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Bauer, Edelsteinkunde.
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Cover Picture

Plate 1 from Bauer's *Edelsteinkunde* published in German in1896 (translated into English by L.J. Spencer in 1904 as *Precious Stones*). The specimens are diamond (1-4), ruby (5-6).sapphire (7-8), spinel (9-10) and zircon (11-13). (See Two types of historical traps: on 'Diamond Softening' and the'Antiquity of Emerald Oiling' by Kurt Nassau p.399-403.)

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Two strongly pleochroic chatoyant gems

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Abstract

This article describes the gemmological features of two rare, strongly pleochroic cat's-eye gems: iolite and tanzanite.

Introduction

Gemstones exhibit a number of visual characteristics which are used by the trained gemmologist to identify them. These include such features as the gem's colour, colour distribution, diaphaneity, brilliance and lustre; virtually every gem can be described in terms of these factors which, in turn, relate to their optical properties.

In addition, a limited number of gems display additional unusual optical effects, which gemmologists refer to as optical 'phenomena'. One broad category of these includes a number of effects caused by the interference of light, such as opal's play-of-colour, fire agate's iridescence, pearl's orient, and labradorite feldspar's 'labradorescence' (or 'schiller') (Webster, 1983).

Another general class of optical phenomena results from reflections of light from internal structures or inclusions within the host gem. These include the glittery aventurescence or spangled effect seen in such natural gems as aventurine quartz, sunstone feldspar and 'bloodshot' iolite, as well as in the man-made 'goldstone' glass; the asterism or 'star effect' exhibited by some rubies, sapphires, garnets, rose quartzes and other gems; and the chatoyancy or 'cat's-eye effect' exhibited by several gems (Webster, 1983; Gübelin and Koivula, 1986).

This last phenomenon, chatoyancy, is most often caused by reflections of light from fine, parallel, elongated inclusions contained within the gem. These may be either solid, acicular crystals of such minerals as rutile or goethite, as for example in some cat's-eye chrysoberyl or diopside, or they may be hollow growth tubes as is the case of some cat's-eye tourmaline and beryl. Less commonly, chatoyancy results from a fine, parallel acicular structure of the gem itself, cat's-eye actinolite being a prime example. In such gems, the effect will only be seen when the stone is cut en cabochon and oriented so that the planes of the acicular inclusions/structure are parallel to the base of the stone (Liddicoat, 1989).

Chatoyancy is seen with varying frequency in a number of gem species. In addition to those mentioned above are apatite, enstatite, kornerupine, scapolite, sillimanite and zircon (Liddicoat, 1989). Recently the authors have had the opportunity to examine a number of unusual chatoyant gems. Two of these in particular, cat's-eye iolites and a cat's-eye tanzanite, are exceptional for both their great rarity and the fact that they are highly pleochroic gems.

Cat's-eye iolites

The gem material iolite, known to mineralogists as cordierite, is usually fashioned into gems which exhibit a blue to violet face-up body colour and no optical phenomena. Some material from Sri Lanka and India, however, contains small metallic magnetite, hematite and/or lepidocrocite platelets which produce a silvery (magnetite) or reddish (hematite/lepidocrocite), glittery effect; as mentioned above, material with reddish aventurescence has been called 'blood-shot' iolite.

On two separate occasions recently the authors had the opportunity to examine iolite cabochons which exhibited distinct chatoyancy. The first stone, a 23.65 carat gem, was shown to us at the 1990 Tucson Gem and Mineral Show. The gem had a fairly light blue body colour, an overall 'cloudy' appearance, and exhibited a sharp chatoyant band (Koivula and Kammerling, 1990). This was the first such phenomenal iolite that either author had seen, although apparently similar gems have been reported infrequently in the gemmological literature (see, for example, Brown *et al.*, 1982; Fryer *et al.*, 1982).

The second stone, an attractive oval double cabochon weighing 8.25 carats and measuring 14.84

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Fig. 1. When examined face-up, this 8.25 ct cat's-eye iolite shows a light bluish-grey body colour on either side of the sharp chatoyant band. *Photo by Robert Weldon, Gemological Institute of America.*

Fig. 2. When examined from the side, the cat's-eye iolite shown in Figure 1 appears a dark violet colour due to strong pleochroism. *Photo by Robert Weldon, Gemological Institute of America.*

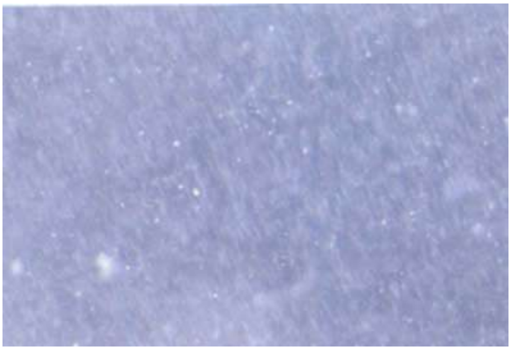

Fig. 3. Magnification reveals the cause of the chatoyancy in the cat's-eye iolite to be minute, whitish-appearing parallel fibres. *Photomicrograph by John I. Koivula, Gemological Institute of America.* Magnified 30x.

× 11.78 × 7.58 mm, reportedly originated in South India. The stone appears semi-transparent when viewed from above but would be almost transparent were it not for the fact that the base had been roughly ground. In surface-reflected incident light it exhibits an exceptionally strong chatoyant band; this is even quite evident under diffused overhead fluorescent lighting. When examined face-up it shows a light bluish-grey body colour on either side of the chatoyant band (Figure 1) while the periphery of the base shows a medium dark violet colour due to the stone's strong pleochroism (Figure 2).

Gemmological properties determined for the second stone were as follows:

Refractive Index: 1.53, determined by the distant vision ('spot') method on the apex of the cabochon with a Duplex II refractometer and white light source.

Optic Character: Biaxial, determined by resolution of an optical interference figure between crossed polaroids. During the polariscope examination the investigators noted that the chatoyant band appeared to bisect the 2V angle.

Pleochroism: Very strong, in dark violet, light bluish-grey, and light brownish-yellow, as observed with a calcite dichroscope.

Chelsea Filter reaction: Inert (appeared green).

LWUV fluorescence: Inert; no phosphorescence.

SWUV fluorescence: Inert; no phosphorescence.

Absorption spectrum: No distinct features observed.

Specific gravity: 2.60, estimated using the sink-float method with heavy liquids.

Magnification: Microscopic investigation revealed the cause of the chatoyancy to be minute, whitish-appearing parallel fibres (Figure 3). Also noted were small, low-relief, colourless crystals of undetermined identity.

Cat's-eye tanzanite

Another chatoyant gem mentioned in the literature but very rarely seen is cat's-eye tanzanite. It thus came as a pleasant surprise when we were shown the stone pictured in Figure 4. This semi-transparent, high-domed oval cabochon with a slightly convex base weighs 2.69 carats and measures 8.21 × 6.81 × 5.51 mm. When examined from above it exhibits an attractive medium dark greyish violet-blue body colour and a sharp chatoyant band.

Gemmological properties determined for the chatoyant tanzanite were as follows:

Refractive Index: 1.69, determined by the distant vision ('spot') method on the apex of the cabochon with white light source.

Optic Character: Biaxial, determined by resolution of an optical interference figure between crossed polaroids.

Pleochroism: Very strong, in blue, purple and greyish green, as observed with a calcite dichroscope. It was interesting to note that, as with the cat's-eye iolite described above, a deeper colour was noted when the stone was viewed down the sides in both the long (Figure 5) and narrow directions.

Chelsea Filter reaction: Inert (appeared green) in most directions with a slight orangy overtone when viewed down the length of the cabochon.

LWUV fluorescence: Inert; no phosphorescence.

SWUV fluorescence: Inert; no phosphorescence.

Absorption spectrum: No distinct features observed.

Specific gravity: 3.38, estimated using the sink-float method with heavy liquids.

Magnification: Microscopic investigation revealed the cause of the chatoyancy to be numerous parallel whitish channels running perpendicular to the 'eye' (Figure 6). Spike-shaped 2-phase inclusions were also noted. When looking down the length of the channels a light transmission effect similar to that shown by the mineral ulexite (so-called 'television stone') was also noted.

Discussion and conclusion

As is the case with cat's-eye alexandrite and some other strongly pleochroic chatoyant gems, orienting the iolite and tanzanite described herein so as to centre the chatoyant band across the dome of the cabochon resulted in less than the best face-up colour.

It is also possible that light reflections off the chatoyancy-producing inclusions in these two gems 'whitened out' the true body colour and contributed to less than ideal colour appearance when viewed from above. This would be similar to the case of some silky Australian sapphires, in which masses of fine acicular inclusions reflect and scatter the two polarized rays as they pass through the stone, resulting in the blue and blue-green dichroic col-

Fig. 4. This 2.69 ct tanzanite also exhibits distinct chatoyancy. *Photo by Robert Weldon, Gemological Institute of America.*

Fig. 5. As with the cat's-eye iolite, due to its strong pleochroism the chatoyant tanzanite pictured here displayed a deeper colour when viewed down the sides. Note also the ends of the chatoyancy-causing parallel channels. *Photomicrograph by John I. Koivula, Gemological Institute of America.* Magnified 25x.

Fig. 6. Magnification shows the cause of the chatoyancy in the tanzanite to be numerous light reflecting parallel whitish channels running perpendicular to the 'eye'. *Photomicrograph by John I., Koivula, Gemological Institute of America.* Magnified 30x.

ours merging into one undesirable greenish blue hue. The effect in such sapphires may be so complete that the stone appears the same in any direction of observation (Coldham, 1985).

Acknowledgements

The authors would like to thank Mr Kim D. Barr of Inter-Gems in Sherman, Texas, for bringing the 23.65 ct cat's-eye iolite to our attention; Mr Yianni Melas, an instructor at the Gemological Institute of America in Santa Monica, California, who first brought to our attention the 8.25 ct chatoyant iolite and Mr Manu Nichani of Temple Trading Company in Encinitas, California, who subsequently loaned the stone for gemmological examination; and Peter and Bobbi Flusser of Overland Gems in Los Angeles, California, for the loan of the cat's-eye tanzanite.

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Two types of historical traps: on 'Diamond Softening' and the 'Antiquity of Emerald Oiling'

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Introduction

The interpretation of ancient texts is always a hazardous undertaking. It is easy to fall into two types of traps: scoffing at apparently ridiculous statements at one extreme; accepting apparently reasonable statements at face value without careful analysis at the other extreme.

An example of the *first* type of trap, on which I was able to shed some light, is the 'softening of diamond' with warm goat's blood as mentioned in the 'Natural History' of Pliny (Gaius Plinius Secundus, Roman historian, 23 AD to 79 AD). A trap of the second type into which I myself fell previously, is involved with Pliny's description of emerald oiling, the apparent antiquity of which is sometimes cited as justification for current practice.

Pliny's 'Diamond Softening'

An example of the first type of trap is Pliny's statement on diamond: "Adamas ... can be broken up by goat's blood. But it must be steeped in blood that is fresh and still warm ..." (Eichholz, 1962, p. 209). In his commentary on this passage Ball (1950, p. 252) calls this a myth and cites derivative statements by later writers. These frequently describe this process as a technique for 'softening' diamond for easier cutting, some stating that it did not work, with others claiming that they had used it successfully!

When I originally came across this passage, I was greatly amused, just as everyone else. It was only while studying the even older 'Papyrus Graecus Holmiensis', an Egyptian manuscript titled Baphika (on dyeing) written by Bolos of Mendes about 200 BC (e.g. see Nassau and Hansen, 1985) that I realised this 'mythical' recipe actually works! For the papyrus describes in several recipes in varying details, a process which is still in use today, although it is given by Pliny in a rather garbled form.

This process applies not to diamond but to quartz, for the term 'adamas' then included both materials. It uses goat's blood – today we use water which works just as well! And the papyrus includes a step which Pliny and later recipes omit, the step of heating the quartz before dropping it into the liquid; for the whole process was intended to crackle the quartz for subsequent dyeing.

Exerpts from a new translation (Nassau and Hansen, unpublished) of just three of the many recipes in the 'Papyrus Graecus Holmiensis' will illustrate the process as it was used over two thousand years ago:

> No. 29. Mordanting [or Softening] of Stones.
>
> ... hide them [the stones] in a dried fig or [in] plump dates. These should be worked over charcoal and blown with bellows until they [the fig or dates] burn and become charred. And take out [the stones] with tongs not with your hand [implying that they are too hot to touch], and thereupon plunge while warm into the dye solution and let cool there ...
>
> No. 36. Softening of Crystal.
>
> To soften crystal take goat's blood, heat the crystal over a gentle fire and dip it in until it pleases you.
>
> No. 46. Dipping for Lychnis [a red stone, possibly tourmaline or ruby].
>
> Begin by mordanting [or softening] as above. Take orchil and alkanet [both red substances] and vinegar. Drop the stone into this until it pleases you.

In 200 BC and later the first part of this two-step process was called 'mordanting' or 'softening' by analogy with the 'softening' of wool by a mordanting process which was in use from ancient times until quite recently to make the wool more receptive to dyes (Nassau, 1984, pp. 9 and 158). However, classicists preparing the previous translations of this papyrus had missed the essential point from not knowing enough gemmology. It required a new translation involving my interaction with Professor A.E. Hansen of the Classics Department of Prince-

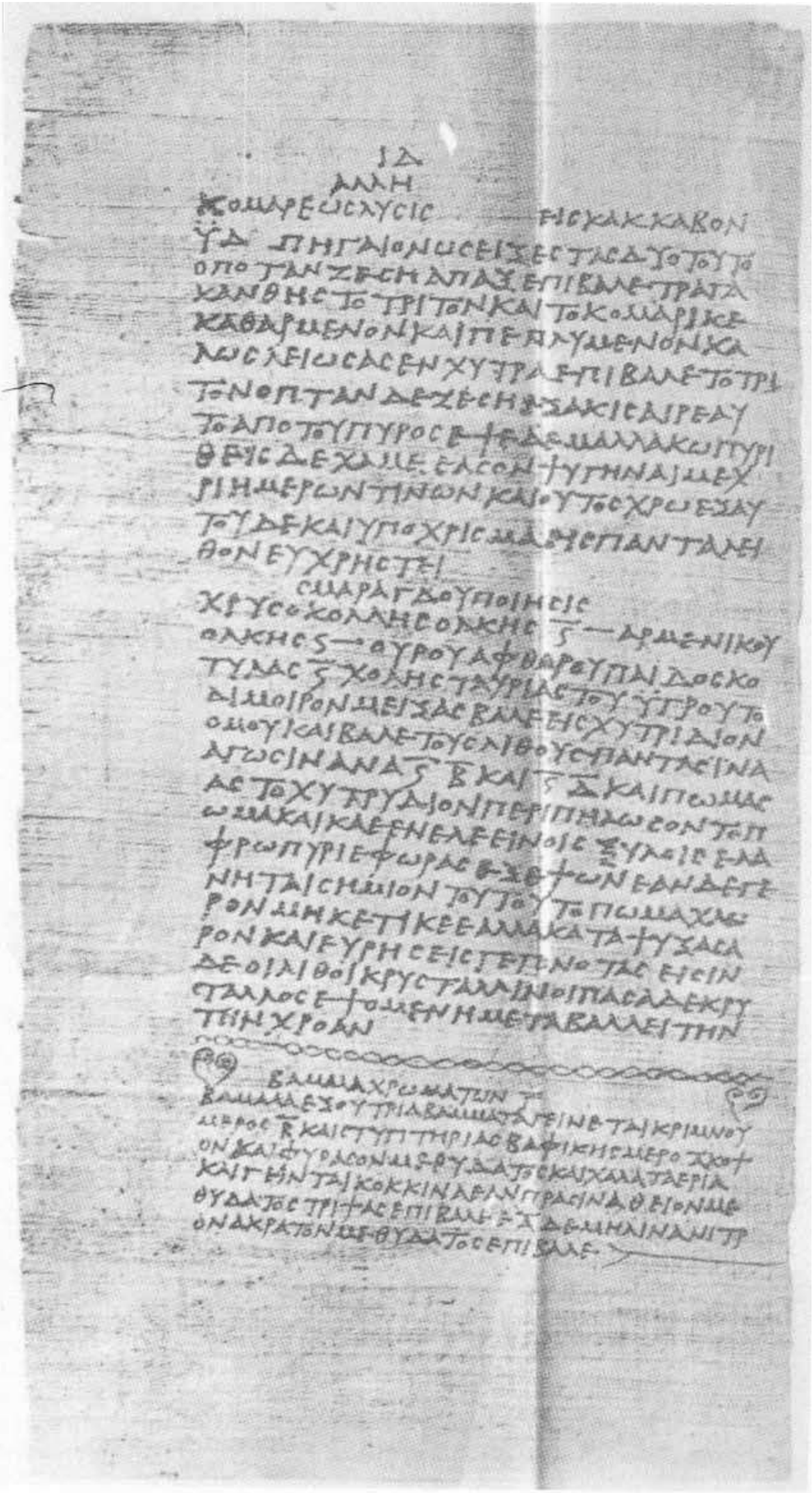
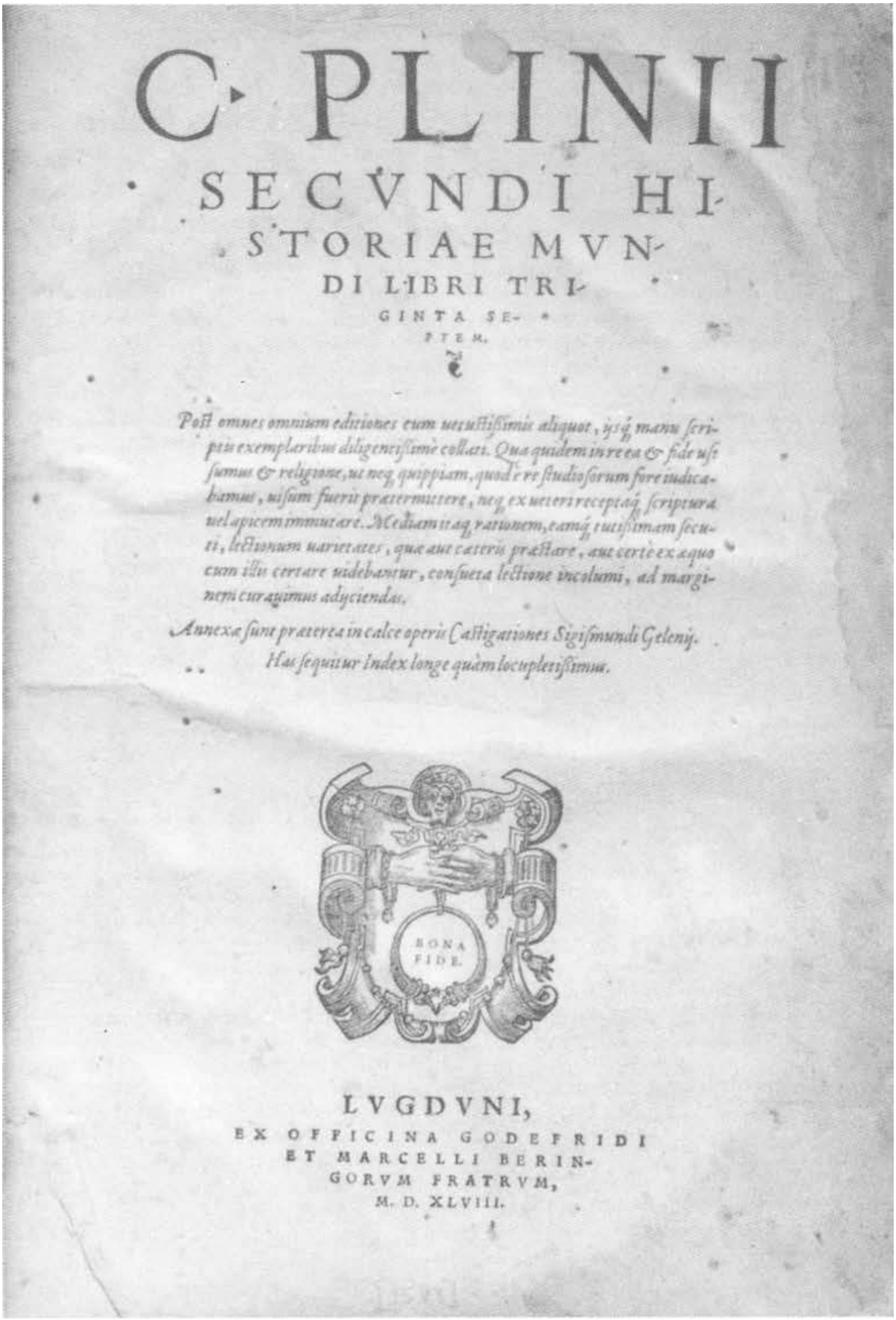


Fig. 1. A page from *Papyrus Graecus Holmiensis*, the first gemstone treatment text, about 2000 years old, copied about 300 AD.



C. PLINII
SECVNDI HISTORIAE MVNDI LIBRI TRIGINTA SEPTEM.

Poſt omnes omnium editiones cum uetuſtiſſimis aliquot, iiſq́; manu ſcriptis exemplaribus diligentiſſimè collati. Qua quidem in re ea & fide uſi ſumus & religione, ut neq; quippiam, quod è re ſtudioſorum fore iudicabamus, uiſum fuerit prætermittere, neq; ex ueteri receptaq́; ſcriptura uel apicem immutare. Mediam itaq; rationem, eamq́; tutiſſimam ſecuti, lectionum uarietates, quæ aut cæteris præſtare, aut certè ex æquo cum illis certare uidebantur, conſueta lectione incolumi, ad marginem curauimus adijciendas.

Annexæ ſunt præterea in calce operis Caſtigationes Sigiſmundi Gelenij.
Has ſequitur Index longe quàm locupletiſſimus.

LVGDVNI,
EX OFFICINA GODEFRIDI
ET MARCELLI BERINGORVM FRATRVM,
M. D. XLVIII.

Fig. 2. Title page of 1548 edition of *Natural History* by Pliny, written in the first century AD, the first book containing extensive gemmological information.

ton University to achieve understanding of the subtleties involved and this also resulted in an understanding of Pliny's 'myth', which almost certainly was based on the papyrus recipe No. 36 cited above.

Pliny's 'Emerald Oiling'

The routine oiling of emerald without disclosure is sometimes considered to be justified on the claim that it has been in use for at least two thousand years. We are here speaking of the use of a colourless oil to fill open cracks and fissures in emerald to make these defects invisible or at least less obvious to the naked eye. The claimed antiquity of this process is based on a passage in Pliny. I myself accepted the conventional interpretation of this source in one of my books (Nassau, 1984, pp. 7, 100) and elsewhere, but have now investigated this matter in detail, reaching a very different conclusion.

Here again, it is absolutely vital to establish exactly what the words used meant. First of all, the word 'smaragdus' is stated by Pliny to include twelve varieties. These are now recognised to encompass not only emerald but also other green to bluish-green materials such as green sapphire, turquoise, malachite, amazonite, lapis lazuli, green alabaster, green jasper, and so on (Eichholz, 1962, p.213; Ball, 1950, pp. 140 ff, 256 ff). Pliny himself states that all smaragdi except the Scythian, Egyptian, and Attic ones are found in copper mines. Eichholz (1962, p. 214) concludes that only the Scythian and Egyptian smaragdi of Pliny were true emeralds.

Another critically relevant fact is that green gemstones were preferred to blue ones at that time. As one example, Pliny says: "... of all colours, green is the most pleasing to the eye" (Ball, 1950, p. 140). Again, Pliny states (Ball, 1950, p. 143) with respect to Persian smaragdus (probably turquoise): "... they have this fault that they have the colour either of gall or the sky ... but are still not green".

With these two considerations in mind, let us examine what Pliny actually does say about the oiling of smaragdus in Chapter 18 of Book 37. Here are the three authoritative translations of the passage:

> I: "Such smaragdi [of Media] as are not naturally green may be improved and reach their full beauty by being washed in wine and oil" (Ball, 1950, p. 144, based on Philemon Holland's translation of 1601).
>
> II: "... [Median smaragdi] appear naturally of a green colour, but become improved by the addition of oil" (Bostock and Riley, 1898, p. 412).
>
> III: "Such stones [Median smaragdi], in spite of their varied colours, seem to be green by nature, since they may be improved by being steeped in oil" and footnote: "Pliny probably means that green seems to be the natural colour, because this colour is the one 'restored' by steeping the stones in oil" (Eichholz, 1962, p. 221).

There is general agreement that Median smaragdus is not emerald: it is either malachite (Eichholz, 1962, p. 220), turquoise or intergrown malachite and azurite (Ball, 1950, p.144). If it is malachite, then a poor chalky grade could have its colour improved by oiling. A much more likely candidate is turquoise, a material that does occur in 'varied colours' – both blue and green – and can be readily changed from blue to the then-preferred green colour by acid, acidic perspiration, and undoubtedly by oil, especially if it is mixed with acid wine or is acidic from rancidity.

If it means anything at all, Pliny's 'oiling of smaragdus' can thus be interpreted as the turning green by oiling of blue turquoise or of poor quality malachite!

Essentially all the occasional references to emerald oiling in the centuries that followed are clearly based on the usual misinterpretation of Pliny's smaragdus oiling. As one example (King, 1860), the Abbot Marbod, writing in France about 1070 AD, also cites twelve varieties of smaragdus, as did Pliny, and again paraphrases Pliny:

> "If steeped in verdant oil or bathed in wine
> It's deepened hues with perfect lustre shine."

There is also mention of the use of oil on gemstones in the much earlier papyrus discussed above, but there the oil is the medium that carries dyes and pigments into crackled stones to produce imitations. There seems to be no hint of the use of a colourless oil merely to hide defects.

