny octahedral crystals of red spinel. A flask of copper sulphate solution served to cool and concentrate the beam of light on to the microscope. The spectroscope sat on top of an old brass microscope used solely as a light gathering source. Basil Anderson, well over six feet tall, looked comfortably down through the mounted spectroscope, but as Dina is petite, we stood her on a strong low stool for better viewing. Success was achieved, but on viewing this extremely fascinating sight for her first time Dina nearly came over backwards with delighted reaction. She has a very genuine love and appreciation for the many beautiful inclusions and optical effects seen in natural, synthetic and imitation stones.

Mlle Level has written many fascinating articles for the 'Revue française de gemmologie' in a lively

ISSN: 0022-1252

but learned manner. Her appearance on National Television literally swept audiences off their feet with her exuberant enthusiasm for the hidden beauties of gemstones.

In a report of her talk on television, the writer uses as a heading Dina's own words, 'Pierre tu vas me dire quelque chose' (gemstone you are going to tell me something); quoting and translating loose subtle nuances such as the intimate 'tu' for a gem. It is difficult to convey the feeling expressed by Dina Level. These are the kind of papers which stop me when I start to tidy up. They can be easily assimilated by readers who may enjoy a break from the heavier 'meat', mentioned in the *Journal's* editorial.

In an article entitled 'Les Mystères de la Coupe Verte, racine d'émeraude ou?' Mlle Level gives a description of an oval green cup on show in the Louvre Museum, Paris. It is exhibited among the 'Agates' of Monseigneur le Dauphin. It has an oval bowl, baluster stem and oval foot, all three pieces being of the same material. It has simple classic lines and has an overall lightly scratched appearance. The foot and stem are ornamented by twisted enamelled cordons of gold. Three earlier inventories in 1723, 1791 and 1876 gave precise details but failed to agree on the correct nature of the material. The first entry in 1723 stated, *prime d'émeraude;* this is old style French used wrongly for prase, fluor or jade. According to M. J.P. Poirot, Director of the Paris Laboratory, Prime d'émeraude is untranslatable. The second description in 1791 described the cup as prase but with an interior crystallization not yet determined. Both descriptions stated that the cup had been repaired (cassée et remastiquée). The third description of 1896 described the cup as prase and attributed it to the reign of Henri IV, but made no mention of included crystallization.

Members of the Société Française de Gemmologie were able to make a detailed examination of the cup and produced the following details. Softer than quartz, old conchoidal fractures, inert to ultra violet rays and inert through the Chelsea Filter. Examination by progressive magnification with the microscope revealed furrow-like scratches all over; some appear to come from within. Polishing has cut across and sectioned some furrows. Intersecting lines in the interior have a star-like effect with clear rounded green centres. The material is slightly translucent. The chevron or star effect is unlike that of any natural material, or even purpurine glass. Eventually an analysis proved it to be lead glass which was surprising considering its low refractive index of 1.54.

Where the high power of the microscope failed Mlle Level succeeded – with a detailed examination using a 10x lens. She was looking for 'the natural signature of the artificial' – a bubble. A 10x lens is more manoeuvrable than a microscope. Dina Level found a small milky bubble typical of glass and then two more. She finishes her discussion and describes the deception afforded by the cup; it is no less interesting because of the material, in itself rare, its manufacture unknown. She writes of the cup's own soliloquy, 'for a century and a half you have described me as *prime d'émeraude*, then prase (with reservations), then prase again. Almost a century after, the year of grace 1973, is the year of my disgrace. What would Monseigneur le Dauphin have said?' Dina Level apologises to the cup saying 'excuse me little cup for upsetting you; gemmology thanks you for allowing the examination and the sight in your furbelows of those precious "pearls" – your bubbles'.

Mlle Level writes of, and talks to gems; she delves with delight into the world of moss, needles, doubling, dichroism and shatter marks; she is poet, enthusiast and scientist. As a respite from the heavier going, hers is the kind of gemmology that stops me in my tracks.

References

Level, D., 1973. Les mystères de la Coupe Verte, racine d'émeraude prase ou? *Revue de Gemmologie*, 35, 8-9.

[*Manuscript received 26 January 1988*]

Etch figures on beryl

John I. Koivula

Gemological Institute of America, 1660 Stewart Street, Santa Monica, California 90404, USA

Abstract

The surface features of several natural solution-etched beryl crystals were photomicrographically documented using Nomarski Differential Interference Contrast microscopy (Brightman, 1982). The observed etch figures are characteristic for the mineral beryl and can be useful in the identification of even badly corroded crystals.

Solution etched beryl

When examining rough crystals of the mineral beryl it will be noticed that the condition of the individual faces on those crystals varies greatly from crystal to crystal, and even from face to face on the same crystal. While some entire crystals, or separate faces on certain crystals, will appear to be mirror smooth, others will be quite obviously pitted or corroded looking. This apparent corrosion, or etching, is the result of dissolution or the dissolving away of previously formed crystal faces.

Dissolution is a term that can be applied to any solution-etched crystal. Natural crystals, such as beryl, that grow in solution, are always susceptible to solution etching or dissolution should the chemical environment change sufficiently.

If one closely examines the corroded looking surfaces of a solution-etched beryl crystal, the apparently haphazard irregular appearance gives way to a delightful array of geometric patterns known to mineralogists as etch figures.

These etch figures, decorating the surfaces of the solution-attacked beryl, reflect the internal symmetry of the crystal's underlying structure. But the three-dimensional structural framework of beryl varies with direction in the crystal. So it follows that crystal faces which are identical would display similar etch figures. And, those etch features would be visibly different from the etch figures found on dissimilar faces. Therefore each facial plane (or crystal form) on a solution-etched beryl would have its own set of characteristic etch figures.

In his excellent book, *Emerald and Other Beryls* (1981) John Sinkankas illustrates, through a series of black-and-white line drawings, some of the possible etch figures that have been observed on the various faces of beryl. He shows twenty two different figures for the prism faces alone. While another eighteen drawings serve to show some of the patterns that have been found and described on the pyramidal and pinacoidal faces.

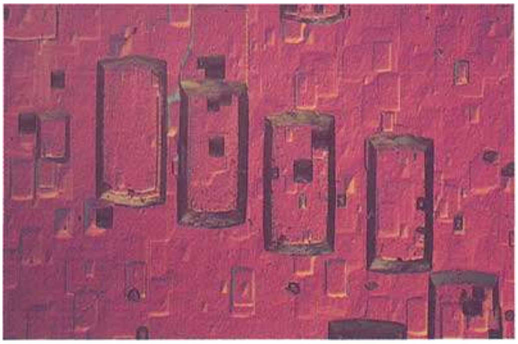


Fig. 1. Rectangular etch figures on a first order prism face of a Brazilian aquamarine. Nomarski Differential Interference Contrast. The *c*-axis runs in the long direction. 80x.

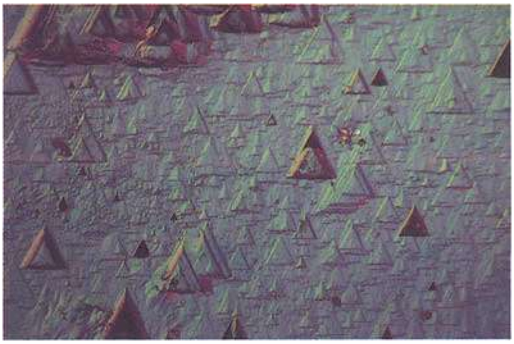


Fig. 2. Triangular etch patterns on a first order bypyramid of a Brazilian aquamarine Nomarski Differential Interference Contrast. 80x.

ISSN: 0022-1252

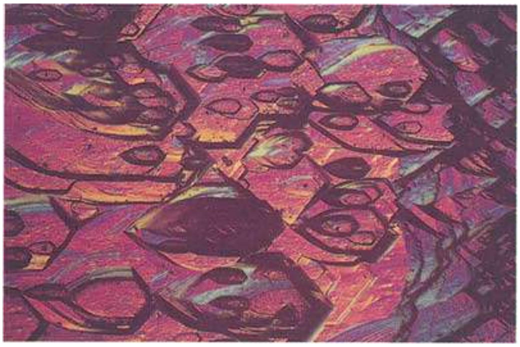


Fig. 3. Shield-shaped etch figures on a second order bypyramid of a Brazilian goshenite. Nomarski Differential Interference Contrast. 80x.

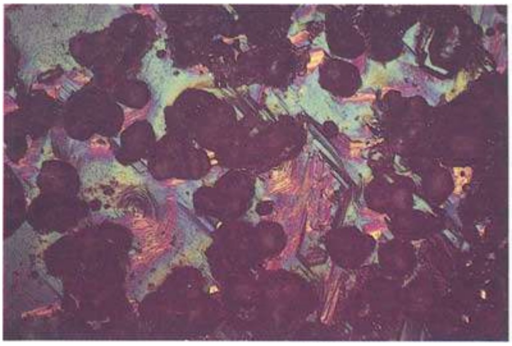


Fig. 4. Hexagonal solution cavities on the basal pinacoid of an aquamarine from Brazil. The *c*-axis is perpendicular to the image. Nomarski Differential Interference Contrast. 80x.

It would be beyond the scope of this article, and the budget of most journals, to provide colour photomicrographs depicting all the etch figures illustrated by Sinkankas in *Emerald and Other Beryls*. So only the most common etch figures observed on the prism (Cover Photomicrograph and Figure 1), pyramid (Figures 2 and 3) and pinacoid faces (Figure 4) are shown.

It is hoped that these few colourful photomicrographic images will excite others to microscopically explore the dissolution hallmarks of beryl.

References

Brightman, R. F., 1982. Surface Topography of gem crystals. *Australian Gemmologist*, 14, 11, 301-4.

Sinkankas, J., 1981. *Emerald and Other Beryls*, Chilton Book Company, Radnor, Pennsylvania.

[*Manuscript received 3 March 1988*]

GEMDATA

A computer program for gem identification

Now available in an expanded version with colour-enhanced text, GEMDATA will run on any IBM PC-compatible computer. It is designed to help with both appraisal identifications and gemmological studies. A full report of the program was given in the *Journal of Gemmology*, **20**, 7/8, 467-73.

Optional yearly update of GEMDATA will be available.

GEMDATA is supplied on a 5¼-inch double-sided, double-density disk, and contains the following three sections:-

1. Gem Identification from a databank of over 220 gems
2. Gem Comparisons (side-by-side display of the constants of selected gems)
3. Gem Calculations (S.G., reflectivity, critical angle, Brewster angle)

The GEMDATA package, complete with disk, operating notes and gem index, costs £75.00 (plus postage and VAT).

To order your package please use the coupon given on p. 206.

Gemmological Association of Great Britain
Saint Dunstan's House, Carey Lane, London EC2V 8AB
Telephone: 01-726 4374 Fax: 01-726 4837
Cables: Geminst, London EC2

Characterization of Russian hydrothermally-grown synthetic emeralds

Dr Karl Schmetzer

Institute of Mineralogy and Petrograph , University of Heidelberg, West Germany

Abstract

Russian hydrothermally-grown synthetic emeralds are characterized with respect to chemical, physical, and spectroscopic properties, growth structures and inclusions. Physical properties such as specific gravity, refractive indices, colour and pleochroism, as well as absorption bands in the visible and infrared region are caused by the extraordinary chemical composition of the samples containing high amounts of Cr_2O_3, Fe_2O_3, Ni_2O_3 and CuO. Microscopic features such as growth structures and inclusions are due to the experimental conditions of crystal growth. In summary, all features of diagnostic value are explainable with respect to the details of synthesis applied to the growth process of this exceptional type of synthetic emerald by Russian scientists. All properties determined are compared with features of natural emeralds from different sources.

I. Introduction

Synthetic emeralds have been manufactured in Russia by hydrothermal techniques since 1965 (Emel'yanova *et al.*, 1965). Commercially produced faceted samples were first mentioned in gemmological literature by Fryer *et al.* (1983) and Koivula (1984, 1985). Chemical data were published by Hofmann *et al.* (1985), Gübelin (1986) and Lind *et al.* (1987). In all three papers cited, exceptional high iron contents for beryl or emeralds between 3.07 and 5.32 wt.% Fe_2O_3 were mentioned. In addition, a remarkable nickel content of 0.62 wt.% NiO was found by Hofmann *et al.* (1985).

Spectroscopic data were published by Gübelin (1986), Lind *et al.* (1987) and Scarratt (1987). The first author briefly mentions absorption lines and absorption bands which are typical for Cr^{3+} in beryl. In the paper of Lind *et al.* (1987), the absorption bands found in the spectra which were recorded for several samples of Russian hydrothermally-grown synthetic emeralds were assigned to Cr^{3+}, Fe^{3+} and Fe^{2+} ligand field transitions as well as to a Fe^{2+}/Fe^{3+} charge-transfer absorption. In other words, the absorption spectrum was interpreted to be typical for emeralds containing a distinct aquamarine component in addition to the chromium-vanadium spectrum of emerald. Beryl samples of this type reveal a pleochroism of blue $\parallel c$ and yellowish-green $\perp c$, and emeralds of this particular colour originating from Miku, Zambia, were first described by Schmetzer & Bank (1980, 1981). In the paper of Scarratt (1987), non-polarized absorption spectra of two samples are pictured, which were recorded at angles of 90° to each other, but oblique to the optical axis of the rough and faceted stone, respectively. Some extraordinary features of the spectra are mentioned, but no explanation for these properties could be given.

Microscopic observations were described in all papers cited above dealing with information on seed plates, irregular growth structures, reddish-brownish and opaque platelets as well as two- and three-phase inclusions.

During a systematic study of absorption spectra of natural and synthetic emeralds, the present author was able to record the spectra of some faceted samples of Russian synthetic hydrothermally-grown crystals which were made available as a loan from Prof. Dr E. Gübelin of Meggen, Switzerland in December 1986. The first spectroscopic results indicated the presence of some absorption bands, which were not able to be assigned to the known chromium, vanadium and iron absorptions of emerald (cf. Lind *et al.*, 1987; Scarratt, 1987). In addition, using X-ray fluorescence analysis, traces of nickel and, most surprisingly, copper were found to be present. From these preliminary results, a more comprehensive study of chemical, physical and spectroscopic properties as well as microscopic features of this exceptional type of synthetic emerald was initiated. All characteristics observed are in good agreement with Russian literature dealing with properties of hydrothermally-grown synthetic beryl doped with traces of chromium, iron, nickel and copper. In addition, most observations are useful for determinative purposes, i.e. for a recognition of samples of unknown origin as well as for distinction of natural and synthetic emeralds.

ISSN: 0022-1252

II. Materials and methods

For the present study, 13 faceted samples of Russian hydrothermally-grown synthetic emeralds were available for non-destructive investigations. Eleven square cut samples in the range of 0.35 to 0.52 ct in weight and about 4 × 5 mm in size (Figure 1) originally came to Europe as pre-shaped or cut samples via Hong Kong in 1986. One faceted sample 0.88 ct in weight and 5 × 5.5 mm in size came to Great Britain in 1986 and was already described by Scarratt (1987). Another cut sample 2.34 ct in weight and 6.5 × 10 mm in size was given to a private collector in 1979 during a visit to the Institute of Geology and Geophysics, Siberian branch of the USSR Academy of Sciences, Novosibirsk, USSR.

By scientists of this research institute, the complete development of growth processes for hydrothermal synthesis of emeralds was undertaken and complete descriptions of chemical, physical and spectroscopic properties as well as growth structures of this research material were published in the Russian language (Solntsev *et al.*, 1976, 1978; Il'in *et al.*, 1980; Klyakhin, 1980; Lokhova *et al.*, 1980; Bukin *et al.*, 1980, 1981; Shatsky *et al.*, 1980, 1981; Klyakhin *et al.*, 1981a,b; Solntsev, 1981a,b; Lebedev & Askhabov, 1984; Lebedev & Dokukin, 1984; Pugachev, 1984; Lebedev *et al.*, 1986). However, according to Russian literature, the commercial production of hydrothermally-grown synthetic emerald, which was reduced to practice on jewellery plants in Sverdlovsk, Leningrad, L'vov and Estonian (Lebedev, 1987), is performed at L'vov, Ukraine, USSR (Godovikov *et al.*, 1982). At present, hydrothermally-grown synthetic emerald is produced in limited amounts of nearly 1-2 kg a year on contract with private businessmen from the USA and Canada. Only limited information about properties of this commercially produced type of synthetic emerald is available to the present author from Russian literature (Godovikov *et al.*, 1982; Granadchikova *et al.*, 1983), but according to the features of the material available for this study, growth conditions and properties of the Russian scientific research material and the commercial Russian production are similar or almost identical. One important difference, i.e. the different materials used for autoclave walls, will be discussed later in this article (cf. section IV).

Fig. 1. Faceted Russian hydrothermally-grown synthetic emeralds. Size of samples approx. 4 × 5 mm (*Photo by O. Medenbach, Bochum, West Germany*).

For the present study, all samples available were spectroscopically examined in the range of about 11,500 to 32,500 cm^{-1} using a double-beam UV-VIS spectrophotometer (Leitz-Unicam, model SP.800). Five samples representing the complete variability of spectroscopic properties were selected for chemical analysis by electron microprobe (ARL, model SEMQ, used for main and trace elements) and X-ray fluorescence techniques (Siemens, model SRS 300, used for trace elements). As internal reference materials, samples of synthetic emeralds grown by Chatham, Gilson and Lechleitner were included in the chemical study, and fragments of the identical crystals were simultaneously analyzed for colour causing trace elements by destructive techniques using inductively coupled plasma atomic emission spectrometry (Perkin-Elmer, model ICP 6000). For the determination of unit cell dimensions as well as for infrared spectroscopy small amounts of powder were scraped from the girdle of one faceted stone. This powder was used in order to obtain an X-ray powder diffraction pattern for the calculation of unit cell dimensions (Debye-Scherrer camera, diameter 114.6 mm, FeK_α radiation) as well as for the preparation of a KBr pressed disk for infrared spectroscopy using a double-beam IR spectrophotometer (Perkin-Elmer, model IR 180).

III. Results

III.1 Chemical and physical properties of Russian hydrothermally-grown synthetic emeralds

Chemical data of Russian hydrothermally-grown synthetic emeralds obtained by non-destructive techniques are presented in Tables 1 and 2. The analytical results indicate remarkably low values of MgO and Na_2O compared with most sources of natural emeralds (Hänni 1981, 1982; Schrader, 1983; Stockton, 1984), but surprisingly high, but varying amounts of colour-causing trace elements such as Cr_2O_3, Fe_2O_3, Ni_2O_3 and CuO (cf. Figure 2). The valence states and lattice positions of these transition metal elements are determined by an

Table 1. Chemical and physical properties of Russian hydrothermally-grown synthetic emerald (sample a)

Chemical properties						Physical properties	
Chemical analysis [wt.%]		Cations calculated to Si=6			Lattice Site	Unit cell dimensions [Å] (refined from 20 d-values)	
CuO	0.10	Cu	0.007	3.000	tetrahedron	a_0	9.234 (3)
BeO[1]	13.58	Be	2.993			c_0	9.197 (4)
MgO	0.04	Mg	0.005	2.021	octahedron	Specific gravity [g/cm³]	
MnO	<0.01	Mn	—				
Al_2O_3	16.05	Al	1.736			$d_{obs.}$	2.69 (1)
V_2O_3	<0.01	V	—			$d_{calc.}$	2.703
Cr_2O_3	0.35	Cr	0.025				
Fe_2O_3[2]	3.00	Fe	0.207			Refractive indices	
Ni_2O_3[3]	0.72	Ni	0.048			n_o	1.580 (1)
SiO_2	65.38	Si	6.000		tetrahedron	n_e	1.573 (1)
Li_2O	n.d.	Li	0.x		channel	Δn	0.007
Na_2O	0.03	Na	0.005				
K_2O	0.03	K	0.004				
H_2O[4]	0.98	H_2O	0.300				
Σ	100.26						

n.d. not determined, but present according to infrared spectroscopy
1 calculated for Σ Be+Cu = 3.00
2 total iron as Fe_2O_3
3 total nickel as Ni_2O_3
4 calculated for H_2O = 0.30

Crystal chemical formula:
$(Cu_{0.01}Be_{2.99})(Mg_{0.01}Al_{1.74}Cr_{0.03}Fe_{0.21}Ni_{0.05})Si_6O_{18}(Li_{0.x}Na_{0.01}K_{0.01}H_2O_{0.30})$

Table 2. Colour-causing trace elements in Russian hydrothermally-grown synthetic emeralds [ppm]

Sample	V	Cr	Fe	Ni	Cu
e	<100	2580	21700	3050	6760
d	<100	4240	30100	2310	4240
c	<100	2740	20300	4260	3470
b	<100	4070	19600	6100	1080
a	<100	2400	21000	5100	800

assignment of absorption bands in the visible and ultraviolet area (compare section III.3). According to these data, copper was found in the divalent state replacing beryllium in tetrahedral sites. Chromium, iron and nickel are found exclusively in the trivalent state in octahedral aluminium sites.

The value for BeO was calculated according to crystal chemical principles as Σ Be + Cu = 3.00. However, due to a possible presence of small amounts of lithium replacing beryllium in tetrahedral sites, the calculated BeO content is assumed to be an approximation only.

The presence of water was established by infrared spectroscopy (see section III.4), and the total amount of water was calculated for a reasonable value of 0.3 water ions in the formula unit. This value represents an average for hydrothermally-grown Russian beryl, which was found to contain between 0.10 and 0.62 water ions in the formula unit (Il'in *et al.*, 1980; Klyakhin *et al.*, 1981a,b; Shatsky *et al.*, 1981; Lebedev & Dokukin, 1984; Pugachev, 1984; Lebedev *et al.*, 1986).

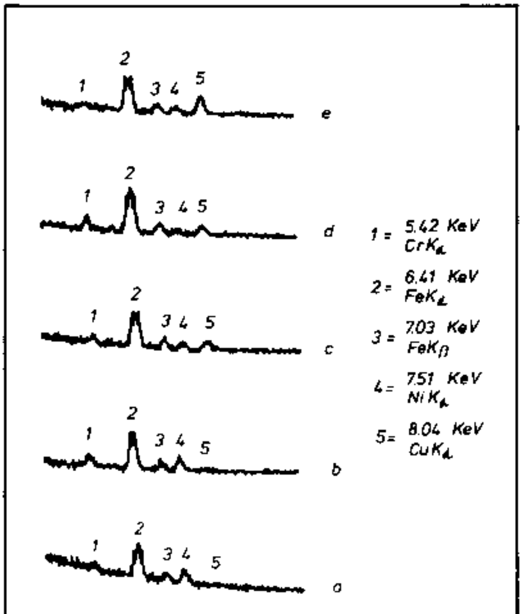


Fig. 2. Energy-dispersive X-ray fluorescence spectra of colour causing trace elements (Cr, Fe, Ni, Cu) in samples (a) to (e) of Russian hydrothermally-grown synthetic emeralds (cf. Table 2).

The presence of distinct amounts of lithium in channel sites of the beryl lattice is derived indirectly from infrared spectroscopical investigations in connection with the low quantities of Na_2O, which were analytically determined by electron microprobe analysis (cf. section III.4). However, the quantitative amount of Li_2O in Russian synthetic emerald was unable to be determined by non-destructive methods. The crystal chemical formula of one specimen (sample a) reads $(Cu_{0.01}Be_{2.99})(Mg_{0.01}Al_{1.74}Cr_{0.03}Fe_{0.21}Ni_{0.05})Si_6O_{18}(Li_{0.x}Na_{0.01}K_{0.01}H_2O_{0.30})$. Samples of hydrothermally-grown synthetic beryl which are similar or almost identical in chemical and physical properties were recently described by Klyakhin *et al.* (1981b) and Lebedev *et al.* (1986).

From the 13 faceted gemstones of Russian synthetic emeralds investigated in the present study, microscopic investigations revealed the presence of residues of colourless seed plates in six of the samples. Three of the synthetic emeralds were cut in a direction leaving the residue of the seed plate as table facet of the stone (cf. Figure 6), and in three of the samples part of the seed plate was found to form the culet of the cut synthetic emerald (cf. Figure 7). Thus, refractive indices of hydrothermally-grown emeralds were obtainable from the table facets of ten samples using a standard Rayner refractometer, and the refractive indices of seed plates were obtainable for three cut stones. Specific gravities of Russian synthetic hydrothermally-grown emeralds were measured for those seven samples without residues of seed plates.

The results (Table 3) indicate a slight variability for optical data as well as for specific gravities of the synthetic emerald material and constant values for the optical properties of seed plates. According to gemmological standard reference books, these values are within the range of natural emeralds from different localities. On the other hand, specific gravities and refractive indices of these Russian synthetic hydrothermal emeralds are found in the upper part or even slightly above the range known for synthetic emeralds with the exception of Lechleitner synthetic emeralds (emerald-coated natural

Table 3. Range of refractive indices and specific gravities for Russian hydrothermally-grown synthetic emeralds

Synthetic emerald			
n_o	n_e	Δn	d[g/cm^3]*
1.580 to 1.586	1.573 to 1.579	0.006 to 0.007	2.68 to 2.70

*for samples without seed plate

Seed plate			
n_o	n_e	Δn	d[g/cm^3]
1.571	1.565	0.006	not available

beryl cores). The values were also found to be distinctively higher than Russian flux-grown synthetic emeralds (cf. Koivula & Keller, 1985).

In general, in natural and synthetic beryl and emerald, increasing amounts of alkali metal oxides such as Li_2O, Na_2O, K_2O, Rb_2O, and Cs_2O (with Li^+ in tetrahedral Be sites as well as in channel sites, and all other alkalis located in channel sites of the beryl structure), as well as increasing amounts of MgO and transition metal oxides such as V_2O_3, Cr_2O_3, MnO, FeO, Fe_2O_3, CoO, Co_2O_3, NiO, Ni_2O_3, CuO (located in octahedral and/or tetrahedral sites of the beryl structure) cause increasing values of unit cell dimensions (especially of a_0, dependent on replacements of octahedral sites, and of c_0, dependent on replacements of tetrahedral sites), refractive indices and specific gravities (Pavlova, 1963; Bakakin *et al.*, 1967, 1970; Filho *et al.*, 1973; Černý & Hawthorne, 1976; Solntsev *et al.*, 1976; Rodionov & Pavlyuchenko, 1980; Bukin *et al.*, 1980; Klyakhin *et al.*, 1981a,b; Shatsky *et al.*, 1981; Franz, 1982; Pugachev, 1984; Lebedev *et al.*, 1986; Deer *et al.*, 1986).

Increasing amounts of transition metal elements in general are responsible for increasing refractive indices and specific gravities in synthetic emerald. The differences in physical properties of Russian synthetic hydrothermal emeralds compared with other synthetic emeralds of various producers are due to the high amounts of colour-causing trace elements such as Cr, Fe, Ni, and Cu in the Russian material (compare section III.3), which exceed the amounts of transition metal elements found in other flux-grown or hydrothermally-grown synthetic emeralds. An exception is observed for Lechleitner synthetic emeralds (emerald-coated beryl seeds) with extraordinarily high refractive indices. The thin overgrowth of this synthetic emerald may contain up to 10.01 wt.% Cr_2O_3 causing refractive indices up to n_o 1.610, n_e 1.601 (Schmetzer *et al.*, 1981a,b).

The amounts of colour-causing trace elements in Russian hydrothermally-grown synthetic emeralds also exceed the range which is generally found in natural emeralds from different localities. According to these data alone, the refractive indices of the Russian material should also exceed the values of natural emeralds. On the other hand, most natural emeralds reveal higher amounts of MgO and alkali metal oxides (especially Na_2O contents) than the samples described in this paper. In general, an increase of alkali metal contents in natural and synthetic emeralds is responsible for an increase of refractive indices. Thus, in Russian hydrothermally-grown synthetic emeralds, the influence of high amounts of colour-causing transition metal oxides is partly compensated by the low contents of MgO and alkali metal oxides. Regarding these facts, refractive indices and specific gravities in the range of natural emeralds become understandable.

The unit cell dimensions of Russian synthetic hydrothermally-grown emeralds (Table 1) are found to lie within the range of natural beryls as well as within the range of hydrothermally-grown samples described in Russian literature, which contain transition metal oxides between 2.0 and 5.0 wt.% in octahedral aluminium sites and lower lithium and/or copper contents in tetrahedral beryllium sites (Bakakin *et al.*, 1967, 1970; Filho *et al.*, 1973; Solntsev *et al.*, 1976; Il'in *et al.*, 1980; Bukin *et al.*, 1980; Klyakhin *et al.*, 1981a,b; Shatsky *et al.*, 1981; Franz, 1982; Pugachev, 1984; Lebedev *et al.*, 1986). Samples of this type of natural and synthetic beryl, in which octahedral replacement of Al^{3+} is dominant over tetrahedral replacement of Be^{2+} are called o-beryls (Bakakin *et al.*, 1967, 1970).

All samples investigated were inert to long- and short-wave ultraviolet radiation. This result is understandable in view of the high concentrations of iron in the synthetic material, which is responsible for the quenching of chromium fluorescence.

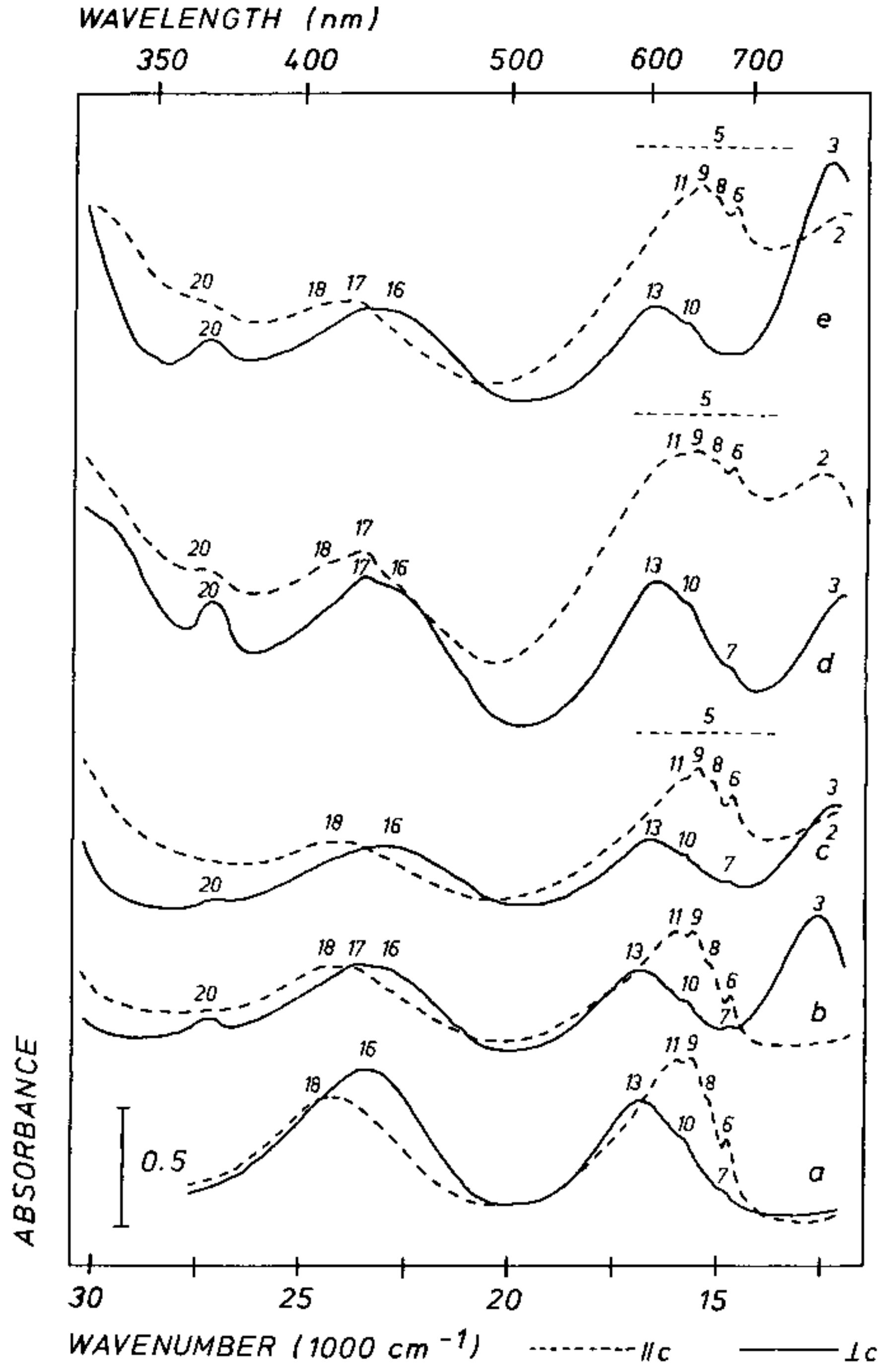


Fig. 3. Polarized absorption spectra of natural emeralds from different sources; sample (a) from Chivor, Colombia, representing a typical chromium-vanadium emerald spectrum without distinct Fe absorption bands; sample (b) from Jos, Nigeria, representing a typical chromium-vanadium emerald spectrum with an Fe^{2+} absorption band in the near infrared (polarization $\perp c$) and two Fe^{3+} bands in the bluish-violet and ultraviolet; sample (c) from Ankadilalana, Madagascar, sample (d) from Sta. Terezinha de Goiás, Brazil, and sample (e) from Miku, Zambia, representing the superimposed spectra of chromium-vanadium emerald and aquamarine in various intensity ratios (the aquamarine spectrum consisting of two Fe^{2+} absorption bands in the near infrared [polarization $\parallel$ and $\perp c$], two Fe^{3+} bands in the blueish-violet and ultraviolet, and an Fe^{2+}/Fe^{3+} intervalence transition in the red area [polarization $\parallel c$]); the positions of absorption minima and pleochroism of the samples are given in Table 4, the positions and assignments of absorption maxima are given in Table 5.

