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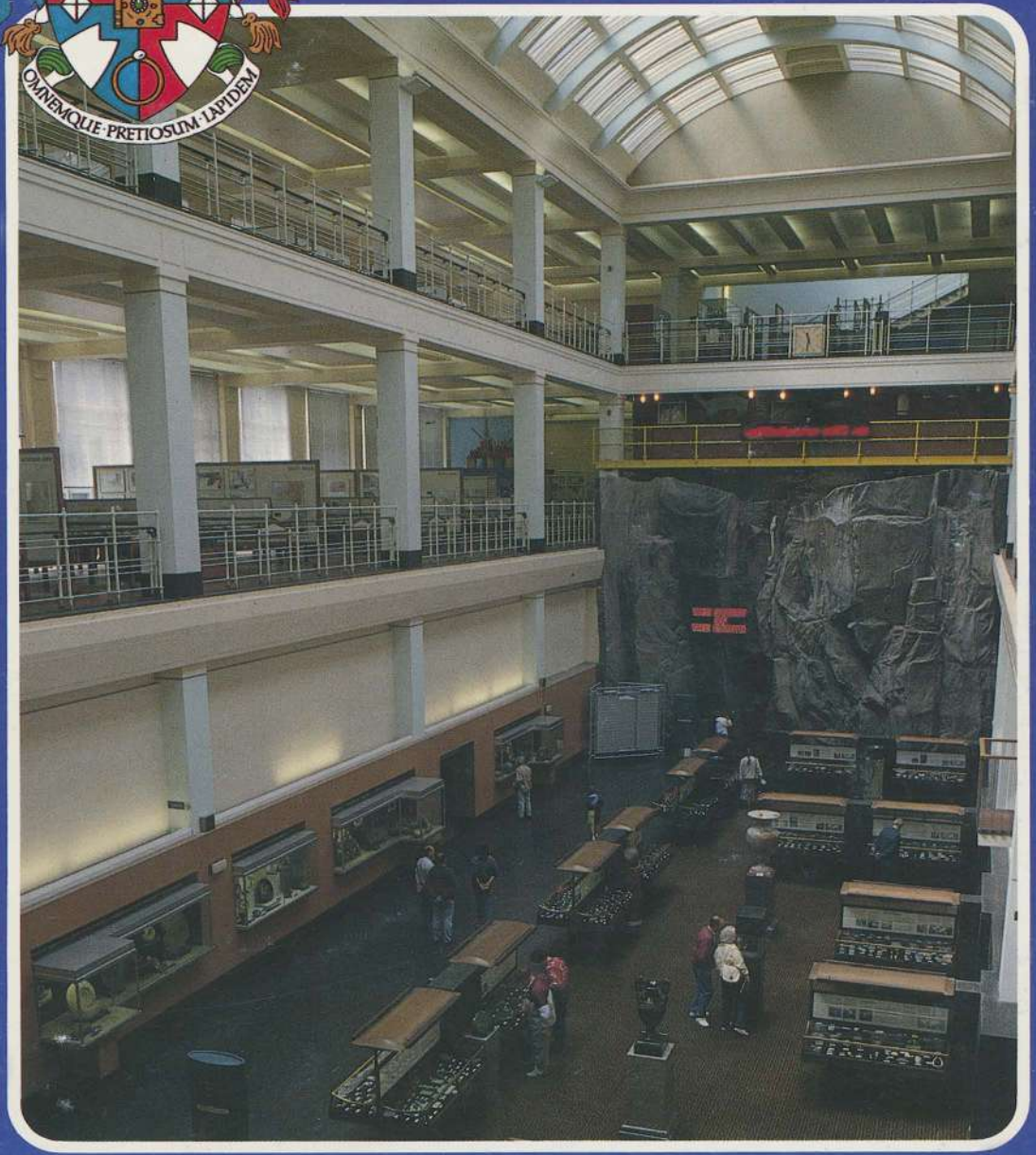

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Telephone: 071-404 3344

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Cover Picture

The gemstone exhibition in the Geological Museum, London (now designated part of the Earth Sciences Galleries of the Natural History Museum). This comprehensive display is threatened with closure, and all readers are urged to take the opportunity to view it again before it is dismantled.