In summary, there are no convincing ancient reports of emerald oiling. This is not to say that some may not have tried these instructions in the conventionally misinterpreted form throughout the centuries and obtained an improvement in appearance from the filling with oil of the cracks in the emerald. But we do not have any persuasive documentary evidence of it. Therefore we cannot attribute the emerald oiling process to antiquity.

Modern emerald oiling

When we examine more recent sources, such as the writings of the great gemmologists of the nineteenth and twentieth centuries, we find an even more surprising situation. None of these refers to emerald oiling before the 1960s! This is most astonishing in the case of Max Bauer, whose *Precious Stones* of 1904 is one of the most detailed gemmological treatises ever written. In his text he mentions many treatments, but for emerald only green foil backings for pale stones and closed black settings for fissured stones. Equally astonishing is the absence of emerald oiling in early editions of Webster's authoritative *Gems*, where only in the fourth edition of 1983 (Webster and Anderson, 1983) does an account finally appear. (The 'oiling' with kerosene by Brazilians mentioned on p.91 of Webster's third edition of 1975 is clearly *not* the modern oiling process). There is also no mention of emerald oiling in early editions of Liddicoat's *Handbook of Gem Identification* or Anderson's *Gem Testing*.

The first reference to modern emerald oiling that I have been able to locate is in Liddicoat's 6th edition (1962, p.280), where it is referred to as a 'longstanding' process. The process itself is outlined for the first time in an unsigned article in 1981 in the *Retail Jeweller* (Anon., 1981), soon followed by a detailed description by Ringsrud in 1983. I should like to hear if any reader knows of earlier references to the modern oiling process which I have overlooked.

Unable to locate older convincing documentary mention of the modern oiling process, I finally turned to the memory of the master gemmologists Richard T. Liddicoat and Robert Crowningshield of the Gemological Institute of America, to both of whom and their associates I am grateful for help. They also checked with several octogenarian sources accessible to them. The earliest any of these sources could definitely locate trade emerald oiling was about 1910. There was also some feeling, but certainly no proof, that trade emerald oiling may *not* have existed before 1910.

If we then assume that trade emerald oiling began soon after the turn of the century, how to explain the 'conspiracy of silence' that existed among gemmologists for some half a century, with but a minimal mention over the next 30 years? An examination of the aquamarine heating process may be relevant: this enhancement has been used to convert essentially all green aquamarine to the currently more desired blue colour (blue is rare for aquamarine as mined). Here again there is no mention of this process in Bauer; Liddicoat first refers to it in 1981 in the eleventh edition of his *Handbook of Gem Identification*; Anderson mentions it only in the ninth edition of his *Gem Testing* in 1980; but a description does occur as early as 1962 in Webster's first edition of *Gems*. There is thus an earlier complete absence of mention of this process and subsequently only rarely a reference to it. It is usually accepted that the reason for this derives from the widespread use of aquamarine heating being known by all, with everyone recognizing it as obvious and indeed to be expected. Perhaps this type of explanation applies equally well to trade emerald oiling in the twentieth century. There is, of course, one significant difference between these two products: the colour of heat-treated aquamarine is stable in normal use, but the oil in oiled emerald may dry out or be washed out by detergent.

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Anomalous behaviour of certain geuda corundums during heat treatment

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Abstract

A geuda variety known as 'ottu' with dark blue patches on the outer surface when heat treated at (1800-1850)°C under reducing conditions produced three types of samples. They showed (a) good blue colour and clarity (b) insufficient blue colour but good clarity (c) formation of a thick white precipitate ('dead milk') on the outer surface. In order to understand the cause of these changes EPMA results were studied.

The results, while confirming that Fe and Ti are necessary for producing a good blue colour, indicate that the presence of other minor impurities hinders this process. The results also indicate that a high concentration of Fe and Ti, together with V and some other impurities gives rise to the formation of the thick white precipitate on the outer surface during heat treatment.

Introduction

Sri Lanka has a large reserve of the low quality gem variety called 'geuda'. Geuda is the term used to describe the whitish or pale blue corundum of poor colour and clarity. Heating at temperatures in the range (1600-1900)°C could transform these into good quality blue sapphires. Depending on the visual character, terms such as blue geuda, diesel geuda, silky geuda, ottu etc. are used in the trade to describe different varieties.

Light blue or colourless stones with dark blue patches on outer surfaces – varieties of 'ottu' – when heat treated under reducing conditions in the temperature range 1800-1850°C produced three types of results. They were:

(a) Clear blue stones
(b) Clear stones that did not attain a satisfactory colour
(c) Stones with a non-transparent white coating ('dead milk').

Over 50% of the results belong to the (c) group.

When the initially heated stones were re-heated under oxidising conditions in the temperature range 1600-1800°C, types (a) and (b) showed a reduction of blue colour. No change was observed in type (c) stones. This white coating could not be removed even after heating at higher temperatures. Hence an investigation was initiated using the Electron probe micro-analyser (EPMA) to study the cause of these changes.

Experimental details

Around 50 stones of the 'ottu' variety all with dark blue patches on the outer surfaces were heat treated in the temperature range 1800-1850°C for 1 hour under reducing conditions. The types (a), (b) and (c) obtained after heat treatment were selected and analysed using the EPMA (Schimadzu – Model 8705). This is a unit with multiple wavelength dispersive X-ray spectrometers (WDX) to enable elements from $_4$Be to $_{92}$U to be detected. The 3 channel spectrometer was used with the spectral crystals RAP, PET and LIF. Accelerating voltage and specimen current were set at 15kV and 0.05 μA respectively throughout the analysis. Constant beam width of 100μm was always employed to analyse the samples.

The samples were scanned at a very low scanning speed of 0.1Å/min to carry out qualitative identification of the trace elements. Exact peak positions were searched for elements of interest and cumulative counts were recorded at the peak positions and background for 10 second intervals.

Since this analysis was concentrated mainly on colour-causing impurities such as Fe and Ti similar procedure was repeated to analyse standard solid samples with varying concentration of Fe and Ti in Al_2O_3 (Fe,Ti range: 0.01%-0.5%). Calibration curves were used to estimate trace elements semi-quantitatively.

The selected areas on the samples were flattened and mirror polished. Cross sections of the stones of type (c) were taken to analyse the blue (centre) and dead milk areas (edge).

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Results and discussion

The samples were scanned at very low scanning speeds under the same experimental conditions using the EPMA, and the results were analysed and averaged. The lowest detecting limit of Fe and Ti was 0.03%. The concentration levels were classified as: low – 0.03% to 0.15%; medium – 0.15% to 0.3%; high – above 0.3% (see Table 1).

Table 1: EPMA results of heat treated 'geuda' corundums

Samples	Fe	Ti	V	Minor Trace Level Impurities
(a) Good blue stones	*	X	ND	Na, K, Mn
(b) Very pale blue/ colourless stones	*	*	ND	Na, K, Ca, Si, Zn
(c) Stones with 'dead milk'				
(i) 'dead milk' area	**	***	Y	Na, K, Ca, Mg, Ga, Mn, Si, Cr
(ii) blue area	*	*	Y	Na, K, Mg, Si

* – low (0.03-0.15%)
** – medium (0.15-0.3%)
*** – high (above 0.3%)
X – average value below lowest detecting limit
Y – significant minor impurities
ND – Not detected

It is generally accepted that the blue colour of sapphires was caused by the formation of the $(Fe.Ti)^{6+}$ bi-particle (Nassau, 1984; Eigenmann and Gunthard, 1972; Harder & Schneider, 1986; Ediriweera & Perera, 1989).

The average results (Table 1) show that the concentration level of Fe in types (a) and (b) were similar, whilst the concentration level of Ti seemed to be lower in type (a) than in (b). The majority of the type (a) samples showed Ti up to about trace impurity level and a few samples showed a slightly higher level similar to Fe. The only detected additional impurities in (a) were Na, K and Mn. Some type (a) specimens did not even show traces of any of the minor impurities. However in type (b) stones, the presence of a number of minor impurities were clearly noticeable (Na, K, Ca, Zn, Si).

When the 'dead milk' areas in type (c) stones were analysed, relatively higher concentration levels of Fe and Ti were detected than in clear areas. In all these type (c) samples the Ti level was noticeably higher than Fe (Table 1). Among other minor impurities V was always present in all the type (c) samples analysed. In 'dead milk'-free areas the Fe and Ti levels were much lower than in the 'dead milk' areas and the number of minor impurities were also low.

However the reported minor trace impurities were identified during the qualitative analysis. Since presence of V was possibly more significant than the other minor impurities, those results were tabulated separately, but no quantitative estimates are available for V.

The possibility of contamination due to sample preparation was ruled out by analysing similar types of samples without employing the special preparation method. Further detection of similar impurities in natural corundums have been reported by Schmetzer and Bank (1980, 1981), Bosshart (1982), Schmetzer and Bosshart (1983) and Schrader (1986).

Conclusion

This study suggests that whilst the presence of Fe and Ti is necessary to give a blue colour to corundum, the presence of other minor impurities could prevent the formation of the required bi-particle and hence not produce an acceptable blue colour. This confirms the hypothesis of Schmetzer and Bank (1980) in the explanation of different behaviour of heat treated corundums due to other additional impurities.

The formation of the thick white precipitate ('dead milk') on the outer surface was apparent in stones with high impurity concentration levels especially Fe and Ti. It is possible that V and some of the other impurities present in the sample may have helped this process.

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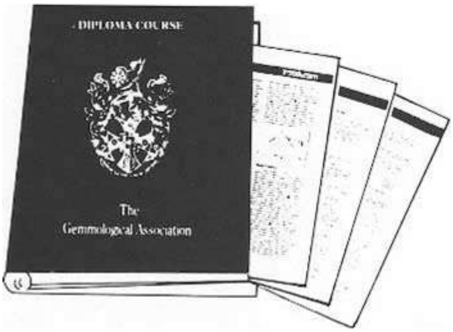

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Emeralds from Colombia (Part 2)*

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Switzerland

Abstract

A condensed historical and mining survey is followed by a compilation of the most notable crystals of Colombian emeralds ever found and of the details of their chemical composition. A summary of the elemental substitutions and their effects on the outlined range of gemmological data is given.

Special emphasis is placed on the cause of the famous, vividly green coloration, i.e. on the selective absorption of orange-red and violet light, dictated by minor contents of the chromophoric elements Cr and V substituting for Al^{3+} in octahedrally coordinated sites of the beryl lattice ($Cr \approx V$, with the Cr/V ratio found to be ranging from 4.5 to 0.5, in extreme cases from about 10 to 0.1). Iron, however, has barely been detected in the UV/VIS absorption spectra of Colombian emeralds. Though generally present in slightly larger amounts than Cr^{3+} iron does not recognizably influence the colour (little Fe^{2+} and possibly some Fe^{3+} positioned in the axial channels of the ring-silicate structure).

A detailed presentation of the currently known internal characteristics (inclusions and growth structures) is supplemented by a discussion of identification problems with treated emeralds and the disclosure of the treatment during transactions in the wholesale and retail trade.

Allocation of the emeralds to individual Colombian mines on the basis of inclusion patterns does not appear possible in most instances. However, the differentiation of Colombian emeralds from other natural emeralds (such as those from the Panjsher Valley exhibiting very similar (s,l,g) three-phase inclusions) or from difficult, modern hydrothermal and flux synthetics is shown to be feasible by a combination of microscopy, refractometry, and absorption spectrometry (UV/VIS and NIR/MIR), assisted by chemical analysis only in the most difficult cases. Safe identification of authenticity, treatment, and origin of emeralds, however, is increasingly becoming the task of the experts in the specialized laboratory.

The mineralogical definition of emerald as a yellowish to bluish-green variety of natural beryl is shown to be valid for any Cr and V-containing variety except possibly the rare, absolutely chromium-free (V,Fe)-beryls (modification of the former definition of type II emerald): in many of the preferred Colombian emeralds, chromium is clearly dominated by vanadium (Cr/V ratio < 1). However, chromium has a higher efficiency of coloration than vanadium and a much higher one than iron ions in the various substitutional and interstitial lattice sites of beryl. Cr influences colour even at very low trace levels.

An extensive and up-dated selection of literature, covering all aspects cited, completes the synopsis.

The introduction to this review is based on the study of a fraction of the extraordinarily extensive literature on Colombian emeralds.
The main part of the paper (Part 2) contains data collected and findings achieved over many years in the SSEF Laboratory in Zurich.
Part 3 will deal with the difficulties encountered in identifying treated emeralds and with the disclosure necessary when selling them and will discuss the possibilities of differentiation between Colombian and other natural emeralds and the synthetic emeralds.

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*This is a paper which will be published in *The Journal* in three parts. The complete bibliography is presented with Part 1.

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Table 1. Some of the largest known Colombian emerald crystals of special quality, in the chronological order of their discovery

(1831)	Muzo (Devonshire Emerald)	1384 ct	unknown (once Brit. Mus., London)
1920	Chivor (Patricia Emerald)	632 ct	Amer. Mus. Nat. Hist., New York
(1950)	Muzo (five crystals, 220-1796 ct)	1759 ct	Banco de la República, Bogotá
1967	Vega de San Juan (Gachalá)	858 ct	Smithson. Inst., Washington DC
1969	Las Cruces, Gachalá (Emilia)	7025 ct	private Colombian collection

Gemmological properties

C1. *Morphology, quality and size of the emerald crystals*

The crystal forms most commonly observed in Colombian emeralds are the first and second-order hexagonal prisms with flat end faces (basal pinacoid) and their modification with small pyramidal faces. It is definitely rarer to find the dihexagonal prism, the dihexagonal bipyramid and combinations of crystal forms with still more faces. Elongated crystals often grow parallel to each other or form fan-shaped or radiating aggregates. Such growth types may contain cavities.

Most Colombian occurrences produce a wide range of emerald qualities with respect to colour and transparency. The opaque material called *'moralla'* presents the poorest quality grade. Good qualities, however, are very saleable in Europe and, according to statistics, even more so in Japan, for instance as centre stones in finer jewellery.

The showy *Trapiche emeralds* from Muzo, Coscuez and Peñas Blancas on the other hand appear to be collectors' items more than jewellery components. The name 'Trapiche' is derived from the hexagonal cog-wheel barrel used in Colombian sugar mills. The growth forms of Trapiche emeralds are fairly variable looking. They consist of six sectors respectively six radial emerald crystals, regularly arranged around a steeply tapering hexagonal pyramid and separated from each other by white albite or dark carbonaceous shale particles (cf. special literature). Very rarely *cat's-eye emeralds* have been reported also (a specimen of 4.6 ct is housed in the Smithsonian Institution, Washington DC).

Outstanding emerald crystals have grown to prism lengths of 10 cm (and more) and to diameters of 6 cm, corresponding to weights of the order of 4000 carats. This is phenomenal for emeralds, yet not unusual for other beryl varieties, with beryls of industrial quality reaching weights of several tons.

Probably the largest emerald crystal of good quality ever found weighed 3204 g (16,020 ct) and was baptised 'Muzo' after its place of origin. The largest polished emerald also came from Muzo and is a perfume bottle, 10.9 cm in height, which was engraved in the year of 1641 by Dyonisio Miseroni in Prague. It weighs 2680 ct and can be admired in the Treasury of the Hofburg in Vienna. 'Patricia', the unofficially most beautiful emerald was reported to have been dethroned by two single crystals dug out in Muzo in 1988, measuring 5.8 and 5 cm in prism length.

C2. *Chemical composition, chromophore and trace element contents*

In natural emerald the major constituents of beryl – BeO, Al_2O_3, and SiO_2 – are commonly accompanied by minor constituents and trace elements, the individual amounts of which vary considerably. Three kinds of minor constituents can be differentiated:

- water molecules (in the open Si_6O_{18}-ring channels),
- alkalis (mainly Na_2O and MgO) and
- chromophores (mostly Cr_2O_3 and Fe_2O_3, but also FeO and V_2O_3).

In his review *Esmeraldas*, Schwarz (1987) compiled a significant number of published chemical compositions of emeralds.[3a] The data vary in part widely from author to author.

From the compiled compositions it can be deduced that the *water content* of the Colombian

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[3a] The formula of the cyclosilicate structure of emerald is $Be_3(Al,Fe,Cr,V)_2[SiO_3]_6.xH_2O$, with $x < 1$. According to literature, synthetic emeralds produced by flux or hydrothermal procedures show minimal contents of the major constituents BeO, Al_2O_3 and SiO_2 of 13, 17 and 64.5 weight % respectively. The corresponding values of most natural emeralds are below these limits, while those of Colombian, Afghani and Nigerian ones are slightly above. Numerous natural, many Colombian and some Afghani emeralds show a higher content of MgO and Na_2O than the synthetics (maximum values of the synthetics so far are 0.6 and 0.3 wt.% respectively). Apart from that, the Colombian, like all other natural emeralds, contain zeolitic water of type I and II (while the flux synthetics do not). Conversely, the Colombian emeralds are free from chlorine (Cl can be found in the hydrothermal synthetics of Linde and Biron/Pool, as well as in the fluid inclusions of Colombian emeralds, of course). They do not contain nickel (Ni^{3+}) and only traces of lithium and moderate iron (unlike the recent hydrothermal synthetics of Russian manufacture, Schmetzer 1988).

[3b] Schwarz (1990a) found the following subdivision useful for the characterization of minor constituent contents in emeralds:

low	*medium*	*high*	
< 1.5	1.5 – 2.5	> 2.5	wt% MgO
< 1.0	1.0 – 2.0	> 2.0	wt% Na_2O
< 0.2	0.2 – 0.4	> 0.4	wt% Cr_2O_3
< 0.5	0.5 – 1.0	> 1.0	wt% FeO

emeralds (0.5 to 1.9 weight% H_2O) is below or equal to the average of natural emeralds of other origins.

The infrared spectra of Colombian emeralds usually indicate a slight predominance of type II water over the free type I water. This is mainly due to the presence of Na^+: As electric dipoles, water molecules are orientated and bonded in the ring channels by neighbouring alkali and other cations and thus called type II water. Type I water is not alkali-bonded (Wood & Nassau 1968).

A *coupled atomic substitution by alkalis* regularly takes place in natural emerald: Mg^{2+} mainly replaces Al^{3+} on the lattice sites of beryl while the larger-sized Na^+ ion is built into the ring channels of the crystal structure for electric charge compensation.

The *magnesium and sodium oxide contents*[3a,3b] of Colombian emeralds (averaging 0.7 and 0.6 wt% respectively) are definitely lower than the corresponding values of natural emeralds of metamorphic and other provenance, excepting the very low Mg and Na contents of the recent emerald finds from Jos, Nigeria.

Colombian emeralds take up a central position with regard to the substitution of aluminium in the beryl structure by the colouring transition elements, *the chromophores* Cr^{3+} *and* V^{3+} (in company with some Fe^{3+} and Fe^{2+}). Often they contain a little more Cr than V and relatively little total Fe (averaging about 0.3, 0.1 and 0.3 oxide%[3b] respectively and a Cr/V ratio of approximately 3). In the next chapter, the effects on absorption and colour will be compared to those of natural emeralds with higher iron or vanadium contents.

In addition to these minor constituents, the following *trace elements* (and molecules) foreign to the beryl formula have been reported in Colombian emeralds:

Ca,Sr,Ba,Mg^{2+} / K,Rb,Cs^+ / CO_2(?), F_2 and radiogenic He in the structural ring channels

Li^+ (and vacancies) on the tetrahedrally coordinated Be^{2+} lattice sites (i.e. each beryllium ion is surrounded by four oxygen ions located in the corners of a slightly distorted tetrahedron)

Ti^{4+},Sc^{3+} / Mn,Ni,Fe^{2+} / Li^+ (and vacancies) on the octahedrally coordinated Al^{3+} lattice sites (AlO_6 octahedra) and

Al^{3+} on the tetrahedrally coordinated Si^{4+} lattice sites (SiO_4 tetrahedra).

All the properties discussed below are the results of the fluctuating supply of chemical elements during emerald growth and of the imperfect structure of these crystals. This so-called real structure has been considerably disturbed by the incorporation of foreign chemical elements and by inhomogeneous growth conditions (rapid pressure/temperature changes, geotectonic stress, etc.).

C3. *Light absorption, colour and fluorescence*

Chromophores causing green colour in beryls (and other silicates) by means of selective absorption of light are the transition metals *Cr,V,Fe,(Mn),Ni,Co and (Cu).*[4]

Cobalt and copper appear to be absent in Colombian emeralds. Their iron contents and traces of manganese and nickel have no colouring effect in the presence of chromium and vanadium as will be shown in the evaluation of the spectra.

If (Cr,Fe)-emeralds are designated 'normal' or type I emeralds and the yellowish-green (V, Fe,Ni,Mn,Cr)-beryls as type II (Taylor 1977), the Colombian emeralds with their Cr/V ratio averaging about 3 may be classified as the last representatives of the more frequent type I. This type shows Cr/V ratios from 1.0 to 40 (in extreme cases to over 100). Thus the Colombian emerald population is bordering the rarer type II which has Cr/V ratios below 1 (normally far below parity). Therefore they could also be considered as an intermediate emerald type.

Most other natural type I emeralds are lower in vanadium (V-free to V-poor) but higher in Fe^{3+} and Fe^{2+} (ferriferous to Fe-rich). They display a bluish-green to blue-green colour, most obvious in the border-cases between emeralds and aquamarines like in certain stones from Miku, Zambia.

The other extreme is represented by the (V,Fe)-beryls, e.g. by those from Salininha (Bahía). They are nearly free from chromium ($Cr/V < 0.1$) and are still green, yet more yellow-green than the Colombian emeralds. On average, their absorption minima are shifted only 10-15 nm towards the yellow (in Figures 2a and 3 from approximately 502 to 513 nm for the mean value of the *o* and *e* spectra). Usually Biron synthetics also show a higher content of V than of Cr (Cr/V ratios from about 0.2 to 0.7).

Evaluation of the absorption spectra

The absorption diagrams of emeralds do not allow a quantitative analysis of the colouring agents Cr, V, Fe, etc.:

In the visible (VIS) region of the electromagnetic spectrum, chromium efficiently masks medium iron and vanadium contents (Figures 2a,b,c) due to its very high absorption coefficient (a beryl plate of 10 mm thickness is discernibly coloured by as little

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[4] According to the mineralogical definition, emerald is the yellow-green to blue-green variety of beryl. Every gemmological attempt to sharply separate Cr-emeralds from other green beryls must fail regardless of whether the criterion is the absolute chromophore content (i.e. colour saturation) or the ratio of the individual chromophore contents (i.e. colour hue). Delimitations of the emerald term for the needs of the gem trade as proposed by Superchi & Rolandi (1980) suggesting the use of the DIN 6164 Colour charts are remarkable but lack the international approval and a generally accepted, simple usage.

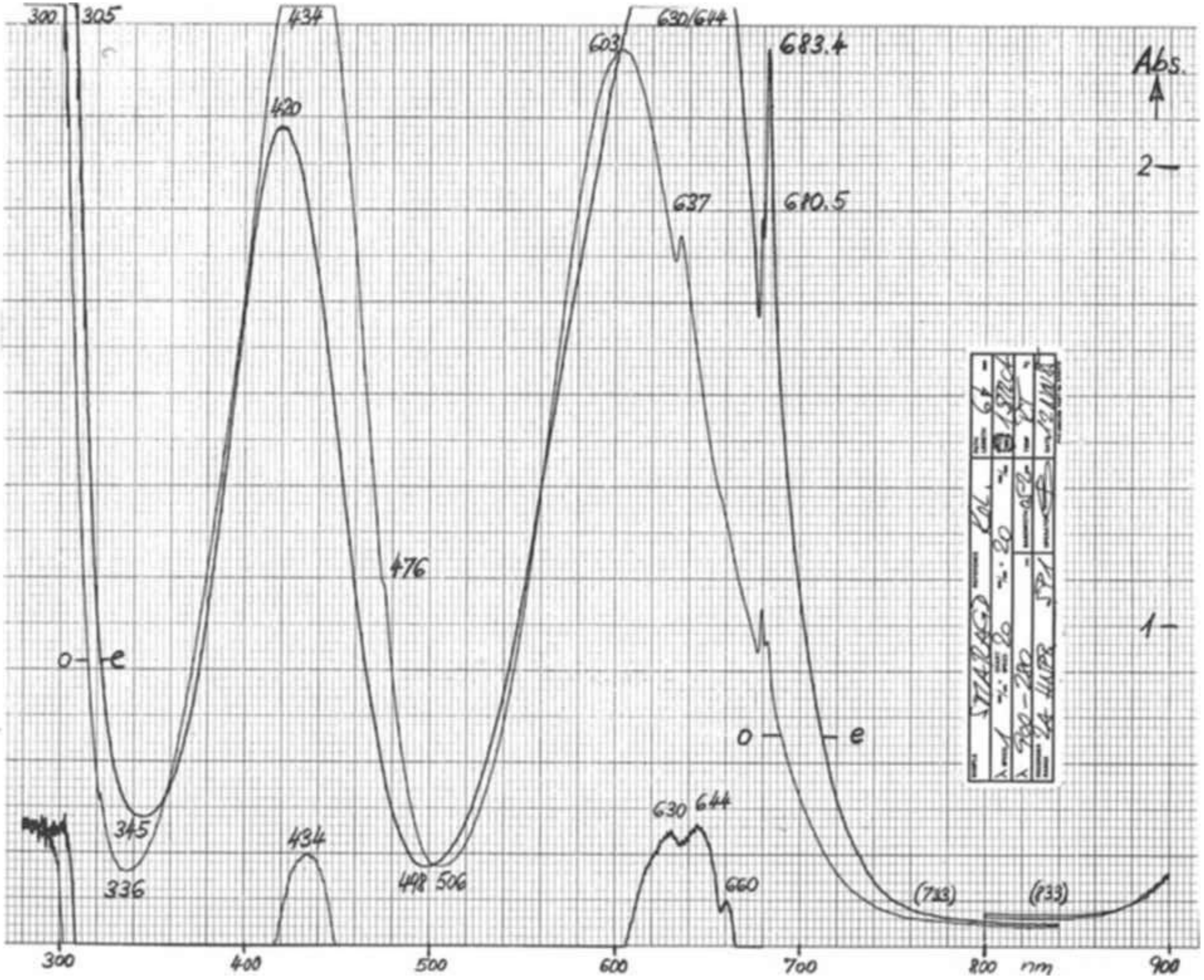

Fig. 2a. Polarized absorption spectra of a saturated green Colombian emerald. Emerald type I due to a Cr/V ratio ≥ 1 (here Cr/V ≈ 1.5). Weight 1.872 ct, density 2.713 g/cm³, $n_{D,e}$ 1.578, $n_{D,o}$ 1.585, optical path length nearly 6 mm. Medium chromium content (high for a Colombian emerald). Ordinary (o) and extraordinary (e) ray spectra with polarization perpendicular and parallel respectively to the optical axis, recorded at ambient temperature in the first focal locus of a Pye Unicam SP8-100 UV/VIS spectrophotometer (Bosshart 1982), with a Polaroid HNP'B polarizer filter mounted in front of the detector.