III.2 Absorption spectroscopy and colour of natural and synthetic emeralds

In gemmological nomenclature it is generally accepted that emerald is the green variety of beryl, the colour of which is caused by traces of chromium or by traces of vanadium and chromium. In natural and synthetic beryl, the two spin-allowed strong absorption bands of Cr^{3+} in octahedral Al^{3+} sites are located in the red and blue range of the visible region. The two spin-allowed strong absorption bands of V^{3+} in octahedral sites of the beryl structure reveal similar absorption maxima (Wood & Nassau, 1968; Beckwith & Troup, 1973) and, thus, in samples bearing both transition metal elements, chromium and vanadium, the absorption bands of Cr^{3+} and V^{3+} are superimposed and no separated absorption maxima are observable (Schmetzer, 1982).

Natural emeralds from most sources show distinct amounts of both colour-causing trace elements, chromium and vanadium, and in samples from some localities, e.g. in some emeralds from Muzo, Colombia, the amount of V_2O_3 even exceeds the amount of Cr_2O_3 (e.g. Nassau & Jackson, 1970; Franz, 1982). But in general, the intensities of both absorption bands of Cr^{3+} in the red and blue areas are increased due to the presence of V^{3+}. Only one commercially interesting source of vanadium-bearing, chromium-free green beryl is known (Salininha, Bahia, Brazil), and some samples of a similar type were also described from other localities (e.g. from Kenya; cf. Schmetzer, 1982; Ghera & Lucchesi, 1987). For samples of this type of green beryl, their acceptance as emerald in gemmological nomenclature is still in discussion.

In synthetic emeralds which are commercially produced, in general the amount of chromium exceeds the amount of vanadium, but samples with $V_2O_3 > Cr_2O_3$ were also described in literature (e.g. Biron synthetic emeralds; Kane & Liddicoat, 1985).

In natural and synthetic iron-bearing beryl, three basic types of spectra are observed, which are assigned to three types of iron in the beryl lattice. Though different authors came to various models for the assignment of iron absorption bands in beryl (e.g. Wood & Nassau, 1968; Samoilovich *et al.*, 1971; Schmetzer *et al.*, 1974; Price *et al.*, 1976; Parkin *et al.*, 1977; Goldman *et al.*, 1978; Platonov *et al.*, 1978, 1979; Blak *et al.*, 1982; Solntsev *et al.*, 1984, 1985), the positions of absorption maxima are not in discussion.

In general, two absorption maxima in the near infrared (maximum I at 12,000 cm^{-1} $\parallel c$, and maximum II at 12,200 cm^{-1} $\perp c$) are assigned to bivalent iron in two different lattice sites. Two absorption bands in the bluish-violet and the ultraviolet range (maximum I at 23,500 cm^{-1}, $\parallel c > \perp c$; and maximum II at 27,000 cm^{-1}, $\perp c \gg \parallel c$) are assigned to Fe^{3+} replacing Al^{3+} in octahedral coordination. A broad absorption band in the red area (from 16,700 to 13,300 cm^{-1}, $\parallel c$) is assigned to a Fe^{2+}/Fe^{3+} charge-transfer process. This intervalence transfer absorption in the red is not observed in samples revealing distinct absorption bands of Fe^{3+} in the bluish-violet (at 23,500 cm^{-1}) and ultraviolet (at 27,000 cm^{-1}) range and the Fe^{2+} absorption with polarization $\perp c$ (at 12,200 cm^{-1}) in the near infrared. However, in all samples which show an additional absorption of Fe^{2+} with polarization $\parallel c$ (at 12,000 cm^{-1}) in the near infrared, the Fe^{2+}/Fe^{3+} charge-transfer absorption in the red is also observable. This absorption band is responsible for the blue colour of aquamarine.

In the most recent papers of Solntsev *et al.* (1984, 1985), the band with polarization $\perp c$ (at 12,200 cm^{-1}) is assigned to Fe^{2+} in tetrahedral Be^{2+} sites and the 12,000 cm^{-1} band with polarization $\parallel c$ is assigned to Fe^{2+} in octahedral Al^{3+} sites. Consequently, the charge-transfer absorption in the red between 16,700 and 13,300 cm^{-1} with polarization $\parallel c$ is assigned to a Fe^{2+}/Fe^{3+} intervalence absorption within Fe^{2+} and Fe^{3+} ions, both located in adjacent octahedral sites of the beryl structure.

In natural emeralds from different sources, all types of iron absorption bands which are known in colourless to intense blue beryls are also observable. In samples from some localities, e.g. in part of natural emeralds from Colombia or Pakistan, no absorption bands of ferrous or ferric iron are observable by spectroscopic investigations (Figure 3a). The pleochroism of these samples is described as green or slightly bluish-green $\parallel c$ and yellowish-green $\perp c$, absorption maxima are given in Table 4.

Natural emeralds from other localities, e.g. some samples from Jos, Nigeria; Sandawana, Zimbabwe; Lake Manyara, Tanzania; Itabira, Brazil or Ural Mountains, USSR, reveal the presence of a dominant absorption band of Fe^{2+} in the infrared at 12,200 cm^{-1} with polarization $\perp c$ and two strong absorption bands of Fe^{3+} in the bluish-violet and ultraviolet area at 23,500 and 27,000 cm^{-1} (Figure 3b). Both types of iron do not influence the visible part of the absorption spectrum and, thus, do not influence or change the chromium-vanadium colour and pleochroism of the samples (cf. Table 4). In these emeralds, an absorption of Fe^{2+} in the infrared with polarization $\parallel c$ is not observable or is found to be very weak in intensity, and no intervalence transfer absorption of Fe^{2+}/Fe^{3+} in the red area with polarization $\parallel c$ is present.

In a third type of natural emerald, variable amounts of bivalent iron are present in two sites (tetrahedral and octahedral) and trivalent iron is

Table 4. Examples for absorption minima in the visible range and pleochroism of natural emeralds as well as Russian hydrothermally-grown synthetic emeralds

Natural emeralds Locality/ sample	Pleochroism		Position of absorption minima				Spectrum
	$\parallel c$	$\perp c$	$\parallel c[cm^{-1}]$	[nm]	$\perp c[cm^{-1}]$	[nm]	
Miku, Zambia (e)	blue	yellowish-green	20,600	485	19,800	505	Fig. 3e
Sta. Terezinha de Goiás, Brazil (d)	blue	yellowish-green	20,400	490	19,700	508	Fig. 3d
Ankadilalana, Madagascar (c)	blue	yellowish-green	20,400	490	19,700	508	Fig. 3c
Jos, Nigeria (b)	bluish-green	yellowish-green	20,100	498	19,900	503	Fig. 3b
Chivor, Colombia (a)	bluish-green	yellowish-green	20,000	500	19,800	505	Fig. 3a

Russian hydrothermally-grown synthetic emeralds

Sample	Pleochroism		Position of absorption minima				Spectrum
	$\parallel c$	$\perp c$	$\parallel c[cm^{-1}]$	[nm]	$\perp c[cm^{-1}]$	[nm]	
(e)	blue	yellow-green	20,400	490	19,900	503	Fig. 4e
(d)	blue	yellow-green	20,300	493	19,900	503	Fig. 4d
(c)	blue	yellow-green	20,300	493	19,800	505	Fig. 4c
(b)	greenish-blue	yellow-green	20,200	495	19,800	505	Fig. 4b
(a)	greenish-blue	yellow-green	20,200	495	19,800	505	Fig. 4a

present in octahedral sites (Figure 3c,d,e). These emeralds reveal a complete absorption spectrum of aquamarine consisting of two Fe^{2+} bands in the infrared (at 12,000 cm^{-1}, polarization $\parallel c$, and at 12,200 cm^{-1}, polarization $\perp c$), two Fe^{3+} bands in the bluish-violet and ultraviolet (at 23,500 and 27,000 cm^{-1}) as well as a Fe^{2+}/Fe^{3+} intervalence transfer absorption band in the red (between 16,700 and 13,300 cm^{-1}; polarization $\parallel c$). Like in natural aquamarines, the amounts of all these types of ferrous and ferric iron may be variable, and thus the Fe^{2+}, Fe^{3+} and Fe^{2+}/Fe^{3+} absorption bands are found to vary in intensity, too.

This complete aquamarine spectrum is superimposed on the ordinary chromium-vanadium spectrum of emerald, causing a distinct shift of the absorption minimum in the spectrum $\parallel c$ from green to bluish-green, greenish-blue or blue, i.e. towards higher wave numbers (lower wavelengths; cf. Table 4). This principle was first described for emeralds from Zambia with a strong aquamarine and a weak emerald component, revealing a pleochroism of blue $\parallel c$ and yellowish-green $\perp c$ (Table 4). Meanwhile, similar types of absorption spectra consisting of an aquamarine component as well as of a chromium-vanadium (emerald) component, were found by the present author in additional samples from different sources, e.g. in emeralds from Santa Terezinha, Carnaiba, Itabira and Socotó, Brazil; Ankadilalana, Madagascar; Lake Manyara, Tanzania; Gravelotte, South Africa; Habachtal, Austria; Maria Mine, Mozambique; Machingwe, Zimbabwe. The pleochroism of these samples varies according to the intensity ratio of the aquamarine and emerald components (Figure 4c,d,e) from bluish-green to greenish-blue and blue $\parallel c$, with yellowish-green $\perp c$ (cf. Table 4).

In commercially available synthetic emeralds from different producers with the exception of Lechleitner synthetic emeralds (emerald-coated colourless natural iron-bearing beryl seeds), no absorption bands of bivalent iron in the infrared with polarization $\parallel$ or $\perp c$ are found to be superimposed to the chromium-vanadium emerald spectrum. In Russian and Gilson flux-grown synthetic emeralds, absorption bands of Fe^{3+} are found in the bluish-violet and ultraviolet range. According to Nassau (1980), this type of iron-bearing synthetic emerald was produced by Gilson for a short period of time. Consequently, the presence of iron bands

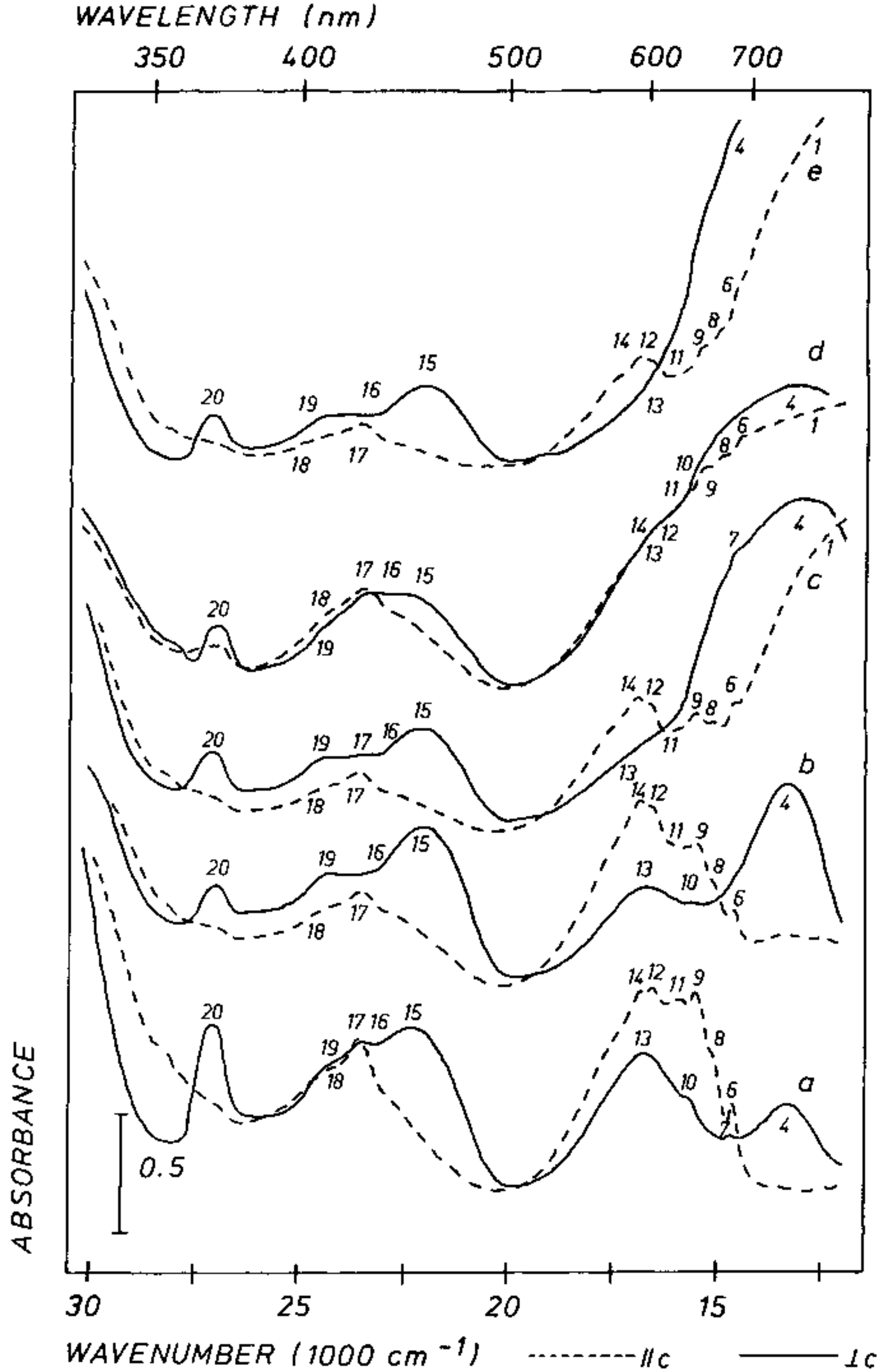


Fig. 4. Polarized absorption spectra of samples (a) to (e) of Russian hydrothermally-grown synthetic emeralds; the spectra reveal a superimposition of absorption bands of Cr^{3+}, Fe^{3+}, and Ni^{3+} in octahedral sites and Cu^{2+} in tetrahedral sites, all four colour-causing trace elements being present in variable amounts in different samples (for analytical data cf. Table 2); the positions of absorption minima and pleochroism of the samples are given in Table 4, the positions and assignments of absorption maxima are given in Table 5.

The orientation of the c-axis of sample (d) versus the facets of the cut stone was very unfavourable in order to obtain polarized spectra of good quality; only in this special case spectrum ---- represents a condition with polarization $\parallel c$ > polarization $\perp c$, and spectrum —— represents a condition with polarization $\perp c$ > polarization $\parallel c$.

Table 5. Spectroscopic data of natural emeralds and Russian hydrothermally-grown synthetic emeralds

Position of absorption maxima natural emeralds [cm^{-1}]	 [nm]	 synthetic emeralds [[cm^{-1}]	 [nm]	Polarization of absorption bands	Assignment	Designation in Figs. 3 and 4
		10,900*	917*	$\parallel c$	Cu^{2+} tetr.	1
12,000	833			$\parallel c$	Fe^{2+} oct.	2
12,200	820			$\perp c$	Fe^{2+} tetr.	3
		13,300	752	$\perp c$	Cu^{2+} tetr.	4
13,300–16,700	752-599			$\parallel c$	Fe^{2+}/Fe^{3+}	5
14,600	685	14,600	685	$\parallel c$	Cr^{3+} oct.	6
14,700	680	14,700	680	$\perp c$	Cr^{3+} oct.	7
15,100	662	15,100	662	$\parallel c$	Cr^{3+} oct.	8
15,500	645	15,500	645	$\parallel c$	Cr^{3+} oct.	9
15,700	637	15,700	637	$\perp c$	Cr^{3+} oct.	10
15,900	629	15,900	629	$\parallel c$	Cr^{3+} oct.	11
		16,500	606	$\parallel c$	Ni^{3+} oct.	12
16,600	602	16,600	602	$\perp c$	Cr^{3+} oct.	13
		16,800	595	$\parallel c$	Ni^{3+} oct.	14
		22,000	555	$\perp c$	Ni^{3+} oct.	15
23,200	431	23,200	431	$\perp c$	Cr^{3+} oct.	16
23,500	426	23,500	426	$\parallel c > \perp c$	Fe^{3+} oct.	17
23,800	420	23,800	420	$\parallel c$	Cr^{3+} oct.	18
		24,200	413	$\perp c$	Ni^{3+} oct.	19
27,000	370	27,000	370	$\perp c \gg \parallel c$	Fe^{3+} oct.	20

*after Solntsev (1981a,b), Lebedev *et al.* (1986)

assigned to bivalent iron or to bivalent as well as trivalent iron in an emerald sample of questionable origin is sufficient to prove the stone as natural emerald.

Though nickel was determined in natural emeralds from Cobra mine, Transvaal, South Africa, in concentrations up to 0.025 wt.% (Schrader, 1983), nickel absorption bands (for the position of absorption maxima confer Table 5) were found neither in the spectra of samples from Cobra mine nor in spectra of emeralds from other localities. Thus, the influence of nickel on the colour of natural emeralds of known sources is negligible.

III.3 Absorption spectroscopy and colour of Russian hydrothermally-grown synthetic emeralds

According to chemical data (section III.1; Tables 1, 2; Figure 2), samples of Russian hydrothermally-grown synthetic emeralds investigated in this paper contain variable but high amounts of four colour-causing transition elements: chromium, iron, nickel and copper. As described in section III.2 in detail, natural emeralds, in general, contain traces of vanadium, chromium and, in most instances, iron. The pleochroism of Russian hydrothermal synthetic emeralds varies from greenish-blue to blue $\parallel c$, with yellow-green or greenish-yellow $\perp c$ (Table 4). The absorption spectra of all samples consist of several absorption bands in the infrared, visible and ultraviolet range (Figure 4a-e) which are assigned to Cr^{3+}, Fe^{3+} and Ni^{3+} in octahedral sites and to Cu^{2+} in tetrahedral sites (Table 5). These assignments are based on the known positions of Cr^{3+} and Fe^{3+} absorption bands (e.g. Wood & Nassau, 1968; Solntsev, 1981a, Klyakhin *et al.*, 1981b) and on the positions of Ni^{3+} and Cu^{2+} absorption bands as published in the most recent Russian literature (Solntsev, 1981a,b; Klyakhin *et al.*, 1981b; Lebedev *et al.*, 1986).

Only in some older papers, the nickel doublet at 16,500 and 16,800 cm^{-1} (polarization $\parallel c$) is assigned to Ni^{2+} (Solntsev *et al.*, 1978; Il'in *et al.*, 1980; Bukin *et al.*, 1981), but in the samples investigated in the present paper no further spectroscopic criteria for the presence of Ni^{2+} were found. These data support the assignment of this doublet to Ni^{3+} as published in the most recent Russian publications. Obviously, under the oxygen partial pressures used for hydrothermal synthesis of emerald by Russian scientists, iron, nickel and chromium ions predominantly substitute Al^{3+} in octahedral sites as

Fe^{3+}, Ni^{3+} and Cr^{3+} and copper is found to replace Be^{2+} in tetrahedral sites as Cu^{2+}. Consequently, only subordinate amounts of Fe^{2+}, Ni^{2+} and Cu^{+} ions are assumed to be incorporated into the beryl structure during crystal growth (cf. Klyakhin *et al.*, 1981b).

Non-polarized absorption spectra of hydrothermally-grown Russian synthetic emeralds and the pleochroism of these beryls are similar with spectra and pleochroism of natural emeralds revealing a chromium-vanadium (emerald) and aquamarine component. Due to these similarities overlooking the high amounts of nickel and copper in the samples as well as additional absorption maxima, the absorption spectra of Russian synthetic hydrothermally-grown emeralds were assigned to Cr^{3+}, Fe^{3+}, Fe^{2+} as well as to an intervalence transfer absorption of Fe^{2+} and Fe^{3+} (Lind *et al.*, 1987). However, spectra recorded in polarized light (cf. Figure 4a-e) clearly indicate the presence of absorption bands of both trace elements, Ni and Cu (Table 5), which is confirmed by chemical data (Table 2; Figure 2). No evidence has been found up to now either for the presence of bivalent iron in tetrahedral or octahedral coordination or for the presence of the Fe^{2+}/Fe^{3+} charge-transfer absorption band in the red region of visible light.

In the absorption spectra of Russian hydrothermal synthetic emeralds the absorption bands of chromium and nickel are found to be dominant in the visible area, and the influence of iron and copper bands is subordinate. The colour of synthetic nickel-doped beryl is described as yellowish-green with a pleochroism of blue $\parallel c$ and yellow-green or yellow $\perp c$ (Emel'yanova *et al.*, 1965; Solntsev, 1981a; Lebedev *et al.*, 1986). Due to the presence of a strong nickel absorption doublet at 16,500 and 16,800 cm^{-1} (polarization $\parallel c$), the absorption minimum of the ordinary chromium-vanadium (emerald) spectrum is shifted from green or bluish-green to greenish-blue and blue (cf. Table 4). On the other hand, the presence of an absorption band of Ni^{3+} at 22,000 cm^{-1} (polarization $\perp c$) causes an increase of yellow in the spectrum $\perp c$. Thus, due to the presence of high amounts of nickel, the pleochroism of ordinary chromium-vanadium emerald (bluish-green $\parallel c$, yellowish-green $\perp c$) is increased and changed to greenish-blue or blue $\parallel c$ and to yellow-green $\perp c$ (Table 4). This interpretation of colour and pleochroism in chromium- and nickel-bearing emeralds is consistent with Russian literature (Lokhova *et al.*, 1980; Bukin *et al.*, 1981; Solntsev, 1981a,b; Lebedev *et al.* 1986).

The influence of iron and copper on the colour of Russian hydrothermally-grown synthetic emeralds is subordinate. In samples containing lower amounts of copper, the absorption bands of Cu^{2+} do not influence the visible part of the absorption spectrum and the colour of the crystals (cf. Figure 4a,b). With increasing copper contents, a distinct influence on the visible part of the absorption spectra becomes evident (Figure 4c,d,e), especially in polarization $\perp c$. The influence of copper, however, does not distinctly shift absorption minima in the yellow to blue range (cf. Table 4) and thus, the influence of copper on the colour of Russian chromium- and nickel-bearing synthetic beryls is subordinate. The absorption band of Fe^{3+} in the bluish-violet area at 23,500 cm^{-1} is superimposed on the maxima of Cr^{3+} and Ni^{3+} in this spectral range, and thus the influence of Fe^{3+} on the colour of the samples is negligible.

Consequently, the colour and pleochroism of Russian hydrothermally-grown synthetic emeralds is due to the presence of high amounts of chromium and nickel. In samples of this type, additional high amounts of trivalent iron and bivalent copper do not remarkably contribute to the colour of these beryls.

III.4 Infrared spectroscopy and types of water in Russian hydrothermally-grown synthetic emeralds

Two types of water molecules were characterized in channel sites of natural and synthetic beryls and emeralds using infrared spectroscopy. Type-I water molecules have their two-fold symmetry axis perpendicular to the crystallographic six-fold axis of the beryl crystal and are not adjacent to alkali ions. Type-II water molecules have their two-fold symmetry axis parallel to the crystallographic six-fold axis of the beryl crystal and are adjacent to alkali ions. In high alkali natural emeralds, predominant absorption bands of type-II water are observed and only subordinate bands of type-I water are found. In low alkali natural emerald, e.g. in Colombian emeralds, absorption bands of both types of water are present. Up to 1980, in synthetic hydrothermally-grown emeralds, e.g. in Linde synthetic emeralds, only type-I water molecules were found. Flux-grown synthetic emeralds do not contain any water molecules and thus do not reveal water absorptions in the infrared (Wood & Nassau, 1967, 1968; Flanigen *et al.*, 1967; Nassau, 1976, 1980; Nassau & Nassau, 1980).

However, in the papers of Klyakhin *et al.* (1981b), Shatsky *et al.* (1981), Kodaira *et al.* (1982) and Lebedev *et al.* (1986), hydrothermally-grown synthetic beryl containing alkalies as well as type-I and type-II water molecules were described. According to the most comprehensive work of Shatsky *et al.* (1981), high concentrations of type-II water were incorporated only in sodium- and lithium-bearing synthetic beryl, bot not in potassian, rubidian and cesian beryls. Most recently, high pressure hydrothermal treatment of flux-grown

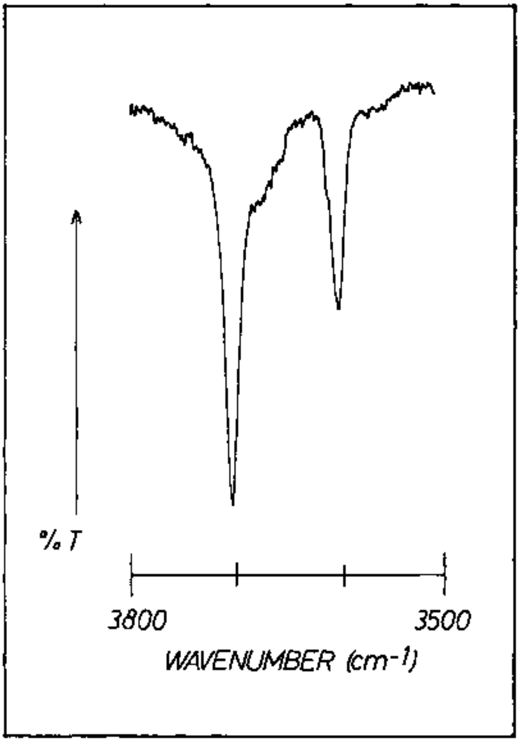


Fig. 5. Infrared spectrum of Russian hydrothermally-grown synthetic emerald indicating the presence of type-I and type-II water molecules.

beryl was described and the incorporation of type-I and type-II water molecules was observed (Kodaira *et al.*, 1984).

Infrared spectra of the commercially grown type of Russian hydrothermal synthetic emerald (Figure 5) clearly reveal two strong absorption bands at 3,595 and 3,698 cm^{-1} and, consequently, the incorporation of water molecules of types I and II is indicated. According to the presence of sodium only in very small amounts (Table 1), type-II water molecules obviously are adjacent to lithium ions in channel sites of the beryl structure.

Due to the presence of both types of water molecules, the infrared spectra of Russian hydrothermally-grown synthetic emeralds are identical with those of low alkali natural emeralds, e.g. with part of natural emeralds from Colombia. Therefore, infrared spectroscopy is unable to distinguish between these particular varieties of natural and synthetic emeralds. These results are consistent with the paper of Stockton (1987), in which similarities between infrared spectra of Russian synthetic hydrothermal emeralds and natural emeralds are described. Unfortunately, no explanation for these similarities or identities is given or discussed in the paper cited.

III.5 Microscopic features of Russian hydrothermally-grown synthetic emeralds

In half of the cut synthetic emeralds investigated residues of the seed plate consisting of colourless beryls were found (Figures 6-8). In all samples, the angle between the boundary seed plate/synthetic emerald and the optical axis of the synthetic emerald was determined by means of an especially developed sample holder (Schmetzer, 1985, 1986). For all samples, this angle was measured between 30 and 32°, indicating that for all samples seed plates parallel to $(5\,5\,\overline{10}\,6)$ were used which form an angle of 31.05° with the optic axis of beryl (calculated for hexagonal beryl with $a{:}c = 1{:}0.9967$).

In all samples with seed, families of parallel growth lines connected with colour zoning were found parallel to the boundary seed plate/synthetic emerald (Figures 6-8). In faceted samples without residues of the seed plate, families of parallel growth lines connected with colour zoning were also present (Figures 9-10), and the angle between these faces and the *c*-axis of the synthetic emerald was measured to be equal to 31°. Thus, all 13 samples examined were grown from beryl seeds parallel to $(5\,5\,\overline{10}\,6)$. This detail of growth conditions is mentioned in some Russian publications (e.g. Klyakhin *et al.*, 1981b; Lebedev & Askhabov, 1984; Lebedev *et al.*, 1986) to be one of the standard techniques suitable for hydrothermal synthesis of beryl (cf. growth conditions for Linde hydrothermally-grown synthetic emeralds; Flanigen, 1971; Flanigen & Mumbach, 1971). Samples which are grown from seed plates parallel to $(11\bar{2}0)$ were also mentioned in the Russian papers cited above, but obviously no synthetic emerald of this type was available for the present investigation. Since growth zoning parallel to $(5\,5\,\overline{10}\,6)$ is subordinate in natural emeralds, if present at all, the recognition of this structural feature by microscopic examination is sufficient to characterize a sample of unknown nature as synthetic emerald.

The application of colourless beryl seeds which are cut parallel to $(5\,5\,\overline{10}\,6)$ causes the development of additional characteristic growth microstructures which are never found in natural emeralds (Figures 6-11, 13-16). These growth structures, which partly resemble growth structures in Linde hydrothermally-grown synthetic emeralds, are easily observable with the gem microscope using immersion liquids. Similar or almost identical structures were already mentioned by Russian authors (Klyakhin *et al.*, 1981b; Granadchikova *et al.*, 1983; Lebedev & Askhabov, 1984; Lebedev *et al.*, 1986). In general, the observations described in the papers cited are confirmed by the investigations of the present author, and a small part of this information is also found in gemmological papers published so far.

Microscopic investigations of the boundary seed plate/synthetic emerald as well as the examination of growth lines parallel to ($5\ 5\ \overline{10}\ 6$) at high magnifications reveals the presence of a distinct type of step-like microstructure. The boundary between the seed plate and the synthetic emerald does not reveal a plane surface but shows a cobbled appearance. This boundary consists of a cellular pattern which is formed by several crystal faces with slightly oblique orientation with respect to the seed plate (Figure 11). From each of these cellular centres of nucleation, sub-individuals of synthetic emerald are grown with a preferred subparallel orientation oblique to the seed plate (Figure 12). The size of these sub-individuals and the form of the polycentrically growing step-like surface (Figures 7-10) is continuously changed during the growth process.