The celebrated Mineral Gallery in the Natural History Museum is also scheduled to share the same fate. It is planned to combine the two exhibitions in a very considerably contracted area on one side of an upper gallery of the Geological Museum.

See 'The case of the disappearing gemstones' on page 130.

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The case of the disappearing gemstones

Many of our readers will be familiar with both the magnificent mineral and gemstone display in the Mineral Gallery of the Natural History Museum, and the remarkable gemstone exhibition on the ground floor of the Geological Museum (see front cover illustration).

These two displays together probably constitute the world's finest reference display of gemstones and minerals, and attract visitors to London from all over the world.

We understand that the 'management' of the Museums (the Geological Museum was 'given' by the British Geological Survey to the Natural History Museum in April 1985) intend shortly to combine these two displays onto part of one side of one of the upper galleries of the Geological Museum. The drastically reduced area will inevitably mean that the vast majority of the collections will go into storage, never to be seen again. This will be made worse by the intention that the new exhibition will be a 'theme' rather than a 'reference' display. This apparently means that only a very few items will be displayed, so that the least intelligent visitor to the Museum will not get confused.

We urge our readers to visit the current displays before the Museums' management perpetrate what is likely to be the greatest jewel robbery ever inflicted on the unsuspecting public who are, after all, the actual owners of the National Museums and their collections.

STOP PRESS.....MURDER MOST FOUL.....STOP PRESS

Since writing the above, we have learnt that the Museum management, as part of its plan to perpetrate the jewel robbery, has literally *killed gemmology* within the *Museums*.

The Director, Dr Neil Chalmers, has announced a new corporate plan. This involves a major reduction in the scientific staff, and the complete withdrawal from several scientific areas, including all gemstone related services and research. The post of Curator of Gemstones is to be abolished. The posts of the only other qualified gemmologists (two in 'exhibition design') are also to be axed.

This means that there will soon be nobody employed by the Museums who will be qualified to identify gemstones, including those in the Museums' own magnificent collections.

Whilst by no means ameliorating the current situation, it is worth mentioning here that the Gem Testing Laboratory of Great Britain (the oldest such laboratory in the world) is ready and able to provide any gemmological testing services previously supplied by the Museums.

It is hoped that the Laboratory will, later this year, merge with the Gemmological Association of Great Britain (the world's oldest gemmological association), ensuring that the United Kingdom retains at least one strong gemmological organization.

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A black jade dilemma

John I. Koivula, C. W. Fryer, Robert E. Kane and Robert C. Kammerling

Gemological Institute of America, California, USA

Abstract

Three of four opaque black gems being represented in the trade as the pyroxene jadeite were identified by X-ray diffraction as rocks containing a major component of amphibole, probably kaersutite. The fourth stone showed the diffraction pattern for jadeite. Since the basic gemmological properties of some amphiboles like kaersutite overlap those of jadeite, routine gemmological testing cannot separate the two. More advanced testing techniques, such as X-ray diffraction and chemical analysis, are needed to make this separation.

Introduction

Four opaque, black stones (Figure 1) were submitted for identification to the GIA Gem Trade Laboratory, Inc. It was reported that these and similar stones were being sold in the trade as black jadeite jade. The source of these stones was reported to be Guatemala; black jadeite is known to come from Guatemala in significant amounts (David Hargett, Personal Communication).

The values obtained for refractive index, specific gravity and hardness, and the lack of either ultraviolet luminescence or an absorption spectrum, indicated that the stones could be jadeite jade. However, the very nature of opaque black jade-like materials is such that they are not conducive to identification by routine gemmological testing because there are other minerals and rock types with the appearance and properties overlapping those of jadeite. Therefore, the two polished oval cabochons weighing 23.66 and 44.66 carats and the two polished table cuts at 8.05 and 26.52 carats respectively, were subjected to further testing by X-ray powder diffraction and chemical analysis in an effort to determine the true nature of this material.

Gemmological Testing

Visual Appearance

All four stones at first appeared to be quite similar when examined in oblique incident light with the unaided eye. When each stone was studied more carefully, however, some slight differences were noted. The smaller oval cabochon and the two rectangular table cuts (Figure 1) possessed a good polish with a vitreous lustre. They also appeared to be mottled with tiny whitish spots that stood out against the black background. Although the larger oval cabochon (Figure 1) also had a good to very good polish with a vitreous lustre, it lacked the tiny whitish spots and had a very dark grey, rather than black, body colour when viewed with strong fibre-optic incident light.