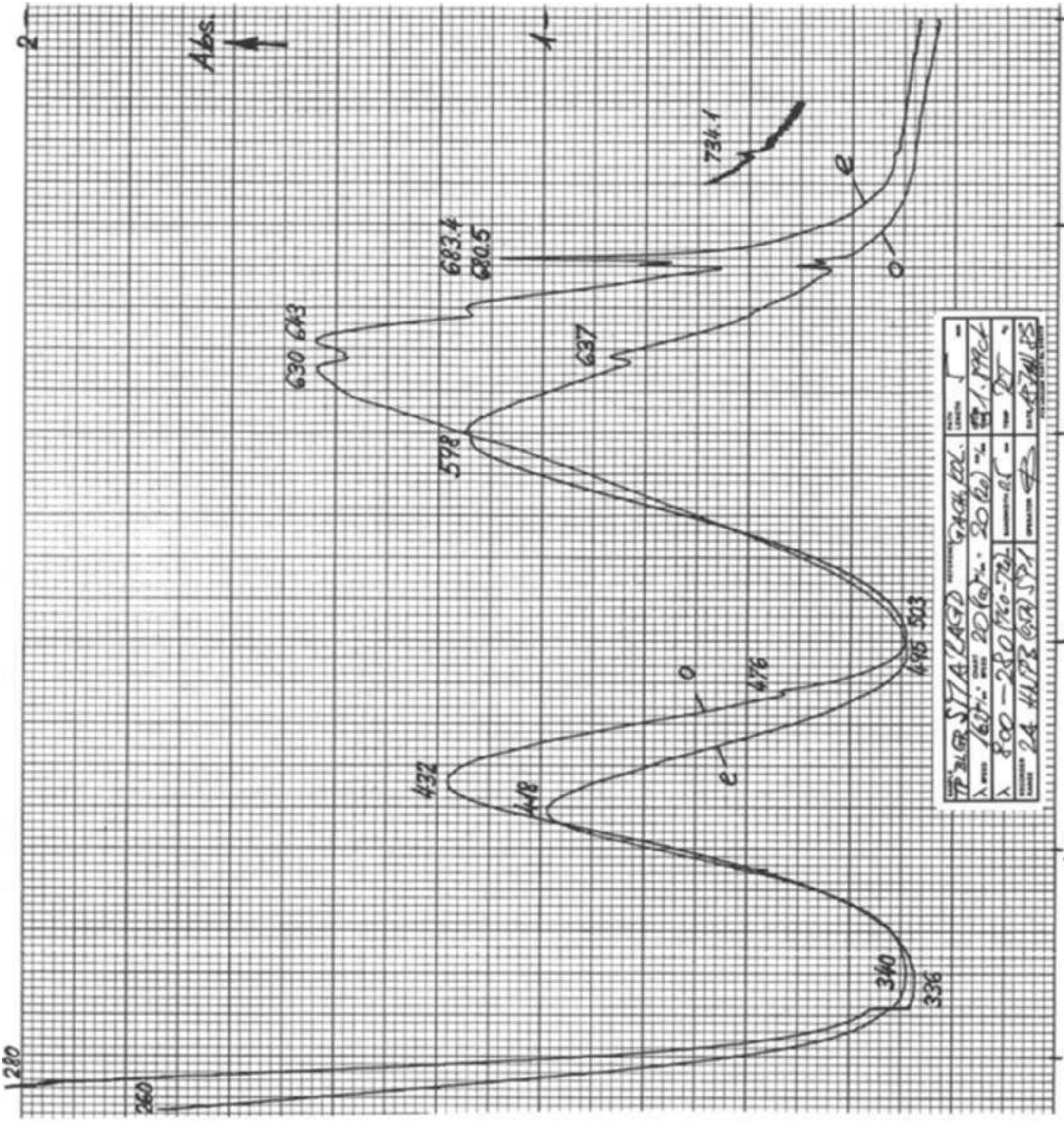

Fig. 2b. Polarized absorption spectra of a pale bluish-green emerald from Gachalá(?), Colombia. Emerald type I, Cr/V ≈ 4. Weight 1.899 ct, density 2.687 g/cm³, $n_{D,e}$ 1.574, $n_{D,o}$ 1.580, optical path length about 5 mm.

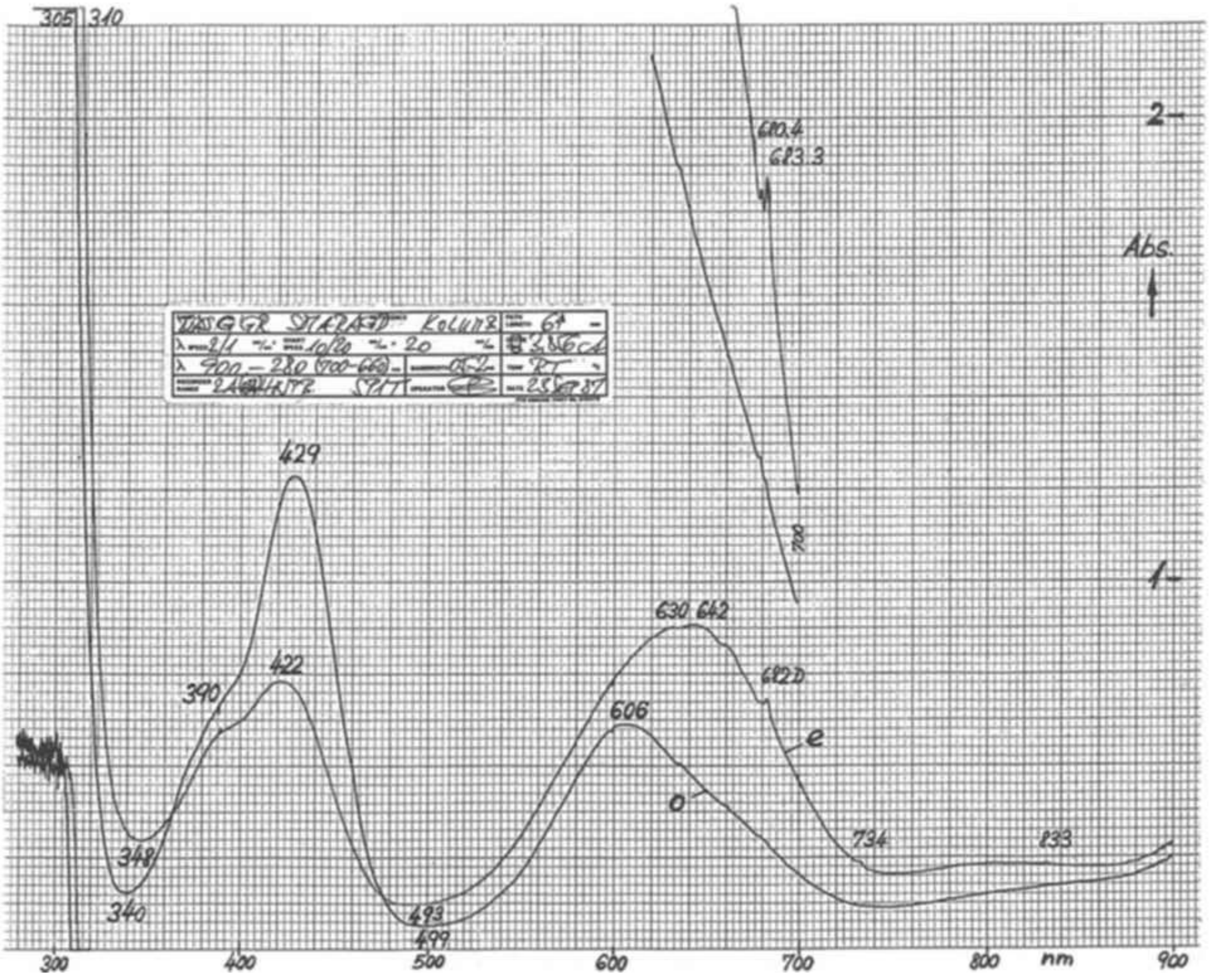

Fig. 2c. Polarized absorption spectra of a pale yellowish-green Colombian emerald. Emerald type II, Cr/V ≈ 0.8 (possibly less). Weight 3.856 ct, density 2.690 g/cm^3, $n_{D,e}$ 1.572, $n_{D,o}$ 1.579, optical path length about 6 mm.

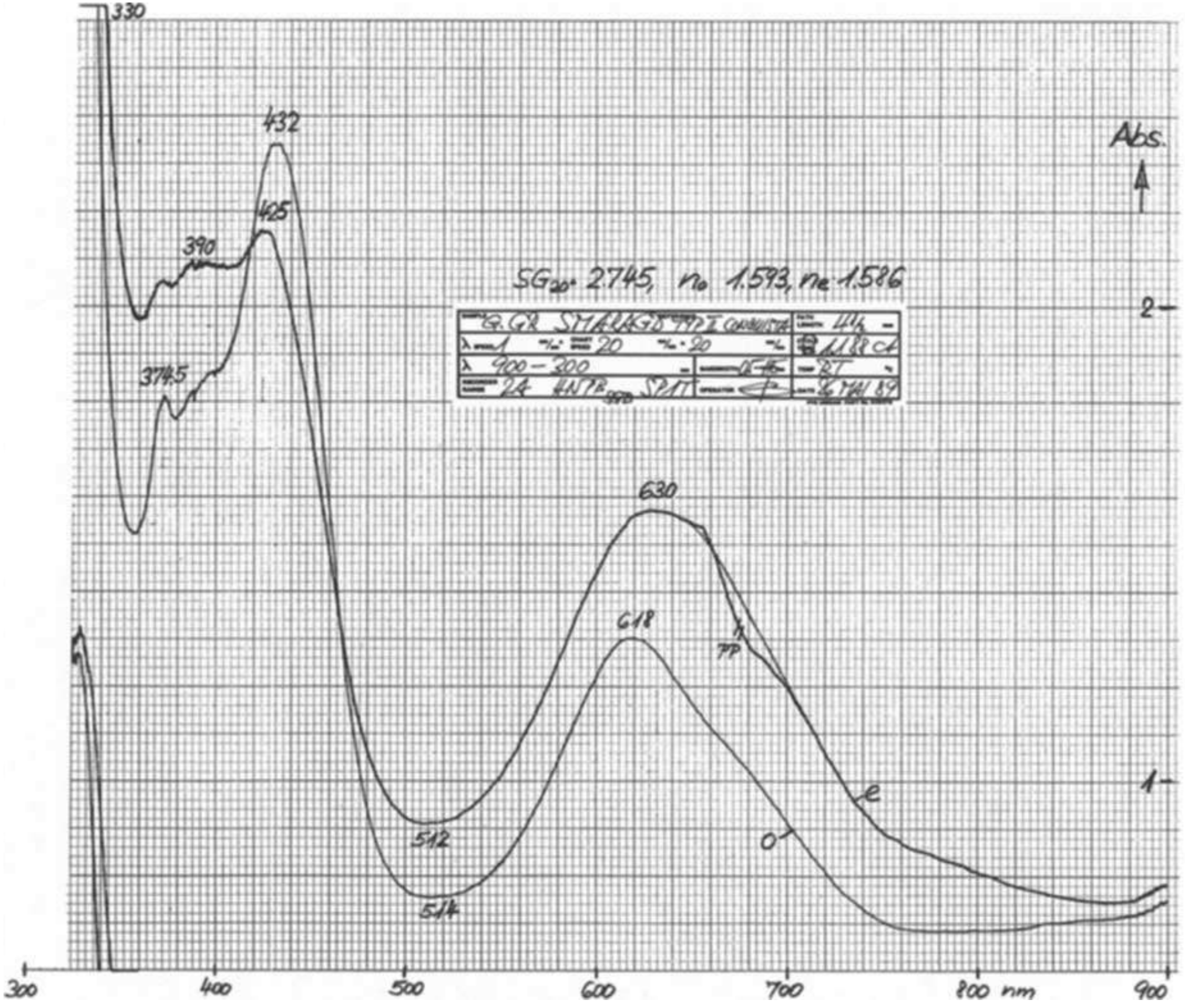

Fig. 3. Polarized absorption spectra of a yellowish-green Brazilian emerald from Conquista(?). Emerald type II, Cr/V < 0.1. Weight 1.188 ct, density 2.745 g/cm^3, $n_{D,e}$ 1.586, $n_{D,o}$ 1.593, optical path length about 4.5 mm.

as 0.0025 % = 25 ppm Cr_2O_3, Wood & Nassau 1968).

In addition, the vanadium spectrum in the VIS (Figure 3) is very similar to that of chromium Fe^{3+} and Fe^{2+} may be positioned in various lattice and channel sites and then absorb in variable hues and mostly in low intensities.

a. The *positions of both colour-decisive*[4] *absorption bands in the violet and orange-red spectral region* are nearly identical for Cr and V:

polarization perpendicular to the *c*-axis (ordinary-ray vibration, *o*)
Cr bands near 430 and 593 nm,
V bands near 434 and 618 nm

polarization parallel to the *c*-axis (extraordinary-ray vibration, *e*)
Cr bands near 416 and 628/644 nm,
V bands near 426 and 630 nm.

While Al-substitution by chromium causes the well known *absorption lines* at
476, 637 nm (*o*), 660 nm (*e*) and
680.5/683.4 nm (doublet, $e \gg o$).
in addition to the bands cited above, absorption lines in the V spectrum are looked for in vain (they are situated in the near infrared region, according to personal communication with K. Schmetzer, 1989). Thus vanadium is optically masked in the VIS by the presence of chromium.

Nevertheless, well polarized, low-iron spectra enable a *rough estimate of the Cr/V ratio* by evaluating the position of the absorption bands. Overlapping of the Cr and V spectra produces intermediate positions of the absorption maxima, with laboratory recordings for Colombian emeralds averaging approximately
431 and 600 nm for the *o*-ray and
419 and 628 nm for the *e*-ray.
On this basis the average Cr/V ratio amounts to about
2.5 (variation from 0.5 to 4.5).
However, the most recent microprobe analyses (Schwarz 1990b, 1991), prove that V may be distinctly superior to Cr and in individual cases even much superior (or inferior). The variation of the Cr/V ratio of Colombian emeralds thus is wider, ranging from approximately 0.1 to 10.

The unexpected but incontestable fact is that the most cherished Colombian emeralds frequently are type II (vanadium) and not type I (chromium) emeralds.

b. Superposition of the Cr and V spectra intensifies the VIS absorption bands and increases the steepness of their slopes, thus creating the *brilliant and pleasingly pure colour* of the Colombian emeralds. Their slightly yellowish or bluish-green hue is highly valued. Hue and saturation are not caused by a particularly high Cr content as in the emeralds from Sandawana (Zimbabwe), Santa Terezinha (Goiás) or the Swat Valley (Pakistan) (in the latter two combined with high iron). Hue and saturation of the Colombian emeralds rather are generated by a subtle combination of low to medium amounts of the colour inducing elements Cr and V with comparatively little Fe.

The *dichroism* (*o*-ray yellowish-green, *e*-ray bluish-green) is weak in the majority of these stones, thus generally less distinct than in the ferriferous emeralds from metamorphic occurrences with their definitely aquamarine-blue *e*-ray component.

The *colour saturation* can vary considerably from one Colombian emerald to another. Apart from that, the colour distribution within a single crystal can be extreme to such an extent that a colourless zone is adjacent to a saturated green one. As a rule, the colourless zone is the older prismatic nucleus enveloped by a younger green skin, or there are paler zonal lamellae intercalated between saturated green basal growth layers. Conversely, even large emeralds can show an homogeneous and strong green saturation.

Colourwise, emeralds from the various Colombian mines cannot be distinguished, perhaps with the exception of those from Gachalá. They tend to be paler and a little more bluish-green than other Colombian emeralds (Figure 2b). Chemical data of Gachalá emeralds are scarce. The most recent analysis[5] demonstrates that this colour is not caused by a higher iron content but by lower Cr and V concentrations. Fe is also much lower than the Colombian average (0.3 wt%), and an aquamarine component in the *e*-ray absorption (due to Fe^{2+}/Fe^{3+} charge transfer) is not present.

c. UV/VIS absorption spectra of emeralds permit statements to be made with respect to chromophore ratios and colour, as well as *differentiations between*

[5] *Partial chemical analysis of eight Gachalá emerald crystals*
Microprobe data, in weight % (Schwarz 1991)

	Variation	Mean
SiO_2	66.77 – 67.55	67.22
Al_2O_3	16.69 – 17.48	17.15
Cr_2O_3	0.02 – 0.43	0.10
V_2O_3	0.02 – 0.15	0.09
FeO (Fe_{tot})	0.03 – 0.12	0.07
TiO_2	n.d. – 0.02	0.01
MnO	n.d. – 0.03	0.02
MgO	0.15 – 0.48	0.34
Na_2O	0.14 – 0.29	0.25
CaO	n.d. – 0.02	0.01
K_2O	n.d. – 0.01	0.01
Sum		85.27

BeO and H_2O not analysed | Cr/V ≈ 1.1

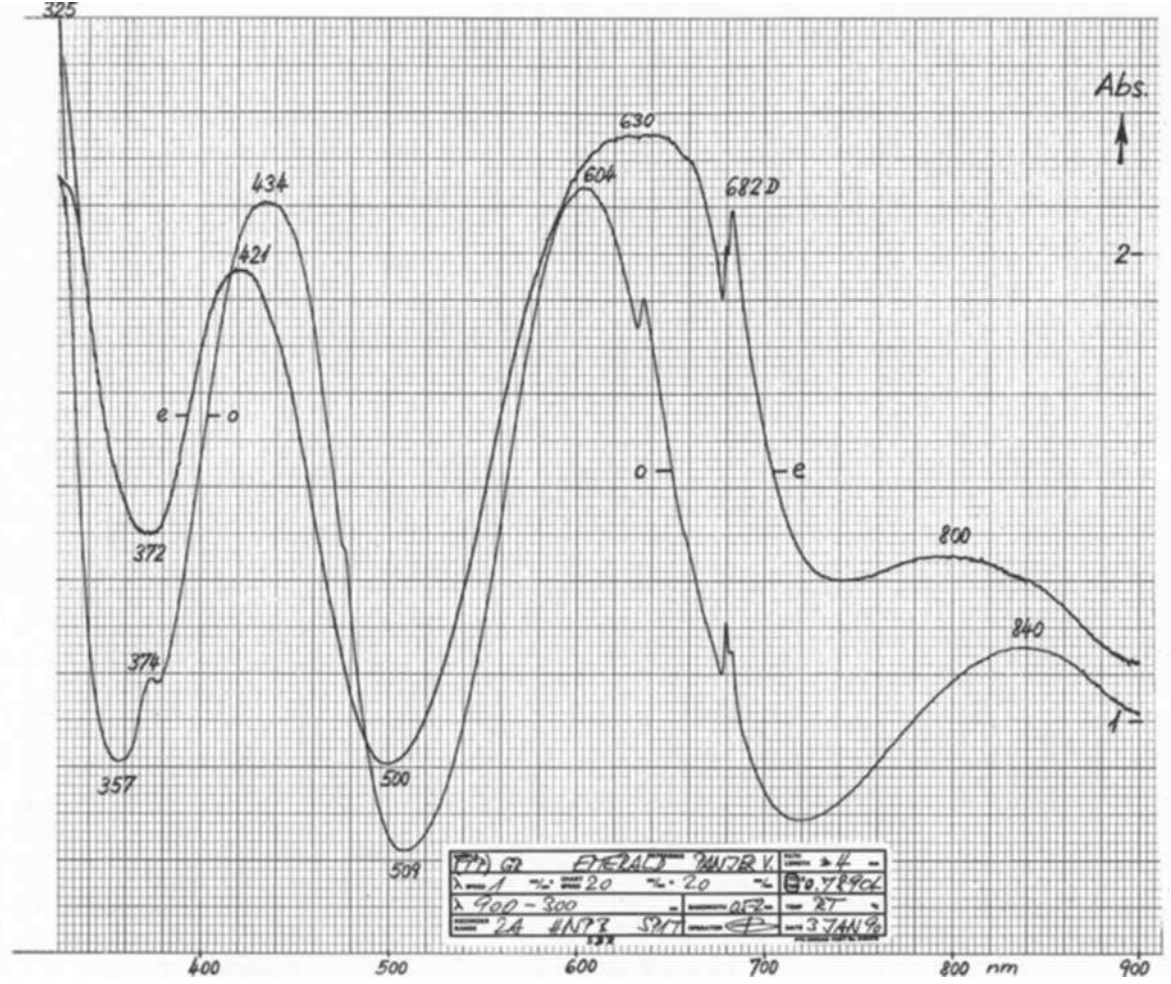

Fig. 4. Polarized absorption spectra of a bluish-green emerald from the Panjsher valley, Afghanistan. Emerald type I, Cr/V ≈ 1.5. Weight 0.789 ct, density 2.721 g/cm^3, $n_{D,e}$ 1.580, $n_{D,o}$ 1.588, optical path length about 4 mm.
Maxima of the absorption bands near 430 and 630 nm and of the line doublet near 682 nm quenched by stray light losses on the dense inclusion pattern.

certain origins and synthetic productions. For the latter, evaluation of the absorption features is carried out in the UV, similarly to that pertaining to the natural and synthetic rubies (Bosshart 1982), as well as in the very near infrared (see special literature for near and mid-IR analysis).

The average *position of the absorption minima in the ultraviolet region* for Colombian emeralds is at

340 (±5) nm for the *o*-ray and at
346 (±5) nm for the *e*-ray.

Transition from the *absorption edge* to the general absorption, on average, is at

298 (±15) nm for the *o*-ray and at
304 (±10) nm for the *e*-ray.

These UV minima and absorption edge positions have been found to be at lower wavelengths than those of natural emeralds from other deposits, including Jos, Nigeria, and Panjsher, Afghanistan (Figure 4), as well as those of synthetics containing iron or iron, nickel and copper (certain Gilsons, Inamori; Vasar USSR, etc.). Moreover, the UV minima of the Colombian emeralds are more deeply developed.

On the other hand, the low-iron synthetic emeralds (Chatham, Biron etc.) can be differentiated by their absorption edges at lower wavelengths and by their broader UV minima.

Absorption bands in the very near infra-red caused by Fe^{2+} (near 820 nm) have hardly been detected in Colombian emeralds nor in low-iron synthetics. In most natural emeralds (Figure 4) and in Fe-containing synthetics (Vasar), however, they can be observed. The structural position of Fe^{2+} is disputed (Al^{3+} octahedral, Be^{2+} tetrahedral or structural channels?).

The moderate Fe^{3+} content of Colombian emeralds usually does not make its appearance in their absorption spectra: the substitution of Al^{3+}oct. and Si^{4+}tetr. is very subordinate and the aquamarine component from Fe^{2+}/Fe^{3+} charge transfers on Al lattice sites is absent. Therefore the colour-inefficient positioning of Fe^{3+} might be suspected to take place in the structural channels.

Two minor absorption lines at 733.8 and 833.4 nm ($e \gg o$) are virtually always observed in Colombian stones, but have also been noticed in a Panjsher emerald and a synthetic Biron individual. The cause of these absorption lines is not evident.

d. Marginal notes for the practising gemmologist:

Cr absorption (and emission) lines can be seen through the spectroscope in type I but not necessarily in type II emerald (see Figures 2 and 3). However, because of the V masking discussed above, the observation of Cr lines in the hand spectroscope does not infallibly mean that the examined stone is a type I emerald containing more Cr than V, or even no V (examples Figure 2c and Biron synthetics).

The *UV-fluorescence* under long-wave radiation varies in Colombian emeralds from inert to medium weak red. The reaction to short-wave UV rays is nearly always inert. This, as also the behaviour observed with a Chelsea filter, is undiagnostic and not suited for the discrimination of emeralds from many synthetic emeralds.

A typically turbid, red *VIS-fluorescence* may be excited in many Colombian emeralds with strong, UV-poor lateral illumination from a fibre-optic beam (Figure 10).

C4. *Optical values and density*

The values given in Table 2 are low to average, compared to those of other natural emeralds. They relate to the numerous and largely independent substitutions by water, alkalis and chromophores which can be small to medium in amount. Accordingly there is *no strictly linear correlation of n and D.* This irregularity can be explained by the variable addition of zeolitic water (H_2O type I and II in the channels) which appears to influence density more than the optical values.

The sets of data taken from the literature and the values collected at the Laboratory largely agree. Table 2 does not include data for Trapiche emeralds nor moralla, but only for mediocre to excellent quality grade. The n (RI) and D values of Colombian gem-quality material are unlikely to lie outside the given ranges, yet slightly higher figures are to be expected for the rare specimens with abnormally high chromophore (or alkali) contents. Abnormally low density values such as 2.64_6 g/cm^3 (laboratory minimum 2.676) relate to enclosed cavities or artificial resin-like organic fillers (applied in new, permanent treatments).