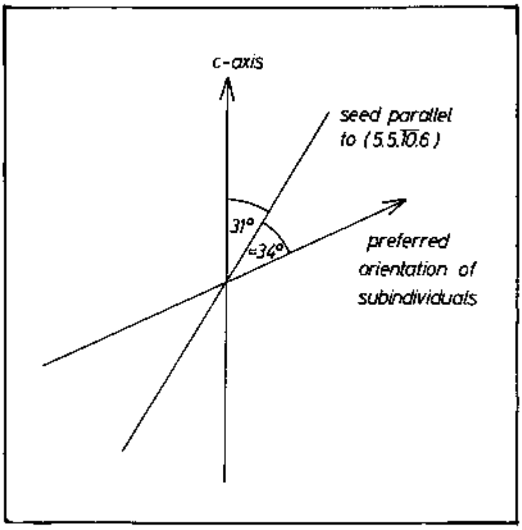


Fig. 12. Schematic representation of the orientation of the seed plate parallel to ($5\ 5\ \overline{10}\ 6$) in Russian hydrothermally-grown synthetic emerald versus c-axis and preferred orientation of sub-individuals.

In a certain direction which is inclined about 34° versus the seed plate, a characteristic block structure of subparallel orientated sub-individuals with curved surfaces is observable (Figures 13, 14). In some synthetic emeralds a distinct colour zoning was observable between different sub-individuals, and interference striations were found confined to the subgrain boundaries. These boundaries between sub-individuals of variable size are characterized by growth features, forming angular growth patterns with the edges of the sub-individuals as bisectors of the respective angles (Figures 15, 16). Irregular growth structures, which are not consistent with that general scheme are rare (Figure 17).

Confined to the boundaries between seed plates and synthetic hydrothermally-grown emerald, small opaque particles were observed (Figure 18), which were obviously trapped at the start of the growth process. The synthetic emeralds themselves were found to be extremely pure, and in some faceted samples, only growth structures but no foreign inclusions were observable.

In several gemmological papers, opaque hexagonal-shaped platelets are mentioned as inclusions in Russian hydrothermally-grown synthetic emeralds (Gübelin, 1986; Lind *et al.*, 1987) and some inclusions of this type were also found in the 13 samples investigated by the present author (Figure 19). The presumption of Gübelin (1986), that these particles are platinum platelets seems unlikely according to growth conditions of commercially produced samples (cf. section IV). In the publication of Granadchikova *et al.* (1983) these platelets are also pictured, and a possible explanation is found in the paper of Klyakhin *et al.* (1981b), who mentioned hematite as an inclusion in hydrothermally-grown synthetic emerald. This explanation seems more reasonable according to growth conditions of the samples using oxide buffers in the equilibrium field hematite-magnetite.

In addition, Klyakhin and his co-workers also mentioned two- and three-phase inclusions, which were occasionally found in the samples examined for this paper. Typical are double refractive crystal inclusions confined to growth tubes with liquid or two-phase fillings (Figures 20, 21) or similar multiphase-inclusions, which are not confined to a small crystal (Figure 22). Some of the synthetic emeralds also contained feathers consisting of liquid, two-phase and three-phase inclusions (Figures 23, 24), probably filled with two immiscible liquids and one gaseous phase.

IV. Growth conditions and properties of Russian hydrothermally-grown synthetic emeralds

Two papers in Russian dealing with growth conditions and properties of industrially-grown synthetic hydrothermal emeralds are available to the present author. In the paper of Godovikov *et al.* (1982), some details about industrial growth processes of synthetic gem materials in USSR are described. In the publication of Granadchikova *et al.* (1983), properties of natural emeralds from Ural mountains, flux-grown and hydrothermally-grown research material and synthetic emeralds of the industrial hydrothermal production in USSR are compared. According to Godovikov *et al.* (1982), industrial growth of hydrothermal synthetic emerald in USSR is performed at L'vov, Ukraine. The

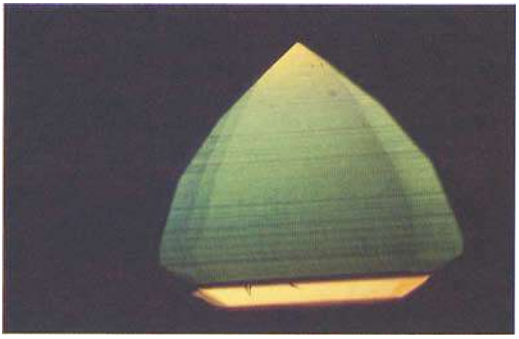


Fig. 6. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed parallel to the table, growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald. Crossed polarizers. 20x.

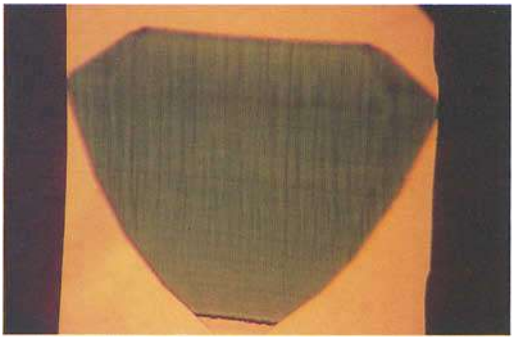


Fig. 7. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed at the culet, step-like growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald, irregularly changing subgrain boundaries almost perpendicular to seed plate and colour zoning. 38x.

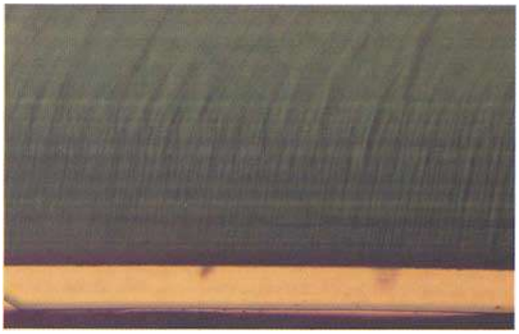


Fig. 8. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed parallel to the table, step-like growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald, irregularly changing subgrain boundaries almost perpendicular to seed plate and colour zoning. Crossed polarizers. 40x.

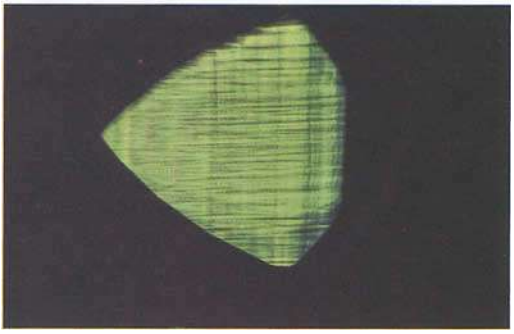


Fig. 9. Russian hydrothermally-grown synthetic emerald; faceted sample without residue of the seed, step-like growth lines and colour zoning, irregularly changing subgrain boundaries almost perpendicular to the colour zoning. Crossed polarizers. 20x.

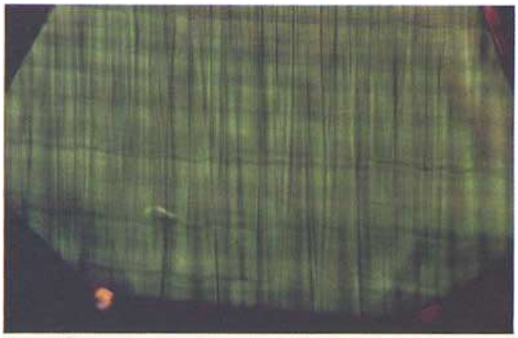


Fig. 10. Russian hydrothermally-grown synthetic emerald; faceted sample without residue of the seed, step-like growth lines and colour zoning, irregularly changing subgrain boundaries almost perpendicular to the colour zoning. Crossed polarizers. 40x.

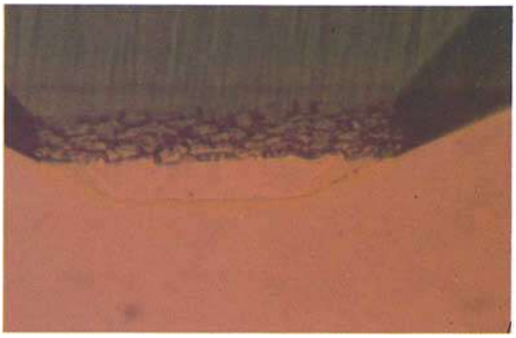


Fig. 11. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed at the culet, cellular pattern of the boundary seed plate/synthetic emerald, subgrain boundaries between subindividuals originating from each of this cellular nucleation centres with cobbled appearance. 90x.

Fig. 18. Russian hydrothermally-grown synthetic emerald; opaque particles confined to the boundary colourless seed/synthetic emerald. View in a direction perpendicular to the boundary. 40x.

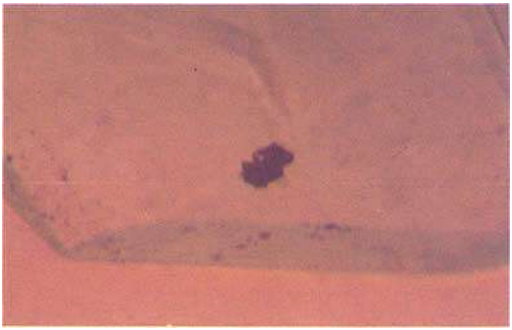
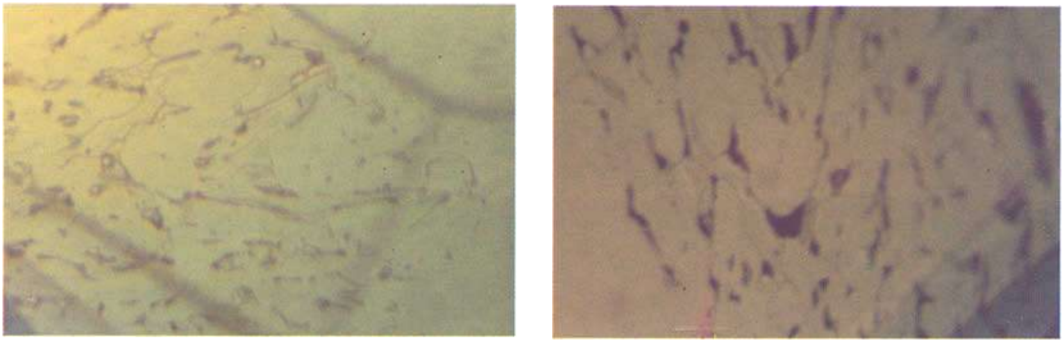


Fig. 19. Russian hydrothermally-grown synthetic emerald; inclusions of opaque hexagonal platelets, most probably hematite. 100x.

Fig. 20. Russian hydrothermally-grown synthetic emerald; inclusion of a double refractive crystal. Crossed polarizers. 100x.



Figs. 23, 24. Russian hydrothermally-grown synthetic emerald; feather with three-phase inclusions, probably consisting of two immiscible liquids and one gaseous phase; dependent on the direction of view, all three phases show transparency (Figure. 23), or two liquid phases show transparency and the gaseous phase shows total internal reflection, or one liquid phase shows transparency and one liquid and one gaseous phase show total internal reflection (Figure 24). Figure 23, 70x; Figure 24, 95x.

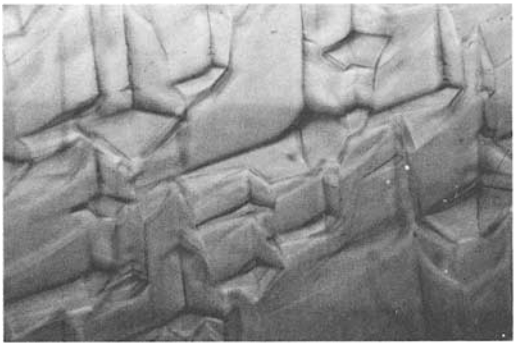


Fig. 13. Russian hydrothermally-grown synthetic emerald; block structure of subparallel orientated sub-individuals with curved surfaces. 30x.

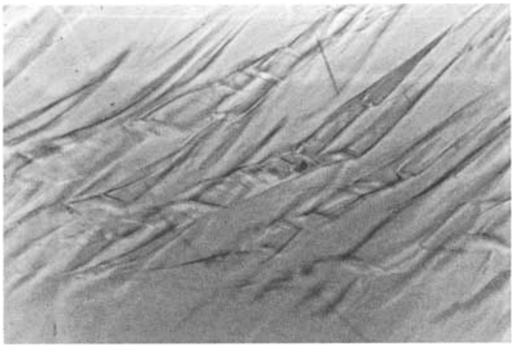


Fig. 14. Russian hydrothermally-grown synthetic emerald; irregularly changing subgrain boundaries between sub-individuals with preferred orientation. 35x.

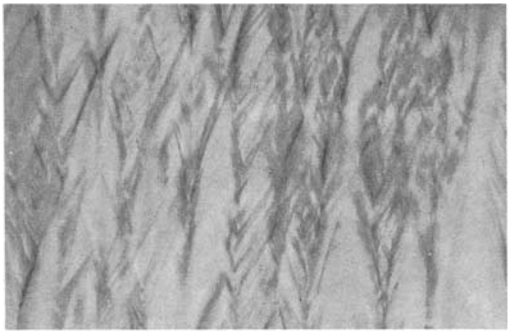


Fig. 15. Russian hydrothermally-grown synthetic emerald; angular growth patterns with the edges of sub-individuals as bisectors of the angles. 45x.

Fig. 16. Russian hydrothermally-grown synthetic emerald; angular growth pattern with the edge of a sub-individual as bisector of the angles. 50x.

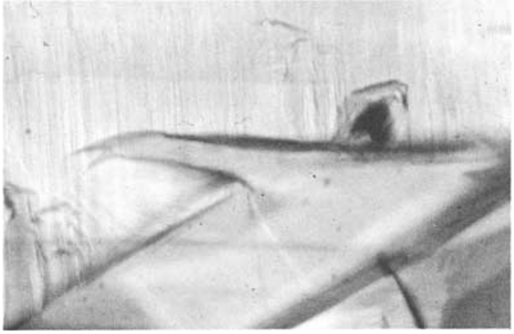


Fig. 17. Russian hydrothermally-grown synthetic emerald; irregular growth structure. 45x.

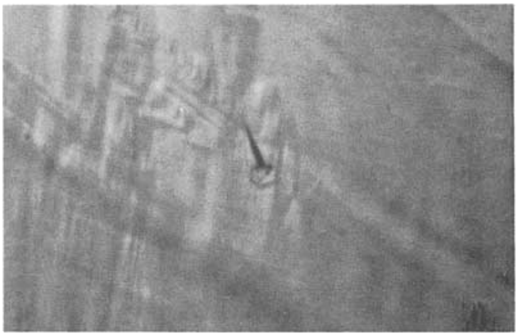


Fig. 21. Russian hydrothermally-grown synthetic emerald; the identical inclusion of Figure 20, consisting of a double refractive crystal and a growth tube with liquid filling. 100x.

Fig. 22. Russian hydrothermally-grown synthetic emerald; three-phase inclusion, probably consisting of two immiscible liquids and one gaseous phase. 100x.

following growth conditions are mentioned: temperature range 550-620°C, temperature gradient method, pressure 1000 bars, stainless steel autoclaves 200-800 ml in volume without precious metal liners are used, growth rate of synthetic emerald 0.2-0.3 mm per day, in 20-30 days from seed plates of about 6 cm^2 in size synthetic emerald crystals of 10-20 grams in weight are grown, the thickness of synthetic emerald layers attains 5-7 mm, natural beryl or oxides of Be, Al and Si are used as nutrients.

No details about the exact composition of the solutions used for the growth process and no information about the temperature gradient applied are given. However, temperature and pressure are in the range of growth conditions mentioned for scientific research material, and growth features of the research material (Klyakhin *et al.*, 1981b; Lebedev & Askhabov, 1984; Lebedev *et al.*, 1986) are identical with properties of industrially-grown samples as described in this paper and by Granadchikova *et al.* (1983). Thus, the compositions of solutions and the temperature gradients mentioned in scientific research papers are assumed to be similar or almost identical with the conditions used for the industrial process.

The solutions are characterized as 'acidic solutions' or as 'fluor-bearing solutions of complex compositions' as well as 'acidic solutions of complex compositions', temperature gradients mentioned are $\triangle T = 45°C$, $\triangle T = 20\text{-}100°C$, or $\triangle T = 70\text{-}130°C$, at growth temperatures between 590 and 620°C and pressures between 800 and 1500 bars (Solntsev *et al.*, 1976, 1978; Il'in *et al.*, 1980; Klyakhin, 1980; Bukin *et al.*, 1980; Solntsev, 1981a; Shatsky *et al.*, 1981; Lebedev & Askhabov, 1984; Pugachev, 1984; Lebedev *et al.*, 1986). According to the valence states and lattice sites of iron, nickel, and copper as they are indicated from absorption spectra (cf. section III.3; Table 5), the samples were grown under oxygen partial pressures in the $Fe_3O_4-Fe_2O_3$ equilibrium field (cf. Klyakhin *et al.*, 1981b).

In the opinion of the present author, the most striking difference between part of the samples grown for research purposes and specimens of the industrial production is the lack of precious metal (platinum or gold) inserts in the industrial process (Godovikov *et al.*, 1982; Granadchikova *et al.*, 1983), which are mentioned in some research papers (e.g. Shatsky *et al.*, 1981; Klyakhin *et al.*, 1981b; Lebedev *et al.*, 1986). According to Granadchikova *et al.* (1983), this experimental detail of growth conditions is responsible for the incorporation of high amounts of iron and nickel in the synthetic emerald crystals, originating from the walls of the steel autoclaves. In the opinion of the present author, the lack of precious metal inserts could also be responsible for the copper contents of the samples. However, it is also possible that certain amounts of iron, nickel and copper are added to the nutrient material, too.

Due to the fact that the influence of chromium and nickel is dominant for the colour of the samples (which is certainly known to the producers), the iron- and copper contents of these synthetic emeralds are most presumably more or less accidental. However, since the influence of nickel on the colour of nickel- and chromium-bearing synthetic emeralds as well as the interpretation of absorption spectra of chromium- and nickel-bearing synthetic emeralds was the subject of various Russian research papers (e.g. Lokhova *et al.*, 1980; Bukin *et al.*, 1981; Klyakhin *et al.*, 1981b), the incorporation of nickel is assumed to be most presumably non-accidental. As described in section III.3 in detail, this nickel content is responsible for a colour and pleochroism of the synthetic emeralds, which resembles that of natural emerald from particular occurrences, e.g. from Zambia, Brazil or Madagascar (cf. Table 4).

The high contents of transition metal oxides are also responsible for some physical properties of the synthetic hydrothermally-grown emeralds, e.g. for specific gravities and refractive indices, which are found to be within the natural range. The presence of both type-I and type-II water molecules in Russian industrially-grown synthetic emeralds, which is typical for natural samples, is also due to growth conditions. Most probably, lithium ions in the channels of the beryl lattice cause the stabilization of type-II water molecules.

The choice of seed plates of colourless beryl, which were cut parallel to $(5\ 5\ \overline{10}\ 6)$, obviously dominates growth structures in the synthetic emerald crystals, e.g. growth zoning parallel to the seed plate as well as the typical block structure of sub-individuals forming the hydrothermally-grown beryl crystals (cf. Lebedev & Askhabov, 1984). Both features are of high diagnostic value; they were never found in natural emeralds before and they are easily recognizable in the immersion microscope.

V. Conclusions

The industrial production of Russian hydrothermally-grown synthetic emeralds is performed in steel autoclaves without precious metal inserts using seed plates of colourless beryl, which are cut parallel to $(5\ 5\ \overline{10}\ 6)$. Due to these growth conditions, distinct amounts of chromium, iron, nickel and copper are incorporated in the synthetic crystals and characteristic microstructures are formed. Both features are of high diagnostic value, they are easily recognizable by non-destructive techniques such as trace element analysis, by absorption spectroscopy in the visible and ultraviolet range and by microscopic examination using immersion liquids.

The chemical composition of the samples, i.e. the high amounts of transition metal oxides present, are responsible for the high values of refractive indices and specific gravities, as well as for the high unit cell dimensions. The colour and pleochroism of the samples is caused by traces of both dominant transition metal elements, chromium and nickel, and the influence of iron and copper is subordinate. The presence of type-I and type-II water molecules, which was regarded to be diagnostic for natural emerald up to now, is explainable by growth conditions, in which alkali ions were incorporated into the channels of the beryl structure. The synthetic emerald crystals consist of sub-individuals, the formation of which is due to the growth conditions applied, especially due to the orientation of the seed plate. With a detailed knowledge of all properties of this exceptional type of hydrothermally-grown synthetic emerald, no difficulties should arise with the recognition of samples of unknown origin.

VI. Acknowledgements

Samples of Russian hydrothermally-grown synthetic emeralds used in this study were kindly loaned by Prof. Dr E. Gübelin of Meggen, Switzerland, by A. Hodgkinson of Glasgow, and by Dr R. Diehl of Freiburg, West Germany. Mrs. M. Vysocanska of Heidelberg, FRG, was helpful with the translation of original literature in Russian language, part of which was made available by Dr A. S. Lebedev of Novosibirsk, USSR. Dipl.-Geol. A. Rüttimann of Terrachem, Mannheim, FRG, was helpful with X-ray fluorescence analysis, and typing was done by Dipl.-Min. L. Kiefert of Heidelberg, FRG.

References

Bakakin, V. V., Rylov, G. M., Belov, N. V., 1967. Correlation between the chemical composition and unit cell parameters of beryl. *Doklady Akad. Nauk SSSR, Earth Sci. Sect.*, **173**, 129-32.

Bakakin, V. V., Rylov, G. M., Belov, N. V., 1970. X-ray diffraction data for identification of beryl isomorphs. *Geochemistry, 1970*, 924-33.

Beckwith, P. J., Troup, G. J., 1973. The optical and infrared absorption of V^{3+} in beryl ($Be_3Al_2Si_6O_{18}$). *Phys. stat. sol.*, (a) **16**, 181-6.

Blak, A. R., Isotani, S., Watanabe, S., 1982. Optical absorption and electron spin resonance in blue and green natural beryl. *Phys. Chem. Minerals*, **8**, 161-6.

Bukin, G. V., Godovikov, A. A., Klyakhin, V. A., Sobolev, V. S., 1980. Synthetic emerald. In: *Gem minerals. Proceedings of the XI general meeting of IMA*, Novosibirsk 1978, publ. Leningrad, 1980, pp. 36-44 [in Russian].

Bukin, G.V., Lokhova, G. G., Ripinen, O. I., Veis, N. S., 1981. Effect of isomorphous impurities on color characteristics of beryls. In: *Issled. Fiz. Svoistv i Sostova Sintet. Mineralov i Monokristallov,* Novosibirsk, 1981, pp. 20-8 [in Russian].

Ćerný, P., Hawthorne, F. C., 1976. Refractive indices versus alkali contents in beryl: general limitations and applications to some pegmatitic types. *Canad. Mineral.*, **14**, 491-7.

Deer, W. A., Howie, R. A., Zussman, J., 1986. *Rock-forming minerals. Vol. 1B, Second Edition, Disilicates and Ring Silicates*. Longman Scientific & Technical, Harlow, England.

Emel'yanova, E.N., Grum-Grzhimailo, S.V., Boksha, O. N., Varina, T. M., 1965. Artificial beryl containing V, Mn, Co and Ni. *Sov. Phys.-Cryst*, **10**, 46-9.

Filho, H. de A. S., Sighinolfi, G. P. & Galli, E., 1973. Contribution to the crystal chemistry of beryl. *Contr. Mineral. and Petrol.*, **38**, 279-90.

Flanigen, E. M., 1971. Hydrothermal process for growing crystals having the structure of beryl in alkaline halide medium. United States Patent, 3, 567, 642.

Flanigen, E. M., Breck, D. W., Mumbach, N. R., Taylor, A. M., 1967. Characteristics of synthetic emeralds. *Amer. Mineral.*, **52**, 744-72.

Flanigen, E. M., Mumbach, N. R., 1971. Hydrothermal process for growing crystals having the structure of beryl in an acid halide medium. United States Patent, 3, 567, 643.

Franz, G., 1982. Kristallchemie von Beryll, Varietät Smaragd. *Fortschr. Miner.*, **60**, Beiheft 1, 76-8.

Fryer, C., Crowningshield, R., Hurwitt, K. N., Kane, R. E., 1983. Emerald, synthetic. *Gems & Gemology*, **19**, 114-15.

Ghera, A., Lucchesi, S., 1987. An unusual vanadium-beryl from Kenya. *N. Jb. Miner. Mh.*, 1987, 263-74.

Godovikov, A. A., Bukin, G. V., Vinokurov, V. A., Kalinin, D. V., Klyakhin, V. A., Matrosov, V. N., Nenashev, B. G., Serbulenko, M. G., 1982. Development of synthesis techniques for minerals of economic importance in the USSR. *Geol. Geofiz., 1982*, 12, 42-54 [in Russian].

Goldman, D. S., Rossman, G. R., Parkin, K. M., 1978. Channel constituents in beryl. *Phys. Chem. Minerals*, **3**, 225-35.

Granadchikova, B. G., Andreenko, E. D., Solodova, Yu. P., Bukin, G. V., Klyakhin, V. A., 1983. Diagnostics of natural and synthetic emeralds. *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, **26**, 87-93 [in Russian].

Gübelin, E., 1986. Die diagnostischen Eigenschaften der neuen Synthesen. *Goldschmiede Zeitung*, **84**, 11, 69-76.

Hänni, H. A., 1981. Chemischer Vergleich zwischen natürlichen und synthetischen Smaragden. *Z. Dt. Gemmol. Ges.*, **30**, 214-8.

Hänni, H. A., 1982. A contribution to the separability of natural and synthetic emeralds. *J. Gemm.*, **18**, 138-44.

Hofmann, C., Schrader, H. -W., Stender, E., 1985. Rasterelektronenmikroskopie. Einige Anwendungen in der Edelsteinforschung. *Goldschmiede Zeitung*, **83**, 6, 76-7.

Il'in, A. G., Klyakhin, V. A., Pavlyuchenko, V. S., Chepurnova, G. A., 1980. Physical properties of single crystals of some varieties of beryl grown under hydrothermal conditions. In: *Vyrashchivanie Kristallov Berillievykh Mineralov i Issled. ikh Svoistv*, Novosibirsk 1980, pp. 3-11 [in Russian].

Kane, R. E., Liddicoat, R. T., Jr., 1985. The Biron hydrothermal synthetic emerald. *Gems & Gemology*, **21**, 156-70.

Klyakhin, V. A., 1980. Method for the study of growth rates of beryl. In: *Vyrashchivanie Kristallov Berillievykh Mineralov i Issled. ikh Svoistv*, Novosibirsk 1980, pp. 30-4 [in Russian].

Klyakhin, V. A., Shatskii, V. S., Lebedev, A. S., Pavlyuchenko, V. S., Il'in, A. G., 1981a. Experimental study for the entry of isomorphous impurities into synthetic hydrothermal beryl. In: *10-E Vses. Soveshch. po Eksperim. i Tekhn. Mineral. i Petrogr.*, Kiev 1981, pp. 188-97 [in Russian].

Klyakhin, V. A., Lebedev, A. S., Il'in, A. G., Solntsev, V. P., 1981b. Growing of hydrothermal beryl. In: *Sintez i Vyrashchivanie Optich. Kristallov i Yuvelir. Kamnei*, Novosibirsk 1981, pp. 45-66 [in Russian].

Kodaira, K., Iwase, Y., Tsunashina, A., Matsushita, T., 1982. High pressure hydrothermal synthesis of beryl crystals. *J. Crystal Growth*, **60**, 172-4.

Kodaira, K., Tsujino, F., Shimada, S., Matsushita, T. 1984. High pressure hydrothermal treatment of water-free beryl crystals. *J. Crystal Growth*, **67**, 654-5.

Koivula, J. I., 1984. Russian hydrothermal synthetic emeralds. *Gems & Gemology*, **20**, 245.

Koivula, J. I., 1985. More on Russian hydrothermal synthetic emeralds. *Gems & Gemology*, **21**, 59-60.

Koivula, J. I., Keller, P. C., 1985. Russian flux-grown synthetic emeralds. *Gems & Gemology*, **21**, 79-85.

Lebedev, A. S. 1987. Private communications.

Lebedev, A. S., Askhabov, A. M., 1984. Regeneration of beryl crystals. *Zap. Vses. Mineral. Obsh.*, **113**, 618-28 [in Russian].

Lebedev, A. S., Dokukin, A. A., 1984. Effect of pressure on entry of water into beryl during hydrothermal synthesis. In: *Fiz.-Khim. Issled. Sul'fidnykh Silik. Sist.*, Novosibirsk 1984, pp. 79-86 [in Russian].

Lebedev, A. S., Il'in, A. G., Klyakhin, V. A., 1986. Hydrothermally-grown beryls of gem quality. In: *Morphology and phase equilibria of minerals. Proceedings of the 13th General Meeting of the International Mineralogical Association*, Varna 1982, Vol. 2, publ. Sofia 1986, pp. 403-11 [in Russian].

Lind, Th., Henn, U., Bank, H., 1987. Nach dem Hydrothermalverfahren hergestellte Smaragde aus der UdSSR. *Z. Dt. Gemmol. Ges.*, **36**, 51-60.

Lokhova, G. G., Ripinen, O. I., Veiss, N., 1980. Color characteristics of beryls activated with iron-group ions. In: *Vyrashchivanie Kristallov Berillievykh Mineralov i Issled. ikh Svoistv*, Novosibirsk 1980, pp. 35-41 [in Russian].

Nassau, K., 1976. Synthetic emerald: the confusing history and the current technologies. *J. Crystal Growth*, **35**, 211-22.

Nassau, K., 1980. *Gems Made by Man*. Radnor, Chilton Book Company, Pennsylvania.

Nassau, K., Jackson, K. A., 1970. Trapiche emeralds from Chivor and Muzo, Colombia. *Amer. Mineral.*, **55**, 416-27.

Nassau, K., Nassau, J., 1980. The growth of synthetic and imitation gems. In: *Freyhart, H. C. (Ed.): Crystals. Growth, Properties and Applications. Vol. 2: Growth and Properties.* Springer, Berlin, pp. 1-50.

Parkin, K. M., Loeffler, B. M., Burns, R. G., 1977. Mössbauer spectra of kyanite, aquamarine and cordierite showing intervalence charge transfer. *Phys. Chem. Minerals*, **1**, 301-11.

Pavlova, I. G., 1963. Dependence of the refractive indices of beryl on composition and mode of genesis. *Doklady Akad. Nauk SSSR, Earth Sci. Sect.*, **150**, 109-12.

Platonov, A. N., Polshin, E. V., Taran, M. N., 1979. On the forms of occurrence of Fe in beryls. *Zap. Vses. Mineral. Obsh.*, **108**, 725-30 [in Russian].

Platonov, A. N., Taran, M. N., Minko, O. E., Polshyn, E. V., 1978. Optical absorption spectra and nature of color of iron-containing beryls. *Phys. Chem. Minerals*, **3**, 87-8.

Price, D. C., Vance, E. R., Smith, G., Edgar, A., Dickson, B. L., 1976. Mössbauer effect studies of beryl. *J. de Physique, Colloque C6, supplement 12*, **37**, 811-17.

Pugachev, A. I., 1984. Effect of Po$_2$ on structural impurities of iron in hydrothermal beryl. In: *Fiz.-Khim. Issled. Sul'fidnykh Silik. Sist.*, Novosibirsk 1984, pp. 87-93 [in Russian].