Refractive Index

The cabochons had polished bases which made them much easier to test for refractive index. Using a GIA GEM Instruments Duplex II refractometer and, in turn, both sodium vapour and white light sources, a refractive index of 1.67 was obtained from a flat, well-polished surface on each of the four stones. No birefringence was noted on any of the specimens.

Specific Gravity

Specific gravity was first estimated using the sink-float method. Both of the table cut stones as well as the larger oval cabochon sank very slowly in pure methylene iodide (specific gravity 3.32), at the same rate as a known jadeite indicator. The smaller of the two oval cabochons, however, barely floated in the liquid with a vertical, base-up tilt, with just a minute portion of the girdle edge breaking the liquid's surface.

The specific gravity was also determined by the hydrostatic weighing method, using a Voland diamond balance, with three readings being taken on each of the four stones. The specific gravity values obtained for the four stones varied slightly from a low reading of 3.29 to a high value of 3.34.

Luminescence Reactions

In total darkness, no reaction to either long-wave (366.0 nm) or short-wave (253.7 nm) ultraviolet radiation was observed, even when ultraviolet contrast control glasses were used. The four stones also proved to be inert to X-radiation.

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Fig. 1. The four opaque black stones studied for this report. The large oval cabochon shown here, weighing 44.66 ct, was identified as primarily jadeite, while the other stones were identified as rocks composed primarily of amphibole(s). *Photography* © *Tino Hammid*.

Spectroscopy

The visible-light spectra were next examined using a GIA GEM Instruments spectroscope unit with a Beck prism spectroscope. In surface reflected light no absorption characteristics were observed in any of the four stones. This is to be expected for dark-coloured jadeite. During this phase of the examination, however, we did observe that very thin edges of the stones transmitted a dark green colour when illuminated with a very strong fibre-optic light source, but this weak transmission was insufficient for transmitted-light spectroscopic testing.

Hardness

Hardness was tested under magnification, using hardness points on an inconspicuous area of each stone. Based on the results of this testing the hardness of all of the samples was estimated to be approximately 6½ on the Mohs' scale.

Microscopy

A binocular gemmological microscope was used to examine the surfaces of the stones in reflected oblique illumination. All four stones showed what seemed to be an intermixing of various grains that appeared whitish to near-colourless and very dark green to black. Shadowed oblique illumination was then employed on a flat surface of the largest table cut stone to see if any individual grains had undercut during the polishing process as would be expected from a rock. Figure 2 shows that undercutting, and therefore slight variations in hardness of the individual grains, exists. The other three stones also showed this same visual evidence of granular undercutting.

The results of these standard gemmological tests suggested that the four stones might be an impure jadeite jade, or more specifically, a rock composed primarily of jadeite with other minerals. X-ray diffraction and chemical analysis were now deemed necessary to identify the material(s) more precisely.

X-Ray Diffraction

Using a sharp-edged diamond scribe, a minute amount of powder was carefully scraped from the girdle of the smallest table cut and a spindle for X-ray powder diffraction was prepared. This spindle was then mounted in a Debye-Scherrer powder camera and exposed for eight hours to X-rays generated at 49 kV and 18 mA from a copper target tube. The resulting pattern, when compared with our standard diffraction pattern for jadeite jade, did not match. By using the Joint Committee for Powder Diffraction Standards Mineral Powder Diffraction File Search Manual and Data Book (1986), however, a close match was obtained with the amphibole kaersutite (ASTM file 17-478).

The remaining three stones were then similarly

tested using X-ray diffraction. Only the largest oval cabochon showed a jadeite pattern, the other two samples also revealing amphibole group X-ray diffraction patterns close to that of kaersutite.

Based on the results of X-ray diffraction, the larger oval cabochon was identified, in its greatest portion, as jadeite jade. At this point the other three stones could now be called amphiboles or amphibole rocks, but could not be classified specifically as kaersutite because of the complex nature of the amphibole group of minerals. Chemical analysis was next employed to try to determine if they could be identified as a specific mineral.