While refractive indices may very occasionally be found to vary on strongly (colour-)zoned emerald individuals, the hydrostatic determination of the density in all cases results in one value only, the bulk density.

C5. *Inclusions and growth characteristics*

Solid and (primary and secondary) fluid inclusions, as well as growth inhomogeneities, are known as the main internal characteristics of Colombian emeralds. They permit conclusions to be drawn as to crystal growth and growth conditions. Characteristic features of Colombian emeralds are three- and multi-phase inclusions (Eppler 1973, Gübelin 1973, Roedder 1982, Gübelin & Koivula 1986, Kozlowski *et al.* 1988).

a. Primary *fluid inclusions* appear in crystallographically orientated, shallow cavities. Pseudo-

Table 2. Optical values and density of Colombian emeralds

Extraordinary refractive index	$n_{D,e}$	1.565 to 1.578	Literature
		1.566 to 1.581	Laboratory
Ordinary refractive index	$n_{D,o}$	1.571 to 1.584	Literature
		1.572 to 1.588	Laboratory
Maximum birefringence	n_e-n_o	-0.005 to -0.007	Literature
		-0.005 to -0.008	Laboratory
Anomalous double refraction		frequently present, strong 'moiré' extinction pattern (due to strain in the optic axis direction)	
Optic axis figure		axial cross, mostly open (abnormal, slight biaxiality)	
Dichroism		often weak (*o*-ray ≥ *e*-ray) *o* yellowish-green, *e* bluish-green	
Density (in g/cm^3)	D	2.64_6 to 2.73_0	Literature
	$D_{20°/4°C}$	2.682 to 2.727	Laboratory

Accuracy of Lab. data (estim.) $n_D \pm 0.002$, $D_{20°/4°C} \pm 0.005$ g/cm^3.

secondary fluid inclusions are usually smaller and not orientated as the primary ones are. In larger numbers, the secondary inclusions are connected to each other. They indicate slightly to strongly vaulted, ancient tension cracks (now healed fissures). In their entirety these *healing fissures* mostly produce but a slight turbidity. The gem trade sometimes calls the eye-visible veil in its green surroundings a 'jardin' (Figure 5).

The individual, more or less shallow primary *cavities* parallel to the main growth axis *c* are typically pointed or tapering into thin tubes. They form jagged peaks like regular fine palisades or coarse stockades (Figures 6,7,8). In basal directions they present more roundish, shape-less or angular contours. A peculiarity which the author until now has only observed in Colombian emeralds, is fluid inclusions bending off from the prismatic to the basal direction (or vice versa). The widespread interpretation as to the formation of the spiky-prismatic voids prior to the basal ones is very doubtful in this light. Their dissimilar shape does not point to a chronological succession but to growth conditions depending from directional differences within the crystals.

The cavities were originally filled with a homogeneous, single-phase brine at a temperature of over 470°C. This was an aqueous solution with a salt content of approximately 40 wt% Cl and Na ±(Ca,Si,Al,(C),K etc.). *At room temperature* and with magnification, this fluid filling is seen to be *mostly exsolved into three phases*: an immobile gas bubble (phase *g*) and one or several similar crystals (*s*, for solid phases, also called daughter minerals), embedded in the saturated residual liquid (phase *l*).

The *gas bubbles* take up 10 to 11%, the crystals 12 to 15% and the brine about 75% of the cavity volumes. The gas bubbles contain carbon dioxide under variable pressure and can be surrounded by a thin crescent of liquid carbon dioxide (≤ 3% CO_2).[6] This can be detected only in shallow cavities (Figure 8). In the thicker ones the bubbles appear too dark because of the strong optical relief. Methane (CH_4) and nitrogen gas (N_2) have also been reported.

The square to rectangular *daughter crystals* have been identified as halite (NaCl, cubic). It is assumed that there is also some subordinate sylvine (KCl, cubic). These 'flattened' cubic crystals are more often found than crystal forms resembling rhombohedra. Considering their anisotropic nature, the latter are assigned to a carbonate. It seems most probable that they are calcite or dolomite crystals (Figure 8).

Hexagonal, small-grained anisotropic crystals exsolved from the fluid fillings have been pictured as well. A single emerald crystal and even a single cavity can house cubic, lozenge and other daughter crystals. Combinations of several types of daughter crystals and a gas bubble in the saturated residual

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[6] The longitudinal extension of fluid inclusions may have been epigenetically constricted or even cut off. This event, called 'necking down' or 'necking', modified the cavity fillings with respect to the relative volumes of the individual, segregated phases as opposed to the normal undisturbed (s,l,g) state. For instance, one very large gas bubble may have built up in one and a daughter crystal may have been cut off in the neighbouring, separated cavity.

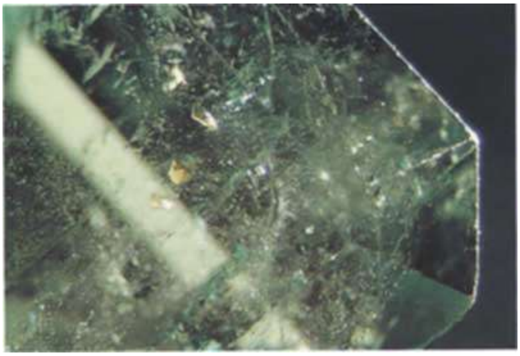

Fig. 5. Dense inclusion array in an octagonal emerald from Colombia. Width of photograph represents approximately 6 mm.

Fig. 6. Predatory octopus and his protégée with full stomachs in a green sea. Three-phase inclusions of variable appearance, the largest one being a 0.4 mm long and unusually thick cavity, spiky on one side and filled with a gas bubble and a salt crystal (also containing an inclusion).

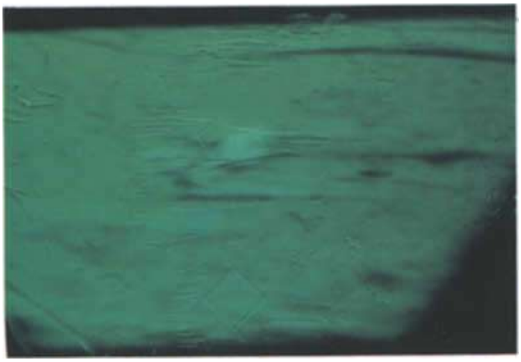

Fig. 7. Exceptionally thin cavities filled with residual brine, slightly brighter gas bubbles (almost without any relief) and two exsolved, zoned halite daughter crystals. Jagging of these primary growth voids running parallel to *c*, the main axis [0001] of the emerald crystal. Width of photomicrograph represents approximately 1.2mm.

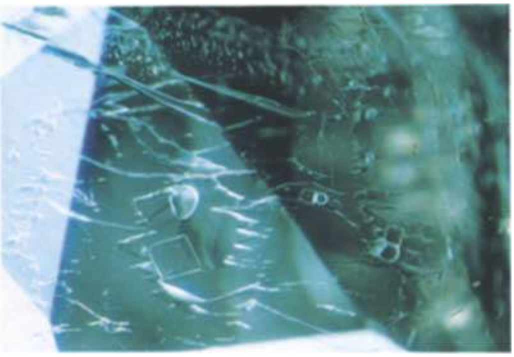

Fig. 8. Primary axial healing fissure with flat cavities containing different exsolution components of constant volume proportions of s/l/g. Largest gas bubble with a delicate crescent seam of liquid carbon dioxide (CO_2), largest daughter crystal with a rhombohedral habit and zonal structure (a carbonate), smaller daughter crystals with a cubic habit (halite). Long diagonal of the rhombohedron circa 0.25 mm.

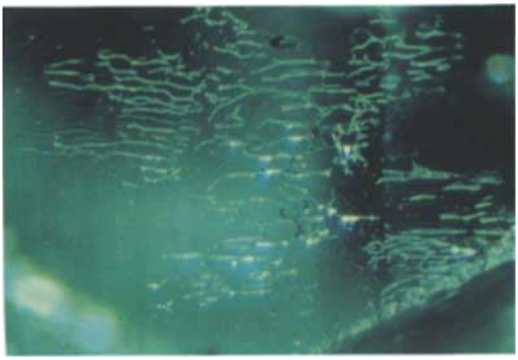

Fig. 9. Plane (pseudo?)secondary gas and fluid network in a Colombian emerald. Width of photomicrograph represents approximately 2.4 mm.

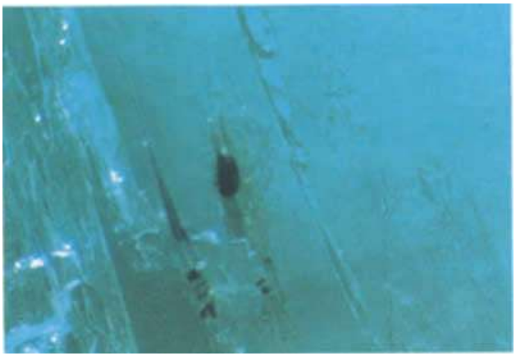

Fig. 10. Yellow and dark brown primary cavity fillings of segregated organic liquids (presumably light carbohydrates). Length of drop about 70 μm (0.07 mm).

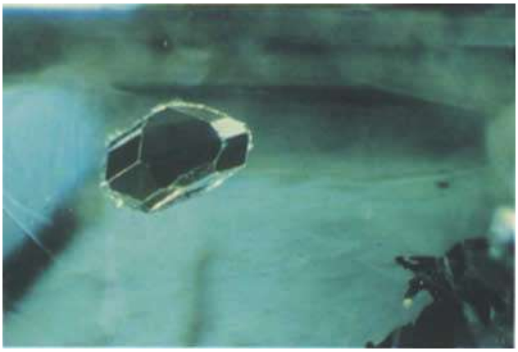

Fig. 11. Distorted polyhedral pyrite crystal with fine tension fissures along its edges, enclosed in a structurally disturbed emerald. Length of pyrite crystal approximately 0.85 mm.

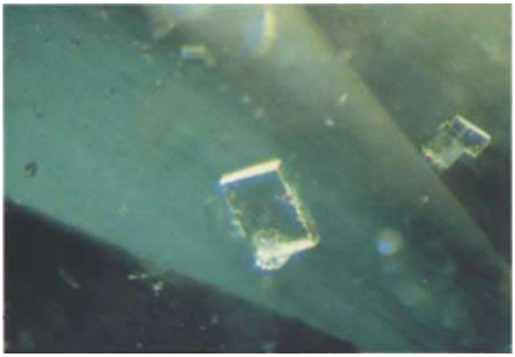

Fig. 12. Rhombohedral, colourless syngenetic mineral inclusion (calcite?) in a very transparent emerald. Smaller grains with less euhedral shapes (albite, quartz, parisite?). Long diagonal of largest rhombohedron about 0.4 mm.

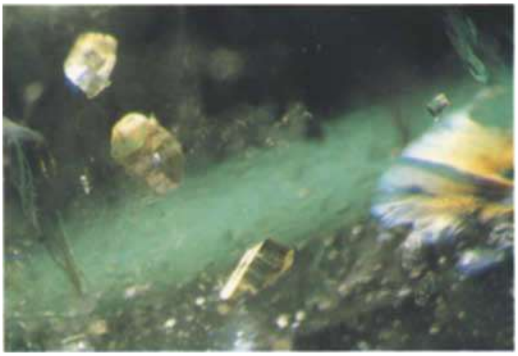

Fig. 13. Loose group of larger, brownish and smaller, yellowish parisite crystals included in the emerald displayed in Figure 5. Barrel-shaped, short-columnar and pyramidal habits. Iridescent tension crack (not 'Opticon'-treated). Width of largest crystal approximately 0.35 mm.

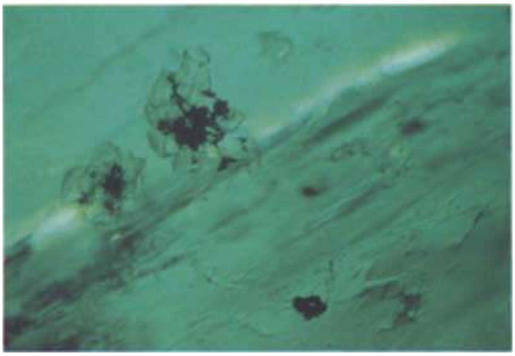

Fig. 14. Aggregate of transparent crystals and small opaque grains (albite or carbonate and carbonaceous shale). Width of largest cluster about 0.3 mm.

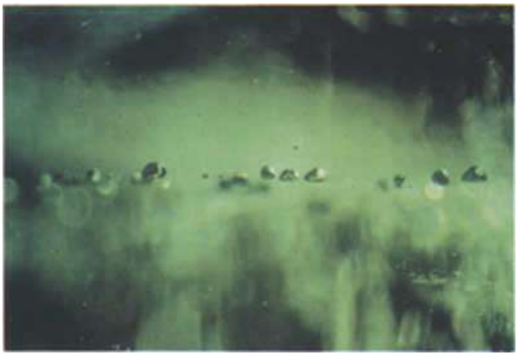

Fig. 15. Small syngenetic pyrite crystals of different shape and size, distributed on a basal plane. Width of photomicrograph represents circa 8 mm.

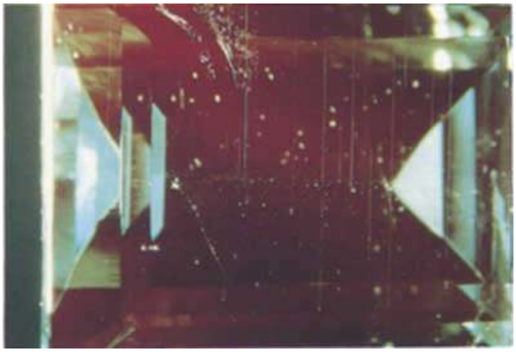

Fig. 16. Red fluorescence (682 nm chromium emission) strongly excited by a 100 watt fibre-optic side illumination in a particularly transparent emerald octagon displaying long axial growth tubes and slightly vaulted pseudosecondary healing fissures. Tiny mineral inclusions having acted as starting points for the slender acicular crystallization disturbances. Width of emerald approximately 9.2 mm.

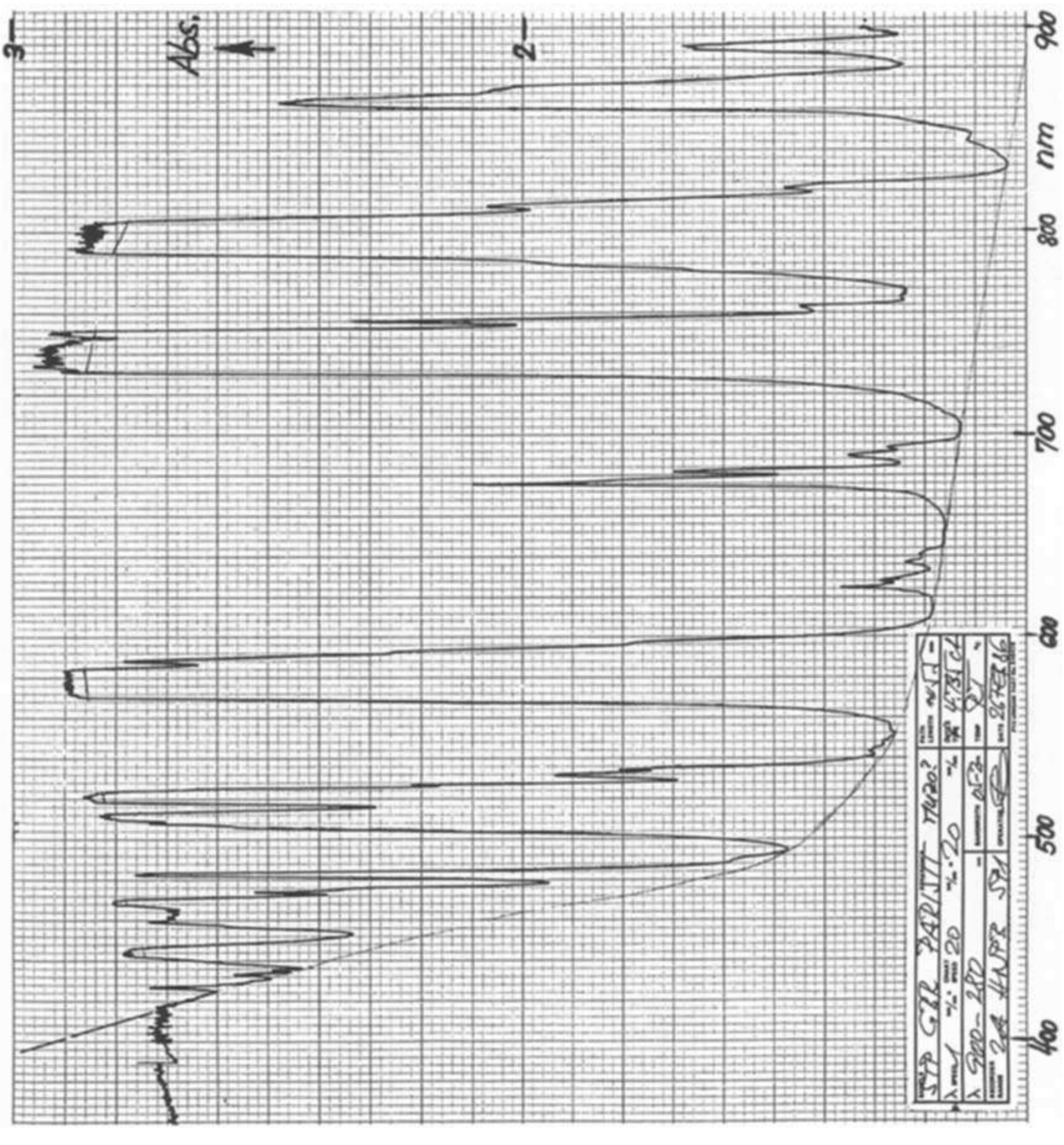

Fig. 13a. Polarized absorption spectrum of a semi-transparent, brownish orange-yellow parisite crystal from Muzo(?), Colombia. Weight 4.735 ct, density 4.34 g/cm^3, optical path length about 5.5 mm. Classical rare earth absorption behaviour: the numerous and very strong but more or less equally spaced absorption bands (line multiplets) in the visible region have a lesser effect on the parisite body colour than the continuous increase of underlying absorption towards the violet-blue region. The multiple absorption centred at 580 nm, however, is the cause of a slight colour-change effect (Bosshart *et al* 1982) seen in some parisites. For the sake of clarity, only the e-ray spectrum is displayed.

solution are known as *multi-phase fillings*. Another kind of multi-phase inclusion can be made up of a fluid, some liquid carbon dioxide, a gas bubble and solid rock salt.

Two-phase fillings in the cavities are noticed less frequently than three- or multi-phase inclusions. In healed fissures these (l,g) inclusions are small and delicate. As autonomous basal networks of liquid and gas, they can show spectacular relief (Figure 9). This is yet another proof that the original chemical composition of the fillings had not to be identical in every single cavity or healing fissure of an emerald.

The observed phenomena point to a complex geological history of the emeralds, marked by syngenetic infiltration of fluid phases into the primary growth voids and by secondary formation and filling of tension cracks.

Occasionally the brine was heterogeneously enclosed together with an immiscible constituent of some dark brown liquid which could well be a cracked mineral oil. Brownish-yellow to dark brown liquids sometimes are also found as *single-phase fillings* of cavities (to present without a surface contact, i.e. sealed in). They are rare and presumably also primary formations. In Figure 10 two types of organic liquids can be distinguished, the darker hydrocarbon having segregated in several instances as droplets from the lighter variety.

b. *Proto- and syngenetic mineral inclusions* are not particularly frequent in Colombian emeralds. They consist of pyrite crystals displaying a bright yellow metallic lustre (Figure 11) and the following colourless minerals: tabular albite, rhombohedral calcite or dolomite (Figure 12, sometimes whitish) and rarely also prismatic quartz.

Small reddish to yellowish-brown spear-shaped crystals of the decidedly rare, trigonal *parisite* $Ca(Ce,La,Nd,Pr)[(CO_3)_3/F_2]$ may be noted in Colombian emeralds.

The most prominent parisite inclusions encountered were fairly large, brownish-yellow barrel-shaped to pyramidal crystals (maximum length 0.7 mm, maximum diameter 0.35 mm, Figure 13). Parisite (Ca(Ce,REE)-carbonate) was successfully identified by the main lines and bands of the rare earth absorption spectrum at 442, 460, 512, *520*, 534, 574/*579*/584 and *678* nm. The spectrum was observed through a hand spectroscope held into the ocular tube of a stereo-microscope and compared to the absorption spectrum of a crystal specimen from Colombia recorded on a spectrophotometer (Figure 13a). Recent chemical investigations by ED-XFA and electron microscope analyses of these inclusions and other Colombian parisite samples confirmed the elements Ca,Ce,La,Nd+Pr and a very good cleavage. In addition, traces of Y and Th were found to be present.

Another, more frequent feature of Colombian emeralds are *aggregates* of tiny, dark grey grains. They are thought to be particles of the wall rocks, that is traces of carbonaceous shale such as those found in Trapiche emeralds (Figure 14). Pyrite, as well as albite, quartz, calcite and parisite, can occur in free crystal groups or grainy aggregates. Accumulation of a single mineral species on a growth plane has also been seen (Figure 15). Bands of fine dust $\parallel$ c are occasionally observed also.

From time to time rusty to yellow-brown goethite turns up as a crust on fissures or as grainy aggregates in cavities. This list of crystal inclusions may not be absolutely complete.[7]

Microscopically and spectroscopically the listed mineral inclusions are not readily identifiable, with the exception of parisite and the ore mineral pyrite.

Statistically speaking, pyrite crystals appear most commonly in Chivor emeralds and calcite and parisite in Muzo emeralds. However, pyrite and calcite are found in emeralds of both districts and parisite also in those from Coscuez. Thus in the individual testing case, determination of origin by mineral inclusions is not feasible.

So far Gachalá emeralds alone seemed to be recognizable to some extent. They exhibit a better transparency (fewer healing fissures), a paler and more greenish-blue colour, more mineral inclusions (albite), more and longer growth tubes and a stronger VIS-fluorescence (Figure 16) than other Colombian emeralds. These properties, however, are said to be virtually identical to those of emeralds from the 'new' Yacopí mine in the Muzo district (personal communication by D. Schwarz, 1989).

c. *Internal growth characteristics* of five different kinds have been noted in cut Colombian emeralds: as colour zoning, colour spindles, growth zoning, growth spirals, and growth tubes. On the other hand, twinning has not been observed in a single instance (twinning in beryl is extremely rare).

As a rule, colour zoning as well as straightforward growth zoning (i.e. zoning without colour contrast, Figure 17) occur as series of prismatic and/or basal planes. Pyramidal zoning is less widespread.

Prismatic colour zoning classically consists of a sharply defined, colourless, yellowish or pale green prismatic core, surrounded by a saturated green shell. Colour distribution can also be inverse. Hosts of colourless 'holes' are met with much less frequently. These are essentially colourless prism-like

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[7] Fujisaki (1976) identified several ore minerals in a Colombian emerald individual: pyrite, pyrrhotine, pentlandite and rutile. The formation of the last three minerals is difficult to explain in the postulated hydrothermal growth environment (especially pentlandite $(Fe,Ni)_9S_8$, cubic) except, if some connection from a remote (ultra)basic source to the deposit had been in existence.

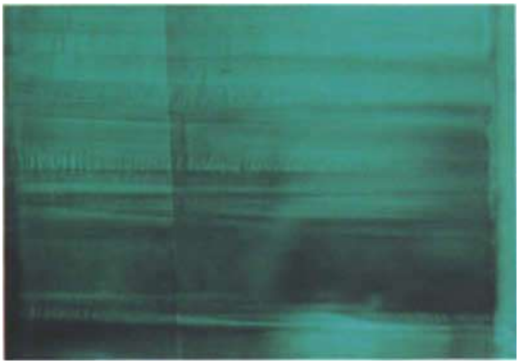

Fig. 17. Lamellar to slightly wedge-shaped basal growth structures with palisades of short spindles on individual growth planes. Photomicrograph height represents 1.50 mm.

Fig. 18. Host of nearly colourless, axial columns in an emerald cabochon. Largest diameter of the columns approximately 1.5 mm.

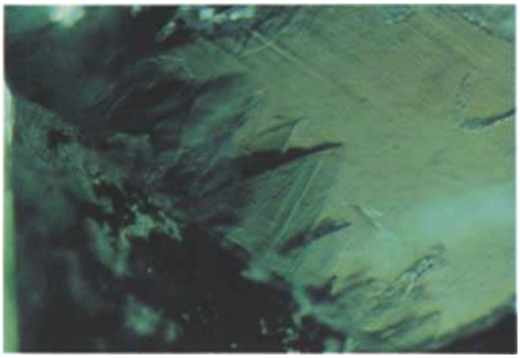

Fig. 19. Steep, saturated green pyramids with axes parallel to the main growth direction *c* of the emerald. Height of pyramids up to about 0.5 mm.

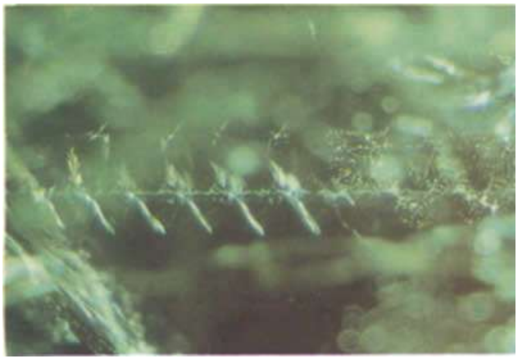

Fig. 20. Axial growth tube with a spiral passing from a fissure into a healing fissure. Next to it a more delicate helix in reverse sense of rotation. Width of photomicrograph represents approximately 2 mm.

Fig. 21. Axial view onto a basal plane covered with corrosion cells. Shallow etch pits structured with modified or hinted hexagonal contours. Width of photomicrograph about 9 mm.