Rodionov, A. Ya., Pavlyuchenko, V. S., 1980. Crystallization of coloured varieties of beryl under gas-transport conditions. In: *Vyrashchivanie Kristallov Berillievykh Mineralov i Issled. ikh Svoistv*, Novosibirsk 1980, pp. 62-70 [in Russian].

Samoilovich, M. I., Tsinober, L. I., Dunin-Barkovskii, R. L., 1971. Nature of the coloring in iron-containing beryl. *Sov. Phys.-Cryst.*, **16**, 147-50.

Scarratt, K., 1987. Notes from the Laboratory – 11. *J. Gemm.*, **20**, 406-22.

Schmetzer, K., 1982. Absorptionsspektroskopie und Farbe von V^{3+} – haltigen natürlichen Oxiden und Silikaten – ein Beitrag zur Kristallchemie des Vanadiums. *N. Jb. Miner. Abh.*, **144**, 73-106.

Schmetzer, K., 1985. Ein verbesserter Probenhalter und seine Anwendung auf Probleme der Unterscheidung natürlicher und synthetischer Rubine sowie natürlicher und synthetischer Amethyste. *Z. Dt. Gemmol. Ges.*, **34**, 30-47.

Schmetzer, K., 1986. An improved sample holder and its use in the distinction of natural and synthetic ruby as well as natural and synthetic amethyst. *J. Gemm.*, **20**, 20-33.

Schmetzer, K., Bank, H., 1980. Smaragde aus Sambia mit ungewöhnlichem Pleochroismus. *Z. Dt. Gemmol. Ges.*, **29**, 149-51.

Schmetzer, K., Bank, H., 1981. An unusual pleochroism in Zambian emeralds. *J. Gemm.*, **17**, 443-6.

Schmetzer, K., Bank, H., Stähle, V., 1981a. Zum Chromgehalt in synthetischen Smaragdüberzügen von Beryllkernen ('Synthetische Smaragde' der Herstellung Lechleitner). *Z. Dt. Gemmol. Ges.*, **30**, 210-3.

Schmetzer, K., Bank, H., Stähle, V., 1981b. The chromium content of Lechleitner synthetic emerald overgrowth. *Gems & Gemology*, **17**, 98-100.

Schmetzer, K., Berdesinski, W., Bank, H., 1974. Über die Mineralart Beryll, ihre Farben und Absorptionsspektren. *Z. Dt. Gemmol. Ges.*, 23, 5-39.

Schrader, H.-W., 1983. Contributions to the study of the distinction of natural and synthetic emeralds. *J. Gemm.*, **18**, 530-43.

Shatsky, V. S., Lebedev, A. S, Klyakhin, V. A., 1980. Micromorphology of crystals of synthetic hydrothermal emerald. In: *Inhomogeneity of minerals and crystal growth. Proceedings of the XI general meeting of IMA*, Novosibirsk 1978, publ. Moskva 1980, pp. 255-61 [in Russian].

Shatsky, V. S., Lebedev, A. S., Pavlyuchenko, V. S., Koveleva, L. T., Kozmenko, O. A., Yudin, A. N., Belov, N. V., 1981. Study of conditions of entering of alkaline cations in the beryl structure. *Geokhimiya, 1981*, 3, 351-60 [in Russian].

Solntsev, V. P., 1981a. Nature of color centres and EPR in beryl and chrysoberyl. *Tr. Inst. Geol. Geofiz., Akad. Nauk SSSR, Sib. Otd.*, **499,** 92-140 [in Russian].

Solntsev, V. P., 1981b. Absorption spectra and EPR spectra of trace impurities in beryllium-containing minerals and their relation to specimen color. In: *Issled. Fiz. Svoistv i Sostava Sintet. Mineralov i Monokristallov*, Novosibirsk 1981, pp. 37-47 [in Russian].

Solntsev, V. P., Bukin, G., V., Klyakhin, V. A., Lokhova, G. G., Pugachev, A. I., 1984. Nature of color centres and EPR of iron-containing beryls. In: *Fiz.-Khim. Issled. Sul'fidnykh Silik. Sist.*, Novosibirsk 1984, pp. 109-19 [in Russian].

Solntsev, V. P., Bukin, G. V., Lokhova, G. G., Veis, N. S., 1985. EPR and optical absorption spectra of iron-containing beryls. *Tr. Inst. Geol. Geofiz., Akad. Nauk SSSR, Sib. Otd.*, **610,** 128-34 [in Russian].

Solntsev, V. P., Kharchenko, E. I., Bukin, G. V., Klyakhin, V. A., Lebedev, A. S., Lokhova, G. G., Ripinen, O. I., 1978. Study of microisomorphic substitutions in natural and synthesized beryl. In: *Issled. po Eksperim. Mineral.*, Novosibirsk 1978, pp. 39-53 [in Russian].

Solntsev, V. P., Lebedev, A. S., Pavlyuchenko, V. S., Klyakhin, V. A., 1976. Copper centres in synthetic beryl. *Sov. Phys. Solid State*, **18,** 805-6.

Stockton, C. M., 1984. The chemical distinction of natural from synthetic emeralds. *Gems & Gemology*, **20,** 141-5.

Stockton, C. M., 1987. The separation of natural from synthetic emeralds by infrared spectroscopy. *Gems & Gemology*, **23,** 96-9.

Wood, D. L., Nassau, K. 1967. Infrared spectra of foreign molecules in beryl. *J. Chem. Phys.*, **47,** 2220-8.

Wood, D. L., Nassau, K. 1968. The characterization of beryl and emerald by visible and infrared absorption spectroscopy. *Amer. Mineral.*, **53,** 777-800.

[*Manuscript received 25 January 1988*]

Radiation induced structural damage in beryl

John I. Koivula

Gemological Institute of America, 1660 Stewart Street, Santa Monica, California 90404, USA

Abstract

Stress-induced structural defects in beryl, similar to those first reported in irradiated topazes, are described and illustrated. As with topaz, the build-up of excess electrical charge and heat in the beryl, during irradiation, is thought to be the cause of these defects.

Introduction

For several years now, colourless topaz has been imported into the United States from Nigeria. Large quantities are brought in annually for the sole purpose of treatment, by a combination of irradiation and heating, to turn the topaz blue.

During linear accelerator (linac) treatment, when high-energy electrons in the 10 to 20 megaelectronvolt range are used, a great deal of heat is generated together with an excessive negative charge within the topaz. Due to the limited depth of penetration of the electrons both the heat and the electric charge are unevenly distributed within the topaz structure (Nassau, 1985; Schmetzer, 1987). This results in strain.

Further, the surfaces of the topaz crystals are cooled with running water during irradiation which sets up extreme temperature gradient, from the outer surface to the core, in the crystals (Nassau, 1985, Schmetzer, 1987). This causes even more internal strain which, in the most severe cases, relieves itself through cleavage along the basal pinacoid and through the formation of needle-like structural defects parallel to the *a*- and *c*-axes (Schmetzer, 1987). In some crystals these defects may take on a bold 'fish skeleton' or 'fern-like' form (Figure 1). But in all cases involving topaz these defects mirror the orthorhombic symmetry of their host.

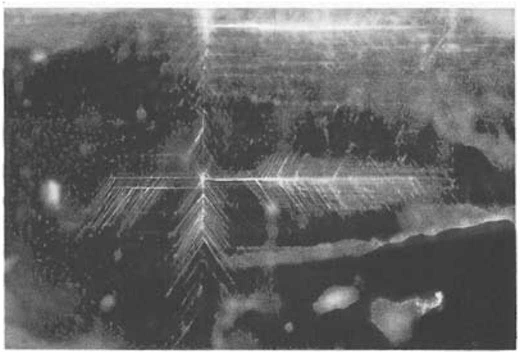


Fig. 1. Electron-induced structural damage showing the orthorhombic symmetry of the irradiated blue topaz host. Viewed perpendicular to the *c*-axis, at an angle inclined to the *a*-axis. 20x.

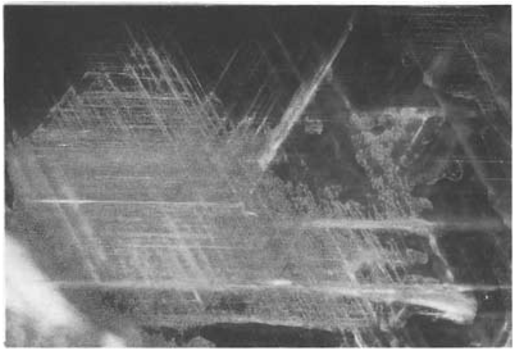


Fig. 2. Electron-induced structural damage showing the hexagonal symmetry of the irradiated yellow beryl host. Viewed parallel to the *c*-axis direction. 35x.

When shipments of topaz are received from Nigeria it is common to have a few crystal sections and fragments of colourless 'goshenite' beryl mixed in with the colourless topaz (Peter and Bobbi Flusser, Personal Communication). But, because of the quantities of rough involved, and the commercial nature of this mass-treatment process, the few

ISSN: 0022-1252

pieces of beryl are never separated from the bulk of topaz before irradiation... but only after the operation.

Description of the beryl

When the treated topaz is removed from the linac it is then relatively easy to spot any beryl 'ringers' that may have been present. Since all the colourless beryl has turned to a golden yellow, it now stands out in stark contrast with the brownish-to-blue topaz.

Three linac-treated yellow, anhedral crystal fragments of Nigerian beryl, weighing betwen 8.92 and 21.05 carats, were recovered from a recent treatment run of topaz and examined using a standard gemmological microscope. Just like some of the electron-treated topazes previously described by Schmetzer (1987), which showed radiation-induced defects that delineated their orthorhombic symmetry (Figure 1), two of these beryls exhibited similar structural defects that mirrored the hexagonal symmetry of their host (Figure 2). Defects such as these have never before been reported as inclusions in beryl from any locality.

In a follow-up examination of several hundred carats of un-irradiated Nigerian beryl no such defects were observed. This suggests that linac generated electron-irradiation is responsible.

Conclusion

Of three linac-treated Nigerian beryls examined, two of them showed the prominent hexagonal defect structure. If these beryls were to be treated on a commercial basis, using a strong beam of electrons generated by a linear accelerator, then perhaps as many as two-thirds of them would develop this internal hexagonal pattern.

The fineness of these defect 'needles', together with their dense, close-packed nature (Figure 2), is reminiscent of the rutile needles found in Sri Lankan star corundums. This suggests that perhaps six-rayed star beryls could be cut from the best of these treated stones.

Acknowledgements

The author would like to thank Peter and Bobbi Flusser of Overland Gems, Los Angeles, California, for supplying the irradiated beryl. Michael Gray of Graystone Enterprises, Venice, California, 'windowed' the beryl for photomicrography.

References

Nassau, K., 1985. Altering the color of topaz. *Gems and Gemology*, **21**, 1, 26-34.

Schmetzer, K., 1987. Colour and irradiation-induced defects in topaz treated with high-energy electrons. *Journal of Gemmology*, **20**, 6, 362-8.

[*Manuscript received 8 January 1988*]

GEMMOLOGICAL INSTRUMENTS LTD.

A wholly owned subsidiary of the Gemmological Association of Great Britain

The Rayner Dichroscope

A useful portable instrument which will easily detect pleochroism within a gemstone or mineral. Rigidly made in tubular metal for durability.

Can be used with either a clip-on attachment or Scopelight for hand held use or table stand with rotating platform.

Dichroscope **£34.70** + p & p + VAT.
Clip-on stone holder **£13.90** + p & p + VAT.

The Rayner Scopelight

A versatile, portable battery-operated light source designed to facilitate the inspection of gemstones when away from the laboratory or work-bench and is suitable for use by the professional gemmologist and student alike. The 'light drum' is fitted with a metal disc with holes of varying diameters to accommodate gemstones of any size. When rotated over the light, the gemstone is illuminated. The light produces a good useable image for both the spectroscope and dichroscope.

The pen torch is fitted with a 9mm MES lens-end lamp rated at 2.5V, 0.3A, with MN 2400 batteries.

Unit supplied complete. **£15.50** + p & p + VAT.

Gemmological Instruments Ltd.
Saint Dunstan's House, Carey Lane, Cheapside, London EC2V 8AB, England.
Telephone: 01-726 4374 Cables: Geminst, London EC2.

The emeralds of Fazenda Boa Esperança, Tauá, Ceará, Brazil: occurrence and properties

D. Schwarz, Dr H. A. Hänni**, F. L. Martin Jr† and M. Fischer***

*Deutscher Akad. Austauschdienst, Gemmological Centre, Federal University of Ouro Preto, Minas Gerais, Brazil
**Mineralogical Institute, University of Basel, Switzerland
†Belo Horizonte, Minas Gerais, Brazil

Abstract

The emerald-producing Fazenda Boa Esperança (Tauá, Ceará) in Brazil, the regional and local geology, and the properties of the emeralds are discussed.

The emerald occurrence is situated in biotite schists and tremolite-bearing schists containing phlogopite and chlorite. Its formation is closely related to anatectic pegmatites which have intruded into the rock series. The emeralds are associated with very large apatite crystals and locally, with corundum.

Chemical analyses show low contents of Cr_2O_3 and V_2O_3 (<0.25 wt.%) and rather high contents of FeO (0.91-1.17 wt.%), MgO (2.42-2.69 wt.%) and Na_2O (1.69-1.96 wt.%).

The following substitutions explain the low Al-contents:-

$Al^{3+,VI} = (Mg,Fe)^{2+} + Na^{+}$
$Al^{3+,VI} = (Fe,Cr,V)^{3+,VI}$

The Tauá emeralds contain many mineral inclusions. So far, phlogopite, tremolite, molybdenite, allanite and apatite have been identified. In addition, accumulations of very small fluid droplets and/or mineral dust and plane cavities occur, mostly exhibiting a one-phase filling. The concentrations of these inclusions lower the gemmological quality of the emeralds.

1. Introduction

The Fazenda (farm) Boa Esperença lies 40 km NNE of Tauá, a small town in the south-east of the federal state of Ceará (Figure 1). The region is one of the driest in Brazil, and the caatinga vegetation typical of this arid area known as the Sertao, consists essentially of low thorny bushes, stunted trees and numerous species of cacti.

The emerald deposit of Fazenda Boa Esperança, which lies less than 1 km east of National Highway BR 020 (linking Fortaleza with the capital Brasilia), has been known for a long time. Since the early 1950s, emeralds (and/or green beryls) have been extracted by garimpeiros (Brazilian freelance miners). At the beginning of the 1970s, the mining company Mineração Sao Pedro Limitada began serious mining operations on a larger scale, but soon gave up due to the high development costs involved. In 1983, the company Mineração Brasileira Ltda. undertook detailed geological mapping of the area (Andrade, 1983; Korpershoek, 1983).

2. Geology

Figure 2 presents the regional geology in which the emerald deposit at Fazenda Boa Esperança is situated.

The following presentation of the regional and local geological conditions of the emerald deposit is based on the work of Gomes *et al.* (1981), Mello *et al.* (1978) and Korpershoek (1984).

2.1 *Regional Geology*

Over 80% of the surface of Ceará State is mainly composed of Precambrian crystalline rocks. Apart from this, granitic and dioritic-gabbroidal intrusive rocks and pegmatites also occur.

At the end of the Brazilian orogenesis (ca. 650-600 million years), the main geological structures including the characteristic faults, had been formed. Tectonic movements along some of the faults during the Palaeozoic-Mesozoic eras led to a partitioning of the crystalline basement into numerous fault blocks. Thus, Fazenda Boa Esperança lies on the southern border of the Bloco Santa Quiteria, which is described in Figures 2 and 3 as Unit II. In the north, the Bloco Santa Quiteria overlies leptites and, to a lesser degree, biotite gneisses of Unit III. On the other hand, in the more southern area the Bloco Santa Quiteria underlies a polymetamorphic volcano-sedimentary unit, the Complexo de Pedra Branca (Unit I in Figures 2 and 3).

The latter is lithologically very varied and is composed of quartzites, leptites, mica schists, para- and ortho-gneisses, migmatites, amphibolites, serpentinites etc. The Complexo de Pedra Branca is

ISSN: 0022-1252

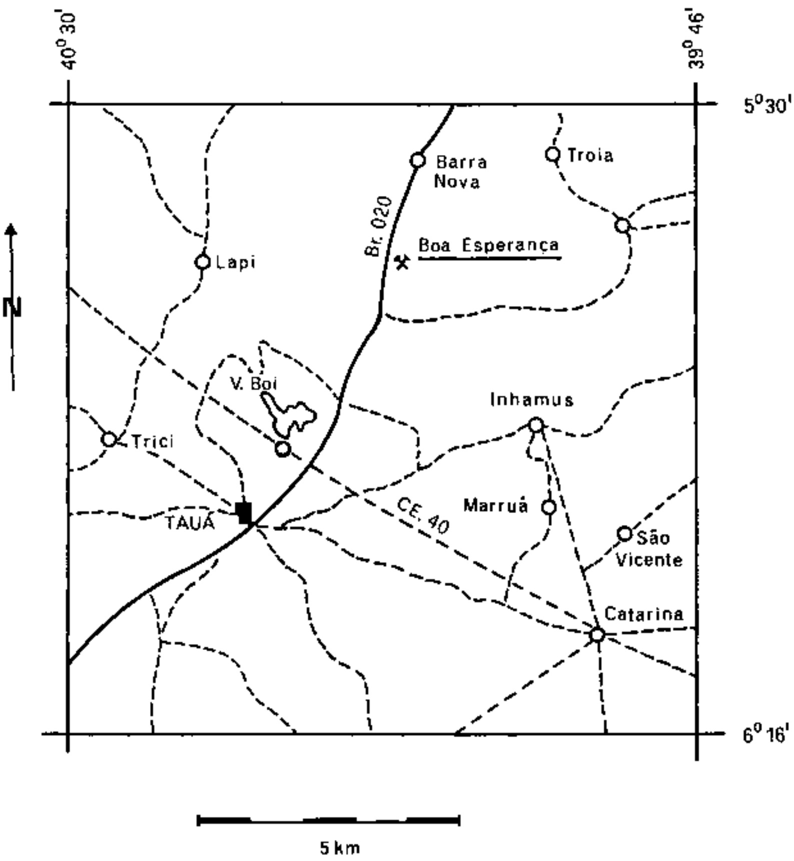


Fig. 1. Geographical situation of the emerald deposit at Boa Esperança, Tauá, Ceará.

regarded as a 'Nucleo Antigo'* at least 2000 million years old, and overprinted by the Brazilian orogenesis.

In the Bloco Santa Quiteria, several diorite massifs occur whose age and stratigraphical correlation are still unknown. Furthermore, several gabbro bodies occur with a minimum age of 1900 million years, and two granite intrusions occur within the largest diorite massif (Diorito de Tauá). The intrusions are considered to be syntectonic with the Brazilian orogenesis.

A system of rhyolitic to dacitic dykes appear in the south-western portion of the Bloco Santa Quiteria, which cut both the Complexo de Pedra Branca and the Tauá diorite. These dykes can be up to 300 metres wide and several kilometres long. Other dykes belonging to the same lithological type, fill concentric fractures in the syntectonic granites near Tauá. The age of these late-tectonic dykes is given as about 600 million years.

2.2 *Local geology and genetic aspects*

Tectonically speaking, the Fazenda Boa Esperança lies on the southern border of the Bloco Santa Quiteria (Unit II in Figures 2 and 3). This area is mainly composed of biotite gneisses and -schists and leptites, as well as ultramafic rocks, amphibolites and a large number of pegmatites (Figure 3).

Emerald is found in the biotite schists near the pegmatite veins. This unit lithologically presents a very varied development and comprises ultramafic rocks (metamorphosed to talc-schists, tremolites etc.), metabasites, amphibolites (often undergoing transformation to hornblende-gneiss), leptites, as well as biotite gneisses and emerald-bearing biotite schists. The latter are, at least partially, described as 'tremolite schists with phlogopite and chlorite' (Cassedanne and Mello, 1979). Additionally, numerous dykes and pegmatite veins occur.

---

*Blocks which split a folded region into different zones. They may have been formed during an earlier period, or originated from the same deformation phase which folded the region but, however, had already consolidated (Khain & Sheynaann, in Gomes *et al.*, 1981).

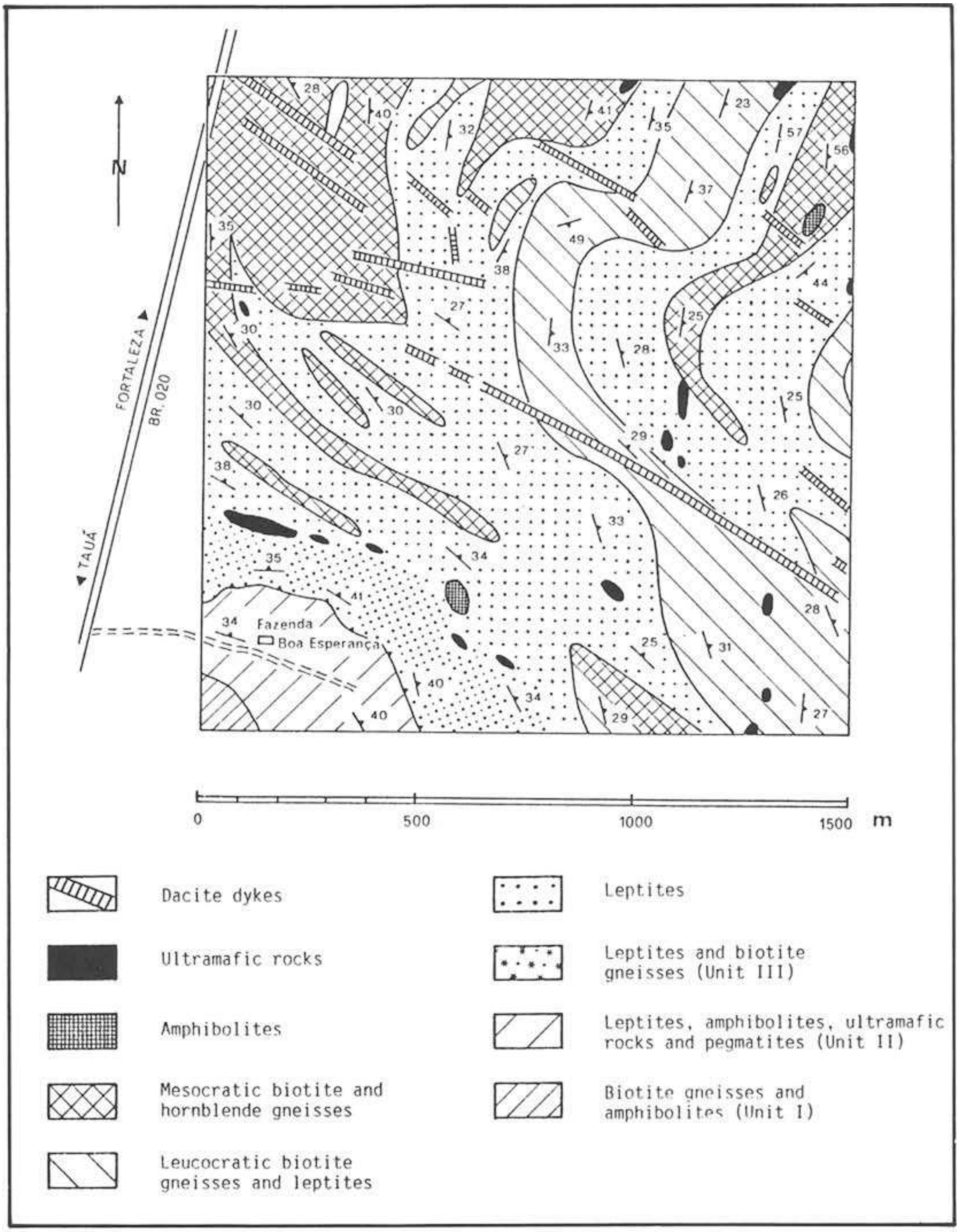


Fig. 2. Regional geology of the emerald deposit.

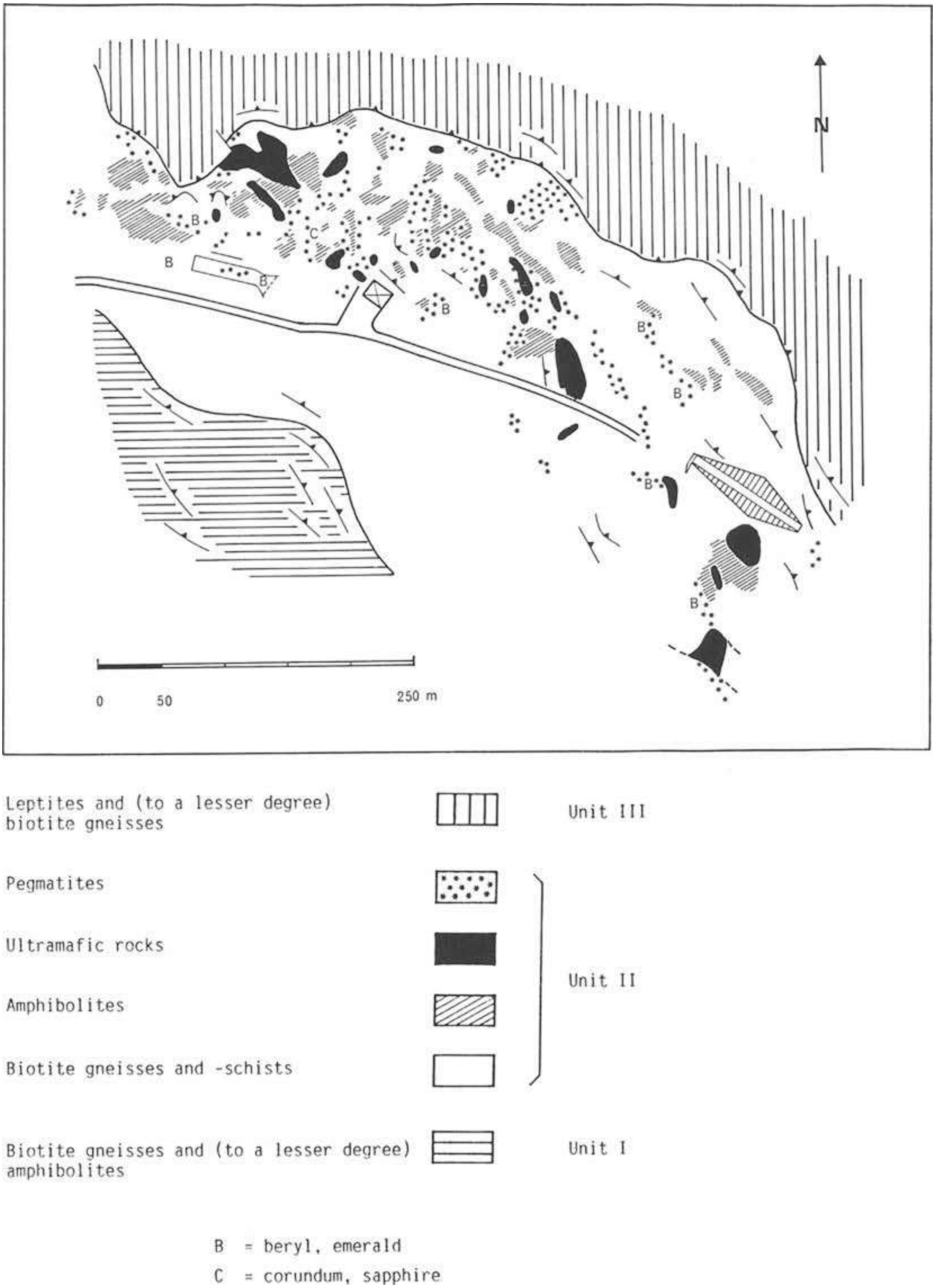


Fig. 3. Local geology of the emerald deposit.

The complete volcano-sedimentary sequence as well as the layers directly overlying it were intensively folded; the volcano-sedimentary unit underwent at least three deformation phases.

The ultramafic rocks occur as oval, lenticular or irregular bodies. These, as did the other rocks of the unit, experienced a regional metamorphism and were transformed to talc-schists, talc-tremolite schists, and tremolitites. Some of the ultramafic rocks contain grains of magnetite and are considerably magnetic.

The numerous pegmatites form long and irregular bodies, and also concordant intrusions. They usually have a simple composition mainly of quartz and albite. They are coarse- to fine-grained, with the latter appearing to be the predominant type.

Cassedanne and Mello (1979) suggest that this fine-grained facies originates from the cataclasis during the tectonic deformation. The pegmatites as well as the leptites contain minute red grains of garnet.

The pegmatites are mainly quite homogeneous. Where differentiated, muscovite-rich portions occur, or, in some, finely-layered biotite can be present. Sometimes, concentrations of quartz are developed. Apart from these, the following minerals are present: beryl, columbite-tantalite, tourmaline, apatite, molybdenite and native bismuth or bismutite (Cassedanne and Mello, 1979).

The pegmatites do not seem to be directly derived from late magmatic processes, which usually are accompanied by significant hydrothermal activity. Such an origin would seem to be improbable, because their unusual composition can only with difficulty be linked to a simple granitic origin. They were probably locally mobilised during the regional metamorphism, when pressure and temperature rose notably. This led to a partial anatexis and to the formation of Na-rich pegmatites, determined by the nature of the host-rock. Their composition differs from the K-rich pegmatites in the hanging wall, reflecting the composition of the neighbouring leptites (Korpershoek, 1983).

The emerald-bearing biotite schists (or tremolitic schists with phlogopite and chlorite) neighbouring the 'anatectic' pegmatites are products of chemical reactions (metasomatism) between the pegmatites and the basic or ultrabasic rocks. By exometamorphic processes, i.e. through the change of the original rock by the addition of components of another surrounding chemical medium, the necessary elements for the formation of beryl can reach the biotite schist and crystallize in the form of exometamorphic beryl (or emerald). Most of the beryls so-formed correspond to those which are found in the pegmatites themselves, i.e. they are mostly pale green; the beryl variety emerald is only formed where an adequate supply of colour-providing elements from the basic or ultrabasic rocks is available. Chromium is possibly supplied by some of the chromian magnetite in the ultramafic rocks.

The emeralds are generally small and seldom longer than 2 cm. Occasionally, fragments of larger crystals have been found. The prismatic crystals (combination of six-sided prisms and basal pinacoid) exhibit different shades of green, whereby an apple-green seems to be the most abundant colour. According to Cassedanne and Mello (1979), this green colour in the Tauá emeralds stems from the addition of vanadium. The authors' chemical analyses could not confirm this, and their work suggests rather that Cr and Fe are responsible for the colour (see section 3).

In a preliminary classification of emerald deposits (Schwarz, 1987), the Tauá occurrence was assigned to the 'classical' type of genesis, charactized by the association of mafic-ultramafic rocks and pegmatites (Be-supplier). As the Tauá pegmatites cannot be considered to be 'true' pegmatites containing light elements, but rather as mobilisations, i.e. anatectic pegmatites, the question as to the origin of the Be has still to be answered. The question of whether this deposit and other similarly-formed emerald mineralizations should be considered to be a sub-type of the classical emerald genesis, or rather as a specifically separate class of genesis, will only be resolved after further detailed studies are carried out.

The emerald is occasionally associated with unusually large (up to 15 cm), beautifully formed apatite prisms. These are dark green to bluish in colour and often so clear and free of inclusions as to make them of great interest to the gem cutter.

Apart from emerald, corundum has been observed in Unit III in three habits (Figure 3) (Korpershoek, 1984). Firstly, the mineral occurs as minute (<0.1 mm) xenomorphic grains of the blue variety of corundum – sapphire, which occurs as an accessory mineral in the tremolite-talc schist. Also, colourless to blue corundum crystals have been found in a contact metamorphic rock mainly composed of oligoclase (20-22% An). These corundums are characterized by a nearly right-angled parting of the rhombohedron $(10\bar{1}\bar{1})$. The third habit of the corundum is as colourless, prismatic crystals, originally up to 3 mm long, which have largely been replaced by sericite, and which occur together with black tourmaline in muscovite schists.