Chemistry

The four stones were turned over to Carol Stockton, Senior Gemologist in GIA's research department, for chemical analysis. Using the electron microprobe at the California Institute of Technology in Pasadena, California, Ms Stockton analyzed the largest table cut and found that titanium was present in amounts up to 0.43 weight per cent TiO_2. Although this is not a high enough weight per cent of titanium to call the sample kaersutite (Deer, Howie and Zussman, 1974) it suggests, together with the diffraction pattern, that some kaersutite may at least be present.

Thin Section Examination

After obtaining permission from the owner, two thin sections were prepared, one each from the apparently different materials, jadeite and amphibole (kaersutite?). The granularity of the two thin sections was then studied in polarized light. The section taken from the cabochon that produced an X-ray diffraction pattern of jadeite was composed of a mass of grains so small (less than 0.001 mm) that none of the typical pyroxene characteristics were observed. This entire section was also veined with an opaque material that appeared as black clouds throughout the thin section (Figure 3). This fine-grained nature results in a lack of microscopically resolvable pyroxene characteristics. However, the combination of the gemmological properties and the X-ray diffraction pattern obtained from this sample served adequately to identify it as jadeite jade.

Although badly fractured, the section taken from the amphibole sample still contained easily visible individual grains up to 0.01 mm in size. Some of these showed the typical prismatic cleavage associated with amphiboles (Figure 4). The impurity of this sample was also apparent, with an abundance of grains not showing any of the characteristics of amphiboles.

In view of these findings, and taking into consideration the inconclusive X-ray diffraction pattern and chemical analysis, the stone from which this

Fig. 2. Undercutting on the largest table cut stone. All four gems showed similar polished-surface undercutting, indicating slight variation in granular hardness and therefore suggesting an impure aggregate nature. Shadowed oblique illumination. 50X.

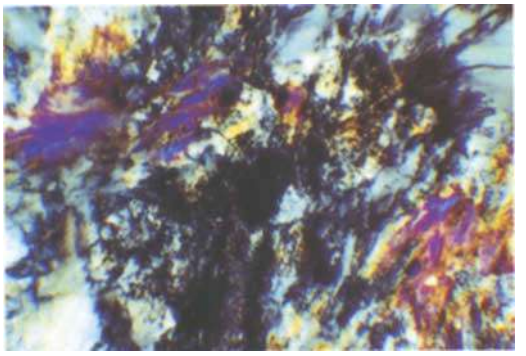

Fig. 3. Polarized light view of the thin section taken from the larger oval cabochon that gave an X-ray diffraction pattern of jadeite. Note the lack of granularity, unusual for a pyroxene like jadeite, and also the opaque black fine-grained contaminant. 100X.

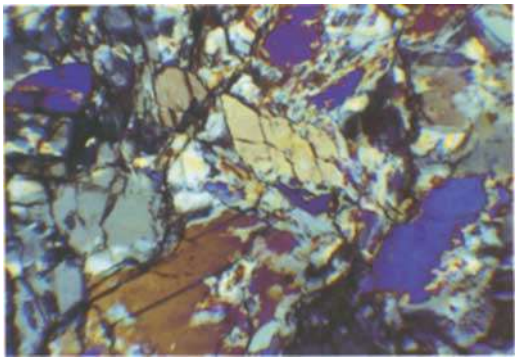

Fig. 4. In polarized light, accented by interference colours, the heavily fractured appearance of the impure amphibole rock is apparent in this thin section. Note also the prismatic 'diamond-shaped' amphibole cleavage shown by the light brown grain near the centre. 100X.

thin section was cut would be best classified gemmologically as a rock containing amphibole(s) as a major component(s), one of which may be kaersutite.

Conclusion

Although it has been seen in the gem trade, truly black jadeite is not common. Most of the black jade on the market, rather, is nephrite, a massive compact variety of actinolite, an amphibole. And even though nephrite is an amphibole, its properties are sufficiently different from jadeite to make their gemmological separation rather straightforward. This is not the case, however, with some other amphiboles, such as those studied for this report.