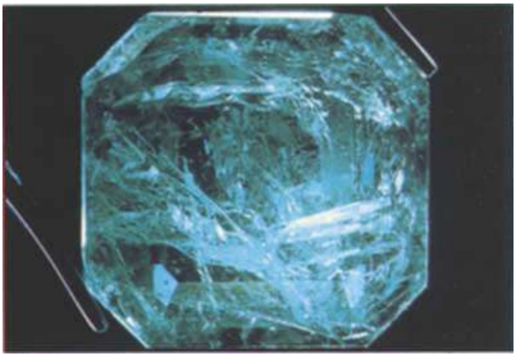

Fig. 22. Faceted Colombian emerald with characteristic, strongly reflective tension cracks, in the de-oiled state. Length of brightest crack approximately 1.25 mm.

columns of small diameter parallel to the *c*-axis in otherwise green crystals (Figure 18).

Basal colour zoning can be a sequence of colourless and green, flat and well defined lamellae. As cutters usually orient the emerald with the *c*-axis almost parallel to the table, the basal zoning can be quite obvious as a colour striation traversing the crown of the stone. Similarly, in the case of the fluid inclusions, transitions can be seen between the prismatic and the basal zoning which, in reality, are combinations of both directions with small pyramidal growth zones in between.

The *pyramidal colour zoning* normally starts on basal planes. These pyramids may show very strong green colour saturation and steeply sloped arches tapering in the growth direction (Figure 19). Pyramids may also be pale in colour and have formed prior to the growth of green zones. Well-defined zigzag formations towards the outside of the crystals do not necessarily stem from irregular pyramidal growth of variable inclination but rather from growth planes separating the older core and the younger shell.

Closely related with the growth pyramids, on the other side, are palisades of flame-like spindles which also originate on basal planes (Figure 17). Neither colourless nor coloured spindles are very common but they can reach lengths of up to 2 mm.

Small hillocks on basal planes reminiscent of the shallow growth pyramids of Linde synthetics have also been detected.

Under the microscope, *basal, prismatic and pyramidal growth zoning* can easily be recognized and differentiated. According to Kiefert & Schmetzer (1990), combinations of zonal structures enable identification of authenticity of Colombian emeralds but not of their exact provenance.

Growth spirals are attractive but sporadic phenomena in Colombian emeralds. They prove two facts: that an emerald crystal does not have to be built up by planar growth fronts and that healing of the spirals by fluid brines can set in and be terminated at any stage of growth (Figure 20). The same phenomena can be observed in the hydrothermal synthetics after Biron (today Pool, Australia), however, without a central growth tube.

Other subtle and quite common characteristics are the *growth tubes*. They run parallel to the main growth direction (Figure 16), occasionally also vertical to the *c*-axis. These tubes are very fine and long and can show two-phase (l,g), three-phase (s,l,g) or multi-phase fillings (s_1,s_2,l_1,l_2,g).

Starting point for the growth tubes are sometimes the mineral inclusions described above because these solids have formed intrinsic obstacles facing the growth front. Tubes are growth gaps comparable to very long negative crystals (often measuring several millimetres).

Actual *negative crystals* have not frequently been encountered among gem quality material, the largest one according to laboratory notes having been a lathe-like cavity measuring about 1.6 × 0.8 × 0.45 mm.

d. Flat primary cavities, colour zoning, growth spirals and tubes are all indicators of emerald crystal build-up. The contrary, decomposition, is much rarer, making its appearance in the form of flat, cellular *etch pits* on basal planes (Figure 21, as occasionally also seen on the base of emerald crystals). These etch marks have been overgrown again, subsequent to the corrosion phase. Under crossed polars they show strain birefringence instead of straight extinction and low optical relief.

Although Figure 21 can also be interpreted as flat hillocks (truncated pyramids) as a consequence of spiral or polygonal beryl growth (cf. Sinkankas 1981, Figures 9-26), this interpretation is less probable than corrosion in view of the irregularity of their contours.

Similar or identical cellular phenomena have also been described as thin, basal layers of calcite crystals.

e. The least desirable properties of many Colombian emeralds are undoubtedly their numerous *tension cracks*. They have formed either during or after growth (and could have been healed out) and some could have formed during mining. Since white light is reflected back from these fractures to the outside after a short light path through the emerald, the cracks are very obvious and look white rather than green (Figure 22).

[*Manuscript received 19 March 1990.*]

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The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones

Part 2: Examples for the applicability of structural features for the distinction of natural emerald from flux-grown and hydrothermally-grown synthetic emerald

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Abstract

The application of diagnostic growth structures for the distinction of natural and synthetic emeralds is discussed. Typical examples for the characterization of natural emeralds from distinct sources as well as of their synthetic counterparts of some producers are given. Criteria which are useful for the recognition of faceted gemstones as natural or synthetic are underlined. Gem materials described in detail are natural emeralds from Colombia and Nigeria, flux-grown synthetic emeralds from Chatham, Russia and Gilson as well as different hydrothermally-grown synthetic emeralds (Linde, Regency, Lechleitner, Biron, Pool, and Russian synthetic emeralds).

Zusammenfassung

Die Anwendung von Wachstumsstrukturen zur Unterscheidung natürlicher und synthetischer Smaragdse wird beschrieben.

Nicht nur typische Beispiele zur Charakterisierung von natürlichen Smaragden verschiedener Herkunft werden erwähnt, sondern auch von synthetischen Gegenstücke.

Nützliche Kriterien zur Erkennung geschliffener Edelsteine als natürlich oder synthetisch werden betont.

Die ausführlichst beschriebene Edelsteine sind natürliche Smaragde aus Kolumbien und Nigeria sowohl nach dem Flußmittelverfahren gezüchtete Smaragde (Chatham, Gilson, Rußland) als auch verschiedene nach dem Hydrothermalverfahren gezüchtete synthetische Smaragde (Linde, Regency, Lechleitner, Biron, Pool und russische synthetische Smaragde).

Resumen

Se, discute la aplicación de marcas de crecimiento diagnósticas para identificar las esmeraldas naturales y sintéticas. Se facilitan ejemplos típicos para la caracterizacion de esmeraldas naturales de yacimientos determinados. Se subrayan criterios que son útiles para reconocer gemas talladas como naturales o sintéticas. Las gemas descritas con detalle son esmeraldas naturales de Colombia y Nigeria, esmeraldas sinteticas Chatham, rusas y Gilson obtenidas por el procedimiento "melt" al igual que otras esmeraldas obtenidas por el procedimiento hidrotermal (Linde, Regency, Lechleitner, Biron, Pool y esmeraldas sintéticas de origen ruso).

I. Introduction

In the first part of this publication (Kiefert & Schmetzer, 1991) a detailed description of methods for the determination of characteristic crystal faces in faceted optical uniaxial gemstones by use of two simple auxiliary means is presented. These means are a two-axial sample holder (cf. Schmetzer, 1986) and a rotatable measuring ocular with cross hairs attached to the lens, both with attached 360° dials and fixable indicators. The best obtainable results, i.e. a complete determination of the structural characteristics present in one sample, are available by a combination of both methods.

This second part of the publication will reveal some examples for the practical applicability of the methods described in the first part in detail. The characterization of natural emeralds from two important sources (Colombia and Nigeria) as well as of some of their commercially available flux-grown

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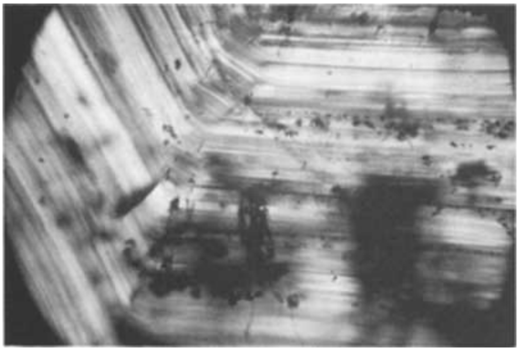


Fig. 16. Growth structures in natural emerald from Colombia; planes parallel to the hexagonal prism *m* and *m'* $\{10\bar{1}0\}$ form an angle of 120°, smaller planes parallel to the prism *a* $(11\bar{2}0)$ are also present. View parallel to the *c*-axis. Crossed polarizers. 18x.

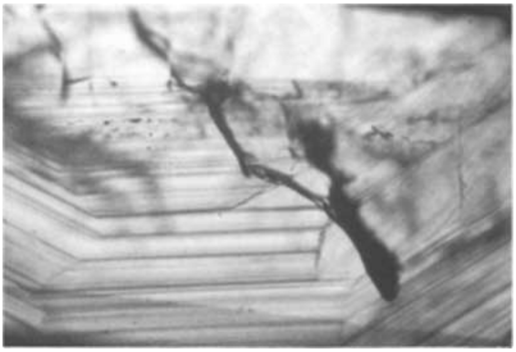


Fig. 17. Growth structures in natural emerald from Colombia; planes parallel to the hexagonal prism faces *m* $\{10\bar{1}0\}$ and *a* $\{11\bar{2}0\}$ form angles of 150°. View parallel to the *c*-axis. Crossed polarizers. 25x.

and hydrothermally-grown synthetic counterparts by means of growth structures is selected as one of the typical and important problems of determinative gemmology.

Figures 1-15 as well as Tables 1-3, which are occasionally referred to in this second part of the publication, are presented in the first part (Kiefert & Schmetzer, 1991).

II. Natural emeralds from Colombia and Nigeria

Natural emerald is mainly found in metamorphic deposits. Emeralds from these sources are recognizable by the presence of many different mineral inclusions such as mica and actinolite. Further diagnostic properties of emeralds from metamorphic deposits are characteristic sodium- and magnesium-contents, which are generally higher than those of synthetic stones. Absorption spectroscopy, which can, besides microscopic investigations, also be used as a non-destructive method, frequently reveals distinct iron absorption bands as well as a characteristic aquamarine component (Schmetzer, 1988). The emeralds from metamorphic source rocks, however, in many cases do not disclose characteristic growth structures of diagnostic value.

On the contrary, emeralds from deposits with a temperature of formation lower than that of samples from metamorphic deposits, reveal characteristic growth features useful for diagnostic purposes. Typical examples for these types of emeralds occur in different deposits in Colombia, in Nigeria, and, occasionally, are also found in material from Afghanistan. Larger quantities of emeralds from Afghanistan are very difficult to obtain and, therefore, samples from this particular source will not be considered in this publication.

Colombian and Nigerian emeralds, in contrast to emeralds from metamorphic source rocks, in most cases do not reveal any diagnostic contents of sodium and magnesium and, using only this feature, are hardly distinguishable from synthetic emeralds. Absorption spectra of Colombian emeralds also disclose no characteristic iron absorption bands, which are very often useful as diagnostic features for natural emeralds from metamorphic source rocks. Consequently, high quality emerald samples from Colombia or Nigeria sometimes create problems in determinative gemmology. In order to determine additional characteristic properties for these two types of emeralds, more than 200 rough and cut Colombian emeralds from different mines, and more than 100 rough and cut Nigerian emeralds were made available for a detailed investigation.

In general, the internal growth structures of Colombian cut emeralds correspond to the morphology of rough samples. The most significant growth planes in all Colombian emeralds are the first-order hexagonal prism *m* $(10\bar{1}0)$ [Figure 16] and the basal pinacoid *c* (0001). Part of Colombian samples additionally reveal the second-order hexagonal prism *a* $(11\bar{2}0)$, most frequently in a size

Fig. 18. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *p* $(10\bar{1}2)$, *u* $(10\bar{1}1)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 80x.

Fig. 19. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *s* $(11\bar{2}2)$ and *a* $(11\bar{2}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 85x. Figs. 18 and 19 are related by a rotation of 30° about the *c*-axis.

Fig. 20. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *p* $(10\bar{1}2)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 80x.

Fig. 21. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *s* $(11\bar{2}2)$ and *a* $(11\bar{2}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 70x. Figs. 20 and 21 are related by a rotation of 30° about the *c*-axis.

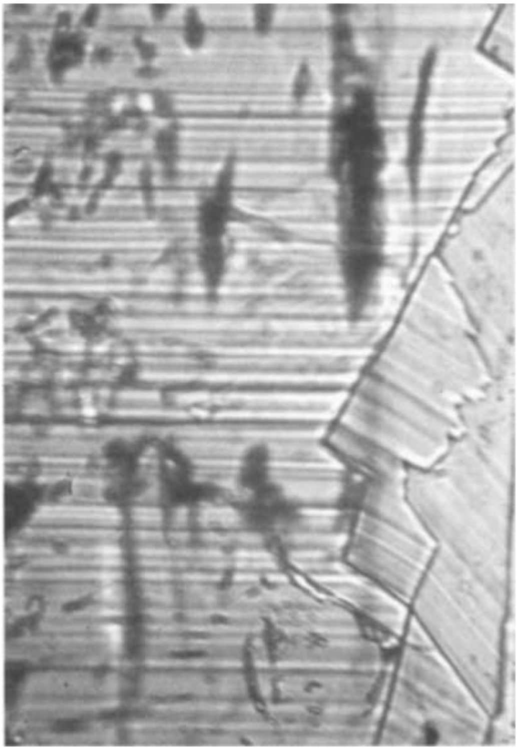
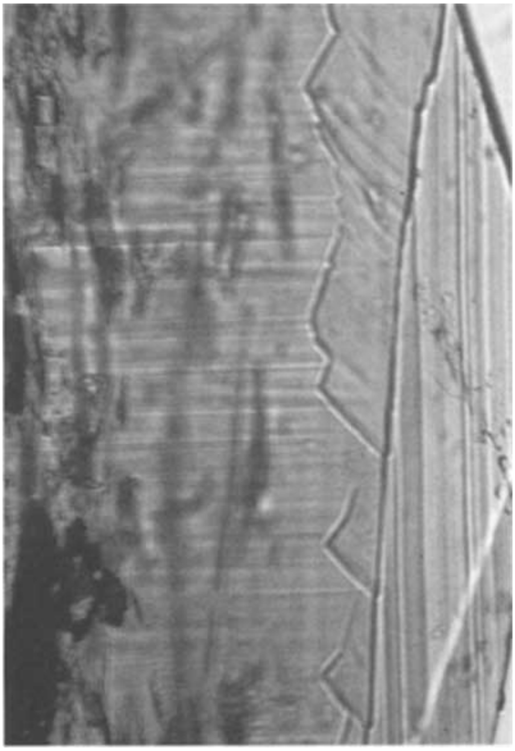


Fig. 18



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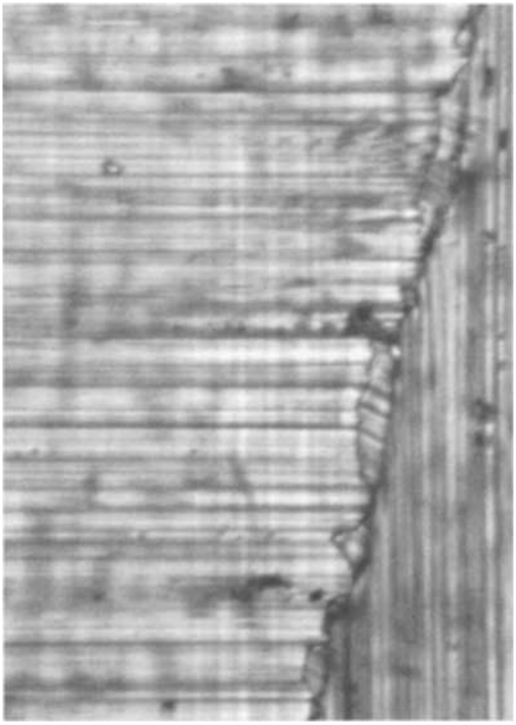

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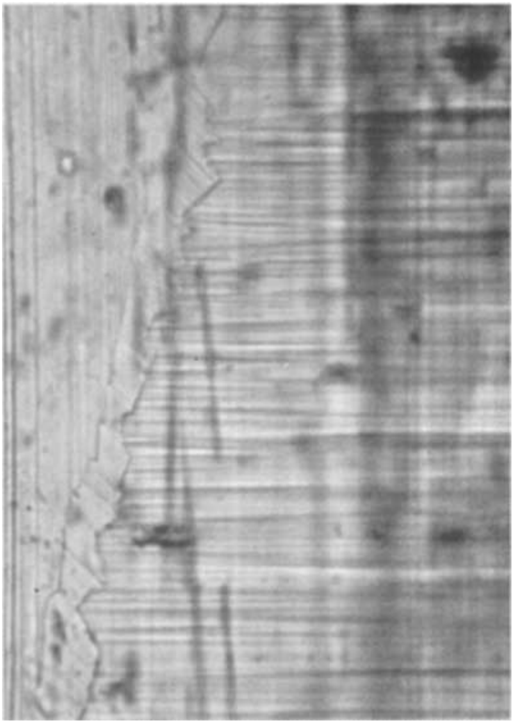
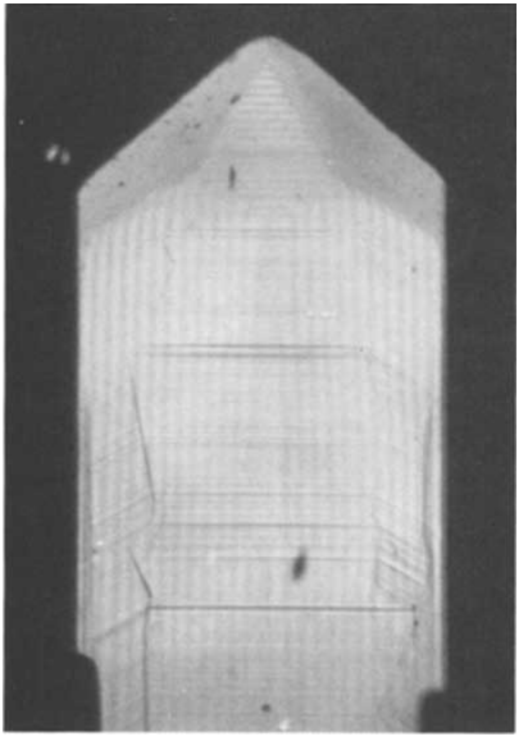


Fig. 21



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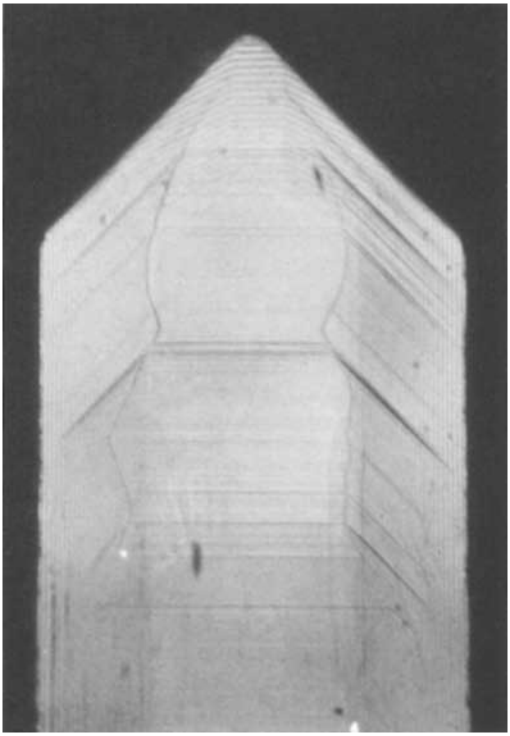

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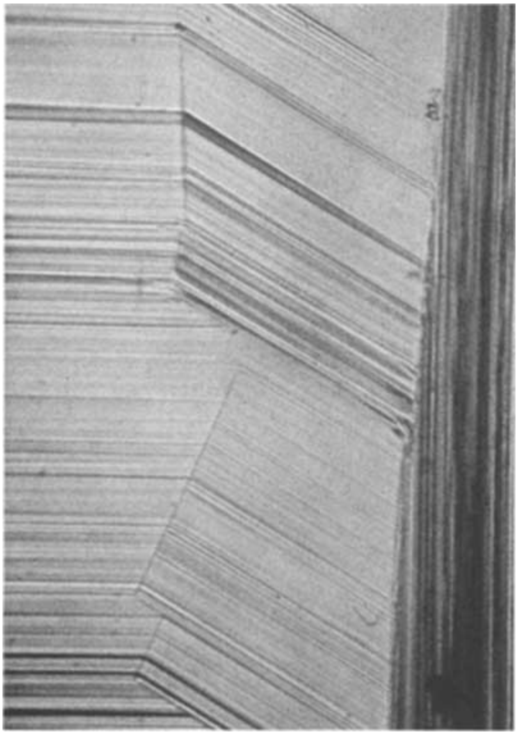

Fig. 24

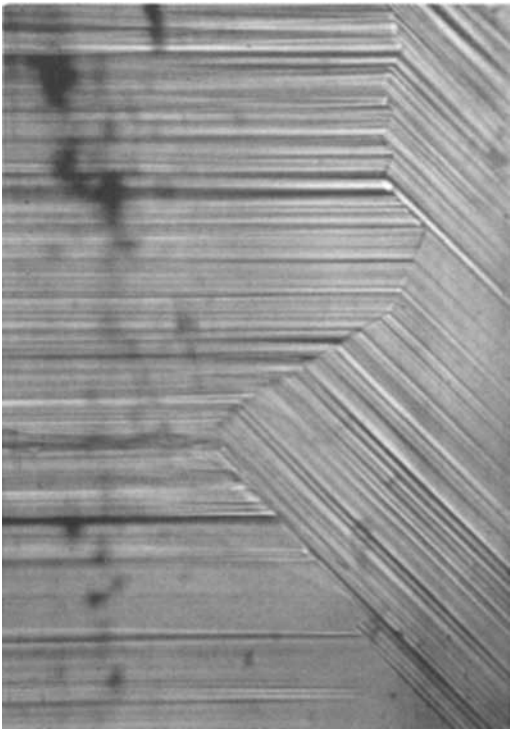

Fig. 25

smaller than the prism *m* as shown in Figures 4c and 16. Occasionally, this face also can reach the same size as the first-order hexagonal prism *m* $(10\bar{1}0)$ [Figure 17]. Additional growth planes are the first-order hexagonal dipyramids *u* $(10\bar{1}1)$ and *p* $(10\bar{1}2)$ and the second-order hexagonal dipyramid *s* $(11\bar{2}2)$ [Figures 4a, 4c, 18, 19]. These dipyramids were found to occur all together in some samples, other samples revealed only the first-order hexagonal dipyramid *p* $(10\bar{1}2)$ and the second-order hexagonal dipyramid *s* $(11\bar{2}2)$ [Figures 4b, 20, 21], and others disclosed, additionally to the above mentioned basal and prism faces, only the second-order hexagonal dipyramid *s* $(11\bar{2}2)$. So far, it has not yet been possible to distinguish between emeralds of the two major mining districts Chivor and Muzo, because part of the material available to the authors, most presumably, was already mixed up in Colombia.

The morphology as well as the internal growth structures of the investigated emeralds from Nigeria are identical with growth structures of aquamarines from the same mining districts (cf. Lind *et al.*, 1986). Beryls from this source always disclose the first-order hexagonal prism *m* $(10\bar{1}0)$ [Figure 27] and the second-order hexagonal dipyramid *s* $(11\bar{2}2)$, as well as the basal pinacoid *c* (0001) in different sizes [Figures 4b, 23, 25]. Besides these crystal faces, Nigerian emeralds very rarely show a small second-order hexagonal prism *a* $(11\bar{2}0)$ or a small first-order hexagonal dipyramid *p* $(10\bar{1}2)$ [Figures 4b, 22, 24, 26]. The first-order hexagonal dipyramid *u* $(10\bar{1}1)$, which is quite common in Colombian emeralds, has not yet been observed in Nigerian samples.

In comparison to synthetic emeralds produced by the flux method, a characteristic feature of emeralds from the two groups of deposits discussed above is the presence of the first-order hexagonal dipyramids *u* $(10\bar{1}1)$ and *p* $(10\bar{1}2)$ as well as the second-order hexagonal dipyramid *s* $(11\bar{2}2)$, which, in general, do not occur in synthetic emeralds produced by the flux method (see section III). However, the crystal faces *c* (0001), *m* $(10\bar{1}0)$ and *a* $(11\bar{2}0)$ can also be present in synthetic emeralds and, therefore, in samples in which only these crystal faces are determined, no definite characterization of the emerald by means of growth structures is possible.

Fig. 22. Growth structures in natural emerald from Nigeria; planes parallel to *c* (0001), *p* $(10\bar{1}2)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. Crossed polarizers. 20x.

Fig. 23. Growth structures in natural emerald from Nigeria; planes parallel to *c* (0001) and *s* $(11\bar{2}2)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 20x. Figs. 22 and 23 are related by a rotation of 30° about the *c*-axis.

Fig. 24. Growth structures in natural beryl from Nigeria; planes parallel to *c* (0001), *p* $(10\bar{1}2)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x.

Fig. 25. Growth structures in natural beryl from Nigeria; planes parallel to *c* (0001) and *s* $(11\bar{2}2)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x. Figs. 24 and 25 are related by a rotation of 30° about the *c*-axis.

III. Some important types of flux-grown synthetic emeralds

The results of some experiments, in which spherical seeds of natural beryl crystals were prepared and subsequently used for growing synthetic emeralds in a flux of V_2O_5 were published by Ushio (1977). During these experiments Ushio observed in the first state of crystal growth the crystal forms *c* $\{0001\}$, *m* $\{10\bar{1}0\}$ and *a* $\{11\bar{2}0\}$ as well as different first- and second-order hexagonal dipyramids. After some days, however, all hexagonal dipyramids disappeared, and the final morphology of the synthetic emeralds produced by this flux method resulted in dominant basal pinacoids *c* $\{0001\}$ and first-order hexagonal prism faces *m* $\{10\bar{1}0\}$, occasionally with a subordinate small second-order hexagonal prism *a* $\{11\bar{2}0\}$.