3. Optical and chemical data of the Tauá Emeralds

Optical data stemming from a number of authors

Table 1. Refractive indices and birefringences of the Tauá emeralds

n_e	n_o	Δn	Reference
1.580 ± 0.001	1.586 ± 0.001	0.006	Cassedanne & Mello (1979)
1.579	1.587	0.008	Branco *et al.* (1984)
1.579 – 1.582	1.585 – 1.589	0.006 – 0.008	Schwarz (1987)*
1.570 – 1.574	1.577 – 1.581	0.007 – 0.008	Schwarz (1987)**

*Range of optical data in dark emeralds
**Range of optical data in light emeralds

concerning the emeralds from Fazenda Boa Esperança are presented in Table 1.

The electron microprobe analyses (Table 2) were carried out with an ARL-SEMQ instrument, in which the WDS spectrometer was used in combination with an energy dispersive system (EDS, TN 2000) (Schwander and Gloor, 1980). The instrumental working conditions were 15kV accelerating voltage, 30mA beam current with a beam diameter of about 2 micrometres. The standards used for the analyses comprised synthetic oxides and simple silicate minerals.

The analyses were cationically normalized to Si = 6 atoms. Low Cr_2O_3 and V_2O_3-values (<0.25 wt.%) contrast with high values for FeO (0.91 – 1.17 wt.%), MgO (2.42 – 2.69 wt.%) and Na_2O (1.69 – 1.96 wt.%). The low Al contents are compensated by Mg and Fe^{2+} through the reactions:

(a) $Al^{3+,VI} = (Mg,Fe)^{2+} + Na^+$

Cr, V and Fe (Figure 4) likewise compensate:

(b) $2Al^{3+,VI} = Fe^{3+,VI} + (Cr,V)^{3+,VI}$

(see Franz *et al.*, 1986).

The calculations at the bottom of Table 2 show that principally substitution-type (a) occurs in the case of these emeralds, and differences in charge between Mg^{2+} and Fe^{2+} versus Al^{3+} are compensated by Na^+. Figure 4, exhibiting a gradient <1 shows a slight excess of (Mg+Fe) over Na. This can be explained by a small amount of Fe^{3+} which need not be compensated chargewise by Na^+. Probe analyses cannot indicate oxidation state nor position of the ions within the lattice and as the Fe can occur either as Fe^{2+} or Fe^{3+} in the octahedral or tetrahedral positions, a certain degree of uncertainty in the crystal chemical treatment of this element can occur. Figure 4 compares chemical plots between the Tauá and Itabira emeralds (Hänni, *et al.*, 1987). The Tauá samples are characterized by a larger

Table 2. Microprobe analyses of Tauá emeralds

SiO_2	66.92	67.13	65.99	63.16	63.76	63.75
Al_2O_3	15.83	15.57	14.84	14.66	14.93	14.84
Cr_2O_3	.10	.19	.06	.23	.10	.23
V_2O_3	.00	.00	.06	.00	.00	.00
FeO	.91	1.17	1.05	1.03	1.00	1.11
MgO	2.46	2.69	2.42	2.46	2.47	2.55
Na_2O	1.69	1.73	1.91	1.85	1.96	1.87
Total	87.91	88.48	86.33	83.39	84.22	84.35
Formula On the basis of 6 Si atoms						
Si	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.673	1.640	1.591	1.654	1.656	1.646
Cr	0.007	0.013	0.004	0.017	0.007	0.017
Fe^{2+}	0.068	0.087	0.080	0.081	0.079	0.088
Mg	0.329	0.358	0.328	0.348	0.346	0.358
Na	0.293	0.300	0.336	0.341	0.358	0.342
Σ	8.370	8.398	8.339	8.441	8.446	8.451

Total Fe calculated as FeO

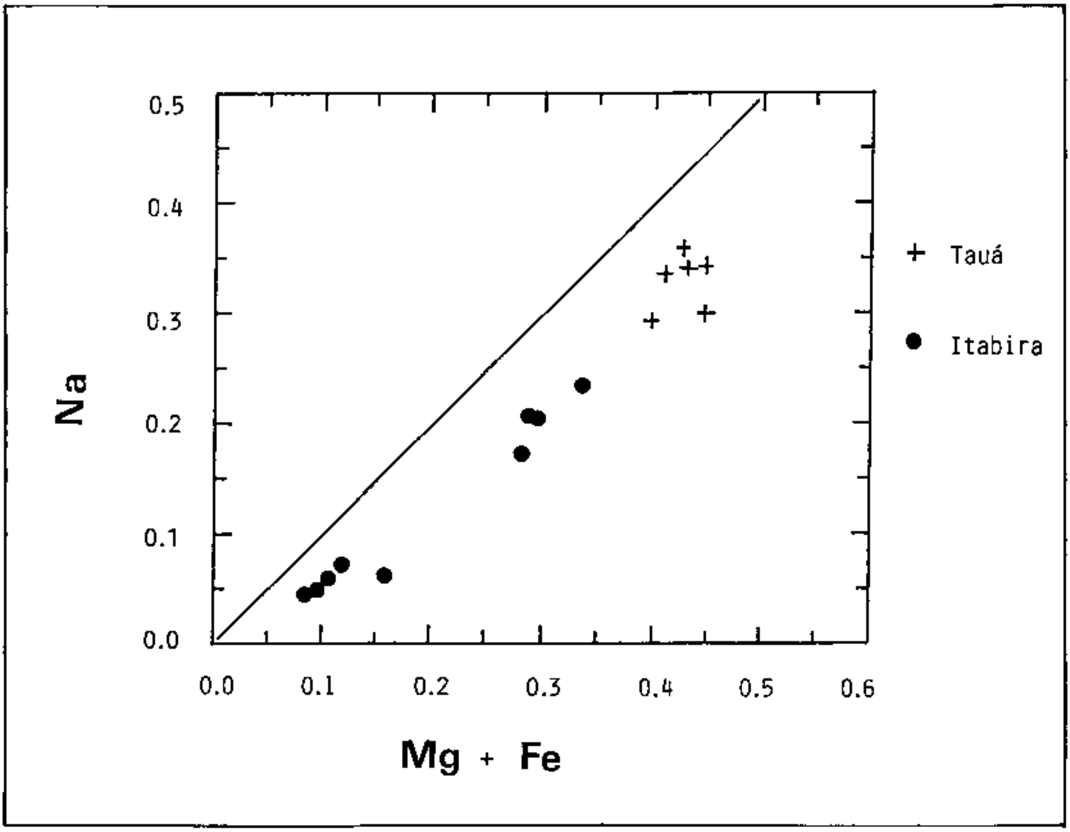


Fig. 4. Comparison between the relationship Na vs. (Mg+Fe) in emeralds from Tauá and Itabira.

amount of Na, Mg and Fe, substituting for Al, than in the Itabira material.

4. Inclusions

The most conspicuous property exhibited by the Tauá emeralds is the presence of numerous mineral inclusions, which strikingly reflect the mineralogy and geology of the area at the time of the formation of the emerald. So far, the following mineral inclusions have been identified:

Biotite/phlogopite

The probe analyses in Table 3 show that the mica inclusions in the Tauá emeralds are phlogopite (Mg/Fe>2). Their distribution pattern in the host crystal as well as variations in habit and colour indicate the occurrence of two distinctively different genetic types; firstly, of protogenetic inclusions mainly of a dark brown colour with irregular or rounded shapes and which are irregularly distributed within the emerald (Figures 10, 11). In contrast to these, mica crystals of syngenetic origin are crystallographically oriented. These are in the form of thin pseudohexagonal platelets lying either parallel to the basal plane of the emerald or parallel to the prism planes of the emerald, intersecting each other at angles of 60 and 120° (Figure 11). Their colour is usually a light brown.

Tremolite

The habit of the tremolite crystals varies from prismatic needles to thick stalks or 'bamboo-like' forms (Figures 5, 6). The crystals are colourless through weakly green to dark green, are randomly oriented throughout the emerald crystal, and sometimes form dense aggregates. These are typical protogenetic inclusions, and are often broken at one or both ends, or 'sharpened' to a pencil-like form (Figure 7). Table 3 gives two typical analyses. The chemical analyses of the amphiboles correspond to tremolite or tremolitic hornblende respectively.

Molybdenite

Although molybdenite (Figure 8) occurs in part as perfect although often warped (pseudo-) hexagonal platelets with a metallic lustre, partially

Table 3. Microprobe analyses of mineral inclusions in Tauá emeralds

	Phlogopite		Tremolite*	Allanite**
SiO_2	42.58	41.68	52.41 – 56.04	31.28
TiO_2	.32	.31	.00 – .12	.00
Al_2O_3	12.44	12.35	2.42 – 4.48	14.43
Cr_2O_3	.11	.17	.22 – .47	.00
V_2O_3	.00	.00	.00 – .03	.00
FeO	6.70	7.68	6.45 – 7.00	10.60
MnO	.04	.00	.12 – .40	.00
MgO	22.90	21.90	19.06 – 20.33	1.27
CaO	.04	.06	11.40 – 12.17	9.71
Na_2O	.63	.56	.63 – 1.17	.21
K_2O	8.74	8.68	.00 – .05	.13
F	~2.4	~2.7	.90 – 1.20	n.d.
Total	96.90	96.10		67.63

* Range encountered in 8 inclusions of tremolite; fluorine not quantitatively determined in all crystals.

** Partial analysis. Cerium was qualitatively determined; usually about 30 wt.% in allanites.

corroded crystals are more common and these then take on irregular 'ink stain' or skeletal forms (Figure 5).

Allanite (orthite)

Allanite appears both as zoned prismatic and thick 'stems' (stalks), and as fibrous columnar crystals with a dark brown colour, mainly arranged in sheaf-like aggregates (Figure 8). Table 3 presents a partial chemical analysis of an allanite crystal.

Apatite

Apatite forms colourless and transparent crystals, occurring mainly as short prisms.

Other mineral inclusions

One of the mineral inclusions could not be identified. This is a strongly orangeish-red coloured irregular crystal (Figures 5, 14).

The Tauá emeralds can contain numerous tremolite crystals (with very little or no mica), but can also be totally free of tremolite. This depends on the composition of the respective host rock of the emerald, i.e. whether the latter is mainly a biotite/phlogopite schist or a tremolite-bearing schist with phlogopite and chlorite.

In general, the Tauá emeralds produced nowadays are not of a high quality, mainly due to the large number of inclusions in them. Apart from the mineral inclusions described above, many minute particles exist which, in part, form dense clouds resulting in reduced transparency. These collections of minute liquid droplets and/or mineral dust are more or less evenly distributed throughout the emerald (Figure 12).

Shallow cavities (mainly containing a single phase) and numerous cracks add to the general opacity (Figure 13).

Acknowledgements

We wish to acknowledge the generous co-operation of the Mineração Brasileira Limitada (MBL) and Mr Peter Bartholomew, during the investigation at the Fazenda Boa Esperança, as well as for the use of maps and unpublished material. Mr Raimundo Mariano G. Castelo Branco kindly supplied material for the chemical analyses and the mineral inclusion studies. One of the authors (D.S.) is grateful to the following institutions for financial support and the provision of materials: Deutscher Akademischer Austauschdienst (DAAD), Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Deutsche Forschungsgemeinschaft (DFG) and the Fritz Thyssen Foundation. We also wish to thank Professor H. Schwander for his support during the microprobe studies.

References

Andrade, H. L. de, (1983). *Mapeamento geológico da área de Boa Esperança.* Relatório interno MBL, Mineraçao Brasileira Ltda., Fortaleza/CE (unpublished).

Branco, R. M. G. C., Schwarz, D., Svisero, D. P., Mendes, J. C., 1984. Dados mineralógicos da esmeralda da Fazenda Boa Esperança, Município de Tauá/CE. *XXXIII Congresso Bra-*

Fig. 7a

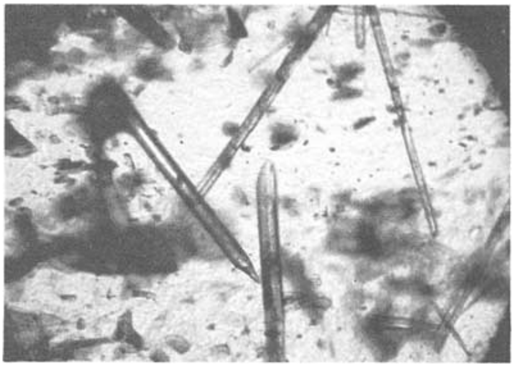


Fig. 7b

Fig. 10

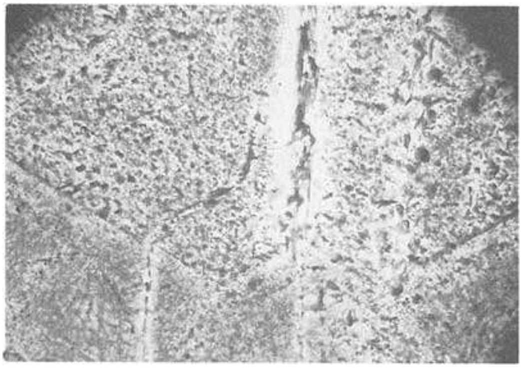


Fig. 12

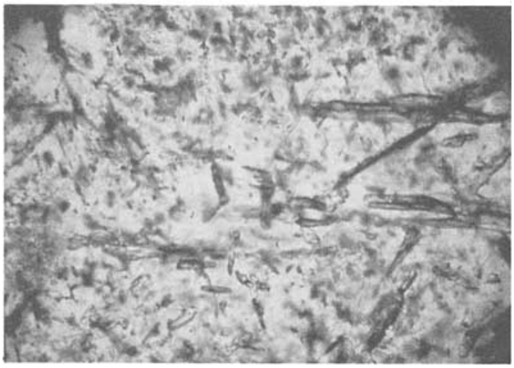


Fig. 13

Fig. 5. Tauá emeralds with numerous protogenetic mineral inclusions. Apart from columnar-prismatic or bamboo-like tremolite crystals with a light- to dark-green colour, brownish, mainly rounded, micas and opaque molybdenite can be seen. The latter mineral is usually strongly corroded when it then forms ink-spot or skeletal textures. On the left of the figure, a strongly orange-red unidentified crystal can be seen. 35x.

Fig. 6. Prismatic crystal of tremolite with a dark green colour, at one end intergrown with molybdenite. 50x.

Fig. 7a. Protogenetic crystal of tremolite. These are broken at one or both ends, indicating the effects of mechanical influences (transport, tectonic movements) prior to inclusion in the emerald. A further indication of the protogenetic origin of these crystals is supplied by the totally random orientation to that of the host crystal. 50x.

Fig. 7b. Pencil-shaped protogenetic tremolite crystals, randomly oriented within the emerald. 50x.

Fig. 8. Perfectly formed, (pseudo-) hexagonal platelet of molybdenite (black, opaque) with dark brown columnar crystals of allanite, which usually occurs in sheaf-like aggregates. 70x.

Fig. 9. Association of mineral inclusions in a Tauá emerald shown in polarized light (crossed nicols): columnar-prismatic tremolite crystals next to mica platelets and opaque molybdenite. 35x.

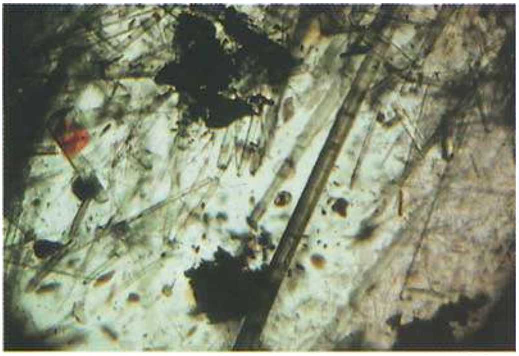


Fig. 5

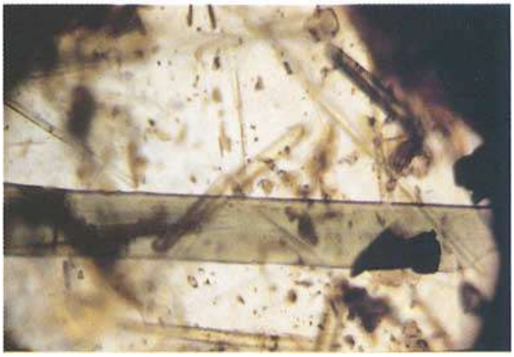


Fig. 6

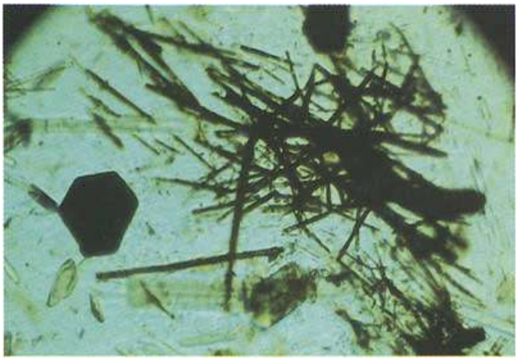


Fig. 8

Fig. 9

Fig. 11

Fig. 14

Fig. 10. Protogenetic dark brown mica inclusion (phlogopite). The crystals are irregularly bordered and randomly oriented in the emerald. 50x.

Fig. 11. This Tauá emerald contains numerous mica crystals which can be classified into two genetic types:
a) mica crystals with a protogenetic origin, and which are characterized by their usually dark colour and irregular forms. They are randomly oriented in the emerald host crystal;
b) syngenetic mica crystals are transparent, light brown platelets usually with a definite pseudo-hexagonal outline. They lie either parallel to the basal plane of the emerald, or parallel to the prism face of the emerald (the crystals appear as dark streaks in the Figure, which intersect at angles of 60 and 120°).

Fig. 12. Numerous minute particles (liquid droplets and/or mineral dust), the large number of which lead to a distinct reduction in the transparency and therefore the gemmological quality of the Tauá emeralds. 50x.

Fig. 13. The reduction of transparency in the emeralds can be caused by the numerous shallow cavities, which often contain a single-phase filling (liquid or gas). 70x.

Fig. 14. Strongly orange-red unidentified crystals on the left/right border of the photograph. 70x.

Note: All photographs were taken using immersion liquids.

sileiro de Geologia, Rio de Janeiro, Resumos, Breves Comunicaçoes etc., 262-3.

Cassedanne, J. J., Mello, F. de, 1979, As esmeraldas de Tauá Pilão Arcado. *Mineração Metalurgia*. **XLIII**, 410, 50-8.

Franz, G., Grundmann, G., Ackermand, D., 1986, Rock forming beryl from a regional metamorphic terrain (Tauern Window, Austria:) Parageneses and crystal chemistry. *Tscherm. Mineral. Petrograph. Mitt.* **35**, 167-92.

Gomes, J. R. de C., Gatto, C. M. P. P., Souza, G. M. C. de, Luz, D. S. de, Pires, J. de L., Texeira, W., 1981. *Geologia, em Radambrasil*, **23**, Folhas SB, 24/25 Jaguararibe/Natal.

Hänni, H. A., Schwarz, D., Fischer, M., 1987. Emeralds of the Belmont Mine, Minas Gerais, Brazil. *J. Gemmol*. **20**, 446-56.

Korpershoek, H. R., 1983. *Report on the Boa Esperança Emerald showing, Tauá, State of Ceará, Northeast Brazil.* Relatório interno MBL, Mineraçao Brasileira Ltda., Fortaleza/CE (unpublished).

Korpershoek, H. R., 1984. Safira na ocorrência de esmeralda de Tauá. *Mineração Metalurgia*, 453, 35-42.

Mello, A. A. de, Souza, E. M. de, Mendonca, J. C. de, 1978. A tectonica linear no Estado do Ceará. *Anais XXX Congr. Bras. Geol.*, Recife, 393-407.

Schwander, H., Gloor, F., 1980. Zur quantitativen Mikrosonden-Analyse von geologischen Proben mittels kombiniertem EDS/WDS. *X-ray Spectrometry*, 9, 134-7.

Schwarz, D., 1987. *Esmeraldas*. Imprensa Universitária, Ouro Preto, 350pp.

[*Manuscript received 28 December 1987*]

Hallmarked synthetic emerald

Alan Hodgkinson, FGA

Clarkston, Glasgow G76 7JD

The flux-grown Lennix emeralds probably provide the most interesting range of synthetic emerald inclusions to date – so much so that their appearance to the inexperienced eye gives a convincing impression of Nature's own handiwork. They were first reported in this *Journal* by Farn (1980) and described in more detail later by Graziani *et al.* (1987). The first specimen seen by the author was loaned in 1983 by Dennis Price, the Midlands lapidary and gemmologist. The latest were received from Monsieur Lens himself in 1987. The author is grateful to both.

The refractive indices for stones of both periods coincide: ray ω 1.564 and ε ray 1.560, DR 0.004. The specific gravity is 2.655. Under ultra-violet light they show a good red response in long-wave radiation and a slightly reduced response in short-wave. Through the Chelsea filter they show a bright raspberry red. These fluorescent effects, due to chromium, are more obvious in the later specimens.

The absorption spectrum shows a strong chromium pattern in the red, but the 477nm line in the blue was more fugitive and showed better when the yellowish-green ω ray was isolated by the polarizer drawing back the chromium cut-off at the violet end of the spectrum.

The crystals seen showed well-developed pinacoids from 5-16mm, whilst the prism faces were from 2.5-5mm in length.

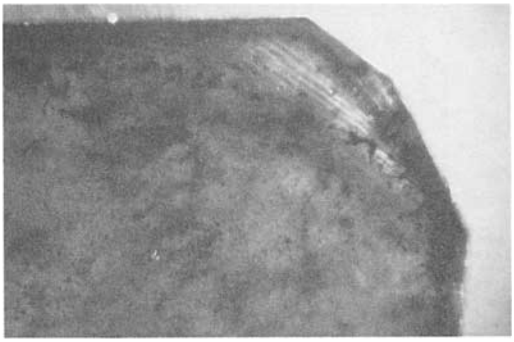


Fig. 1.

Fig. 2.

Figure 1. A view through a pinacoid face reveals part of the hexagonal crystal plan emphasized by chrome variations near the edge with a series of growth lines not always parallel to the outside prism walls. The growth lines repeat perhaps seven or eight times but are only peripheral, while the central area has every appearance of being natural by lens (no pun intended!). Certainly there are various veil-like inclusions floating about, but we see such general apparitions in natural as well as synthetic stones. A horizontal immersion microscope using benzyl benzoate RI 1.57, gave a closer look at the intriguing inclusion repertoire.

Figure 2. (25x) Stockings on a washing line are cavities which hang from the pinacoid washing lines, and the contents beckon you closer with higher magnification.

ISSN: 0022-1252

Fig. 3.

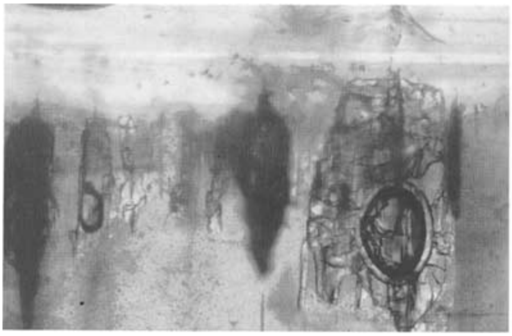


Fig. 4.

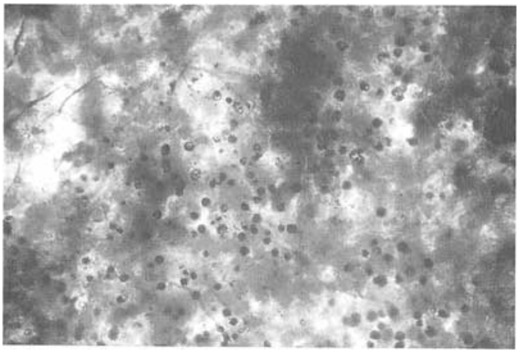


Fig. 5.

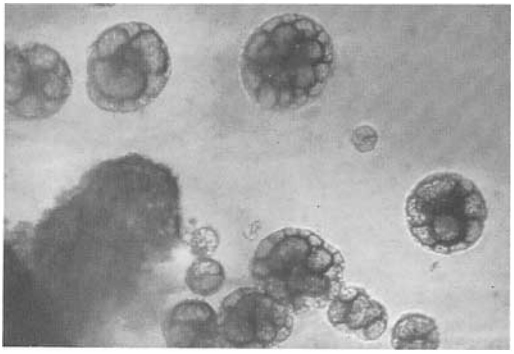


Fig. 6.

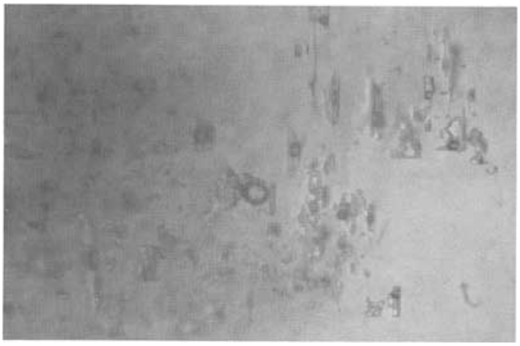


Fig. 7.

Figure 3. (56x) Seems to present three and even multi-phase inclusions cramming all available space in the stocking-like shapes.

Figure 4. (120x) Shows the contents in greater detail and now it can be appreciated that the gas phase is not free living in a liquid filled cavity as in nature, but marooned by the entrapped flux and haloed by what is possibly a glass surround wall which is in turn enclosed by a mosaic of phenakite crystals all enclosed within the one stocking. Note the washing line of chrome variations from which it is suspended.

Figure 5. A general aspect of the Lennix emerald is a series of small diffused spots such as we see in natural stones where mica pages have been unable to precipitate out complete crystals or have been largely devoured by the hostile resorbing growth environment. Closer examination of these diffuse spots in the earlier specimen revealed a curious phenomenon.

Figure 6. (240x) 'Primitive life cells'. The inclusions look for all the world like some living cells in the process of dividing and multiplying into more complex living material. In fact the ball-like aggregate are a multiple generation of daughter phenakite crystals. In the more recent emeralds these seem to be more like a badly broken pavement area.

Figure 7. (120x) 'Indian emerald'! Surely this must be an Indian emerald with the typical feature of parallel negative prism cavities topped or bottomed with a flat pinacoid face and oppositely terminated by a stepping down of the cavity, while the gas phase only adds fidelity. Again we have to gasp at the achievement of Monsieur Lens, that his emerald should so closely mimic the inclusions of the Ajmer province emerald.

Figure 8. Crossed polarized light revealed a shoal of colourful alien crystals swimming parallel and close to the prism walls. The bright interference colours indicate their birefringent crystalline nature. It occurred to me that they too were phenakite crystals. However, the ***Photoatlas of inclusions in gemstones*** (Gübelin and Koivula, 1986) shows what appears to be an identical feature in a Lennix emerald which the authors identified as beryl crystals.

Figure 9. (50x) 'Duty mark'. Islands of flux trapped in this Lennix emerald show a characteristic ripple growth circular and oval frames. The chance likeness to the head of George III and the oval frame are similar to the duty marks on sterling silver made in the UK between 1786 and 1820 which signified that the precious metal duty had been paid. Note even the Teuton nose and periwig. Some would welcome a system of 'hallmarking' which would separate the natural from the synthetic gemstone, but this would spoil all the pleasure of our gemmological sport and it should be mentioned that there are unfortunately those who have transposed hallmarks in the past and doubtless the same fraternity would play gemmological tricks also. It is perhaps fortunate that the Lennix is a flux grown product and as such produces the normally low RI readings below those recorded in nature.

I feel I owe much of my fascination with gemmology to Dr Gübelin's exploration of these largely unplumbed crystal depths. In the same way that we owe so great a debt to the late B.W. Anderson for charting the arena of spectroscopy, so must Dr Gübelin be credited with being somewhat of a Jacques Cousteau in venturing into the subterranean world of gemstones and mapping the way with his masterfully educative photography.

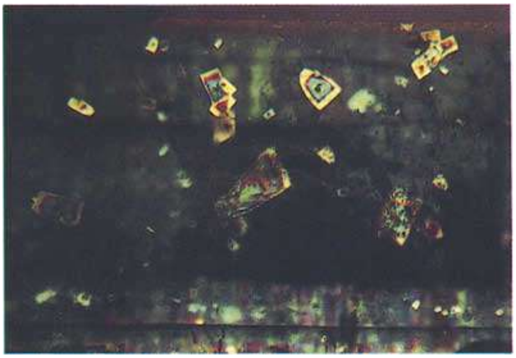


Fig. 8.

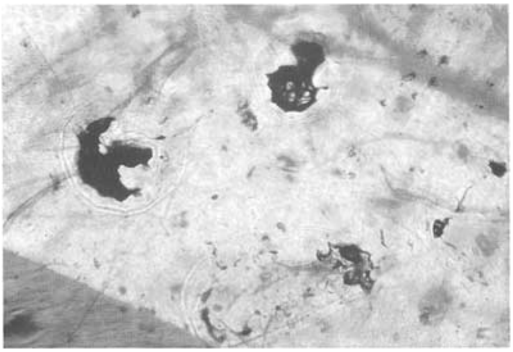


Fig. 9.

References

Farn, A. E., (1980). Notes from the Laboratory. *Journal of Gemmology*, **XVII**, 2, 73-80.

Graziani, G., Gübelin, E., Martini, M., 1987. The Lennix synthetic emerald. *Gems & Gemology*, **23**, 3, 140-7.

Gübelin, E., Koivula, J. I., 1986, *Photoatlas of inclusions in gemstones*. ABC Edition, Zurich.

[*Manuscript received 18 March 1988*]

J. Gemm., 1988, 21, 3

Quantitative cathodoluminescence – a modern approach to gemstone recognition

Dr. Johann Ponahlo

Austrian Gemmological Research Institute, Vienna, Austria

Introduction

The use of cathodorays is well known among physicists, dating back more than one century. But the use of cathodoluminescence (CL) as a means for gemstone recognition is not so well established among gemmologists of today.

It was an Italian mineralogist, A. Pochettino⁽⁶⁾, who, apparently, was the first to investigate the CL-effects in minerals, observing and measuring them as early as 1910. At about the same time the Austrian mineralogist, H. Michel⁽⁵⁾, then keeper of the mineralogical department of the Austrian Museum for Natural History, also one of the first gemmologists of central Europe, began, by visual inspection of CL-colours, to differentiate between genuine and synthetic gemstones. Later on CL of gemstones, unfortunately, became a nearly forgotten or discredited method. Its renaissance in gemmology started when Gaal⁽¹⁾ published his work in the seventies. Besides books by Marfunin⁽⁴⁾ and Lumb⁽³⁾, information on CL of minerals is still sparse and papers are widely scattered among numerous periodicals. Practically nothing is published on CL of gemstones.

Luminescence apparatus

There are two different ways used to generate electrons

a) by using a 'hot cathode' or,
b) by using a 'cold cathode' device.