Pyroxenes such as jadeite, and amphiboles like kaersutite, are known to occur in very close geological association (Mason, 1968; Deer, *et al.*, 1974). In impure, compact, massive form, some amphiboles such as kaersutite have a very dark green to black colour, with their gemmological properties overlapping those of jadeite jade. Therefore, in the course of standard gemmological testing, these amphiboles cannot be separated from black jadeite jade. Rather, additional tests such as X-ray diffraction or chemical analysis are required to make an identification. In view of the above discussion, it is very possible that at least some material being represented as black 'jadeite jade' may be a rock containing amphibole(s) (possibly kaersutite) and not the pyroxene jadeite. It is therefore suggested that, when gemmologists are confronted with opaque black materials showing the outward gemmological properties of jadeite jade, they proceed with caution in their identifications.

Acknowledgement

The authors would like to thank Mr David Hargett, Manager of Gem Identification in the GIA Gem Trade Laboratory, New York, for his valuable comments during the preparation of this report.

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Sapphirine from the Kolonne area, Sri Lanka

R. R. Harding and E. Gamini Zoysa***

*Science Departments: Mineralogy, Natural History Museum, Cromwell Road, London SW7 5BD
**Consultant Gemmologist/Geologist, 91/4A Templars Road, Mount Lavinia, Sri Lanka

Abstract

Gem sapphirine is being recovered from a mine about 9 miles north-west of Embilipitya, Sri Lanka. The geological setting of the deposit is briefly described and electron microprobe and ICPS analyses of the sapphirine are reported. The similarities between sapphirine and serendibite are discussed.

Introduction

Sapphirine is a gem mineral recently discovered and now becoming more generally known in Sri Lanka. It has been reported by Fryer 1985, Scarratt 1987 (from Sri Lanka), Kane 1987 (from Thailand), and Koivula and Kammerling 1988 (from Sri Lanka and Canada), and has also been identified as an inclusion in ruby by Koivula and Fryer 1987.

In Sri Lanka the gem sapphirine comes from a mine located near the 9th milepost along the Rakwana-Embilipitya Road (Figure 1). It is 4 miles east of the village of Kolonne which is already well known for its sapphire, ruby, spinel, zircon, sillimanite (fibrolite), scapolite and fluorite.

This note briefly describes the geological setting of the sapphirine and reports its chemical composition.

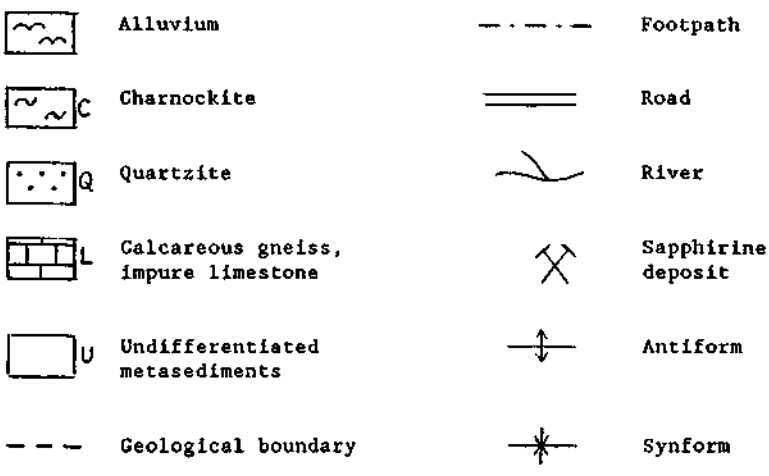
Geological setting

Sapphirine is derived and obtained from rocks of the Highland Series, a sequence of high-grade metamorphic rocks consisting of gneisses, charnockites, quartzites and other metasediments (see Figure 1). Typical terrain and outcrop are shown in Figures 2 and 3. Miners have recovered sapphirine by digging and sorting overburden to depths of 6 feet and sapphirines found locally in biotite gneiss fragments indicate that the source rock is nearby.

More than 75% of the sapphirine fragments are small in size and poor in quality; the remainder are of variable transparency, are dark greenish blue or pinkish brown and exhibit strong pleochroism. The largest gem-quality rough specimen seen by one of us (GZ) is clear pinkish brown and weighs 13.61 carats.