This morphology corresponds to the morphology of flux-grown synthetic emeralds produced by Chatham as well as to Russian flux-grown synthetic emeralds as described in the literature. According to Schrader (1987), crystal growth of Chatham flux-grown synthetic emeralds is performed by the use of small seed crystals. Russian flux-grown synthetic emeralds are produced by means of seeded growth as well as by spontaneous crystallization (Bukin *et al.*, 1980, 1986), which is also mentioned for Chatham flux-grown synthetic emeralds (e.g. Nassau 1976, 1980).

Consistent with literature data dealing with the morphology of both types of flux-grown synthetic emeralds, faceted samples of Chatham and Russian flux-grown synthetic emeralds examined by the authors disclose, as internal growth structures, only a combination of *c* (0001), *m* $(10\bar{1}0)$ and *a* $(11\bar{2}0)$ [Figures 28, 29, 31, 32, 33]. Other growth planes, for example in natural emeralds frequently observed hexagonal dipyramids *u* $(10\bar{1}0)$, *p* $(10\bar{1}2)$ and *s* $(11\bar{2}2)$ were not found in these flux-grown synthetic emeralds, and residual seeds were not observed. In addition to growth structures, another common feature of flux-grown synthetic emeralds is the zoning of residual flux parallel to dominant growth planes [Figures 30, 32], which does not arise in natural stones in this particular form.

As an example for flux-grown synthetic emeralds often containing residual seed plates, properties of

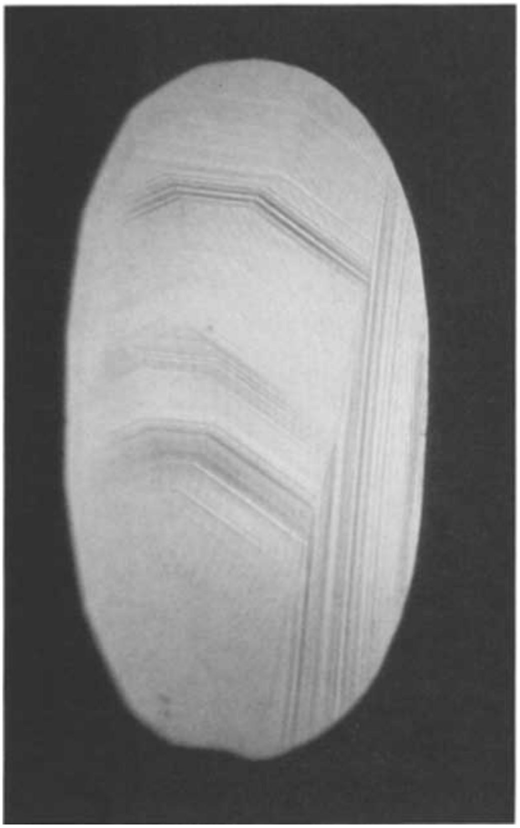

Fig. 26. Growth structures in natural emerald from Nigeria; planes parallel to *c* (0001), *p* (10$\bar{1}$2) and *m* (10$\bar{1}$0). View perpendicular to the *c*-axis, the *c*-axis runs almost vertically. Crossed polarizers. 12x.

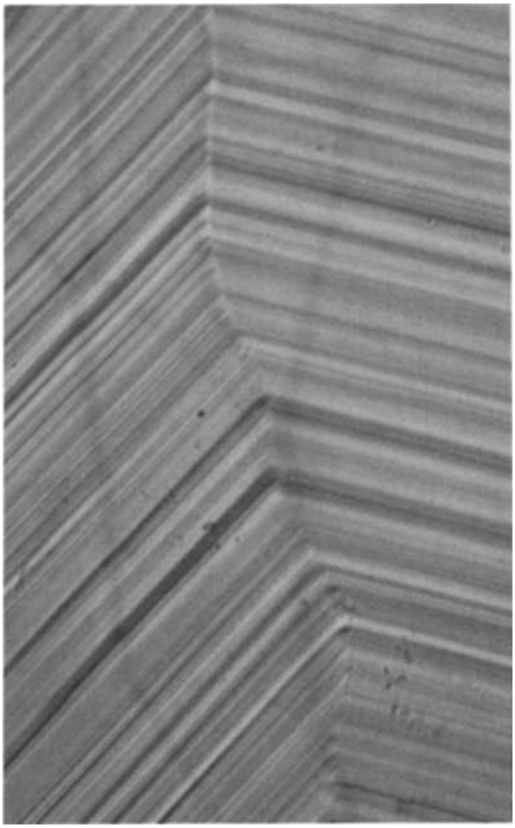

Fig. 27. Growth structures in natural beryl from Nigeria; planes parallel to the hexagonal prism *m* and *m'* {10$\bar{1}$0} form an angle of 120°. View parallel to the *c*-axis. 30x.

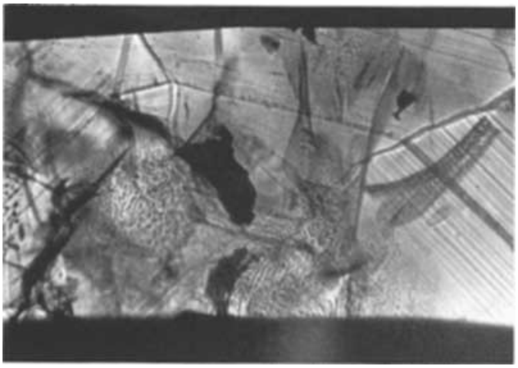

Fig. 28. Growth structures in Chatham flux-grown synthetic emerald; planes parallel to the hexagonal prism faces *m* {10$\bar{1}$0} and *a* {11$\bar{2}$0} form angles of 150°. View parallel to the *c*-axis. Crossed polarizers. 35x.

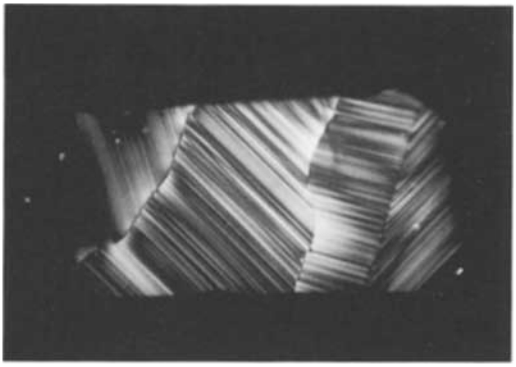

Fig. 29. Growth structures in Russian flux-grown synthetic emerald; planes parallel to the hexagonal prism faces *m* {10$\bar{1}$0} and *a* {11$\bar{2}$0} form angles of 150°. View parallel to the *c*-axis. Crossed polarizers. 20x.

Fig. 32. Growth structures in Chatham flux-grown synthetic emerald; planes and zoning of residual flux parallel to the basal pinacoid *c* (0001). View perpendicular to the *c*-axis, the *c*-axis runs vertically. 40x.

Fig. 33. Growth structures in Russian flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces (*m* or *a*) form an angle of 90°; an intense colour zoning is also visible, growth zones confined to the prism are intense green, growth zones confined to the basal pinacoid are light green. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 25x.

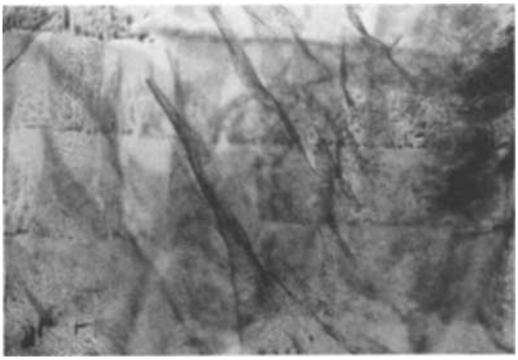

Fig. 30. Growth structures in Chatham flux-grown synthetic emerald; zoning of residual flux parallel to the basal pinacoid *c* (0001). View perpendicular to the *c*-axis, the *c*-axis runs vertically. 20x.

Fig. 31. Growth structures in Russian flux-grown synthetic emerald; planes parallel to the hexagonal prism *m* and m' $\{10\bar{1}0\}$ form an angle of 120°, smaller planes parallel to the prism *a* $(11\bar{2}0)$ are also present. View parallel to the *c*-axis. Crossed polarizers. 20x.

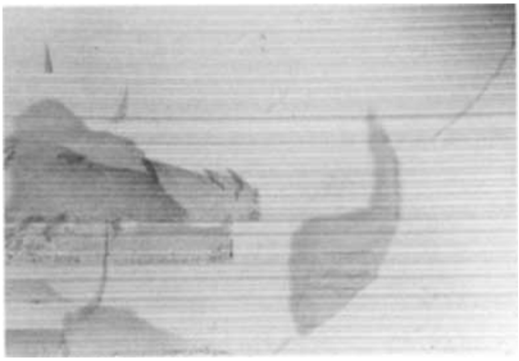

Fig. 34. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001). View perpendicular to the *c*-axis, the *c*-axis runs vertically. 40x.

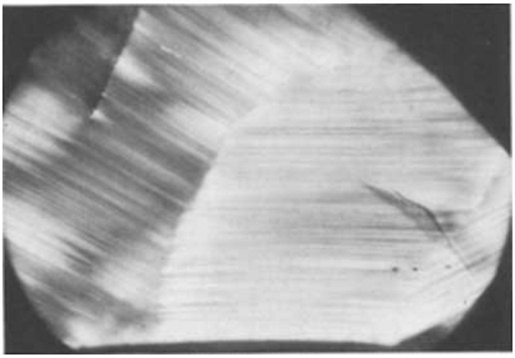

Fig. 35. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the hexagonal prism faces *m* $\{10\bar{1}0\}$ and *a* $\{11\bar{2}0\}$ form angles of 150°. View parallel to the *c*-axis. Crossed polarizers. 34x.

Gilson synthetic emeralds will be discussed in some details. In an earlier state of the production of Gilson synthetic emeralds, most presumably seed plates cut parallel to the basal pinacoid *c* (0001) were used (Sinkankas, 1981; Schrader, 1987), which is recognizable in cut samples by growth structures parallel to this dominant growth plane (cf. Schmetzer, 1989).

Obviously, the orientation of seed plates in Gilson synthetic emeralds was changed for the more recent commercial production. According to Diehl (1977), a tabular seed plate of natural colourless beryl cut parallel to the second-order hexagonal prism *a* $(11\bar{2}0)$ was observed in a rough crystal of Gilson synthetic emerald. Later on, seed plates of synthetic emerald were cut in the same orientation from the synthetic overgrowth of the colourless beryl seed and used instead of that (Nassau, 1976, 1980). During crystal growth, a morphology is developed, which, in addition to the basal pinacoid *c* {0001}, consists of two larger second-order hexagonal prism faces *a* and *a'* $\{11\bar{2}0\}$ on opposite sides of an octagonally shaped crystal, as well as of six crystal faces built by the first-order hexagonal prism *m* $\{10\bar{1}0\}$. This information is based on the investigations of rough crystals of Gilson synthetic emeralds by Diehl (1977, 1982) and Schrader (1987), and part of it is also found in the publication of Schwarz (1987).

The information given in the above mentioned publications corresponds to the observations made by the present authors. However, it has to be underlined that the material available for this investigation only consisted of faceted Gilson flux-grown synthetic emeralds weighing up to about 5 cts. This means that only structures were observable, which are characteristic for parts of the whole rough crystal plates of Gilson synthetic emerald. During the investigation of faceted samples, which were cut out of the crystal plates described above, emeralds with part of the seed plate and stones without residuals of the seed could be distinguished. Consistent with the more recent literature cited above, the samples examined by the authors contained only seed plates of flux-grown synthetic emerald. Depending on the position from which the stone was cut out of the synthetic emerald crystal, different possibilities of growth structures are observable in cut samples.

In those without part of the seed plate a number of stones revealed only a distinct zoning parallel to the basal pinacoid *c* (0001) as growth structure [Figure 34], others showed only structures parallel to one of the prism faces *m* $(10\bar{1}0)$ or *a* $(11\bar{2}0)$. In another part of this type of cut stones growth structures were observed, which revealed two sets of prism faces *m* and *m'* or *m* and *a* [Figure 35]. In other examples, the basal pinacoid *c* (0001) in combination with one of the two prism faces *m* $(10\bar{1}0)$ or *a* $(11\bar{2}0)$ was found [Figure 36].

In natural emeralds, no growth structures resembling those mentioned above were observed because of the size of natural emeralds. In other words, no natural samples with growth structures parallel to only one single basal or prism face in the whole cut sample or parallel to one prism face and the basal pinacoid were observed by the authors. For natural stones, it is not customary to cut only a small section out of a crystal with more or less prismatic natural habit. Faceted natural emeralds, in general, reveal growth structures of the whole rough crystals, e.g. the basal pinacoid *c* (0001) in combination with six larger prism faces *m* $\{10\bar{1}0\}$ and six smaller prism faces *a* $\{11\bar{2}0\}$ as well as different hexagonal dipyramids.

In Gilson flux-grown synthetic emeralds, in which part of the seed plate was still observable in the cut samples, the following different kinds of growth structures were examined: some of the stones could be determined, which showed growth

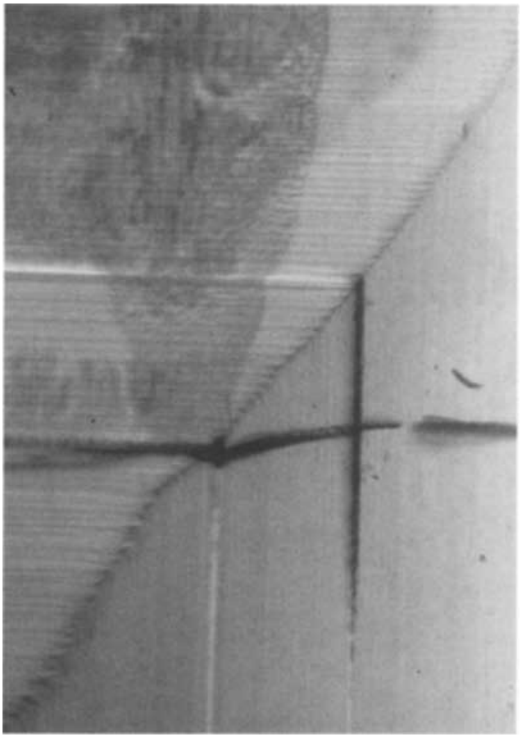

Fig. 36

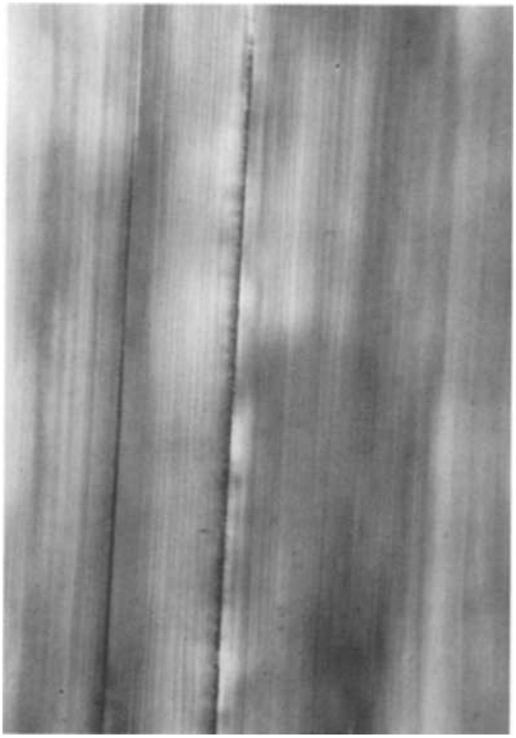

Fig. 37

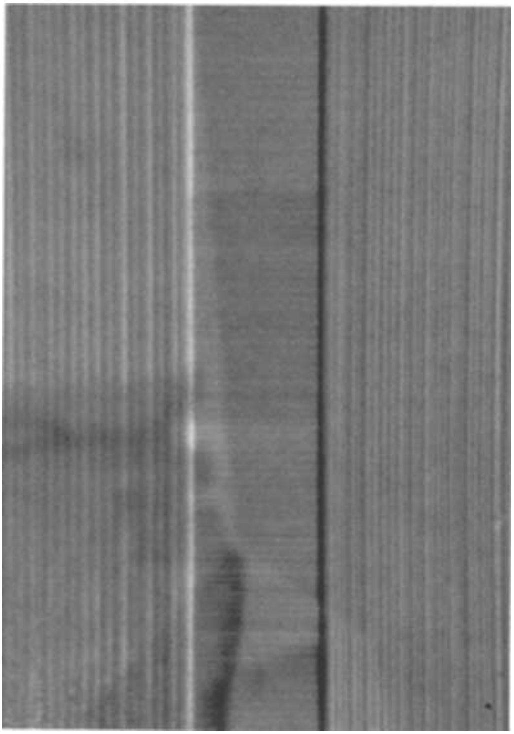

Fig. 38

Fig. 36. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces (*m* or *a*) form an angle of 90°. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x.

Fig. 37. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to one of the hexagonal prism faces (*m* or *a*) are found in the seed and the overgrowth. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x.

Fig. 38. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) are found in the seed, planes parallel to one of the prism faces (*m* or *a*) are found in the overgrowth. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 40x.

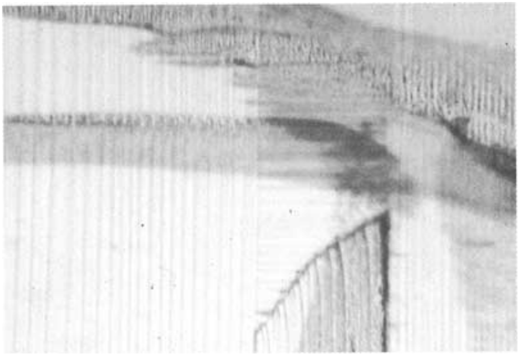

Fig. 39. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces (*m* or *a*) are found in the seed, planes parallel to one of the prism faces (*m* or *a*) are found in the overgrowth. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 65x.

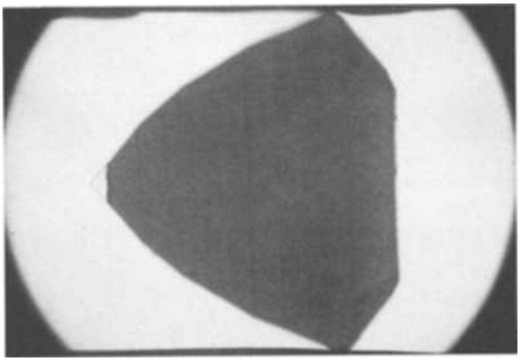

Fig. 40. Growth structures in Russian hydrothermally-grown synthetic emerald; residue of the seed at the culet, step-like growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald, irregularly changing sub-grain boundaries. View 31° inclined to the *c*-axis. 34x.

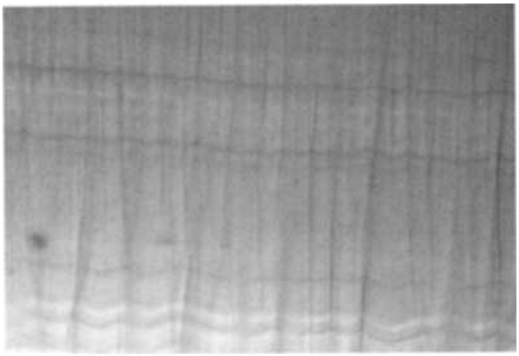

Fig. 41. Growth structures in Russian hydrothermally-grown synthetic emerald; step-like growth lines and colour zoning, irregularly changing sub-grain boundaries almost perpendicular to the colour zoning. View 31° inclined to the *c*-axis. 25x.

planes parallel to one of the prism faces, both in the synthetic emerald seed and in the emerald overgrowth [Figure 37]. In other samples the growth structures of the seed were orientated parallel to the basal pinacoid *c* (0001), whereas the overgrown areas showed growth planes parallel to one of the prism faces [Figure 38]. In others, growth planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces were observed in the seed, and the additionally grown synthetic emerald showed structures parallel to one prism face [Figure 39]. In the remaining stones examined, the seed revealed one of the growth structures mentioned above, whereas in the overgrown areas both the basal pinacoid (*c*) and one of the prism faces (*m* or *a*) were found as growth structures.

All these types of growth structures were never observed in any natural emerald. Furthermore, the pyramidal faces *u*, *p*, and *s*, which are characteristic for part of natural emeralds, e.g. from Colombia or Nigeria (cf. section II), do not occur in synthetic flux-grown emeralds. An additional feature of Gilson flux-grown synthetic emeralds are residues of flux materials which occur in zones confined to growth structures. This phenomenon is caused by growth intervals, which lead to a varying incorporation of flux in different areas of the crystal. This kind of structure is also a feature of synthetic emeralds and does not occur in natural stones.

IV. Hydrothermally-grown synthetic emeralds

The most characteristic feature of hydrothermally-grown synthetic emerald is the orientation of the seed plate. According to the patents of Flanigen (1971) and Flanigen & Mumbach (1971), crystal growth is most efficient if seed plates are cut in an angle of 45° to the *c*-axis of the beryl. Satisfactory results were also obtained by using seed plates with angles between 30 and 60° (Flanigen, 1971) or between 10 and 60° to the *c*-axis (Flanigen & Mumbach, 1971). Poor crystal growth was observed when the seed plate was cut parallel to the basal pinacoid *c* (0001) or parallel to one of the prism faces.

The orientation of the seed plate parallel to one of the prism faces was used in the experiments by Swarovski, Austria. These synthetic emeralds, however, were never produced commercially. All other commercially produced hydrothermally-grown synthetic emeralds available to the authors are made by using seed plates cut oblique to the *c*-axis.

In faceted stones, due to this kind of orientation of the seed plate, either residues of the seed plate with a distinct boundary of a seed plate versus the overgrowth, or, in the hydrothermally-grown part itself, dominant growth structures parallel to the

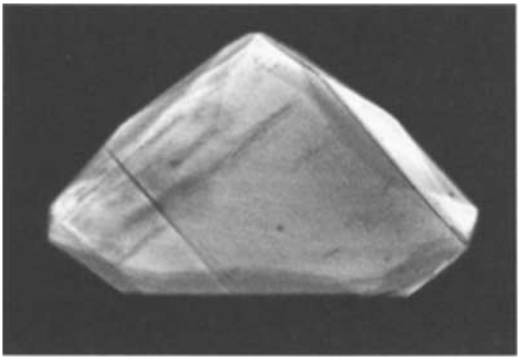

Fig. 42. Growth structures in Biron hydrothermally-grown synthetic emerald; residue of the seed [right], dominant growth line parallel to the boundary colourless seed/synthetic emerald [left]. View 23° inclined to the *c*-axis. Crossed polarizers. 20x.

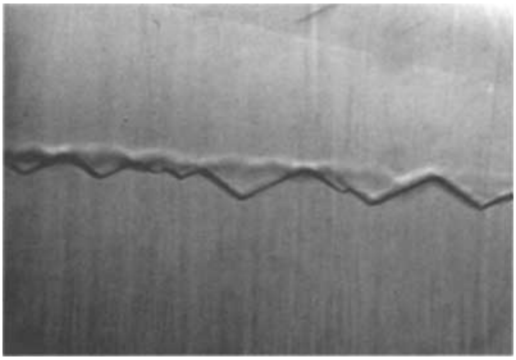

Fig. 43. Growth structures in Biron hydrothermally-grown synthetic emerald; step-like growth line and colour zoning, irregularly changing sub-grain boundaries almost perpendicular to the growth line. View 23° inclined to the *c*-axis. 50x.

orientation of the seed plate were detected.

In Linde hydrothermally-grown synthetic emeralds, which were produced according to the patents mentioned above, the angles between the *c*-axis and dominant growth structures were measured by the present authors between 36 and 38°, which is quite a constant factor (cf. Galia, 1972). Regency hydrothermally-grown synthetic emeralds, which are manufactured by use of the same patents as applied for the growth of Linde synthetic emeralds (O'Donoghue, 1983), revealed angles of 38° between dominant growth structures and the *c*-axis [Figure 45]. A number of samples of Lechleitner hydrothermally-grown synthetic emeralds showed a variation of angles between 32 and 40° (cf. Schmetzer, 1990). Biron synthetic emeralds, on the other hand, with angles of 22 to 23° [Figures 42, 43] as well as Pool synthetic emeralds, which are supposedly grown by the same hydrothermal process (Brown & Snow, 1988; Scarratt, 1989), with angles of 22 to 24° [Figure 44], reveal a certain constancy, too. So do Russian hydrothermally-grown synthetic emeralds with quite constant angles between 30 and 32° [Figures 40, 41] (cf. Schmetzer, 1988).

As a general rule, in faceted synthetic samples of all these producers or types, one dominant set of growth structures parallel to the orientation of the seed plate can be determined, which are most frequently connected with a distinct colour zoning. In addition, the oblique orientation of the seed plate is responsible for the formation of sub-grain boundaries (cellular structures), which have already been discussed in detail for Russian hydrothermally-grown synthetic emeralds (Schmetzer, 1988). In general, similar or almost identical growth structures were found in each commercial type of hydrothermally-grown synthetic emerald.

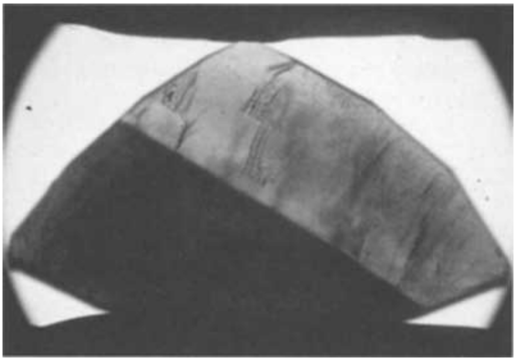

Fig. 44. Growth structures in Pool hydrothermally-grown synthetic emerald; dominant growth line and colour zoning. View 24° inclined to the *c*-axis. 22x.