The 'hot cathode' apparatus requires a high vacuum and precise alignment of the filaments. Samples need a conductive coating as a pretreatment to prevent surface charges. But the

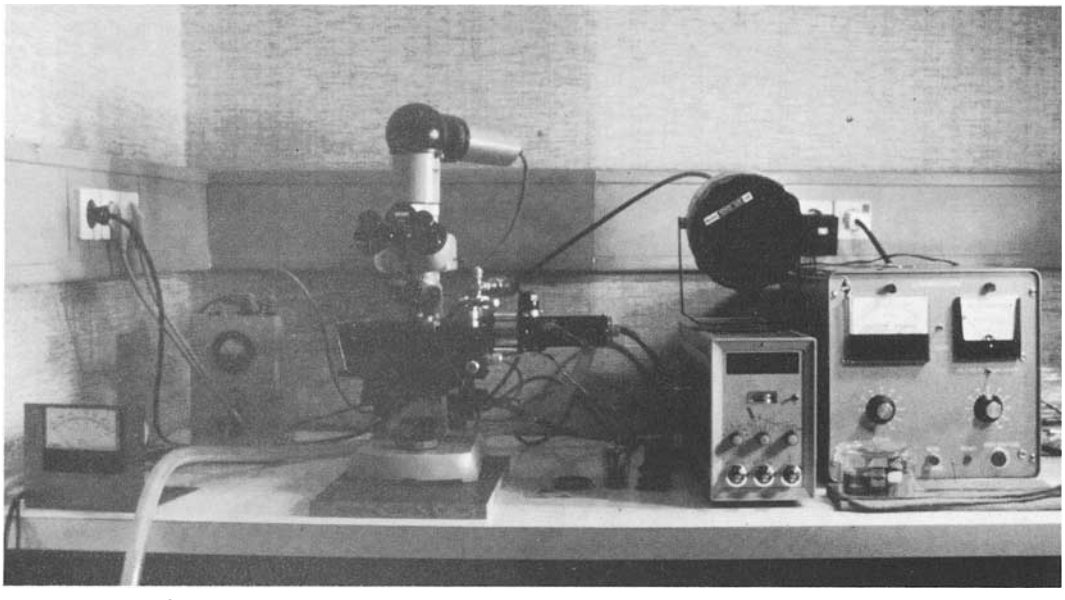


Fig. 1. Luminoscope® mounted on a Zeiss-Standard WL microscope with Zeiss-photomultiplier SF and amplifier. On the right a box for the generation and regulation of accelerating high voltage and current, with coil-current regulator for the electron-beam and vacuum meter.

ISSN: 0022-1252

apparatus can be operated at voltages above 60 kV.

The 'cold cathode' technique demands less sophisticated equipment which can operate in a low vacuum at voltages up to 20 kV. During its operation enough positive ions are produced to neutralise any electrostatic charging.

The CL-investigations described later were carried out by means of a 'cold cathode' equipment, called a Luminoscope®, supplied by the Nuclide Corp., Acton, USA. The research was undertaken by the Austrian Gemmological Research Institute of the Erste Österreichische Gemmologische Gesellschaft e.V., Vienna, Austria. Details of the apparatus were already published by Ponahlo & Koroschetz(7,8). Figure 1 shows the Luminoscope® mounted on a microscope Zeiss-Standard WL.

A few words on CL-theory

We know that CL-effects in solids depend on the existence of so-called '*centres*' which are capable of absorbing energy from photons or electrons that are impinging on their surfaces. The centres can be divided into '*intrinsic*' and '*extrinsic*' ones. Primarily the former are lattice imperfections. The latter are caused by certain impurity elements present in the host-crystals. When considering CL-effects of emeralds or rubies attention should be paid to extrinsic centres only.

The impurity elements can roughly be grouped into

a) '*activators*' which give rise to spontaneous CL, even when present in trace amounts. With most gemstones these are the transition metal ions: V^{+3}, Cr^{+3}, Mn^{+3} and/or Mn^{+2}.

b) '*quenchers*' which impede any spontaneous luminescence process to take place, even in the presence of some activator material in the same crystal. Of the 3d-elements, the transition metal ions Fe^{+2}, Co^{+2} and Ni^{+2} are considered to act in such a way.

When measuring CL-intensities of emeralds and rubies the following relationship (1) was found to exist between I = intensity of the emitted CL-colour (red with emeralds and rubies) and W = i.V = power of excitation of electrons; i = exciting current and V = exciting voltage.

$$I = a + b.W + c.W^2 + d.W^3 \qquad (1)$$

This cubic equation results from statistical polynomial regression of the experimental data. With $d>0$ equation (1) is characterized by a curve showing a convex form with respect to the abscissae at low values and a maximum at high values of power of excitation. The former is known as dark voltage effect which results when electrons of an activator element are lacking enough energy for a quantum jump. The latter arises as an effect of saturation at high power of excitation when no more electrons are available for quantum jumps. With emeralds equation (1) was simplified to become equation (2)

$$I = a + b.W \qquad (2)$$

This is the equation of a straight line. Such straight lines are shown in Figure 4 having different gradients (or angles of inclination).

When measuring the CL-intensities of rubies an exponential equation (3) was found to give the best fit with experimental data:

$$I = a.W^b \qquad (3)$$

which for ease of statistical treatment and presentation of results (in Figure 8) was used in its logarithmic form (4):

$$\log I = \log a + b.\log W \qquad (4)$$

Results of CL-measurements on emeralds

From Figure 4, it is evident that with emeralds there exist two different areas of CL-intensities that can be clearly separated from each other, if the values of I (measured in arbitrary units, proportional to the amplifier photocurrent) are plotted as ordinate figures against the values of the power of excitation W (measured in watts) on the abscissa. Within certain predetermined conditions of power of excitation, the values of I decrease linearly with decreasing W. The results are straight lines for each emerald tested, with '*steep gradients*' representative of synthetic stones, and with '*low gradients*' exclusively characteristic of each genuine emerald tested so far, regardless of origin.

For ease of comparison of data for a larger number of both genuine and synthetic emeralds – including each time the measurement of the same reference stone – the entire data were saved on magnetic tape of a Hewlett Packard HP-41CV pocket calculator with HP-Digital Cassette Drive and HP-Thermal Printer plus HP-Interface module. These data were then subjected to statistical treatment. By means of a coordinate transformation program any slight change of the gradient of the straight line of the reference stone could easily be corrected to standard conditions previously fixed. The same procedure was applied, with equally good results, to the logarithms of the CL-intensities versus power-of-excitation data obtained with rubies as will be shown later.

Growth lines were easily observed in many Gilson synthetic emeralds. The new Lennix synthetic emeralds exhibited a blueish tinge of CL-colour with a rather brilliant brick red showing through. Figure 3 gives an example for both features. In previous studies on such synthetic emeralds an even more intense blueish overcast could be observed.

Lower gradients than for all other synthetic emeralds resulted from measurements of hydrothermally man-made Lechleitner emeralds. But

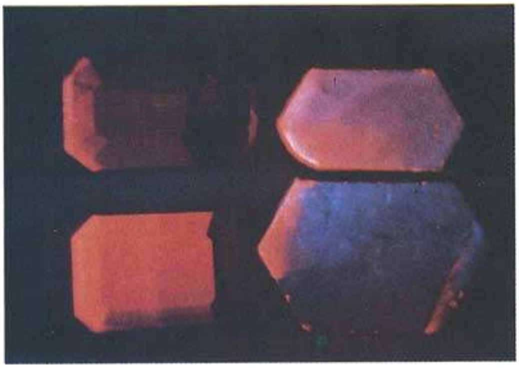


Fig. 2. CL of emeralds: upper left (dark) a genuine Colombian emerald (reference stone 0.85 ct), lower left a synthetic Gilson emerald showing growth-lines (0.86 ct), upper and lower right two synthetic Lennix emeralds with bluish overcast on scarlet-red basic CL-colour (0.96 and 1.67 ct); 7.5 kV at 0.8 mA.

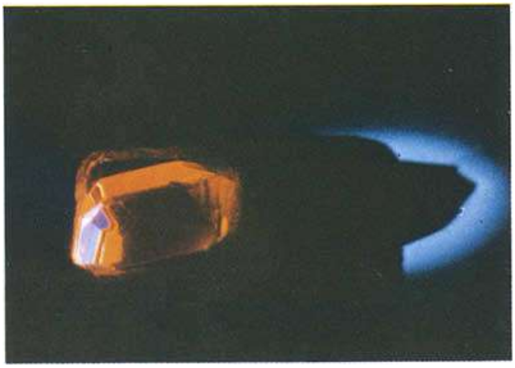


Fig. 3. Crimson-red CL-colour of a Lechleitner synthetic emerald with bluish and white blots; 8.5 kV at 0.9 mA.

Fig. 5. Seven rubies placed in vacuum-chamber of the Luminoscope® (flashlight); for details see text.

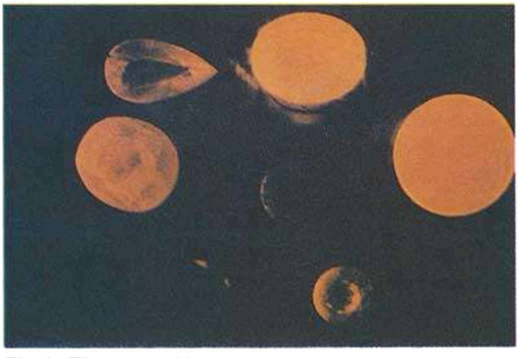


Fig. 6. The same rubies as in Figure 5 during bombardment with electrons exhibiting CL-intensities of marked differences; for details see text.

Fig. 7. A Knischka synthetic ruby (above) and a less intensely luminescing Ramaura synthetic ruby during the impact of electrons; for details see text.

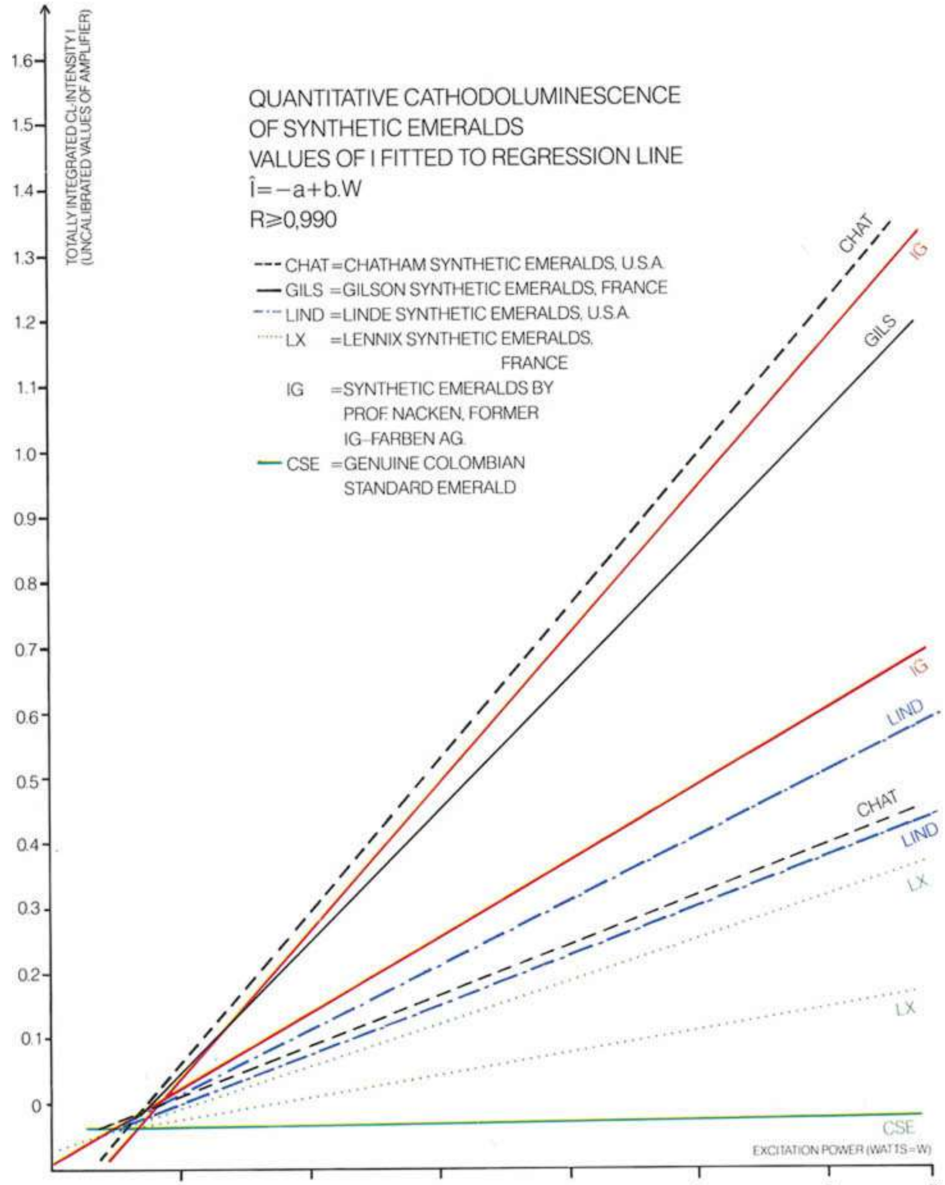


Fig. 4. Quantitative cathodoluminescence of synthetic emeralds.

these stones showed different CL-colours than those observed on any of the natural emeralds tested. Furthermore, their CL-intensities were not uniformly distributed over the entire irradiated surface, as can be seen from Figure 3.

Recent measurements on a newer synthetic stone, the Regency-created emerald, indicated strong CL-intensity, nearly as intense as that obtained with any of the old or new Chatham man-made emeralds tested.

Thus, each 'I-versus-W-plot' of data obtained from quantitative CL-tests would reveal quickly either the genuine or the synthetic origin of the stone depending on the 'gradient' of the straight line relative to the gradient of the genuine Colombian emerald reference stone (compare Figure 4).

Results of CL-measurements on rubies

Similar results were obtained with quantitative CL-intensity measurements on rubies. Pronounced differences could be found between all genuine rubies from Thailand tested so far and their synthetic counterparts regardless of their producers. Man-made stones by Kashan, Chatham, Ramaura, Knischka, Lechleitner and old and new Verneuil synthetics were investigated.

To present the entire data a plot based on formula (4) was used. Three different logarithmic ordinate scales, each differing by one order of magnitude (10) from the other, and one logarithmic scale on the abscissa had to be chosen as can be seen from Figure 8. Outer left is the logarithmic ordinate scale with the lowest figures. It was used to plot the (log I)-values of CL-intensities of genuine Thai rubies with their (log W)-values on the abscissa. The 95% confidence band results from regression analyses of data measured on more than forty Thai rubies. Note the narrow confidence band of these data in the diagram (hyperbolae drawn as solid lines from uppermost left to lowest right in Figure 8).

The inner left-hand logarithmic scale of (log I) has ten times greater values than the left-hand outer scale. Such higher values were consistenly found when measuring CL-intensities of synthetic Kashan rubies. The two broken lines enclose a broad band valid for all Kashan synthetic rubies that could be investigated. So far no exception has been found.

In order to plot the data for Knischka synthetic rubies another tenfold increase of the logarithmic ordinate scale was necessary. This scale is projected on the outer right-hand ordinate of Figure 8. Because of the few Knischka synthetic stones available one dotted straight line is reproduced in Figure 8. It is located in the middle of a broad band (dash-dotted lines) results of measurements on synthetic Chatham rubies. From Figure 8 it is evident that both Knischka and Chatham rubies show up to *hundred times stronger* CL-intensities than genuine rubies from Thailand.

Ramaura synthetic rubies exhibited distinctly weaker CL-intensities than the Chatham man-made products, somewhat between those of Knischka and Kashan rubies. Figure 7 gives a visual impression of the CL-intensities of a Ramaura and a Knischka synthetic ruby.

Recent tests made with new synthetic Lechleitner rubies furnished nearly the same results as found with Kashan synthetic rubies.

The photomacrograph of Figure 5 showing seven rubies was taken in incandescent light: two genuine rubies from Thailand (centre and lower left), one drop-shaped Knischka synthetic ruby (upper left), one brilliant-cut Ramaura synthetic ruby (lower right), two oval stones, one a Chatham synthetic (in the middle of the uppermost row), the other a Lechleitner synthetic ruby (second left in the middle row), and a round disc of a Verneuil ruby. Figure 6 shows these stones in identical arrangement luminescing during a bombardment with electrons. Note the subdued CL-intensity of the two genuine Thai stones. A distinctly higher CL-intensity is displayed by both the Ramaura and the Knischka synthetics. A more intense glow is displayed by the Lechleitner synthetic ruby. A marked increase in CL-intensity becomes obvious when observing the CL-intensities of the two oval stones, one a Chatham synthetic and the other a Verneuil ruby.

Other genuine rubies from Burma, India, Kenya, Sri Lanka and Tanzania, which were included in these measurements, gave inconsistent results of CL-intensities. Therefore, at present, genuine rubies from these localities *cannot* be differentiated from their synthetic counterparts by means of this method.

CL-spectra of jadeites and some jade-like minerals

'Jade' in its proper sense comprises two minerals only: jadeite, a clinopyroxene, and nephrite, an amphibole. But there exists numerous other green ornamental stones frequently mixed up with both of these minerals. Among them green grossulars (erroneously called 'Transvaal jade') and amazonites are often met with in gemmologial laboratories. Each of these ornamental stones can be separated from the other by making use of their CL-colours and/or CL-spectra, as will be described below.

Figure 9 is a photomacrograph of a broken cabochon-jadeite, (centre), flanked by a round green translucent African grossular (above) and a dyed green agate (below). Figure 10 demonstrates the vivid CL-colours of two of these minerals. The jadeite luminescing canary-green and the grossular intensely orange-yellow with a brownish tint. Figure 11 shows a polished translucent mottled-green jadeite ring in its natural colour. This ring was mistaken for grossular because of its rather strong yellowish-green CL-colour (compare Figure 12). However, when more specimens had been tested, it was realized that the lack of a brownish tint in the CL-colour shown could be considered an indicator for jadeite. With grossular, the orange-yellow CL-colour and its brownish tint were always already noticeable at exciting energies as low as 5 kV. Nevertheless, such subtle differences in CL-colours called for an improvement of the method; the more so since cut and polished true jadeites are costly objects. Finally, when it became obvious that

CL-spectra of gemstones are practically unknown to gemmologists and in the literature, preliminary tests were started.

Basic requirements for recording and analysing CL-spectra of gemstones were the installation of additional and more complicated apparatus. The SF photomultiplier mounted on the body tube of the Zeiss-Standard WL microscope had to be replaced by a newly developed fibre-optic system (Zeiss-Schott) to guide the light emitted from the irradiated specimen through the microscope to a VIS-NIR-monochromator. Then the photomultiplier had to be flanged to the exit slit of the monochromator. The CL-light could thus be diffracted into its spectral components which, in turn, were converted into electric signals by means of the photomultiplier. Finally, the electric signals of the entire CL-spectrum were amplified (at low noise level) by means of a Zeiss-amplifier MPC 64. By this means, then, the CL-colours emitted from the surface of the irradiated specimen could be recorded as spectral components in a wavelength range between 380 and 1000 nm. The whole assemblage was automated and operated by a Hewlett-Packard 2000 S computer. Spectra could be stored in a double-floppy disk and reproduced using both a printer and a plotter.

Figure 15 shows two jadeite CL-spectra: the one with higher peaks originating from the canary-green luminescence of the broken cabochon of Figure 10 (centre). The other spectrum was taken from a jadeite exhibiting a pinkish CL-colour. The natural colours of the latter were a vivid green and white. The peaks of both spectra are centred at 407, 557 and 692 nm. Such CL-spectra seem to be typical of many natural green or white translucent or opaque jadeites.

However, some green jadeites displayed royal blue CL-colours, visible only under bombardment with highly energized electrons above 12 kV. Sometimes, after prolonged irradiation, the blue CL-colour would change into a pinkish-red. Then, the peaks originally found at 407, 557 and 692 nm, gave way to a new strong and broad band with a peak maximum at 766 nm (NIR). This follows from Figure 16 which contains one spectrum of Figure 15 for comparison.

One green jadeite luminesced in a rather intense blueish-violet CL-colour; Figure 17 shows its CL-spectrum. If the peak wavelengths of this spectrum are compared with those of the spectra of Figures 15 and 16, they are found to occur at the same wavelengths. This would indicate that the different CL-colours of the specimens tested so far are caused by different peak-intensities relative to each other.

The CL-spectrum of the jadeite-ring of Figure 12 with its canary-green CL-colour is reproduced in Figure 18. The peaks in the bluish-violet range are no longer visible, whereas the weak band in the yellowish-green range has more than doubled its intensity. No obvious change of peak-wavelengths has occurred. The medium strong band in the (NIR) at 766 nm is found again, as in the spectrum of the white jadeite whose blue CL-colour turned into pink (see Figure 16). This band in the NIR may exert some influence on the CL-colour of jadeites.

The sharp lines visible in many CL-spectra are emission lines of the helium gas used to generate a plasma with a steady leak of gas in the cold cathode tube during experiments. Besides a carrier gas of electric charges helium exerts a cooling effect of the samples under test.

Quite different CL-spectra were recorded from the green grossulars tested so far. In Figure 19 three CL-spectra typical of grossulars are presented. They differ from each other in their peak intensities only. All specimens were luminescing with an orange colour and brownish tint. A grossular CL-spectrum, thus, consists of two distinct bands with peak-wavelengths at 590 and 719 nm. Considering EPR-studies made on African grossulars (cf. Hage, Zabinski & Amthauer [(2)]) the band at 719 nm could be due to Cr^{+3}, a trace element which has always been found in these green grossulars.

Another type of CL-spectrum occurred when amazonites from both South Africa and Brazil were tested. This is demonstrated in Figure 20. Such spectra consist of three peaks occurring at 506, 690 and in the range 830 to 840 nm; one in the blue and one in the orange part of the visible spectrum and another one in the NIR. According to the high intensity of the 506 peak the corresponding CL-colour of all the amazonites tested was a brilliant sky-blue. But there seems to be a subtle difference between the amazonites from South Africa and from Brazil which might become obvious in further investigations. The spectrum contained in Figure 20 belongs to that Brazilian amazonite whose photomacrograph of blue CL-colour is shown in Figure 14. The spectrum of the amazonite from South Africa is reproduced in Figure 21. In this CL-spectrum the 690-band is missing. Yet, it is noted that this amazonite exhibits nearly the same blue CL-colour, if one compares Figure 14 with Figure 13. With regard to the sparse information published on activator elements in amazonites and the contradictory results found (Marfunin[(4)]) more detailed studies on this peculiar feldspar seem to be necessary and are under way.

Conclusion and summary

In view of the striking results obtained by quantitative CL of emeralds and rubies, i.e. measurements of the variation in the integral intensity of the red CL-colour of these gemstones

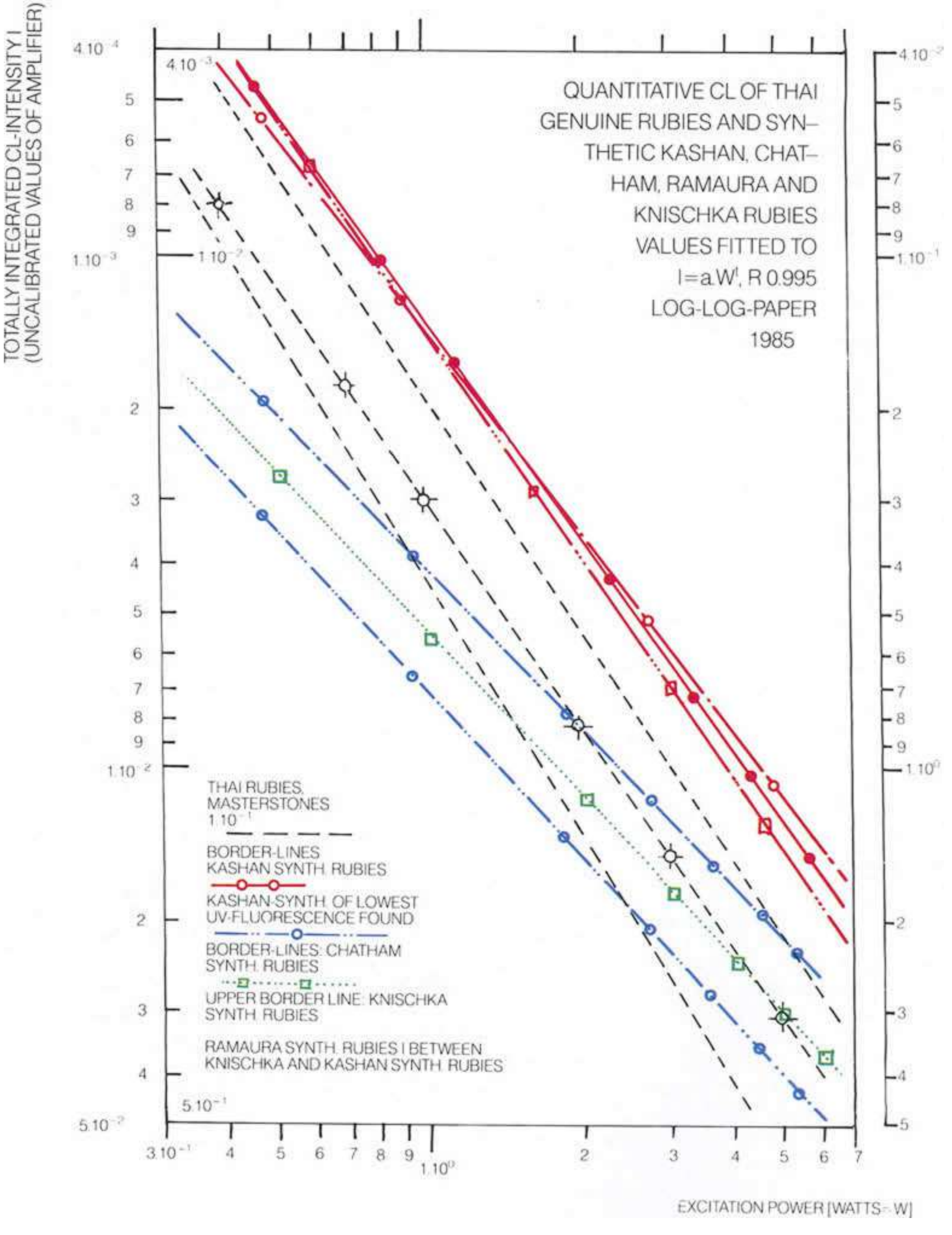


Fig. 8. Quantitative cathodoluminescence of natural and synthetic rubies.

Fig. 9. Translucent green grossular (top), broken drop-shaped green jadeite (middle) and dark green translucent dyed agate ready for CL-test in vacuum-chamber of the Luminoscope® (flashlight).

Fig. 10. The upper two cabochons of Figure 9 under the impact of electrons (10.5 kV at 1.0 mA); note orange-yellow CL-colour of the grossular against canary-green CL-colour of jadeite; dyed agate is non-luminescing.

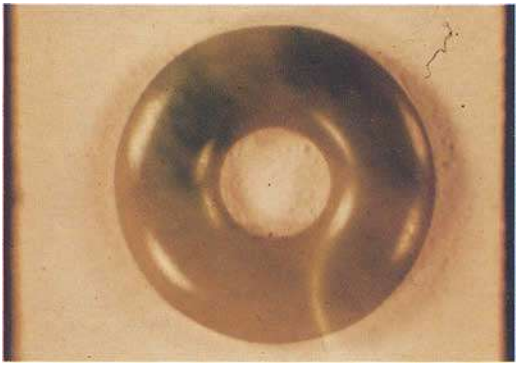


Fig. 11. True jadeite-ring, erroneously identified as green grossular by visual inspection in daylight.

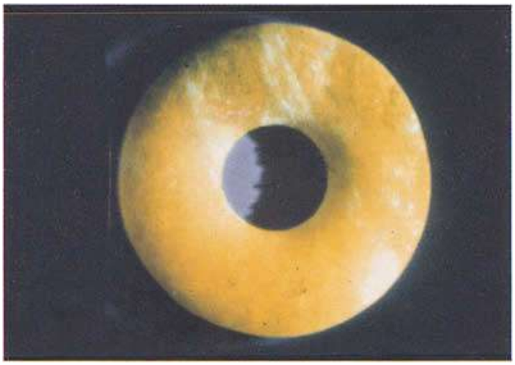


Fig. 12. The same ring showing yellow CL-colours with greenish tint, rather similar to the orange-yellow of the grossular; but note the conditions of test 14.0 kV at 1 mA.

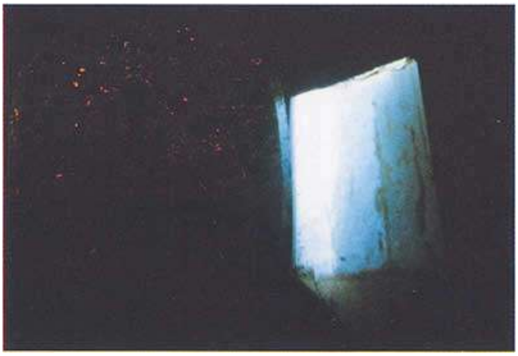


Fig. 13. Plate of green non-translucent African grossular exhibiting numerous small luminescing dots of yellowish-brown CL-colour (left piece) against bright violet-blue CL-colour of a South African amazonite (faceted) with 12.5 kV at 0.7 mA.

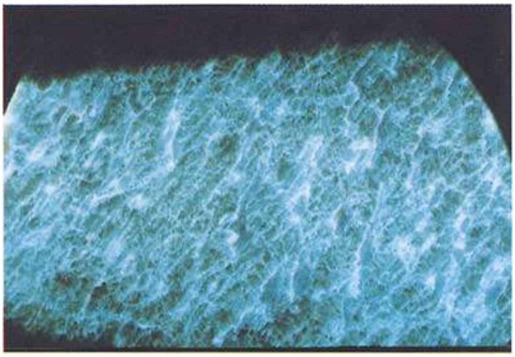


Fig. 14. Brazilian amazonite displaying a vivid blue CL-colour with white twisted bands similar to its natural appearance. The emitted blue CL is strongly polarized. 7.0 kV at 1.0 mA.

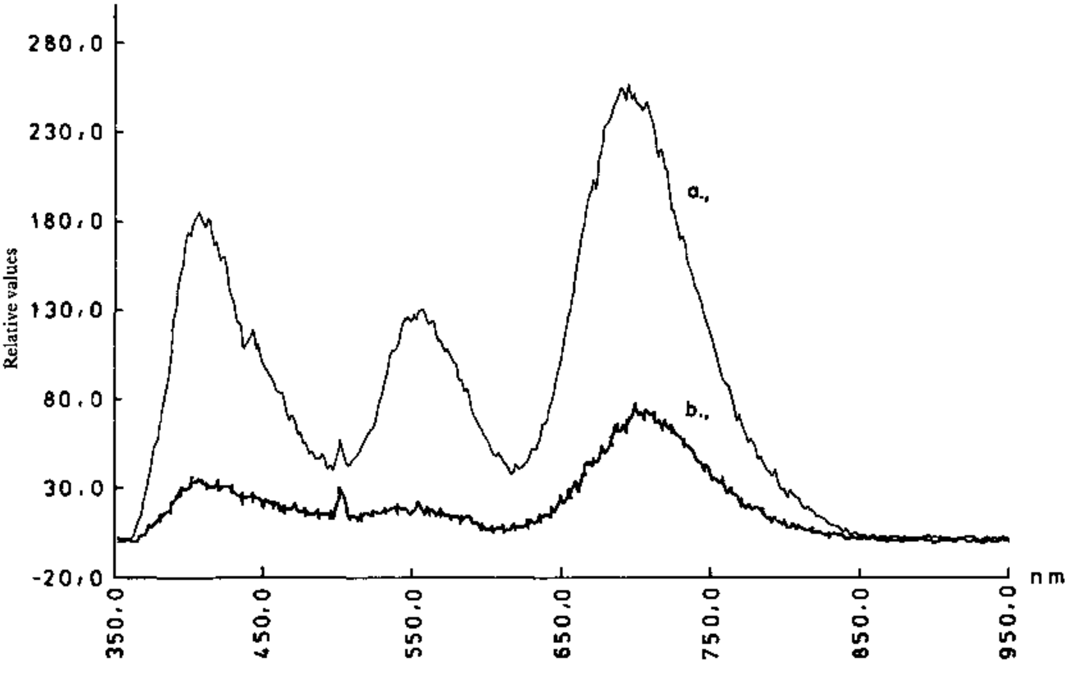


Fig. 15. Two CL-spectra of jadeites, (a) with strong bands typical of canary-green CL-colour, (b) with weaker bands resulting from a white jadeite showing pinkish CL-colour.