Analyses of sapphirine

Two fragments of blue sapphirine, maximum length 8 mm, were examined. Both were confirmed as sapphirine by X-ray diffraction (films 7393F and 7394F). One fragment was set in resin and a polished face prepared. Refractive index readings



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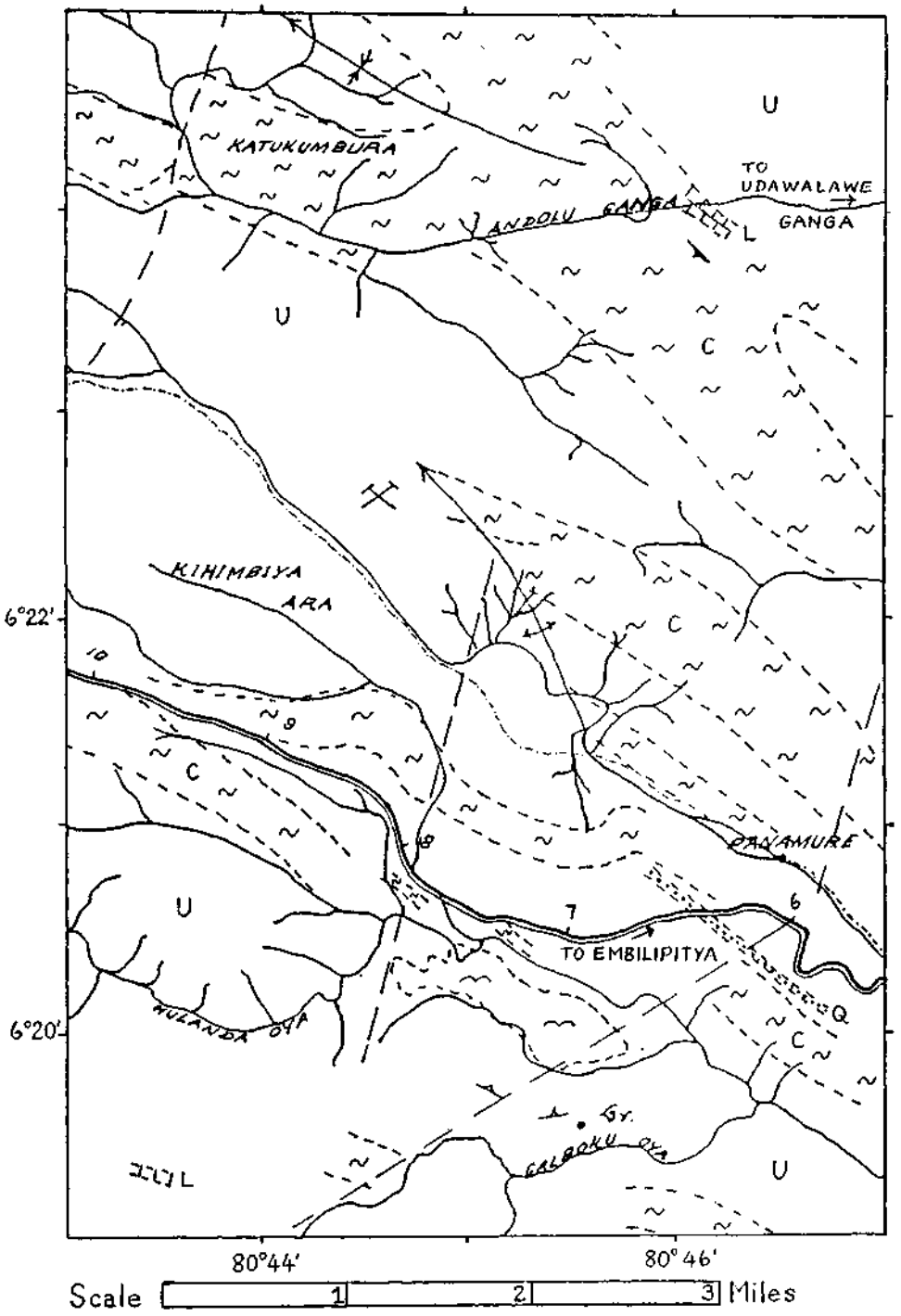

Fig. 1. Geological sketch map of area east of Kolonne.