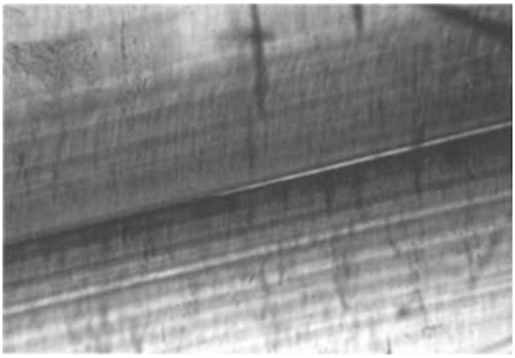

Fig. 45. Growth structures in Regency hydrothermally-grown synthetic emerald; growth lines and colour zoning, irregularly changing sub-grain boundaries almost perpendicular to the colour zoning. View 38° inclined to the *c*-axis. 35x.

Dominant growth structures in orientations comparable to those present in hydrothermally-grown synthetic emeralds, i.e. growth structures forming angles between 22 and 40° with the optic axis, do not occur in natural emeralds (cf. section II). In addition, the growth features caused by the orientation of the seed plate are typical for these varieties of synthetic emeralds and can, therefore, be considered as a characteristic feature of diagnostic value.

V. Conclusions

Frequently, the recognition of emeralds of unknown origin as natural or synthetic is possible by use of characteristic growth structures. In some cases, even the source of a natural emerald or the producer of a flux-grown or hydrothermally-grown synthetic emerald is unequivocally determined according to the presence of characteristic growth structures. However, there are also distinct types of growth faces, which are found in both, natural and synthetic emeralds. In those cases, no unequivocal determination of an unknown sample by means of growth structures is possible. But even in those particular cases, growth structures can be useful to exclude some possibilities for natural or synthetic emerald, i.e. to reduce the possibilities to a limited number of natural sources or producers of synthetic emeralds.

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[*Manuscript received 3 May 1989.*]

Gemmological Abstracts

ALLEN, R.M., 1991. The Yogo sapphire deposit. *Gemmological Digest*, **3**, 2, 9-16. 13 photographs in colour, 2 maps, 1 fig.

Recent work on the Yogo sapphire deposit in Montana, USA, may make the various colours of corundum more available on the market. Short notes on the geology and mining history are given. Rutile is one of the reported inclusions and the best stones rank with some of the finest from other sources. M.O'D.

ATHINEOS, D., 1991. The orchid of the mineral kingdom. *Christie's International Magazine*, **8**, 3, 20-2, 5 figs in colour.

A short but well-illustrated and accurate account of coloured diamonds, many of which have passed through the saleroom. Up-to-date information on colour alteration is given. M.O'D.

BARNES, L.C., BECK, R.J., LEAMING, S.F., TAN, L.-P., 1988. World review of nephrite jade - geology, production and reserves. *Bulletin of the Friends of Jade*, **5**, 14-69, 6 maps.

Nephrite is produced in at least 46 countries but commercial output is restricted to Canada, Taiwan, New Zealand, Australia, China, USA and Korea. World production of nephrite, exclusive of China, amounts to an average of 780 tonnes a year since 1962. China may produce as much as 500 tonnes a year; Taiwan production has ceased. A shortage of nephrite is expected to be relieved by production from the Cowell field in Australia or by increased use of simulants. Commercial deposits are surveyed with a view to estimating future production. Considerable geological detail is given. There is a most useful bibliography. M.O'D.

BECK, R.J., 1988. Jade of the Pacific. *Bulletin of the Friends of Jade*, **5**, 75-8.

The article describes a visit to China and to the Uygur Autonomous Region, Taiwan and South Korea. M.O'D.

BLANKENSHIP, D.T., 1988. The sawing of jade. *Bulletin of the Friends of Jade*, **5**, 70-4.

The various methods used for jade sawing are described with notes on the Chinese terms used. There is a short bibliography. M.O'D.

BLANKENSHIP, D.T., 1989. Orange peel. *Bulletin of the Friends of Jade*, **6**, 81-3.

The surface of nephrite is discussed from the Point of view of the lapidary. The 'orange peel' effect was not apparently a feature of the nephrite from eastern Turkestan. M.O'D.

BOGDANOVIC, K.I., 1989. Nephrite deposits in the Kuen-Lun mountains. *Bulletin of the Friends of Jade*, **6**, 74-80.

Nephrite deposits in eastern Turkestan are described. All in situ deposits are situated in high mountain areas which are difficult to reach. M.O'D.

BOSSHART, G., 1990. Il verde di Dresda*. *La Gemmologia*, **15**,1/2, 7-21, 6 photographs in colour, 1 fig.

The Dresden Green diamond is investigated and found to weigh approximately 41 ct and to belong to Type IIa. Some areas display anomalous birefringence and the stone is well cut to ideal proportions. M.O'D.

BOSSHART, G., 1991. Les emeraudes de Colombie. *Revue de Gemmologie*, **106**, 19-24, 12 photographs in colour, 4 figs.

This part of the paper describes absorption. colour and fluorescence, optical constants, density, inclusions and growth features. Some characteristic inclusions are illustrated. M.O'D.

BRACEWELL, H., 1991. Gems around Australia. *Australian Gemmologist*, **17**, 9, 377-8, 6 figs.

Mrs Bracewell continues her account describing further scenes, finds and adventures in the Bracewell circumtouring of that Continent early in the 1980s. She describes Northern Australia, finding ribbonstone, prehnite and amethyst. R.K.M.

BROWN, G., 1990. A rare baler shell pearl. *Australian Gemmologist*, **17**, 8, 307-8, 5 figs.

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*Translation of a paper first published in *Schweizer Uhren-und Schmuck*, 1989, 2, 513-19.

Found in the large melo amphora shell, which can reach 50cm in length, this rare 68.97 ct non-nacreous pearl is pinkish-orange in colour with a flame pattern reminiscent of that seen in pink conch pearls, SG 2.83, DV/RI value 1.67, inert to UV and no visible absorption. R.K.M.

BROWN, G., 1991. Some Australian turquoise deposits. *Australian Gemmologist*, 17, 9, 369-73, 4 figs.

Turquoise occurs in almost every state, but little of it is of fine quality. R.K.M.

BROWN, G., BEATTIE, R., SNOW, J., 1991. Verneuil synthetic red spinel. *Australian Gemmologist*, 17, 9, 344-7, 6 figs.

Hitherto a difficult synthetic to find, this is now apparently in circulation in fragmented form in Australia and USA. RI 1.720, SG 3.59 and strain free between crossed polars, fluorescing like natural stone and with identical absorption/emission spectra, these stones need close examination under magnification to reveal characteristic inclusions of curved growth banding, tadpole and profilated bubbles [these writers persist in calling these 'proliferated', a term which has quite a different meaning from that intended by Anderson when he coined the new word]. It is not known whether these are old stock or a new production. R.K.M.

BROWN, G., CHAPMAN, J., 1991. Argyle champagne and cognac diamonds. *Australian Gemmologist*, 17, 9, 350-1, 1 fig.

A brief résumé of occurrence, colours and qualities. R.K.M.

BROWN, G., KELLY, S.M.B., BEATTIE, R., BRACEWELL, H., 1990. Gemmology Study Club report. *Australian Gemmologist*, 17, 8, 325-32, 20 figs badly numbered.

A ruby/sapphire combined in one crystal; massive stichtite, a rare ornamental material from Tasmania, are described. A mounted suite of 10 large orange sapphires was found to be yellow synthetic corundum diffusion treated with synthetic ruby; bought for US$35 in Srinagar, Kashmir, one wonders at the economics of the deal [and even more that the purchaser should need them valued]; diffusion-treated synthetic blue sapphire with curved colour zones has been seen. A glass imitation of aquamarine spalled after cutting, while another was made from photo-sensitive glass of the type used for sun-glasses. Emerald from 'Harry's Mine' near Torrington, NSW, is shown to be green beryl rather than emerald, it has no chrome spectrum and is green through the Chelsea filter; sunstone quartz from Tingha near Inverell, NSW, thought to be due to included hematite plates, is described. [The figures in this paper are again numbered in separate groups and there is misuse of the word 'including'. An inclusion should not be said to be 'including' the host mineral.] R.K.M.

BROWN, G., KELLY, S.M.B., BEATTIE, R., 1991. Gemmological Study Club Lab reports. *Australian Gemmologist*, 17, 9, 363-7, 13 figs.

Deals with Hong Kong dyed and waxed jadeite; a coated (heated) sapphire; cerussite; prawn-claws as earrings; pipi blister pearls from Cook Island; carved bone from India and red Kauri gum. [The idiosyncratic numbering of figures in these reports is confusing. In this one there are seven with the number 1. Can editor not do something to rationalize this.] R.K.M.

BROWN, G., KELLY, S.M.B., SNEYD, R., 1990. Russian flux-grown synthetic spinel. *Australian Gemmologist*, 17, 8, 315-17, 10 figs.

A specimen of this fairly new synthetic red spinel was purchased in Hong Kong and conformed very closely in constants with similar octahedral crystals described elsewhere. Etch (growth?) marks and triangular dissolution edges and marks on the octahedral faces, adherant octahedra, dark flux, platinum flakes, air-filled curved fractures and dendrites were seen. Authors conclude that if a visually clean stone could be cut from such material, it would be identical with natural red spinel, undetectable by normal tests. R.K.M.

BROWN, G., KELLY, S.M.B., SUTHERLAND, C., CALLAWAY, P., 1990. Imitation chicken-blood stone. *Australian Gemmologist*, 17, 8, 311-13, 5 figs.

A visually effective imitation of this Chinese valued material was detected by warmth to touch, bubbles in cinnabar imitation and coating, and strong fluorescence to LUV. The grey base material is described as soapy to the touch, while the coloured coating had a waxy feel; both peeled readily. R.K.M.

BROWN, G., LINTON, T., 1991. An inexpensive conversion unit. *Australian Gemmologist* 17, 9, 355, 1 fig.

A metal base which allows a Kiowa microscope to be turned through 90° for horizontal examination of immersed stones. R.K.M.

Brown, G., Tombs, G., 1991. An introductory note on the manmade products of Dominique Robert. *Australian Gemmologist*, 17, 9, 381-2, 5 figs in colour.

Emeraldolite is a synthetic druse of emerald coated onto a large crystal or other base of natural beryl. Heat whitens and opacifies the seed material. Oulongite is another synthetic 'garnet', formula unspecified; colours so far white, blue, green, pink. H about 7.5, SG 6.9, RI 1.93-1.99, Disp. 0.030. R.K.M.

Cairncross, B., 1991. The Messina mining district, South Africa. *Mineralogical Record*, 22, 3, 187-99, 12 photographs (8 in colour), 11 maps and plans.

Quartz crystals coloured sky blue by inclusions of ajoite and measuring up to 5cm in length are reported from the Messina mining area, northern Transvaal, South Africa. M.O'D.

Campbell, I.C.C., 1991. A report on one of a number of emeralds from Madagascar. *South African Gemmologist*, 5, 1, 8-15, 7 figs in colour.

Large emeralds from Madagascar have been seen in the South African gem market. SG is reported as 2.73-2.74, RI 1.585, 1.591, 1.593 [sic] (a previous study gives 1.589-1.591 for the ordinary ray and 1.581-1.585 for the extraordinary ray). Birefringence is reported by the earlier study as 0.006-0.008. Stones are inert to UV and show strong yellowish-green and strong greenish-blue dichroism. The cabochon examined contained goethite, limonite, hematite and colour zoning, as the previous report stated. In addition phlogopite was identified and the stone may have been oiled. Biotite, muscovite, apatite, quartz, tourmaline and two-phase inclusions could not be identified with the limited equipment available, though they featured in the previous report. The strongest absorption was in the region of 680nm and diffuse bands were noted in the region from 650-640nm. There was moderately strong absorption of the orange-yellow from approximately 630-570nm. No absorption was noted in the blue region. Under the colour filter the stone gave a slightly reddish colour with a dull and dark appearance. M.O'D.

Campbell, I.C.C., 1991. Fine quality large cut opal. *South African Gemmologist*, 5, 1, 22, 1 fig. in colour.

A fine quality white opal measuring 28.62 x 21.92 x 9.74mm and weighing 35.16 ct is described and illustrated. M.O'D.

Chancerel, C., 1991. Bloody opals ...! *Revue de Gemmologie*, **106**, 3-7, 20 figs (6 in colour).

A brief account of mining and cutting operations at the Australian field of Lightning Ridge, New South Wales. Some personal cutting experiences are described. M.O'D.

Clunas, C., 1989. Jade carvers and their customers in Ming China. *Bulletin of the Friends of Jade*, 6, 33-52, 7 figs.

Jade carving in China between Han dynasty and the eighteenth century is examined. There is a useful bibliography. It is interesting that the connoisseurs of the Ming period did not appear to regard jade as highly for its tactile qualities as has been thought. M.O'D.

Dyar, M.D., Perry, C.L., Rebbert, C.R., Dutrow, B.L., Holdaway, M.J., Lang, H.M., 1991. Mossbauer spectroscopy of synthetic and naturally occurring staurolite. *American Mineralogist*, 76, 27-41, 7 figs.

Room temperature Mossbauer spectroscopy of 23 natural and 12 synthetic staurolites showed that the majority of the Fe in all samples is Fe^{2+}. This occupies the Fe1, Fe2 and Fe3 subsites of the tetrahedral Fe site in an average ratio of 43/12/27. M.O'D.

Frey, R., 1989. Satellite scans: technical notes and gazetteer. *Bulletin of the Friends of Jade*, 6, 60-1, 1 fig.

A satellite photograph shows the nephrite source of the Karakash River. A short gazetteer gives some of the places shown. M.O'D.

Fryer, C.W., Ed., Crowningshield, R., Hurwitt, K.N., Kane, R.E., Hargett, D., 1990. Gem Trade Lab notes. *Gems & Gemology*, 26, 4, 294-9, 17 figs..

Collection quality mineral specimens of azurite were examined including exceptional ones from Chessy, France and Bisbee, Arizona; the latter with rosettes of azurite on a back-ground of malachite [most beautiful!]. A yellow zirconia was found matched with a yellow diamond in a ring, and had absorption lines at about 453 and 478nm, normally belonging to Cape diamonds. Intense yellow marquise diamonds in a brooch were probably proved by fluorescence and absorption to be natural, but were very like Sumitomo synthetics in appearance. Another diamond shown to be irradiated green by the 'umbrella' around the culet, but had additional dark zoning.

Dyed black cultured pearls fluoresced a distinct yellow under LUV and a tellurium dye was suspected. Bouton cultured pearls had lentil shaped nuclei, not used much because tend to kill the oyster.

A ruby with a glass infill had not been fired to a high temperature. The glass fluoresced chalky yellow in LUV and contained bubbles. A synthetic ruby cabochon had also been glass-filled where damaged and we are warned to look out for bubbles in the glass and curved striae in the ruby. A synthetic sapphire contained prominent lines of tiny bubbles which looked like needles [illustration shows that these were not at the required inclination of 120°]; striae and curved colour zones were less obvious. Robert Kane says a dark blue filter over a transmitted light source makes curved striae and bubbles easier to see in yellow and orange synthetic sapphires, normally quite difficult stones to identify. A large piece of blue material had RI 1.56, H about 2½, SG below 2.57, eliminating turquoise which it was apparently intended to resemble. Acid revealed carbonate plus a plastic binder. R.K.M.

HÖCHLEITNER, R., WEISS, S., 1991. Neue mineralfunde aus Pakistan und Afghanistan. *Lapis*, **16**, 3, 15-16, 3 figs (2 in colour).

Stibiotantalite and tremolite are described from Ştak-Nala in Pakistan and from Nuristan, Afghanistan, respectively. From the illustrations the quality approaches the ornamental. The stibiotantalite is yellow and occurs with tourmaline and albite. The tremolite is white and resembles Alpine adularia. M.O'D.

HODGKINSON, A., 1991. Padparadscha - what is meant by this term? *Australian Gemmologist*, **17**, 9, 378-80, 3 figs.

Discusses various versions of orange/pink corundum sold under this and similar names, and the ruby/pink sapphire question, going on to include synthetic padparadschas, which are by far the commonest of this name. R.K.M.

HUANG, U.T., AUNG, Z., HTEIN, W., 1991. Radioactivity in some minerals in the Mogok area. *Australian Gemmologist*, **17**, 9, 356-9, 2 figs.

Researchers found more uranium in zircon, and more thorium in sphene, than in apatite. An erudite scientific paper having little to do with the gem potential of these stones. R.K.M.

HUGHES, R.W., 1991. There's a rumble in the jungle - the sapphire face-lift face-off saga. *Gemmological Digest*, **3**, 2, 17-28, 11 figs in colour.

Diffusion-treated corundum is discussed with illustrations of treated stones and notes on identification. The history and some of the politics of the method are also discussed. M.O'D.

HUGHES, R.W., SERSEN, W.J., 1991. Vietnamese ruby. *Gemmological Digest*, **3**, 2, 68-70, 7 photographs in colour, 1 map.

Fine quality ruby is reported from Luc Yen, Vietnam, a site about 150km north-west of Hanoi. Stones resemble Burmese material in colour and strong fluorescence. M.O'D.

HUTTON, D.R., TROUP, G.J., 1990. ESR spectrum of Australian synthetic Biron emerald. *Australian Gemmologist*, **17**, 8, 299-301, 5 diagrams.

Electron-spin resonance of this new synthetic is demonstrated in diagrams of spectra [Figure 3 has the wrong caption] and suggests that the material is of laser quality. [Interpretation is not easy for the uninitiated.] R.K.M.

KAMMERLING, R.C., KANE, R.E., KOIVULA, J.I., MCCLURE, S.F., 1990. An investigation of a suite of black diamonds. *Gems & Gemology*, **26**, 4, 7 figs.

Six quite large mounted black diamonds were examined for transparent dark green areas which would indicate artificial irradiation. Minute transparent areas in these stones were white or blue. Facets were pitted and polishing drag lines were prominent, as with most black diamonds. Colour was due to graphite. No distinct absorption lines or bands were seen. Two stones showing blue transparent areas fluoresced strong blue under LUV and green in SUV another stone gave a chalky mottled yellowish-green. All the black stones had been cemented into their settings. probably in deference to the many cleavages which made the stones vulnerable to setting pressures. Thermal conductivity was normal for diamond. A detailed list of possible simulants is given.
R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., 1991. Examination of a plastic coated 'sugar treated' opal. *Australian Gemmologist*, **17**, 9, 352-5, 4 figs.

Submitted for investigation by John Fuhrbach of Amarillo, this stone had been bought as black opal at high cost. It is a dyed (sugar/acid treated) stone which had also been coated with plastic, causing anomalous fluorescence and many included bubbles. R.K.M.

Kammerling, R.C., Koivula, J.I., 1991. Opals displaying cat's-eye effects. *South African Gemmologist*, **5**, 1, 23-7, 3 figs in colour.

A number of natural opals show chatoyancy. Idaho opal mounted as composites show chatoyancy and in this case the phenomenon is attributed to planar faults in the stacking of the silica spheres. An opal whose chatoyancy is attributed to light reflection from parallel acicular inclusions is described. Since the stone showed a weak pleochroism its origin may have been as a pseudomorph after a birefringent fibrous mineral such as goethite. M.O'D.

Kammerling, R.C., Koivula, J.I., Fritsch, E., 1990. An examination of chrysoprase from Goias, Brazil. *Australian Gemmologist*, **17**, 8, 313-15, 2 figs.

The pale yellowish green to dark vivid green is probably due to nickel in the form of bunsenite. RI 1.539, SG 2.64. Rather strangely a quite marked greenish-blue fluorescence in LUV, and fainter in SUV, have apparently not been previously noted. R.K.M.

Kane, R.E., McClure, S.F., Menzhausen, J., 1990. The legendary Dresden Green diamond. *Gems & Gemology*, **26**, 4, 248-66, 16 figs.

A very full investigation of this historic 41 ct diamond by a team which visited Dresden especially for the purpose. Photographs reproduced show the stone in a recently drawn reconstruction as part of the order of the Golden Fleece, which is also used as the front cover of this issue of the journal. Others show a glass copy and the stone itself, which registers as paler than either the copy or the drawing.

The history of the stone is researched with care and it seems certain that the rough came from India, since Brazilian diamonds were discovered only a year or so earlier. It was cut, probably in London, shortly afterwards and in 1742 was incorporated in the Fleece badge only to be broken up four years later, when it was used in a second version which also included the 49.71 metric carat Saxon White diamond. [Two weights are given for this stone, the first being in pre-metric carats.] The badge was again dismantled in 1768 and Dissbach commissioned to fashion the centre part into a shoulder knot and a hat ornament, both of which exist today, the Dresden Green being transferable.

The present team investigated the stone very thoroughly, and report on shape, cut, proportions, finish, clarity and colour. Finish and symmetry are very good and transparency is exceptional. Colour is usually described as apple green; the team call it 'fancy green', photographs of the actual stone published here suggest lightish yellow-green. Graining was seen in three directions and polariscope revealed considerable cross-hatched strain; a powerful source of UV revealed weak green fluorescence. Natural radiation damage was evidenced by small green or brown stains at three places near the girdle, but do not cause the body colour. No distinct spectrum at normal temperatures but low temperature spectroscopy revealed a general radiation pattern, with absorption lines at 594, 495, 470, 310, 393, and a cut-off at 225nm. There are similarities with a known radiation-treated stone. Further details are given, but 594nm is considered to indicate a treated stone, yet the Dresden was known long before such treatment was available. Infrared absorption spectra suggest the stone is a Type IIa diamond, and this leaves the question of separating natural from artificially treated green Type IIa diamonds wide open. R.K.M.

Keverne, R., 1988. Worldwide view of the jade market, 1986. *Bulletin of the Friends of Jade*, **5**, 7-13.

Details of jade pieces sold at auction are given (hammer prices excluding the 10% commission levied on the buyer). Sales conducted by Christie's and Sotheby's are covered worldwide. Jadeite vessels were strong performers over the year and good qualities did well while sub-standard pieces failed to attract buyers. Jewellery of the best colours did well. M.O'D.

Keverne, R., 1989. Worldwide view of the jade market 1987 (1988). *Bulletin of the Friends of Jade*, **6**, 8-19 (20-32).

Considerable enthusiasm exists, on the basis of the Christie's and Sotheby's sales in the two years reviewed, for high quality jade artefacts. The 1988 season in particular was the most successful since the early 1970's. Fine jewellery and good white carvings were in strong demand. M.O'D

Koivula, J.I., 1990. Snail shells in amber. *Australian Gemmologist*, **17**, 8, 309-10, 2 figs.

In common with other animals and plants in amber from the Dominican Republic, these lcm spiral (pulmonata) snail shells are remarkably well preserved for forty million years old. Author says that one area of Panama has an estimated snail population today of over seven million snails per acre, mostly of sizes suitable for such entrapment. [He also says that most snails serve as scavengers of dead plant and animal matter. The million or so in my garden are much braver and tackle living plants with considerable appetite!] These two are small, the larger about 1cm in length. R.K.M.

Koivula, J.I., Kammerling, R.C., 1990. Gem news. *Gems & Gemology*, **26**, 4, 300-9, 16 figs.

Diamonds

De Beers have grown a 14.2 ct good quality industrial yellow stone thought to be the largest yet, but not commercially viable; only industrials are aimed at in such experiments. Nearly half the China-cut diamonds offered in Singapore were sold; development and exploration of diamond mining in Guyana has been agreed.

Coloured stones

Vast gold reserves found in Afghanistan, with gem mining, this is expected to attract foreign investment; cat's-eye opal triplets, synthetic corundum stars and quartz cabochons backed with computer chips are among new assembled stones; black coral is being exploited in the Mexican Caribbean; heavy excavating equipment is being used in Kanchanaburi sapphire mines; a peace pact has been signed between warring factions in the Colombia emerald area, and production is expected to increase; an unusual African grossular garnet was parti-coloured yellowish brown and orange with different RI (1.38, light, and 1.4 darker area).

Australian research is investigating use of safe heavy organic water-soluble compounds for mineral separation; a black cat's-eye opal from Mexico is described and illustrated; a 14 x 10 cm gem quality opal found at Boi Morto Mine, Brazil, was brownish white in colour with pinfire on all surfaces; a 16.39 ct cobalt spinel of violet-blue colour in fluorescent light, turned purple under incandescent light, RI 1.714, red through Chelsea filter, chalky-red in LUV, strong fluorescent line at 686nm weaker one at 552 and broad diffuse absorption at 454-461nm; a large light bluish-green topaz sculpture weighing about 35000 ct has been cut from part of a 79 lb crystal bought by Edward Swoboda in the 1950s, polishing large facets gave a lot of trouble in the final stages; cat's-eye red/blue tourmaline had tubular inclusions in the blue section only, skilled cutting retained the 'eye' at the junction of the two colours; a Welsh firm has exclusive agreement with USSR geology ministries to attract foreign interest in gem mining; waxing of jades was described and illustrated in a Hong Kong magazine.

Enhancements

Robert Crowningshield showed that techniques to detect colour diffusion treatment in loose sapphires can work equally with mounted stones; Aqua Aura treatment of quartz can also use silver or platinum which do not colour the crystal but leave the surface iridescent; synthetic sapphire cabochons are being 'improved' by matt surfacing the backs to reduce transparency; Thailand is now cutting CZ for the US; glass imitations of Imperial jadeite are described and illustrated; pectolite is imitated by blue Imori stone (glass); dyed quartz sold as purple onyx in Indian jewellery in the States seems to be a micro-version of crackled quartz with a strong resemblance to sugilite.

R.K.M.

Krosch, N.J., 1990. Queensland chrysoprase. *Australian Gemmologist*, 17, 8, 303-6, 2 figs, 2 maps.

The exceptionally fine Marlborough chrysoprase, sometimes incorrectly called Queensland jade, has been known for more than thirty years. Mined by open-cast method from nickel-ferrous serpentines. Gemmological details are not quoted.