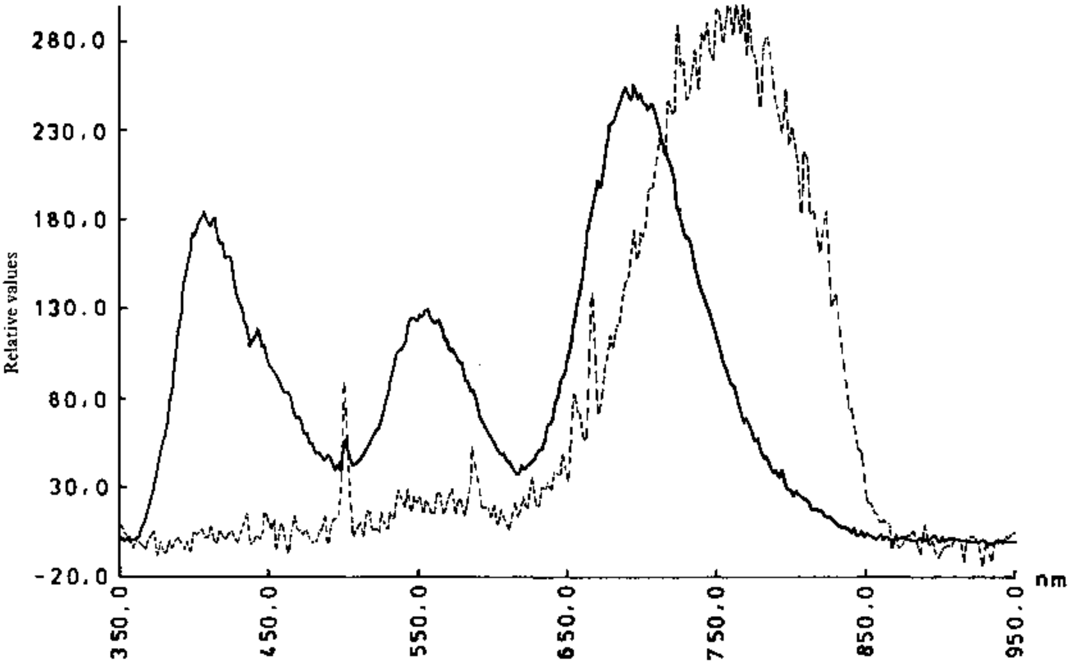


Fig. 16. CL-spectrum of a jadeite showing pinkish-red CL-colour after prolonged irradiation (broken line); CL-spectrum of the canary-green luminescing jadeite of Figure 15 (full line); spectrum was taken by steps of 2 nm.

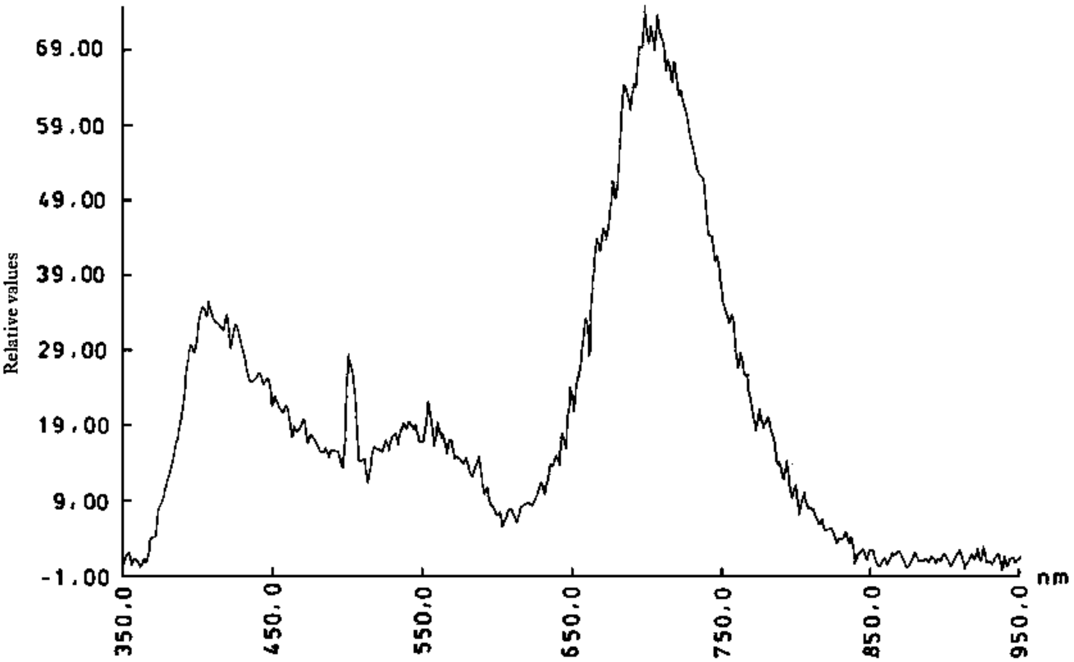


Fig. 17. CL-spectrum of a bluish-violet luminescing green jadeite; spectrum was taken by steps of 3 nm.

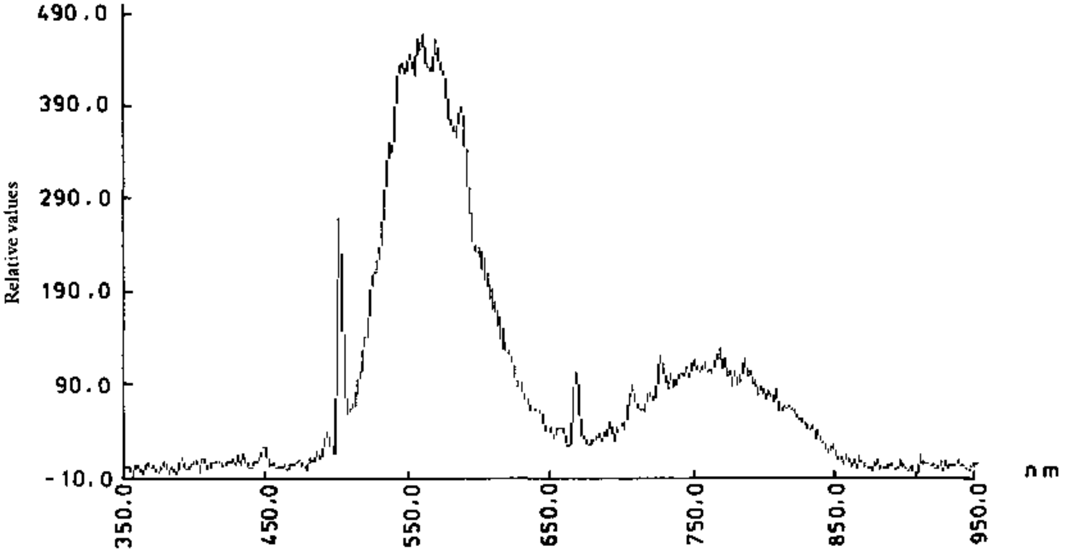


Fig. 18. CL-spectrum of the greenish-yellow luminescing mottled green jadeite-ring of Figures 11 and 12. Spectrum was taken by steps of 4 nm.

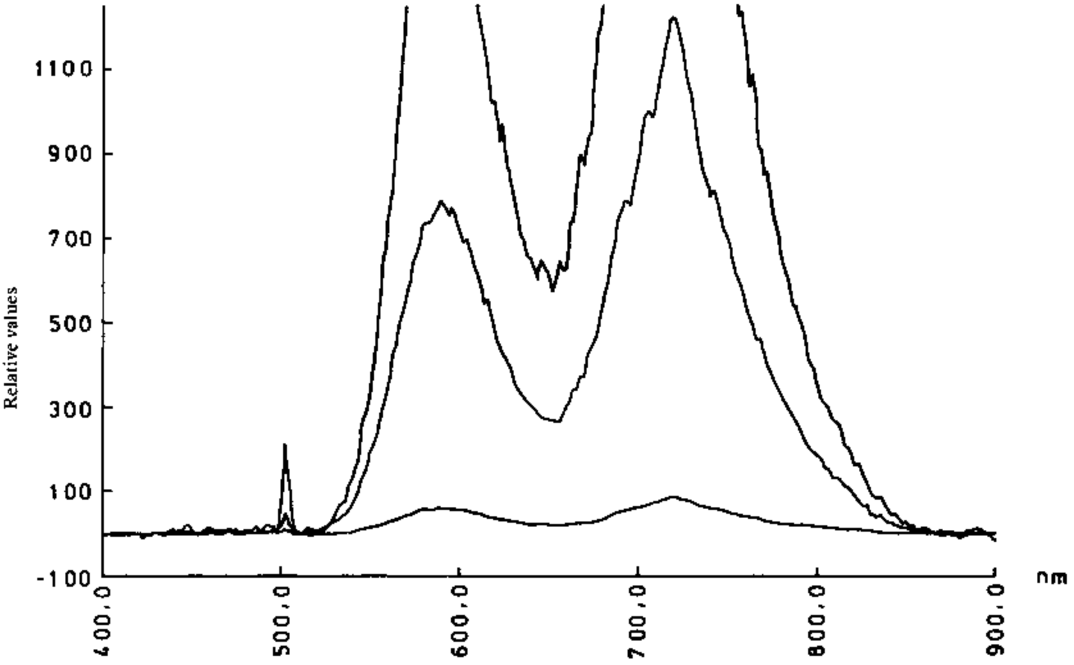


Fig. 19. Three CL-spectra of green African grossulars. Note the different CL-intensities. The two strong bands are characteristics of this mineral with its brownish-tinted orange CL-colour. Spectra were taken by steps of 1 nm.

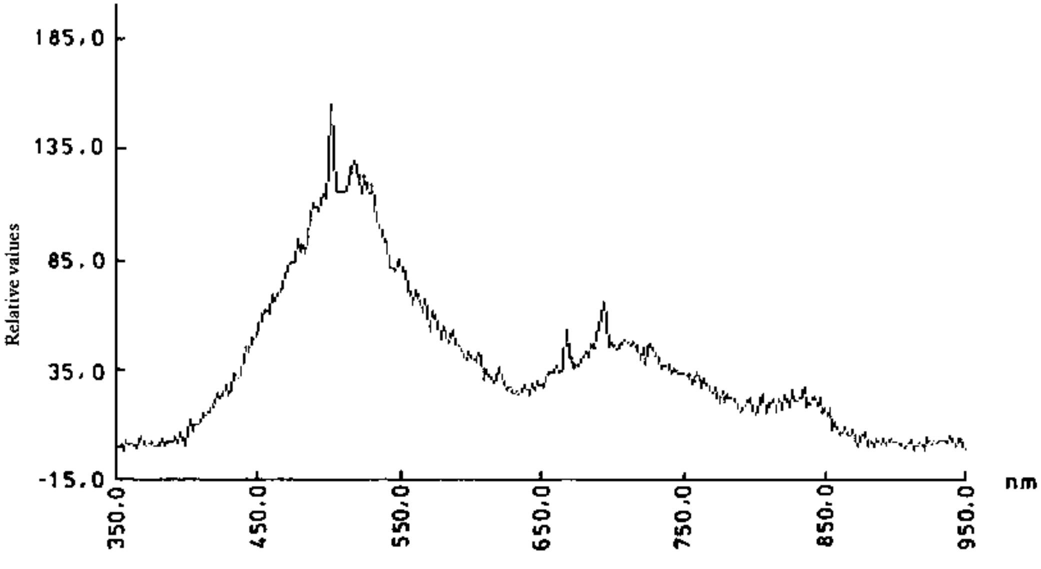


Fig. 20. CL-spectrum of a sky-blue luminescing Brazilian amazonite, taken by steps of 2 nm.

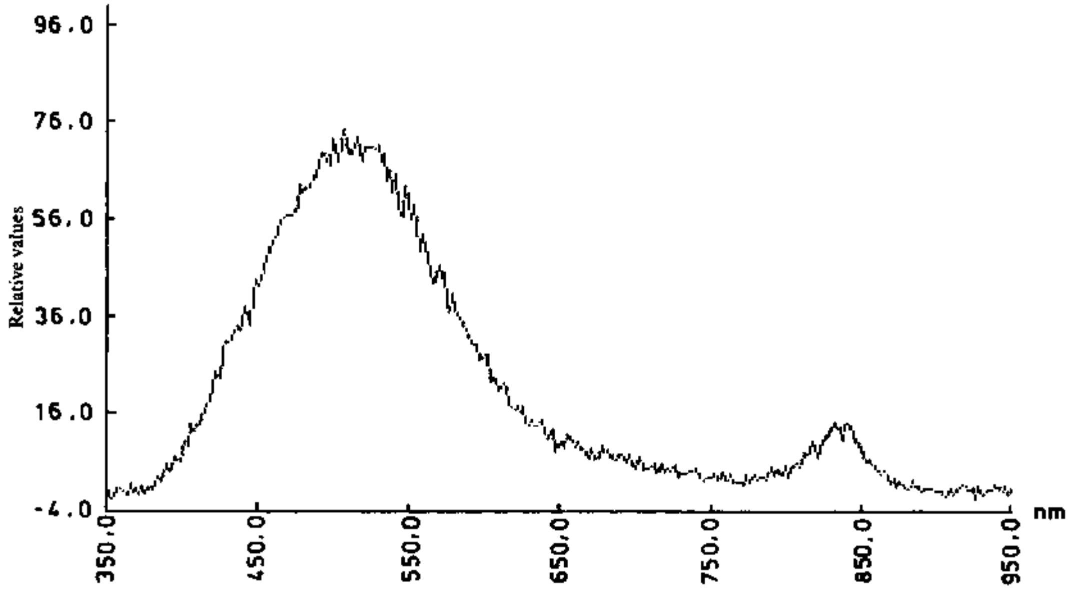


Fig. 21. CL-spectrum of a sky-blue luminescing South African amazonite, taken by steps of 2 nm.

with diminishing exciting power, this method seems to have the potential to develop into a routine procedure in larger gemmological laboratories where new secure diagnostic methods are required to differentiate between genuine and synthetic emeralds and, especially, between genuine Thai rubies and their difficult-to-analyse synthetic counterparts. Considering the high prices of these gemstones which can now safely be separated from any synthetic material, the costs of the whole equipment: microscope, photomultiplier and amplifier, Luminoscope®, vacuum pump and a few accessories, will certainly be of minor importance.

Recording CL-spectra may seem to be a more costly as well as a more sophisticated method. But taking into account the enormous amount of research work, technical experience and monetary investment involved in the crystal growing industry a computerized modern instrument for microspectrophotometry of CL might become a necessity in a gemmological research laboratory within the next few years. Admittedly, there is a long way to go in taking CL-spectra of gemstones. The present work should be considered a first step towards better gemstone recognition.

There are a number of other gemstones containing chromium as an activator element besides the one described in this paper. Spinel, alexandrite, chrome-diopside, hiddenite – to mention a few – are being tested at present. The methods described in this paper will also be tested for application to genuine and synthetic sapphires – some results have already been obtained with treated and untreated corundums – and to many other synthetic gemstones that have no natural equivalent. Future work may be carried out on the application of CL-microspectrophotometry to the location of the origin of certain gemstones.

References

1. Gaal, R. A. P., 1976-1977. Cathodoluminescence of gem materials. *Gems and Gemology*, **15**, 237-44.
2. Hager, H., Zabinski, W., Amthauer, G., 1984. EPR study of South African grossulars (South African jades). *N. Jb. Miner. Mh. H.* 10, 433-43.
3. Lumb, M. D., 1978. *Luminescence spectroscopy*. Academic Press (ed.), London.
4. Marfunin, A. S., 1979. *Spectroscopy, luminescence and radiation centers in minerals*. Springer-Verlag, Berlin, especially pp. 215-6.
5. Michel, H. 1926. *Die künstlichen Edelsteine*. Wilhelm Diebener G.m.b.H., Leipzig.
6. Pochettino, A., 1913. Über die Luminescenzerscheinungen in Krystallen. *Z. Kryst.*, **51**, 113-31.
7. Ponahlo, J., Koroschetz, Th., 1985. Quantitative Kathodolumineszenz – ein neues Verfahren zur Unterscheidung echter von synthetischen Smaragden und Rubinen. *Z. Dt. Gemmol. Ges.*, **34**, 132-42.
8. Ponahlo, J., Koroschetz, Th., 1986. Quantitative cathodoluminescence of gemstones. *Austral. Gemmol.*, **16**, 64-71.

[*Manuscript received 11 October 1987, revised 20 January 1988*]

Gemmological Abstracts

Abdallagh, A., 1988. L'amétrine. (The ametrine.) *Revue de Gemmologie,* 94, 8, 2 figs in colour.

In the opinion of the author, the amethyst-citrine combination known as ametrine has not so far been found naturally. M.O'D.

Bancroft, P., 1988. Mineral museums of eastern Europe. *Mineralogical Record,* **19,** 1, 1-52, illus. in black-and-white and in colour.

Describes the collections, locations, history and access details of fifteen museums in eastern Europe and the USSR. Many collections include fine gemstones. M.O'D.

Brown, G., 1988. Argyle diamonds in the Stuart Devlin Champagne Diamond Exhibition. *Australian Gemmologist,* **16,** 9, 319-22, 9 figs in colour.

A description of the Argyle mine in Western Australia which claims to be the world's largest producer of diamonds, and of a remarkable collection of its fancy coloured diamonds ranging from yellow to blue, with various pinks, champagnes and cognac browns, mounted in exotic jewellery by Stuart Devlin for the Champagne Diamond Exhibition. [Where is it held?] R.K.M.

Brown, G., 1988. Crystalline quartz. *Wahroongai News,* 22, 3, 26-9, many sketched figures.

An exhaustive account of this abundant mineral, which takes the subject rather beyond normal gemmological requirements, compiled from a number of well-known authorities. The 'figuroscope' (conoscope) patterns for colourless quartz and amethyst have been transposed. R.K.M.

Brown, G., 1988. Using the quartz wedge in gemmology. *Wahroongai News,* 22, 3, 26-9, many sketched figures.

An explanation of this accessory to the polarizing mineralogical microscope, advocating its use.
R.K.M.

Bueno de Camarago, M., Isotani, S., 1988. Optical absorption spectroscopy of natural and irradiated pink tourmaline. *American Mineralogist,* 73, 172-80, 16 figs.

Natural pink Brazilian tourmaline irradiated by gamma rays from ^{60}Co was studied with a spectrophotometer for the purpose of making optical absorption measurements at different concentrations of irradiation, the maximum dose being 20MGy. Optical absorption bands observed were 8500 and 14,800cm^{-1} assigned to d-d transitions of Fe^{2+} in b and c sites respectively; 19,500 and 25,500cm^{-1} assigned to $^5E \rightarrow {}^5A_1$ and $^5B_2 \rightarrow {}^5A_1$ d-d transitions of Mn^{3+} respectively. M.O'D.

Cassedanne, J., 1988. L'améthyste au Brésil. (Brazilian amethyst.) *Revue de Gemmologie,* 94, 15-18, 8 figs (1 in colour).

First part of a survey of Brazilian amethyst deposits classified according to type. M.O'D.

Cozar, J.S., 1987. La falsa cacoxenita. (False cacoxenite.) *Boletin del Instituto Gemológico Español,* 29, 30-43, 30 figs (18 in colour).

Inclusions in Moroccan hyaline quartz and in amethyst from Uruguay, though originally believed to be cacoxenite, were found by the electron microprobe to be rutile or goethite. M.O'D.

Deelman, J.C., 1986. Opal-CT in bamboo. *Neues Jahrbuch für Mineralogie, Monatshefte,* 9, 407-15, 3 figs.

Direct X-ray diffraction study has shown that the opal in the culm of the bamboo *Bambusa blumeana* is opal-CT. Precious opal is designated opal-A in a system of terminology that postulates opal-A as highly disordered, nearly amorphous opaline silica, opal-CT as disordered α-cristobalite, α-tridymite and opal-C as well-ordered α-cristobalite. M.O'D.

Fritsch, E., Rossman, G.R., 1988. An update on color in gems. Part 2: Colors involving multiple atoms and color centres. *Gems and Gemology,* **24,** 1, 3-15, 11 figs in colour.

Discusses in detail colour caused by electron interchange between adjacent atoms, e.g. oxygen→metal charge transfer, as in yellow and blue beryl. Some interchanges skip an oxygen atom and occur between metal atoms of different valency, e.g. $Fe^{2+} \rightarrow Ti^{4+}$ in blue sapphire. $Fe^{3+} \rightarrow Fe^{3+}$ gives yellow in corundum and deep red in tourmaline. Delocalization of electrons cause intense colour in amber and lazurite. Colour centres caused by atoms wholly or partially removed by natural or artificial radiation also cause colour, e.g. green diamond. A most informative paper. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1988. Gem Trade Lab notes. *Gems and Gemology*, **24**, 1, 47-52, 18 figs in colour.

Czochralski pulled synthetic alexandrites were free from inclusions and fluoresced more strongly than the natural stones under UV. Chalcedony with dendrite stain painted on; clinohumite; diamond with green luminescence also had cyclotron 'umbrella' effect; diamond was seriously scratched by hardness test with a diamond point; and an unusual banded structure in lapis lazuli, are all illustrated and described.

Examples of early cultured blister pearl found, possibly dating from 1890, backing of saltwater shell did not fluoresce. A fine tiara (comb) had pearls proved natural by their non-fluorescent reaction and by X-radiography. Heat treated sapphire had spalled and had an unusual dark hexagon as an inclusion. Another sapphire had intact, well-formed silk undamaged and was therefore considered not to have been heat treated. Pink, yellow and purplish-red tourmalines from Nepal were examined, RI 1.619-1.637 for the pink, and 1.620-1.648 for the yellowish-green; birefringence varies with colour. Turquoise necklace looked good quality, but found to be gibbsite bonded with plastic.

R.K.M.

GARCIA GUINEA, J., LUQUE DE VILLAR, F.J., 1987. Análisis de las posibilidades de existencia de diamantes en España. (Analysis of the possibilities of the existence of diamonds in Spain.) *Boletin del Instituto Gemológico Español*, 28, 37-44, 6 figs in colour.

No kimberlite occurrences are yet recorded for Spain and most reports of diamond have proved to be quartz. A useful bibliography is appended.

M.O'D.

GARZÓN, J., 1987. Inclusiones de corindones sinteticos. (Inclusions in synthetic corundum.) *Boletin del Instituto Gemológico Español*, 29, 6-28, 110 figs in colour.

A very well-illustrated up-to-date account of the inclusions found in synthetic corundum of all types.

M.O'D.

GARZÓN, J., 1987. Pruebas diferenciales del diamante y de sus imitaciones. (Proofs distinguishing diamond from its imitations.) *Boletin del Instituto Gemológico Español*, 28, 6-14, 20 figs in colour.

A useful account of the present position of diamond identification. M.O'D.

GAUTHIER, J.-P., FUMEY, P., 1988. Une gemme metamicte: l'ékamite. (Ekanite, a metamict gem.) *Revue de Gemmologie*, **94**, 3-7, 7 figs (1 in colour).

A survey of ekanite, including a review of the literature and assessments of the mineral's radioactivity. M.O'D.

GRAY, M., 1988. Faceting large gemstones. *Gems and Gemology*, **24**, 1, 33-42, 9 figs in colour.

With new and improved machines and techniques, larger and larger size gems are cuttable and a topaz of 22,898 ct and a citrine of 19,548 ct are currently the world's heaviest and largest faceted stones respectively. Such sizes are cut for prestige rather than as wearable gems. Describes giant equipment, saws, grinders, laps and dops needed. Cold dopping is best. Table cut and polished first, then pavilion facets, then crown. An interesting paper on problems which few commercial lapidaries need to face. R.K.M.

GÜBELIN, E., 1988. The diagnostic properties of the latest synthetic stones. *Australian Gemmologist*, **16**, 9, 329-34 and 344-5, 46 figs in colour.

This paper deals with Lennix, Biron, Sovient and Seiko synthetic emeralds and with Seiko, Lechleitner and Knischka (rubies) synthetic corundums in considerable detail and with great efficiency. Detection is almost always dependant on recognition of characteristic inclusions. Dr Gübelin is the prime expert in these. R.K.M.

HARDER, H., 1986. Natürliche kobaltblaue Spinelle von Ratnapura, Sri Lanka. (Natural cobalt-blue spinels from Sri Lanka.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 3, 97-100.

Dark blue spinel containing cobalt is described from the Ratnapura area of Sri Lanka. In addition to Co, traces of Fe, Ni, V and Ga are found in the specimens. No Ga has yet been reported from the synthetic product. In the analysed sample the high Co content is 0.09 and this gives too dark a blue for a good quality gemstone. M.O'D.

HARDER, H., SCHNEIDER, A., 1986. Isomorpher Einbau von Eisen und Titan zur Erklärung der blauen Farbe von Rutil-und Spinell-haltigen seidig weissen Korunden nach einer Wärmebehandlung. (Solid solution of iron and titanium as an explanation of the blue colour of rutile and spinel containing silky corundum after heat treatment.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 5, 209-18, 5 figs.

Sample of rutile-bearing corundum annealed to 1600°C for 30 minutes were changed to a fine sapphire blue from milky-white. The change is ascribed to electron transitions between Fe^{2+} and Ti^{4+} now possible in the corundum lattice. M.O'D.

HARDER, H., SCHNEIDER, A., 1987. Die Abkühlungsgeschwindigkeit als Ursache für die Bildung entweder von Sternkorunden oder von kornblumenblauen Saphiren. (The influence of cooling history on the formation of star corundum or cornflower-blue sapphire.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 8, 344-6.

Describes the cause of colour and star formation in blue corundum. M.O'D.

HUDSON, S., 1988. North Georgia's fairy crosses. *Lapidary Journal*, **41**, 11, 55-9, 2 figs (1 in colour).

Staurolite crystals are found at the Hackney Farm near the town of Blue Ridge, Georgia, USA. M.O'D.

KARANTH, R.V., 1988. Silica bead industry in Cambay, Gujarat State, India. *Journal of the Geological Society of India*, **31**, 4, 426-31.

The manufacture of silica beads in Cambay has a tradition going back more than 2000 years. Today it forms an important cottage industry in Gujarat. Mechanised grinding and tumbling processes have been adopted recently but details are given of more primitive methods of shaping, grinding and drilling using a bow drill. Colour enhancement of chalcedony is procured by heating nodules in a covered earthern pot buried in paddy husk which produces a reducing atmosphere. Black onyx is produced by boiling the chalcedony in sugar solution followed by treatment with H_2SO_4. R.A.H.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems and Gemology*, **24**, 1, 56-9, 8 figs in colour.

A report on Tucson '88 Gem and Mineral Show; theme mineral beryl; carved gems, charoite, alexandrites from Hematita, Brazil; 'hot pink' sapphires from several places, some heat-treated; star sapphire, one a fine purple, 23.97 ct, with an excellent star; tsavorite garnets, possibly from new locality; spessartines from Ramona, California; various other garnets; scapolite cat's-eye; Sri Lankan faceted sillimanite 12.23 ct claimed to be the world's largest [Geological Museum in London has one of 19.85 ct]; various synthetics are described. R.K.M.

LINDSTEN, D.C., 1988. But will it last? *Lapidary Journal*, **41**, 12, 57-60.

A description of the role played by hardness and durability in gemstones. M.O'D.

MITCHELL, R.K., 1988. EI and high ice. *Wahroongai News*, **22**, 2, 2-3.

A guest editorial which explains the reason for density of water increasing as temperature goes below 4°C, and for ice floating. (Author's abstract) R.K.M.

NASSAU, K., 1988. The 13 colors of gems and minerals. *Lapidary Journal*, **41**, 11, 32-73, 13 figs (6 in colour).

An abbreviated account of the causes of colour in gemstones taken from the author's *Physics and chemistry of color*, 1983.* M.O'D.

NIEDERMAYR, G., 1988. Mineralien und Smaragdbergbau Habachtal. (The minerals and the emerald-bearing rocks of the Habachtal.) *Emser Hefte*, **9**, 1, 2-48, 39 figs (23 in colour).

The minerals and the emerald deposit of the Austrian Habachtal are described. M.O'D.

POUGH, F.H., 1988. Gem treatment: andalusite. *Lapidary Journal*, **41**, 11, 14-17.

General overview of the varieties of andalusite. M.O'D.

POUGH, F.H., 1988. Apatite. *Lapidary Journal*, **41**, 12, 14-18.

A general survey of the apatite group of minerals with particular reference to those of gem quality. M.O'D.

POUGH, F.H., 1988. More or less altering the color of diamonds. *Lapidary Journal*, **41**, 12, 28-32, 4 figs in colour.

An account of the history and present state of the art of diamond enhancement by one of the original practitioners. M.O'D.

PROCTOR, K., 1988. Chrysoberyl and alexandrite from the pegmatite districts of Minas Gerais, Brazil. *Gems and Gemology*, **24**, 1, 16-32, 16 figs in colour.

A further paper by an author importing gems from these sources. Alexandrites found recently in the Hematita area rival or surpass the original Uralian material in colour and quality and include some fine alexandrite cat's-eyes. Describes localities with maps and excellent photographs. Overcrowding of the worked areas has resulted in disputes and gun-fights. Minas Gerais chrysoberyl mines are probably the world's most productive. R.K.M.

ROBERT, D., 1988. L'émeraldolite, une nouvelle matière. (Emeraldolite, a new material.) *Revue de Gemmologie*, 94, 9-10, 8 figs (2 in colour).

Emeraldolite is an undesirable name given to an overgrowth of emerald on beryl. Eye examination is

---

*Reviewed in *Journal of Gemmology*, 1985, **XIX**, 6, 547.

sufficient to detect the deception. M.O'D.

Robertson, R.S., Scott, D.C., 1988. Precious opal and the weathered profile at Coober Pedy. *Australian Gemmologist*, **16**, 9, 323-7, 2 maps, 10 figs (8 in colour).

A detailed account of the locality, geology and geological history of this important opal area. R.K.M.

Sapalski Rosello, C., 1987. La esfalerita de los Picos de Europa, Santander (España). (Sphalerite from Picos de Europa, Santander, Spain.) *Boletin del Instituto Gemológico Español*, 28, 6-14, 20 figs in colour.

Gem quality sphalerite from Picos de Europa, Santander, Spain, is described and analyses given. M.O'D.

Schmetzer, K., 1987. Zur Deutung der Farbursache blauer Saphire-eine Diskussion. (The cause of colour in blue sapphire – a discussion.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 8, 337-43, 5 figs.

In blue sapphires from different localities a distinct Fe^{2+}/Ti^{4+} charge transfer absorption is always observed with the spectroscope. Natural untreated or heat-treated sapphires without the Fe^2/Ti^4 bands are green. M.O'D.

Schuhbauer, E., 1988. Mineraliensuche in Nevada und Utah. (Mineral seeking in Nevada and Utah.) *Lapis*, **13**, 5, 11-27, 31 figs (19 in colour).

Red beryl and topaz from a number of locations in the south-western United States are described with excellent colour reproductions and occurrence details. M.O'D.

Snow, J., Brown, G., 1988. Sri Lankan ekanite. *Australian Gemmologist*, **16**, 9, 346-8, 7 figs (6 in colour).

An investigation of an 0.512 ct specimen of this extremely rare metamict gem, which was discovered by the late F.L.D. Ekanayake of Colombo in 1953. The constants and absorption spectrum of this stone are slightly at variance with those published for the species, but such variation is to be expected in a metamict substance. R.K.M.