Table 1. Analyses of sapphirine from Sri Lanka

Wt%	1A	2	3	ppm	1B
SiO_2	14.4	14.9	<0.2	Li	52
Al_2O_3	63.8	61.9	<0.2	Be	23
FeO	1.83	1.7	<0.2	Ti	<50
MgO	19.2	19.9	0.45	V	24
CaO	0.08	< 0.1	54.16	Cr	<50
Na_2O	< 0.1	< 0.1	0.41	Mn	85
P_2O_5	0.04	< 0.1	42.74	Ni	40
B_2O_3	0.28	n.d.	n.d.	Cu	<20
Others	0.4	n.d.	n.d.	Zn	45
Total	99.7	98.4	97.76		

Notes: Columns 1A and 1B are results of ICPS analysis using (i) Na_2CO_3 fusion in dil. HNO_3/HCl for Al, Li, B; and (ii) $LiBO_2$ fusion in dil. HNO_3 for remaining elements (analyst V. K. Din). Total Fe is given as FeO. The Hitachi SEM-Link Systems EDS was used to obtain analyses of a polished surface of sapphirine (Column 2, mean of 3 spots analysed) and an apatite inclusion in the sapphirine (Column 3, mean of 3 spots analysed). Boron cannot be determined using this method and n.d. means not determined; total Fe is given as FeO. The low total for the apatite analysis may mean that OH or F is present; Cl was sought but is below detection limits of 0.1%.

obtained on a Rayner Dialdex refractometer were 1.705 and 1.711, giving a birefringence of 0.006.

The polished fragment was then analysed with a Hitachi SEM-Link Systems EDS and the results are given in Table 1, column 2. Energy-dispersive analysis does not provide values for elements with atomic number less than 11 (sodium) and to obtain more comprehensive data the second fragment was analysed by inductively-coupled plasma spectrometry (ICPS). The results are given in Table 1, columns 1A and 1B.

A clear crystal inclusion present at the surface of the polished fragment of sapphirine was identified as apatite (Table 1, column 3), and it is possible that the small amounts of phosphorus and calcium in the ICP analysis are attributable to apatite inclusions.

The ICPS analysis indicates the presence of 0.28% B_2O_3. Boron has not as yet been reported as a constituent of sapphirine (see Deer, Howie & Zussman, 1978, pp 618-621), and it is not known if the boron in this analysis represents a structural component or if it derives from an inclusion containing boron such as sinhalite ($Mg(Al,Fe)BO_4$).

Comment

Sapphirine is very similar in colour to serendibite, a mineral that was first found in Sri Lanka and described in 1903 by Prior and Coomaraswamy; the locality is Gangapitya, about 12 miles east of Kandy. In addition to colour there are other striking similarities between the two minerals and the relevant data below have been taken from Deer, Howie and Zussman, 1978, pp 615, 659.

To the best of the authors' knowledge there are no cut gems of serendibite in existence, but if there were, the above properties suggest that there is no simple gemmological test one can use to separate the two species. Refractive index, birefringence, specific gravity and colour ranges all overlap. Two further properties, absorption spectrum and fluorescence characteristics, may in future provide a means of distinguishing the minerals but preliminary results are not promising. Sapphirine does not have a distinctive spectrum and is inert in long and short wave ultraviolet radiation, while the corresponding data for gem serendibite have not yet been established. Observations on serendibite in rocks from Gangapitya and from Johnsberg, New York, indicate that there is no fluorescence in ultraviolet radiation and that there does not appear to be a distinctive spectrum. Currently either chemical or X-ray determination must be undertaken to confirm an identification.

On the basis of X-ray diffraction measurements the two fragments analysed in this investigation are undoubtedly sapphirine. Nevertheless, in view of the presence of Ca and B in the chemical formula of serendibite, it is interesting to note that small amounts of Ca and B are present in the ICPS analysis of sapphirine (Table 1, column 1A). As

	Sapphirine	**Serendibite**
Refractive index	1.701 - 1.734	1.700 - 1.743
Birefringence	0.005 - 0.007	0.005 - 0.006
Specific gravity	3.40 - 3.58	3.42 - 3.52
Colour	Blue - pale pink	Blue - pale yellow
Crystal system	Monoclinic (−) or (+)	Triclinic (+)
Chemical formula	$(Mg,Fe^{2+},Fe^{3+},Al)_8O_2[(Al,Si)_6O_{18}]$	$Ca_2(Mg,Al)_6O_2[(Si,Al,B)_6O_{18}]$

Fig. 2. Typical terrain near Kolonne.