R.K.M.

Leaming, S., 1989. From the mines in the mountains to the rocks in the river. The development of alluvial jade deposits from jade lodes. *Bulletin of the Friends of Jade*, **6**, 63-8, 1 fig.

The movement of nephrite from in situ deposits to alluvial finds is discussed. The equation

$$T=C\ \frac{D \times W}{E_d \times R} \times U_r$$

where T is the time in years taken for a block to travel, D the distance between two locations, W the weight of the block, E_d the difference in elevation between the two locations, C a constant specific to nephrite, R the roundness of the block and U_r the rate of uplift is postulated. The case in question covers the distance between the mines at Shahidulla to the oasis of Khotan. M.O'D.

Lintner, B., 1988. Along Burma's jade trail. *Bulletin of the Friends of Jade*, 5, 81.

A reprint of an article in *The Far Easatern Review* in 1987 describing the difficulties of working the Jade Tracts in Myitkina, Burma. M.O'D.

Linton, T., Brown, G., 1990. Presidium MiniMate. *Australian Gemmologist*, **17**, 8, 318-20, 3 figs.

Another well-designed and reliable heat-probe for testing mounted diamonds. Usual precautions must be taken in use. R.K.M.

Linton, T., Brown, G., 1990. Presidium

DiaMeter - System Berger. *Australian Gemmologist*, **17**, 8, 301-6, 3 figs.

A slide rule for diameter/weight calculations for well-made round diamonds, combined with an electronic version of the Leveridge gauge. Combination works well for stones of good make. R.K.M.

Linton, T., Brown, G., 1991. The gold-meter. *Australian Gemmologist*, **17**, 9, 360-2, 2 figs.

An assessment of a new electro-chemical meter for testing gold which proved accurate for qualities up to 18ct, but did not specify quality above that. Needs to be used with care. [An obsolete address of Gemmological Instruments Ltd is quoted.] R.K.M.

Maas, H.H., 1991. Museen in Westdeutschland. (Museums in West Germany.) *Aufschluss*, **42**, 2, 29-40.

A useful list of museums in West Germany with geological, mineralogical or fossil collections arranged in alphabetical order of place. The name of the director is given together with hours of opening, telephone number, postal address and main theme of the collections. M.O'D.

Montgomery, R.S., 1991. In the dark: separating synthetic and natural gems by ultraviolet spectroscopy. *Gemmological Digest*, **3**, 2, 45-53, 18 figs (17 in colour).

The Krüss UVS 2000 is evaluated. Significant differences were noted between the spectra of the following pairs: natural and synthetic ruby, heated and unheated rubies, natural and synthetic blue sapphires, heated and unheated blue sapphires and natural and synthetic red spinels. M.O'D.

Pearson, G., 1990. Multiple chatoyancy in Australian sapphire. *Australian Gemmologist*, **17**, 8, 296-8, 8 figs.

An interesting account of 12-ray asterism in a cabochon sapphire from Rubyvale in Queensland, thought to be due to rutile (diffuse white star) and ilmenite (intersecting bronze coloured star showing additional reflective centres). [This is asterism not chatoyancy.] R.K.M.

Peile, J., 1988. Trouble at the mines. *Bulletin of the Friends of Jade*, **5**, 81.

A reprint of an article in *The Times* of London in 1893 describing the difficulties of working the Jade Tracts in Myitkina, Burma. M.O'D.

Pemadasa, T.G., 1991. Gem deposits of South West Sri Lanka. *Australian Gemmologist*, **17**, 9, 347-9 and 351, 4 figs.

A gneissic region with rich sources of alluvial gems including chrysoberyl cat's-eyes, alexandrite, rose quartz, hessonite and other gem species. Yield increases as the Singharaja Hills are approached suggesting that these are the primary source. R.K.M.

Robert, D., 1991. Emeraldolite (letter). *Australian Gemmologist*, **17**, 9, 381-2.

An answer to A. Taylor's letter, claiming that colourless beryl is an excellent foil for the artificial druse of synthetic emerald. R.K.M.

Robert, D., Fritsch, E., Koivula, J.I., 1990. Emeraldolite: a new synthetic overgrowth on natural beryl. *Gems & Gemology*, **26**, 4, 288-93, 7 figs.

A product rather similar to Lechleitner coated emeralds, but opaque in this case, and different in technique from the Lennix process, since fluorine is used as the transport agent. Emerald layer grows in conformity with the substrate crystal, giving even coloration. Spot RI 1.56, SG 2.66. No UV fluorescence or phosphorescence. There were numerous surface specks of white which were thought to be lithium feldspar. Intense red through Chelsea filter, no surface cracking. Unique appearance makes identifying easy. Generally used unpolished, but can be polished or carved. R.K.M.

Schluessel, R., 1991. Des saphirs étoilés synthétiques ... pas comme les autres. *Revue de Gemmologie*, **106**, 10-12, 12 figs in colour.

Several methods of distinguishing natural from synthetic star sapphires are outlined. Inclusions characteristic of the synthetic material are illustrated. M.O'D.

Schuhbauer, E., 1991. Bemerkenswerte Neufunde von Roten Beryllen in den Wah-Wah Mountains, Utah. *Lapis*, **16**, 6, 38, 4 photographs in colour.

Fine red beryl crystals are reported from the southern Wah-Wah Mountains in Beaver County, Utah, USA. The find of particularly good crystals was made in August 1990 at the Violet Claims. M.O'D.

Schwieger, R., 1990. Diagnostic features and heat treatment of Kashmir sapphires. *Gems & Gemology*, **26**, 4, 267-80, 24 figs.

A well-researched paper which serves to distinguish the rare and very lovely Kashmir sapphire from those fine stones from Burma or Sri Lanka, which are often called 'Kashmir' in ignorance. Typical silk and other inclusions are illustrated, and the unique absorption recorded by spectrophotometer is compared with those of stones from other sources. Kashmir sapphires are markedly different in the blue-violet region, while comparison with heated Sri Lankan stones was even more marked. But a Kashmir sapphire, similarly heated, became lighter in colour, some 'snowflake' inclusions dissolved and some areas became colourless. The spectrum also changed and became much more like that of a Sri Lankan sapphire. Unheated Kashmir stones can probably be identified with some certainty, but once heated they may lose colour and identifying characteristics. R.K.M.

SERSEN, W.J., 1991. Gemstones and early Arabic writers. *Gemmological Digest*, 3, 2, 34-9, 4 photographs (3 in colour), 1 fig.

Several Arabic writers of the thirteenth century onwards have commented on aspects of gemstones. Some of these are illustrated with comments on old mines and nomenclature. M.O'D.

SHAW, R., 1989. Visits to High Tartary, Tarkand and Kashgsar 1868/69. *Bulletin of the Friends of Jade*, 6, 69-70.

A nineteenth century account of jade mining in Khotan. M.O'D.

SHEAF, C., 1989. Jade around the clock. Reflections on jade sales at Christie's, Hong Kong. *Bulletin of the Friends of Jade*, 6, 53-9.

An account of the organization of jade auctions in Hong Kong in which both jadeite and nephrite are discussed. M.O'D.

STEIN, M.A., 1939. Sand-buried ruins of Khotan. *Bulletin of the Friends of Jade*, 6, 71-3.

An account of a visit to the jade diggings of Khotan in 1900. M.O'D.

SUNG, W.-H., LIEN, C.-M., 1989. A study of zoo-anthropomorphic jade earrings of prehistoric Taiwan. *Bulletin of the Friends of Jade*, 6, 87-91, 1 map.

A type of earring, hitherto unrecorded, has been found in Taiwan in sites dating from the Neolithic period. The material is either tremolitic nephrite or compact serpentine. [Paper reproduced from Bulletin No. 44 of the Department of Anthropology. National Taiwan University, 1984.] M.O'D.

TANG, S.M., TANG, S.H., MOK, K.F., RETTY, A.T., TAY, T.S., 1991. A study of natural and synthetic rubies by PIXE. *Gemmological Digest*, 3, 2, 63-7, 2 photographs in colour, 2 figs.

Proton-induced X-ray emission is used to examine 160 natural and synthetic rubies. Vanadium and iron are found in the natural stones rather than in the synthetic ones. M.O'D.

TANG, S.M., TANG, S.H., TAY, T.S., RETTY, A.T., 1991. Analysis of Burmese and Thai rubies by PIXE. *Gemmological Digest*, 3, 2, 57-62, 2 photographs (in colour), 2 figs.

Proton-induced X-ray emission techniques are used to identify trace elements in 60 Burmese and Thai rubies. Burmese stones were found to contain higher concentrations of all impurities except iron. They also show a higher concentration of vanadium than Thai stones, which contain on average four times the amount of iron. M.O'D.

TAYLOR, A., 1991. Emeraldolite (letter). *Australian Gemmologist*, 17, 9, 381-2.

Queries loss of water and colour when seed beryl is heated. R.K.M.

TAYLOR, W.R., JACQUES, A.L., RIDD, M., 1990. Nitrogen-defect aggregation characteristics of some Australasian diamonds: time-temperature constraints on the source regions of pipe and alluvial diamonds. *American Mineralogist*, 75, 1290-1310, 11 figs.

Fourier transform infrared microscopy is used to make a quantitative determination of the proportions of aggregated N substitutional defects platelet intensities and bulk N contents in Type Ia diamonds from the Argyle and Ellendale olivine lamproite pipes in the Kimberley block of northwest Australia and from alluvial deposits in western and central Kalimantan (Indonesia) and Copeton in eastern Australia. M.O'D.

TOMBS, G.A., 1990. Argyle diamonds. *Australian Gemmologist*, 17, 8, 321-4, 6 figs.

An account of the typical rough surfaced diamonds found in the Argyle area of W. Australia. Mines operate continuously year round, alternating staff commute from Perth fortnightly. The mines are open-pit and lamproite matrix is crushed and separated by gravity processes on site, computer controlled. Extreme roughness of surfaces is explained; crystals usually badly strained making polishing difficult; about 5% are gem quality. Strong pinks and purples are known but are extremely rare and fetch exceptionally high prices; it is not known whether more of these may be found. [Two captions to figures have been transposed.] R.K.M.

WARD, F., 1988. The search for jade. *Bulletin of the Friends of Jade*, 5, 86-92.

The author describes his work in preparing an article on jade for the National Geographic Magazine. He was able to visit some of the jade-producing areas of the world. M.O'D.

WEISS, S., 1991. Eisenhaltiger gelber Orthoklas - ein wiederentdeckter Edelstein aus Madagaskar. (Iron-bearing yellow orthoclase - a rediscovered gemstone from Madagascar.) *Lapis*, **16**, 3, 13-14, 3 figs (1 in colour).

Fe-bearing yellow orthoclase from Madagascar is described with notes on the location and on the crystal forms encountered. The mineral is of gem quality and is found in pegmatites in the general region of Itrongay. M.O'D.

WILKE, H.-J., POPOVA, E.E., 1991. Das Mineralogische Museum des Leningrader Bergbau-Institute. *Lapis*, **16**, 6, 24-37, 13 photographs in colour.

The museum of the Leningrad Mining Institute contains a fine collection of mineral specimens from the USSR and elsewhere. Exceptional crystals of brazilianite and uvarovite are among those of gemmological interest. M.O'D.

WOODHEAD, J.A., ROSSMAN, G.R., SILVER, L.T., 1991. The metamictization of zircon: radiation dose dependent structural characteristics. *American Mineralogist*, **76**, 74-82, 9 figs.

IR spectroscopy was used to examine a suite of gem zircon samples from Sri Lanka. XRD and chemical analysis were also used. The degree of metamictization increases systematically with U-Th content up to the point of total metamictization. The amount of metamictization is determined by examination of unit cell parameters. In the IR spectrum band widths increase and intensities decrease with increasing U-Th content. Bands related to Si-O bonds persist and bands related to Zr-O bonds disappear thus indicating that the structure of metamict zircon consists of distorted and disoriented isolated silica tetrahedra with few if any displaced Zr cations. M.O'D.

YEUNG, I., 1989. Treasures of Peinan culture found in Taiwan dig. *Bulletin of the Friends of Jade*, **6**, 8-6.

Archaeological examination of sites in the central mountain range of Taiwan has revealed nephrite artefacts in burial sites dating from 2025-1025 BC. Many of the objects are a fine green. M.O'D.

What's new in minerals? 1991. *Mineralogical Record*, **22**, 3, 213-20, 22 photographs (20 in colour).

Gem quality minerals seen at the 1991 Tucson Gem and Mineral show included copper-coloured blue tourmaline from the Batalha mine, Paraiba, Brazil; green diopside crystals from Kaflu (?), Pakistan; aquamarine crystals from the Jaqueto mine, Bahia, Brazil; vesuvianite crystals from the Jeffrey mine, Asbestos, Quebec; pink apatite crystals from Nagar, Pakistan, and fine multi-coloured tourmaline crystals from the Cruzeiro district, Minas Gerais, Brazil. M.O'D.

Book reviews

Fleischer, M., Mandarino, J.A., 1991. *Glossary of mineral species 1991.* The Mineralogical Record Inc., Tucson. pp.256. Price on application.

This is the sixth edition of the invaluable *Glossary*. Since the printing of the previous edition in 1987 about 200 new mineral names have been added and about 900 previous entries have had to be revised. Six new mineral groups have been added. As before the listing is alphabetical with chemical composition, crystal system, colour where necessary, allocation to groups which are themselves listed at the back of the book, dimorphs and polymorphs and particulars of references, mostly in *The American Mineralogist* but also in other journals where appropriate. Where there appears to be a close relationship between minerals without the entire series of compositions between them being known the words 'compare with' are used. 'Isostructural with' is used to denote two crystal structures of the same type with different chemical compositions, as with grossular and berzeliite. There are also boxes which can be completed by the reader to denote what species are found in his collection. M.O'D.

Hurlbut, C.S., Kammerling, R.C., 1991. *Gemology.* 2nd edition. John Wiley, New York. pp. xiv, 336. Illus. in black-and-white and in colour. £43.70.

Since the first edition appeared several years ago there have been a number of developments in gemstone synthesis and enhancement. A new chapter has been added for this reason and the coloured illustrations are more numerous and of good quality. Additional species have been added to the descriptive section and in this edition the more important species are listed first. Both sections are in alphabetical order. Details of important synthetic materials are also given in the sections on their natural counterparts.

The details of instruments and of gem testing are clearly given and the simple diagrams will be useful for students. Refractive index is well explained and the description and details of the use of interference figures are particularly successful. In contrast to many other simple gemmological texts this book includes basic details of fashioning.

The book is well-produced and very suitable for students and the academic background of the authors ensures a balanced presentation of material. M.O'D.

Kerrick, D.M., 1990. *The Al_2SiO_5 polymorphs.* The Mineralogical Society of America. Washington DC. pp. xii, 406. Illus. in black-and-white. US $20.00. [Reviews in mineralogy Vol. 22.]

Gemmologists will be interested in Al_2SiO_5 since andalusite, kyanite and sillimanite are members of the group. The book opens with an introductory section in which facies series and baric regimes are discussed together with tectonic metamorphic analysis of metamorphic belts and geothermometry as applied to the aluminium silicates. The next section covers crystal structures, optical and physical properties and is followed by a lengthy section on phase equilibria, an important feature in minerals displaying polymorphism. Later sections cover non-stoichiometry lattice defects, Al/Si disorder, problems with fibrolite (here the name is distinguished from sillimanite), metamorphic reactions, reaction kinetics and crystal growth mechanisms, aluminium metasomatism and a final section dealing with aluminium silicates in anatectic migmatites and peraluminous granitoids. There is a general list of references at the end of the book. Gemmologists will find the greatest interest in the section discussing colour and chemical composition. M.O'D.

Niedermayr, G., 1990. *Fluorit Mineral des Regenbogens.* Bode, Haltern. pp. 80. Illus. in colour. DM 14.80.

The book covers nine major European fluorite locations, each section being contributed by a different author. British and other world locations are briefly described in a final chapter. Each section has its own valuable list of references and the first chapter deals with the mineral itself with notes on its common modes of occurrence. Maps are provided for major sites and the colour pictures are superb. M.O'D.

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

OBITUARY

Mr Rodney F. Parcel, Jr, FGA (D.1981), Perris, California, USA, died recently.

NEWS OF FELLOWS

On 8 May 1991 **Michael O'Donoghue** gave a talk entitled 'Improved gemstones' to the Snodland Parish Circle.

On 20 May 1991 **Michael O'Donoghue** lectured on gemstones at Sotheby's 'Looking at jewellery' course.

MEMBERS' MEETINGS

London

On 21 May 1991 at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, an Emerald Evening was held. The ICA video entitled 'Colombia emeralds' was shown. Following the video, Ken Scarratt, Harry Levy and John Kessler discussed various aspects concerning emeralds, including localities, synthetics and treatments.

Midlands Branch

On 19 April at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held at which Mr David Larcher, FBHI, FGA, and Mr John Bugg, FGA, were re-elected Chairman and Secretary respectively The AGM was followed by a showing of the Snowman video 'The wonders of Fabergé'.

North West Branch

On 17 April 1991 at Church House, Hanover Street, Liverpool 1, Carol Gibbs gave a talk entitled 'Tortoiseshell of the Gilbert Islands'. On 15 May 1991 at Church House Gordon Brohier gave a talk entitled 'The gems of Sri Lanka'.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 21 March 1991 at 100 Hatton Garden, London EC1, the business transacted included the election to membership of the following:

Gold Laboratory Membership

Raymond Bloch, 74 Rue la Fayette,75009, Paris, France.
Carlo Jewellers Ltd, 25a Hatton Garden, London EC1N 8BN.

Ordinary Laboratory Membership

Chatila Jewellers, 22 Old Bond Street, London W1X 3DA.
Floralake Ltd t/a Bao Bijoux, 59 Beauchamp Place, London SW3 1NZ.
Mozaffarian Jewellers Ltd, 66 Knightsbridge, London SW1Y 7LA.
Palladian Diamond Co. Ltd, 100 Hatton Garden, London EC1N 8NX.
Michael Rose Jewellers, 3 Burlington Arcade, London W1.
Lionel J. Wiffen Ltd, 88-90 Hatton Garden, London EC1N 8PN.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 17 April 1991 at 27 Greville Street, London EC1N 85U, the business transacted included the election to membership of the following:

Fellowship

Argirakou, Ioulia, Volos, Greece. D.1990.
Farkas, Susan, Vancouver, Canada. D.1990.

Ordinary Membership

Blanch, Gloria, London.
Hull, Munira F., Harrow.
Mansfield, James G. London.
Mizuno, Kayoko, London.
Pirkl, Stephen V., Glendale, Calif., USA.

Schupp, Frank J., Pforzheim, Germany.
Shah, Fatehchand J., London.
Windwick, William, Moray.

At a meeting of the Council of Management held on 22 May 1991 at E.A. Thomson (Gems) Ltd, Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship
Berlioz, Roger F.B., Kandy, Sri Lanka. D.1990.
Sinclair, Lesley, Stenhousemuir. D.1990.

Ordinary
Ashton, Donald, Beckenham.
Michels, Hans-Joachim, Dinslaken, Germany.
Newton, Beverly A., Alhambra, Calif., USA
Niblock, Simon G., Ebop, New Zealand.
Nodznaia, Dikran, Southall.
Smith, Penelope A., Cirencester.
Tamada, Tomohide, Kobe, Japan.
Yoshimoto, Yoshihiro, London.

CORRIGENDA

On p.382 above, 2nd column, line 18 from foot, for 'Minerals of Larousse' read 'Larousse of minerals'

FORTHCOMING MEETINGS

London

3-4 November 1991	Conference and Presentation of Awards (see p. 394)

Midlands Branch

Meetings held at Dr Johnson House, Bull Street Birmingham. Further details from David Larcher on 021 554 3871.

13 - 15 September 1991	The Branch will participate, with an exhibition of gem testing, in the National Exhibition of Time to be held at The British Horological Institute, Upton Hall, Nr Newark, Notts.
20 September 1991	Mr F. Deitsch of Mikimoto Pearls. 'Pearls'
18 October 1991	Mr Alan Hodgkinson. 'A taste of Scottish gemmology'
15 November 1991	Mr J. Gosling. 'The Guyana lapidary project'

North West Branch

Meetings held at Church House, Hanover Street, Liverpool 1. Full details from William Franks on 061-928 1520.

18 September 1991	Mr Matthew Girling of Bonhams. 'The selling of jewellery at auction'
16 October 1991	Mr Alan Hodgkinson. 'A gemmological bonanza'
20 November 1991	Annual General Meeting.

Letter to the Editor

From A.E. Farn, FGA

Dear Sir,

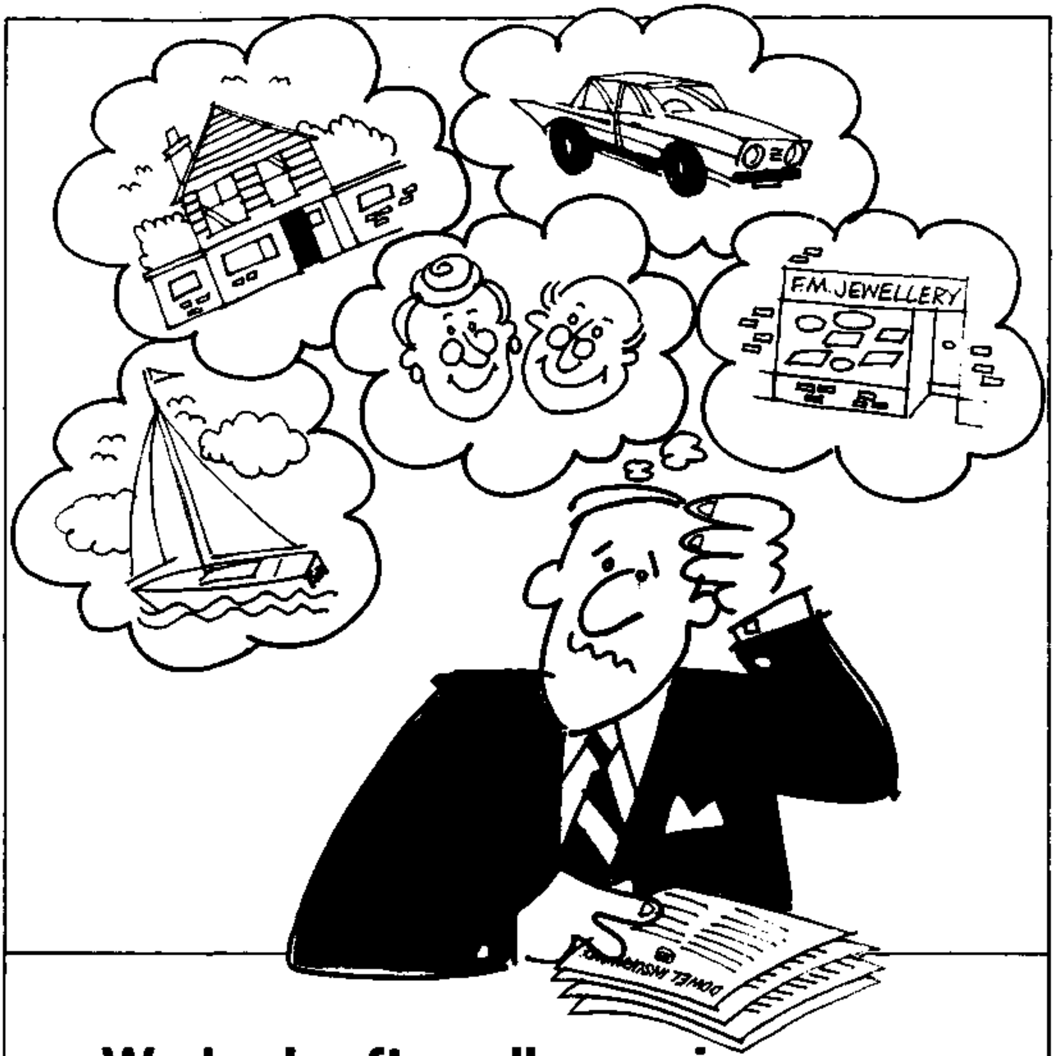
It is always a pleasure to read a 'Letter to the Editor', particularly when penned by our Vice President, R.K. Mitchell. I refer to his letter upon the name changes of methylene iodide and monobromo-naphthalene (The Journal of Gemmology, 1991, 22, 6, 387-8). In B.W. Anderson's day at 55 Hatton Garden I feel sure we termed it alpha-mono-bromo-naphthalene. 'Alpha' was also used by Basil Anderson when referring to the 4155Å line in diamond. That of course was in the days before the dwarfing effect of nanometres.

Keith Mitchell admits to a somewhat tongue-in-cheek frame of mind in his comments. He attributes this to a surfeit of years and a dislike of change. I am completely in accord with his sentiments. This of course, is hardly surprising as we are both elderly trade products and share a great regard for the memory and name of Basil Anderson. Anderson, despite his erudition, had a very human touch and a great sense of humour. He gave names to his favourite gemmological tools, such as Henry and Henrietta respectively for two much used pearl scoops. He also had names for his spectroscopes which may well be mentioned in the forthcoming treatise of Eric Bruton and Keith Mitchell on Anderson's research and work with the spectroscope.

May I take this opportunity to draw attention to a short notice on page 386 of volume 22, no.6, adjoining Keith Mitchell's letter. It is headed 'Verbal Testing at the Laboratory' and then proceeds to describe the method of sending articles for verbal testing by post - this puzzles me. I can understand 'mono' in monocular and 'di' in dichroscope, but fail to relate 'verbal', by post.

Yours in retrospect.
A.E. Farn

6 June 1991
Seaford, Sussex.



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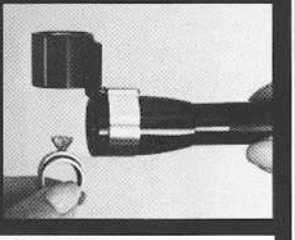

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