Stockton, C.M., Kane, R.E., 1988. The distinction of natural from synthetic alexandrite by infrared spectroscopy. *Gems and Gemology*, **24**, 1, 44-6, 2 figs (1 in colour).

Characteristic inclusions separate most natural alexandrites from their synthetic simulants, but in the absence of such features infrared spectroscopy gives markedly different absorption between the natural and synthetic stones. R.K.M.

Themelis, T., 1988. Appraising colored stones. *Lapidary Journal*, **41**, 11, 43-8, 1 fig. in colour.

The writer gives an account of his work as a gemstone appraiser and illustrates the documentation he uses. M.O'D.

Themelis, T., 1988. Photomicrography. *Lapidary Journal*, **41**, 11, 53-4, 2 figs in colour.

An introductory discussion of the use of photomicrography in gem testing. M.O'D.

Themelis, T., 1988. Flashes in black opal. *Lapidary Journal*, **41**, 12, 19, 2 figs in colour.

Brief account of the cause of the play of colour in opal. M.O'D.

Vargas, G., Vargas, M., 1988. Orienting color in quartz gems. *Lapidary Journal*, **41**, 11, 49-52, 4 figs (3 in colour).

The authors illustrate the best methods of obtaining optimum colour from a given piece of quartz rough. M.O'D.

Westman, B.J., 1988. The enigmatic Hope. *Lapidary Journal*, **41**, 12, 42-105, 3 figs in colour.

A brief history of the blue Hope diamond now in the National Museum of Natural History, Smithsonian Institution, Washington DC. M.O'D.

Wigmore, G., 1988. An uncommon material. *Australian Gemmologist*, **16**, 9, 351, 2 figs in colour.

Describes manganoan sugilite, a massive purple mineral from Kalahari, South Africa, which is being sold as Royal Lavulite, or Royal Azel. [A suggestion that this is the world's rarest gem is surely an exaggeration?] R.K.M.

Wilson, W.E., 1988. The Iron Cap mine, Graham County, Arizona. *Mineralogical Record*, **19**, 2, 81-7, 16 figs (7 in colour).

Fine gem-quality sphalerite is found at the Iron Cap mine, Graham County, Arizona, USA. Crystals are yellow to yellowish-green and may measure up to 2.5cm across. The colour darkens to black with increasing iron content. M.O'D.

Zeitner, J.C., 1988. US diamond prospects. *Lapidary Journal*, **41**, 12, 21-7, 3 figs in colour.

The history of diamond occurrence in the Unites States is summarized. Diamonds have recently been discovered in Wyoming, Colorado and Michigan, and the use of remote sensing techniques may help future prospectors. M.O'D.

1988. Abalone pearls. *Lapidary Journal*, **41**, 11, 40-1, 4 figs in colour.

Good quality pictures of abalone from the Lowell Jones collection. M.O'D.

Book Reviews

Drits, V.A., 1987. *Electron diffraction and high-resolution electron microscopy of mineral structures.* Springer, Berlin. pp. xii, 304. Illus. in black-and-white. DM248.

Though somewhat advanced for most gemmologists, this translation from a Russian original gives a useful insight into practices of mineral surface examination with the most sophisticated techniques and equipment. After an introduction to crystal structures and the basic mechanism of electron scattering by crystals the book goes on to discuss the geometrical analysis of point electron-diffraction patterns. Several chapters deal with various aspects of electron diffraction with electron microscope techniques. Minerals are introduced with the micas in the eighth chapter and layer minerals are examined after this point. The last chapter deals with chain silicates and there is an extensive bibliography. M.O'D.

Gramaccioli, C.M., 1986. *Il meraviglioso mondo dei cristalli.* (The wonderful world of crystals.) Calderini, Bologna. pp. X, 291. Illus. in colour. L50,000.

Despite the title this is a serious study of the forms and habits of a wide range of minerals. The crystals are shown in three-colour diagrams with axes and named faces. Photographs of mineral specimens show examples mostly from Alpine regions. M.O'D.

Leeder, O., Thomas, R., Klemm, W., 1987. *Einschlüsse in Mineralien.* (Inclusions in minerals.) Enke Verlag, Stuttgart. pp.180. Illus. in black-and-white. DM48.

Chapters describe the nature of inclusions, the H_2O, CO_2 and various binary and ternary systems, continuing with notes on the use of thermobarometry and other diagnostic techniques. The remainder of the book is devoted to different types of inclusion with notes on the minerals concerned. There is an extensive bibliography and several pages of good quality black-and-white photographs at the back. M.O'D.

Miller, A.M., 1988. *Gems and jewellery appraising, techniques of professional practise.* Van Nostrand Reinhold, Wokingham. Illus. in black-and-white and in colour. £9.50.

To the best of my knowledge this is the first of its kind, and of course it has to be American. They say what happens first in the USA follows on to this country, sometimes for the good of us all. This book will benefit all those FGAs involved in valuation/appraisal work. Of particular merit are the chapters on setting up as an appraiser which show how important even your stationery can be, including letters, etc., to prospective clients. It even deals with your general appearance; not only should you be good at your work, you must look as if you can do it too!

To me Chapter 7 dealing with court appearances and the whole area of expert witnesses is worth the price of the book. To others it may be something else. What it will not be are the chapters dealing with gemstones and antique jewellery. These are a little basic and have probably been done this way to give the book a broader sales area.

However much of the book, although mainly about the American appraiser and his work, is very professional. It will prove to you that we are some way behind and although the National Association of Goldsmiths' Valuers Scheme is up and running we will have to sprint to catch up. P.S.

Vargas, G., Vargas, M., 1987. *Diagrams for faceting. Vol. 3.* Vargas, Thermal, California. pp. xxiv, 149. Illus. in black-and- white. Price on application.

This third volume of faceting styles sent to the compilers from correspondents consists of suggestions from Australia. Words and numbers are used to describe the cuts. M.O'D.

1987. *Diamonds 1988.* The Economist, London. pp. iii, 38. Price on application.

The report while confident that the diamond market has recovered from the slump of the 1970s and early 1980s states that diamond investment activity is still subdued. World production is not expected to increase very much and there will be a continuing swing to low cost centres of manufacturing. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr Alistair D. Cairncross, JP, FGA (D.1948), Perth, died suddenly on 7 March 1988. He will be missed by many people and particularly by those whom he knew in the trade he loved. A man of many loveable traits, so generous and happy in nature that it has been a privilege for me and our staff at Cairncross Limited to work with him. His talents as an artist and designer, in addition to his exceptional expertise in the Scottish fresh water pearls, made him almost unique. He leaves his wife, Mary, and two children. J.K.C.

Mrs Christina J. Sanders (née Hollander), FGA (D.1950), died in March 1988. She was a partner in the Hollander family gemmology business for very many years and was still actively interested at the time of her death.

Mr John Sopp, FGA (D.1937 with Distinction), Pinner, died suddenly on 20 February 1988. Mr Sopp spent his whole career with J.H.Lucas Ltd, manufacturing jewellers, late of Kirby Street, London EC1, apart from serving in the Royal Artillery during the Second World War. He joined the company as an apprentice designer, studying design at the Central School of Art and gemmology at Chelsea Polytechnic. He then moved to the sales and administration side and finally became Managing Director, largely responsible for the export trade.

It is with great regret that we announce the death of Mr Douglas Wheeler, FGA, former Assistant Secretary of the Gemmological Association of Great Britain, on 7 May 1988. A full obituary is given on p.130 above.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Sir Frank Claringbull for three books: *Precious stones – a popular account of their characteristics, occurrences and applications, with an introduction to their determination, for mineralogists, lapidaries, jewellers, etc., with an appendix on pearls and coral*, by Dr Max Bauer; *Edelsteinkunde Dritte Auflage, vollkommen new bearbeitat von*, by Dr Max Bauer and Dr Schlossmacher; *Der Diamant*, by Fersmann and Goldschmidt.

Mr R. Holt of R. Holt & Co. Ltd., London, for the book *Precious stones and gems* by Edwin W. Streeter, Chapman and Hall, London, 1877.

Dr Margherita Superchi, Milan, Italy, for *Analisi Gemmologica del Tesoro del Duomo di Milano* (Gemmological analysis of the Milan Cathedral treasure), by Centro Informazione e Servizi Gemmologici, Camera di Commercio, Industria, Artigianato e Agricoltura di Milano.

NEWS OF FELLOWS

On 4 June 1988 Mr Peter Read gave a talk on the development of his experimental Brewster-angle refractometer to the German Gemmological Association at their headquarters in Idar- Oberstein. After the illustrated talk he demonstrated the ability of the refractometer to measure the refractive index of stones over a range of 1.40 to 3.3. When questioned on the future development of the instrument, he told the audience that the Raynor Optical Company had nearly completed their work on a pre-production version and that it was hoped that the refractometer, complete with a polarized laser light source, would be available commercially through Gemmological Instruments Limited by the end of the year.

MEMBERS' MEETING

London

On 15 June 1988 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, following the Annual General Meeting (see p.201) a gemmological forum was held, organized by Mr Christopher Cavey, FGA, and chaired by Mr David Callaghan, FGA, Chairman of the Council. The panel consisted of Dr Roger Harding, B.Sc., D.Phil., FGA, Mr Alan Hodgkinson, FGA, and Dr Jamie Nelson, Ph.D., FRMS, F.Inst.P., FGS, FGA. The subjects covered, illustrated by slides, models and practical demonstrations, were as follows: the reasons for maintaining and up-dating collections in museums, visual optics and the body colour of gemstones.

Midlands Branch

On 15 April 1988 at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held at which Mrs Janet S. Leek, FGA, and Mr John R. Bugg, LL B, FGA, were elected Chairman and Secretary respectively. This was followed by a talk by Mr Doug Morgan, FGA, and Mr Dennis Price, FGA, entitled 'Gem cutting and polishing for the amateur lapidary'.

North West Branch

On 18 May 1988 at Church House, Hanover Street, Liverpool, Mr Nigel Grist, FGA, gave a talk about his work as a designer jeweller. Members were able to view samples of his work, in particular specimens of his 'Faberge type' flowers.

On 2 June 1988 members of the Branch visited De Beers Consolidated Mines Limited in Charterhouse Street, London EC1.

JOINT ACTIVITIES WITH OTHER ORGANIZATIONS

Society of Jewellery Historians

On 23 March 1988 at the Geological Museum, Exhibition Road, South Kensington, London SW7, an introduction to practical gemmology was held for members of the Association and the Society of Jewellery Historians.

On 16 April 1988 a symposium entitled 'Glass in jewellery'was held at the Society of Antiquaries, Burlington House, London, by the Association and the Society of Jewellery Historians.

The symposium comprised seven lectures, many given by experts in their field, and looked initially at the composition and structure of glass (Dr Ian Freestone), its identification with respect to gemstones (Ken Scarratt), and its use in ancient jewellery (Jack Ogden). This was followed by a comprehensive talk on glass intaglios and cameos (Gertrud Seidmann), a look at the 17th and 18th century pastes at the Museum of London (Amanda Herries), a fascinating study made on 19th century glass mosaic jewellery (Judy Rudoe), and a lecture on 20th century costume jewellery (Jane Stancliffe).

The Mineralogical Society

On 22 April 1988 a half-day meeting entitled The economic mineralogy and petrology of pegmatites' was held at the Geological Society, Burlington House, Piccadilly, London W1V 4BR, by the Association and the Mineralogical Society.

The meeting comprised the following lectures: Rare metals in pegmatites (Dr P. Moller, Hah-Meitner Institut, Berlin, East Germany); Fluid processes during lithium mineralization in pegmatites from SE Ireland (Mr M. Whitworth, Imperial College, London); Exotic minerals in Gondwana pegmatites (Dr J. Kinnaird, St Andrews University, Scotland); The classification of pegmatitic rocks in SW England and aspects of the pneumatolytic transition (Mr Lin Yucheng and Dr C. Halls, Imperial College, London); Gemstone-bearing pegmatites from Central and Southern Africa (Dr J. Kanis, Cascais, Portugal); Gem-bearing pegmatites of the Pala district, San Diego County, California (Mr M. O'Donoghue, British Library, London); Inclusions in gemstones from pegmatites (Dr E.J. Gübelin, Meggen, Switzerland). During the tea break there was a poster display on pegmatites and their relationship to the chemical evolution of the Galway granite, Western Ireland (Mr M. Whitworth, Imperial College, London, and Dr M. Feely, University College, Galway, Ireland). The meeting was opened by Dr D.J. Vaughan, President of the Mineralogical Society and concluding remarks were given by Mr D.J. Callaghan, Chairman of the Gemmological Association.

MEETINGS OF THE EXECUTIVE COMMITTEE

At a meeting of the Executive Committee held on 6 April 1988 at Saint Dunstan's House, Carey Lane, London EC2, the business transacted included the election to membership of the following:

Fellowship

Aziz, Khalid, Karachi, Pakistan. 1987
Bowers, Norman, Manchester. 1967
Markov, Mark, London. 1987

Ordinary Membership

Bøe, Olav A., Alhus, Norway.
De Winter, Rene, Amsterdam, Netherlands.
Donaldson, Geralyn A., Brussels, Belgium.
Foxwell, Russell N., London.
Harada, Kenji, Tokyo, Japan.
Ishii, Tomoyuki, Tokyo, Japan.
Jinnai, Kouji, Kanagawa Pref, Japan.
Karunanayake, Sarath P., Dehiwala, Sri Lanka.
Kelley, Kellie J., Clinton, Wash., USA.
Lee, Bea W., Seoul, Korea.
Lee, Hung K., Taipei, Taiwan.
Longden, Sharon D., Eckington.
McKay, Kenneth D., Swanage.
Mogi, Masako, Tokyo, Japan.
Nakamura, Chiyo, Hokkaido, Japan.
Neomoto, Naoki, Tokyo, Japan.
Ohmura, Keiko, Tokyo, Japan.
Ohshima, Takako, Osaka, Japan.

Oshima, Hirotomo, Tokyo, Japan.
Otsuka, Masae, Chiba Pref, Japan.
Oudenes, Hendrik, Papendrecht, Netherlands.
Petrides, Eugene, London.
Sekiguchi, Kazuyoshi, Tokyo, Japan.
Shah, Anurag D., Nairobi, Kenya.
Shimizu, Terukazu, Tokyo, Japan.
Sugihara, Kaori, Tokyo, Japan.
Urata, Nami, Osaka, Japan.
Washi, Shoichi, Chiba Pref, Japan.
Yim, Tae Y., Tokyo, Japan.
Yokoyama, Haruaki, Fukuoka Pref, Japan.
Yoshimoto, Misako, Fukuoka Pref, Japan.

At a meeting of the Executive Committee held on 11 May 1988 at Saint Dunstan's House, the business transacted included the election to membership of the following:

Ordinary Membership
Colucci, Thomas R., Chatham, NJ, USA.
Gainer, Pamela, Wokingham.
Hampton, John S., Lancaster.
Moulder, Robert P., Sandbach.
Thompson, Neil C., Maidenhead.
Tirat, Pierre, Poitiers, France.

COUNCIL MEETING

At a meeting of the Council held on 3 May 1988 at the Royal Automobile Club, Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship
Aloy, Richard N., San Jose, Calif., USA. 1976
Gemayel, Farid, Jounieh, Lebanon. 1982
Hellqvist, Ing-Britt E., Tumba, Sweden. 1987
Leung, Wai Hung, Kowloon, Hong Kong. 1987
Verjee, Nasim K., Nairobi, Kenya. 1982

Ordinary Membership
Archard, Trevor J., Hove.
Baldridge, Stephanie A., San Jose, Calif., USA.
Kanis, Jan, Cascais, Portugal.
Langridge, John P., Sompting.
Mulkern, Michael P., Brewster, NY, USA.
Tracy, Joseph M., Kansas City, Mo, USA.

ANNUAL GENERAL MEETING 1988

The 57th Annual General Meeting of the Association was held on 15 June 1988 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7.

The Chairman, Mr David Callaghan, FGA, opened the meeting by welcoming members. He referred to the sad news of the death of Mr Douglas Wheeler, FGA (obituary p.130 above). The late Gordon Andrews and Harry and Douglas Wheeler formed a team that did so much for building the name of the Gemmological Association throughout the world, and Douglas's death marks the passing of the trio.

As a result of the poor financial position the previous year, stringent economies had been imposed by the Executive Committee and the Council. Mr Callaghan was pleased to report that there had been a considerable improvement, and this dramatic change was due to the Secretary, Mr Jonathan Brown, and his team. He thanked Jonathan and the staff for all they had achieved during the year, and particularly Sandra Page for her work on the Diploma course.

Mr Callaghan then thanked the Officers and Council for their help and support during the year.

He announced that there will be a change of venue for the Presentation of Awards this year, due to the closure of Goldsmiths' Hall for alterations. The Presentation is to be held on 25 November 1988 at the original Guildhall in the City of London.

Mr Nigel Israel, Treasurer of the Association, presented the audited accounts for the year ended 31 December 1987. The adoption of the Report and Accounts was duly proposed, seconded by Mr Kenneth Scarratt, and carried.

Sir Frank Claringbull, Mr David J. Callaghan, Mr Noel W. Deeks and Mr Nigel B. Israel were re-elected President, Chairman, Vice-Chairman and Honorary Treasurer, respectively. Messrs. C.R. Cavey, P.J.E. Daly, J.A.W. Hodgkinson, D. Inkersole, B. Jackson and M.J. O'Donoghue were re-elected and Mrs Gwyneth Green elected to the Council. Messrs C.B. Jones and A.W. Round retired from the Council and Mr Callaghan thanked them for the help and support they had given.

Messrs. Ernst and Whinney were reappointed Auditors, and the proceedings then terminated.

GEM TESTING LABORATORY OF GREAT BRITAIN

On 13 June 1988 the Gem Testing Laboratory opened an office at 10 Vyse Street, Birmingham. A qualified gemmologist is in attendance on Monday and Tuesday of each week to provide a 'While you wait' testing service with a verbal report for most types of gemstone. The service is available to members of the Association and further details may be obtained from Alan Clark, FGA, at the London laboratory on 01- 405 3351.

CORRIGENDA

On p.83 above, second column, 7th line, for '0.015', read '0.016'

On p.84 above, second column, first line, for 'possible', read 'impossible'

On p.84 above, in Table 1, the ± signs should have been omitted after 'birefringence'

Letter to the Editor

From Gordon S. Walker, ASTC, FIO, FGAA

Dear Sir,

In reference to a paper in the April 1988 issue of the *Journal,* by R. Keith Mitchell, FGA, entitled 'An important Australian contribution to gemmology', I would like to make the following observations, if I may.

I quite understand Mr Mitchell's doubts concerning the third decimal place accuracy, particularly in reference to the mobility of the spot.

So very often, in my field of study and practice, I find that the actual problems which occur have within themselves their own solutions – and such is the case here.

When in deep water, I can either drown or become a diver!

With the refractometers I use, the spot takes on a rugby ball shape which is made as small as possible.

The technique is as follows:

Using the point of the 'rugby ball' direct your gaze away from this and towards the scale side and even beyond this to utilize more of the peripheral vision of the eye's retina. The central vision of the eye has a high proportion of cones which produce high visual acuity whereas the periphery has more rods which have a higher sensitivity for movement.

By using the mobility of the image, it is easy after some practice to judge equal swings with slightly peripheral vision and record the higher and lower shadow edges of these swings, and taking the middle position of such swings as the third decimal place – such swings should be as small as practical.

This method is not so easy with the Dialdex, but still possible.

It is important to stress that not everyone will be able to get an accurate third decimal place in a short space of time and such should never be expected from a student sitting for an examination is gemmology!

The mobility principle combined with the peripheral vision technique is not new; for this is the very method used by gemmologists who get better than average results with a spectroscope.

The main difference here is that the mobility and peripheral vision technique is horizontal in application instead of vertical in reference to the absorption lines and scale.

I know a gemmologist who has a layman's way of putting it. He says, 'I look around the corner of the edge of the spectrum and then I see the absorption lines'.

It should be noted that the matter of the third decimal place is quite useless unless we address two other considerations which are of paramount importance: for unless we do this, the whole exercise is useless and the results will be at the best very approximate indeed!

The first is to achieve an accurate second decimal reading by using the control of several singly refractive cabochons with flat ground and polished bases which are used as a check on the second (and third) decimal place read.

The result is that 0.01 to 0.02 must be added to the spot reading to give the same result as is achieved on the flat surface. The amount added appears to be standard for each operator.

The second matter that needs to be mentioned is the need of a check on all commercially sold refractometers, for some leave much to be desired. It is wise to check all instruments from time to time with a material with a known RI, such as a flat ground and polished piece of optical crown glass, having an RI of 1.523 (or whatever the manufacturer's specifications are).

In conclusion please thank Mr R. Keith Mitchell for his comments and opinions regarding the original paper.

Yours etc.,

Gordon S. Walker
June 1988
PO Box 37, Belmont, NSW 2280, Australia.

References

Mitchell, R.K., 1988. An important Australian contribution to gemmology. *Journal of Gemmology*, 21, 2, 67-8.
Walker, G.S., 1987. A new 'spot reading' technique for the refractometer. *Australian Gemmologist*, **16**, 7, 253-6.

ANTWERP GEMS '88

OCTOBER 15TH - 20 TH '88

Antwerp - Belgium

A full program of activities and exhibition on diamonds and precious stones, in the Antwerp World Diamond Center, Belgium.

- European Precious Stones Conference
- Diamond High Council Awards
- Gemscapes and Diamondscapes
- Diamonds and Colour Precious Stones
- Workshops
- De Beers International Awards
- New Provincial Diamond Museum

ORGANIZERS

vzw Precious Stones Promotion
in collaboration with and patroned by
- Diamond High Council
- Belgian Federation of Dealers and Manufacturers of Precious Stones
- National Jewellers' Committee

INFORMATION CENTER AND SECRETARIAT

vzw Precious Stones Promotion
c/o Diamond High Council
Hoveniersstraat 22
2018 Antwerp
Tel. 03/222 05 11
Telex 34.889 horadi b
Telefax 03/222 07 24

Dealers in
the gem stones of
the world

Diamonds, Rubies,
Sapphires, Emeralds, and
most coloured gem stones
Pearls & Synthetics.

R.M.Weare
& Company Limited.
67 The Mount York. England. YO2 2AX.
Telephone 0904-621984. Telex: 57697 Yorvex.G

RUPPENTHAL
(U.K.) LIMITED

WE ARE
INTERESTED IN
PURCHASING THE
FOLLOWING ITEMS
FROM THE TRADE:

Old Cut Diamonds

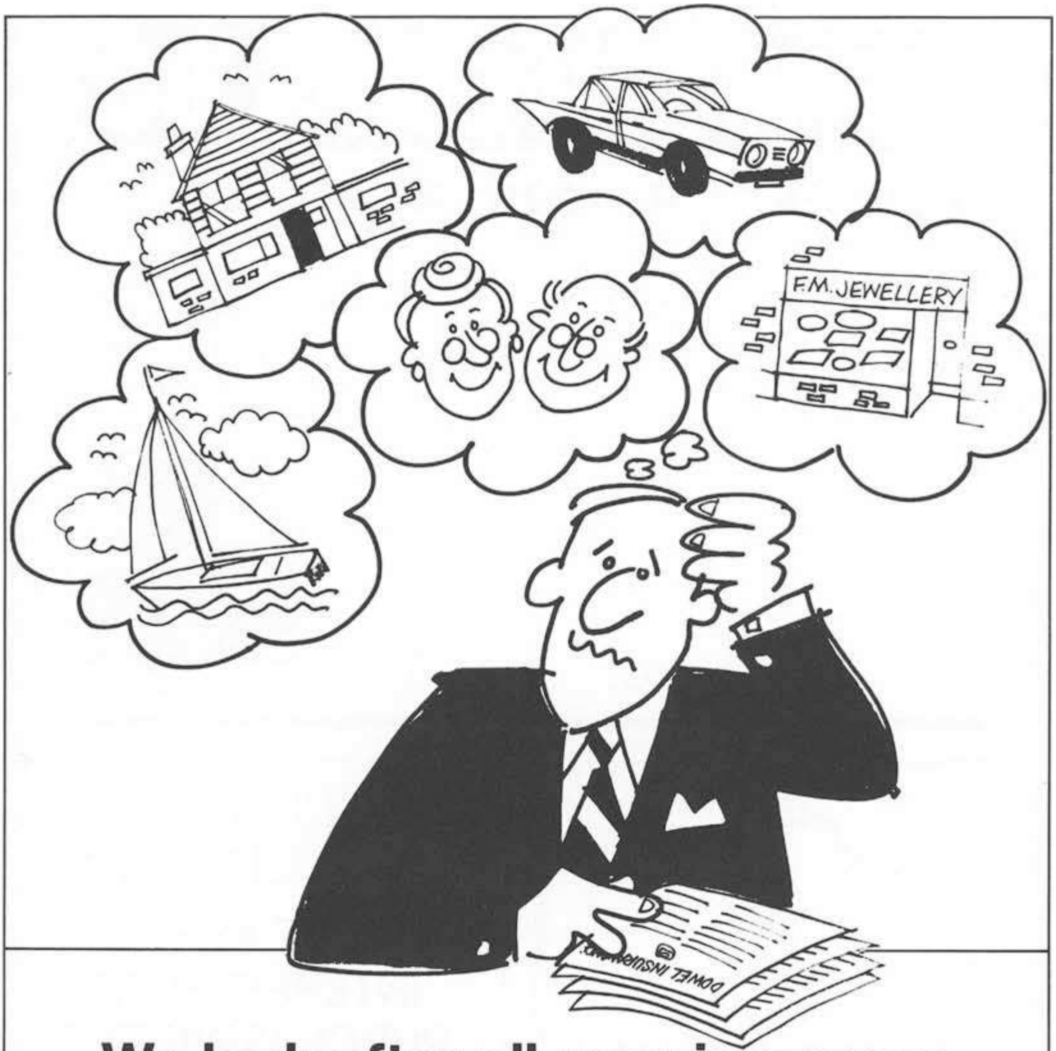
Rose Cut Diamonds

Natural Pearls: Half, Full, Baroque and Necklaces

Old Collections of Gemstones

Manufacturers' Surplus Jobbing Stocks

Please send on approval to:
48 Hatton Garden, London EC1N 8EX


F.M. JEWELLERY
DOWEL INSURANCE

ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

Rates per insertion, excluding VAT, are as follows:

Whole page	£180
Half page	£100
Quarter page	£60

Enquiries to Mrs M. Burland,
Advertising Manager,
Gemmological Association,
Saint Dunstan's House,
Carey Lane, London EC2V 8AB.

BRITISH LAPIDARY & MINERAL DEALERS ASSOCIATION

GEM & MINERAL FAIRS 1988

HARROGATE
Crown Hotel
27th-28th-29th August

*LONDON
Holiday Inn Swiss Cottage
19th-20th November

*Reserve a space now – number of tables considerably reduced.

Fair Organiser:
JOHN F. TURNER
Glenjoy
19/21 Sun Lane
Wakefield. W. Yorkshire
Telephone: 0924 373786

Have you a worn prism?

Arrangements have now been made to offer a speedy repair/overhaul service for Rayner refractometers*.

So if your refractometer glass prism is cracked, chipped or marked, or the refractometer just is not operating satisfactorily, simply send it to the Gemmological Association for overhaul. This will include completely stripping the unit down, checking and replacing, if necessary, damaged internal lens system parts, replacing the top glass prism with a harder glass and generally cleaning and realigning optics to ensure many more years of use.

The cost is just £51.00 plus postage and VAT where applicable.

Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

** Please note that it is not possible to repair some of the old 'black style' refractometers as they are now obsolete.*

GEMDATA

A computer program for gem identification

The GEMDATA Package by Peter Read (see p.144 for full details) is available through the Gemmological Association at £75.00 plus postage, packing and VAT* (*UK only at £11.25). Postal rates are as follows: £3.50, UK and Eire; £4.00, Europe; £6.00 rest of the world.

To order your Package use the form below.

- -

To: Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

Please supply .... copies of the GEMDATA package.
*I enclose remittance £ .... /debit my credit/charge card
(please tick appropriate box)

☐ Access ☐ BARCLAYCARD VISA ☐ AMERICAN EXPRESS ☐ Diners Club

Card No. .... Expiry date ....
Name ....
Address ....
.... Telephone No. ....
Signature .... Date ....

*Delete as applicable

LABORATORY BASED COURSES

For over sixty years the Laboratory has been in the forefront of practical gemmology. Now we can offer short Laboratory based courses on all aspects of practical gem-testing and diamond grading.

Find out more by telephoning 01-405-3351 or write for details to:

GEM TESTING LABORATORY
OF GREAT BRITAIN

27 GREVILLE STREET, LONDON EC1N 8SU

Genesis

- Leaders in gemmological education, specializing in intensive tuition, from scratch to F.G.A. Diploma in nine months. We can claim a very high level of passes including Distinctions amongst our students.
- We organize a comprehensive programme of Study Tours for the student and practising gemmologist, to areas of gemmological interest, including Antwerp, Idar-Oberstein, Sri Lanka and Bangkok.
- Dealers in gemstones and rare specimens for both the student and the collector.
- Suppliers of gemmological instruments, especially the world famous OPL diffraction grating spectroscope, together with a range of books and study aids.

For further details of these and other activities, please contact:–

Colin Winter, F.G.A., or Hilary Taylor, B.A., F.G.A., at GENESIS, 21 West Street, Epsom, Surrey KT18 7RL, England.

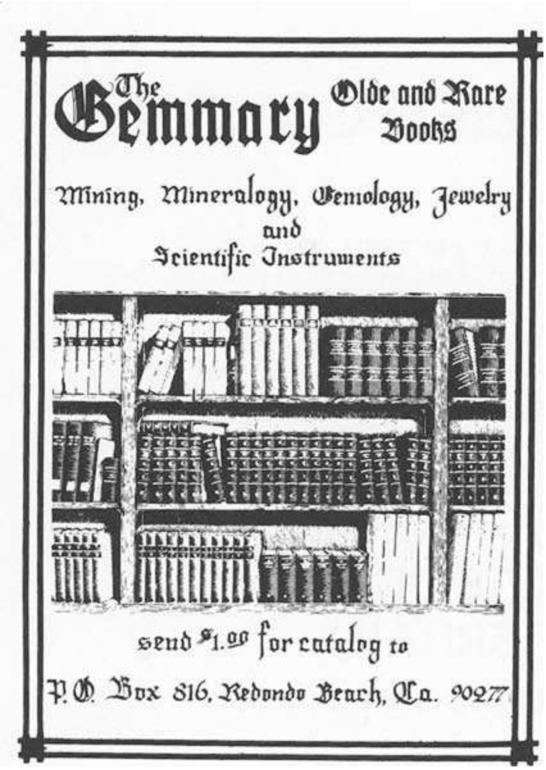
Tel: Epsom (03727) 42974.
Telex: 923492 TRFRT G attn GENS.

ATTENTION:
Museums, Educational Establishments & Collectors

I have what is probably the largest range of genuinely rare gemstones in the UK – from Apophyllite to Zincite. Also rare synthetics, i.e. Scheelite, Bismuth Germanate & Yttrium Vanadate.

Lists available –
(large s.a.e. appreciated)

A.J. FRENCH F.G.A.
Gem Dealer & Consultant
82 Brookley Road
Brockenhurst, Hants SO42 7RA
Telephone: 0590 23214



GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

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

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10'000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

Volume 21 No.3 July 1988

The Journal of
Gemmology

Contents

Beryl papers

Registered Office: Saint Dunstan's House, Carey Lane, London EC2V 8AB

ISSN: 022–1252

Produced by Green Belt Studios: Printed by Quadrant Offset, Hertford, England.