Fig. 3. Typical outcrop near Kolonne.

Fig. 4. Sapphirine crystals in gneiss.

Fig. 5. Gem-quality sapphirine.

Fig. 6. Cut and polished sapphirine 1.06 ct.

mentioned above, further work is needed to decide whether these elements are present in the structure of the sapphirine or as inclusions.

Acknowledgements

We would like to thank J. G. Francis and S. Somogyi for carrying out X-ray diffraction determinations on the sapphirine, V. K. Din for providing the ICPS analysis, and F. Wall for expert help with the Hitachi SEM-Link Systems EDS.

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Testing of colourless natural diamonds by room temperature optical absorption

G. Lifante, F. Jaque, M. A. Hoyos and S. Leguey

Universidad Autónoma de Madrid, Madrid 28049, Spain

Abstract

Highly sensitive optical absorption measurements at room temperature including derivative techniques have been used for colourless natural diamonds. It has been established that the presence of absorption bands due to N3 centres in natural gems can be used to distinguish natural from synthetic colourless gems.

Introduction

Spectroscopic techniques in optical absorption, luminescence, Raman scattering, electron paramagnetic resonance and nuclear magnetic resonance have been successfully applied in previous years to study structure of small cluster and kinetics of impurity precipitations in ionic crystals (Agulló-López, 1986). Recently, these spectroscopic methods, in particular optical absorption, have been used to distinguish natural from synthetic gems. The key for distinguishing them is the presence or not of vibronic absorption bands associated with nitrogen aggregates (N3 centres) (Shigley, 1986). It is well known that the N3 structure is only normally present in natural diamonds (the centre is constructed from three substitutional nitrogen atoms bonded to a common carbon atom) (Davies, 1974), whereas synthetic diamonds exhibit only a gradual absorption increase in the visible region (Shigley, 1986).

The N3 absorption characteristics, which clearly appear at liquid nitrogen temperature (LNT) can still be observed at room temperature (RT), although with lower intensity (Davies, 1974).

This fact is very important because it allows working at RT and thus reduces the risk in the sample manipulation, especially in the cooling stage down to LNT (77 K): the standard cooling rates, about 10 K/min, can produce strains in the sample and consequently cracks in the gem. Most published optical tests have been reported for coloured diamonds, and the potential of this method for colourless diamonds is yet to be published.

It is clear that working at RT with very weak optical absorption requires very sensitive techniques, but if its feasibility is established it could be very interesting taking into account that production and marketing of synthetic colourless diamonds may be a factor in future years.

The purpose of this note is to show that highly sensitive optical absorption measurements at RT together with derivative spectroscopy can be applied to distinguish between colourless synthetic and natural diamonds through the detection and identification of the optical absorption associated with N3 centres.

Experimental

Optical absorption spectra at RT were taken with a Hitachi 150-20 spectrophotometer that was capable of derivative spectra (the optical density OD is defined as $OD = Log_{10}(I_0/I)$, where I_0 and I represent the incident and transmitted light intensity respectively). LNT spectra were taken with a Cary 17 spectrophotometer by means of a cryostat which fits into the spectrophotometer chamber.

Four samples of (H) and of (J) diamond crystals, in the GIA grading scale, have been investigated. Diamonds of approximately 0.20 ct weight, 3.5 mm diameter and 2.3 mm height were supplied by the School of Gemmology of the Universidad Autónoma de Madrid.

Experimental results

Figure 1a shows the absorption spectrum corresponding to a (J) grade diamond sample recorded at RT. It can be seen that three absorption bands in the 390-420 nm region with an optical density of $\approx 10^{-2}$ are present (length of path light through the crystal $\simeq 2$ mm): the position of these bands can clearly be determined by using derivative methods. The first derivative spectrum is given in Figure 1b. The wavelengths corresponding to the maximum of the absorption bands are 415, 403 and 394 nm respectively, values that are in agreement with the position found in colourless natural diamond absorptions due to N3 centres (Davies, 1974). The presence of the N3 absorption bands implies that the diamond studied is a natural gem.

Figure 1c shows the second derivative spectrum corresponding to the same gem. It is important to

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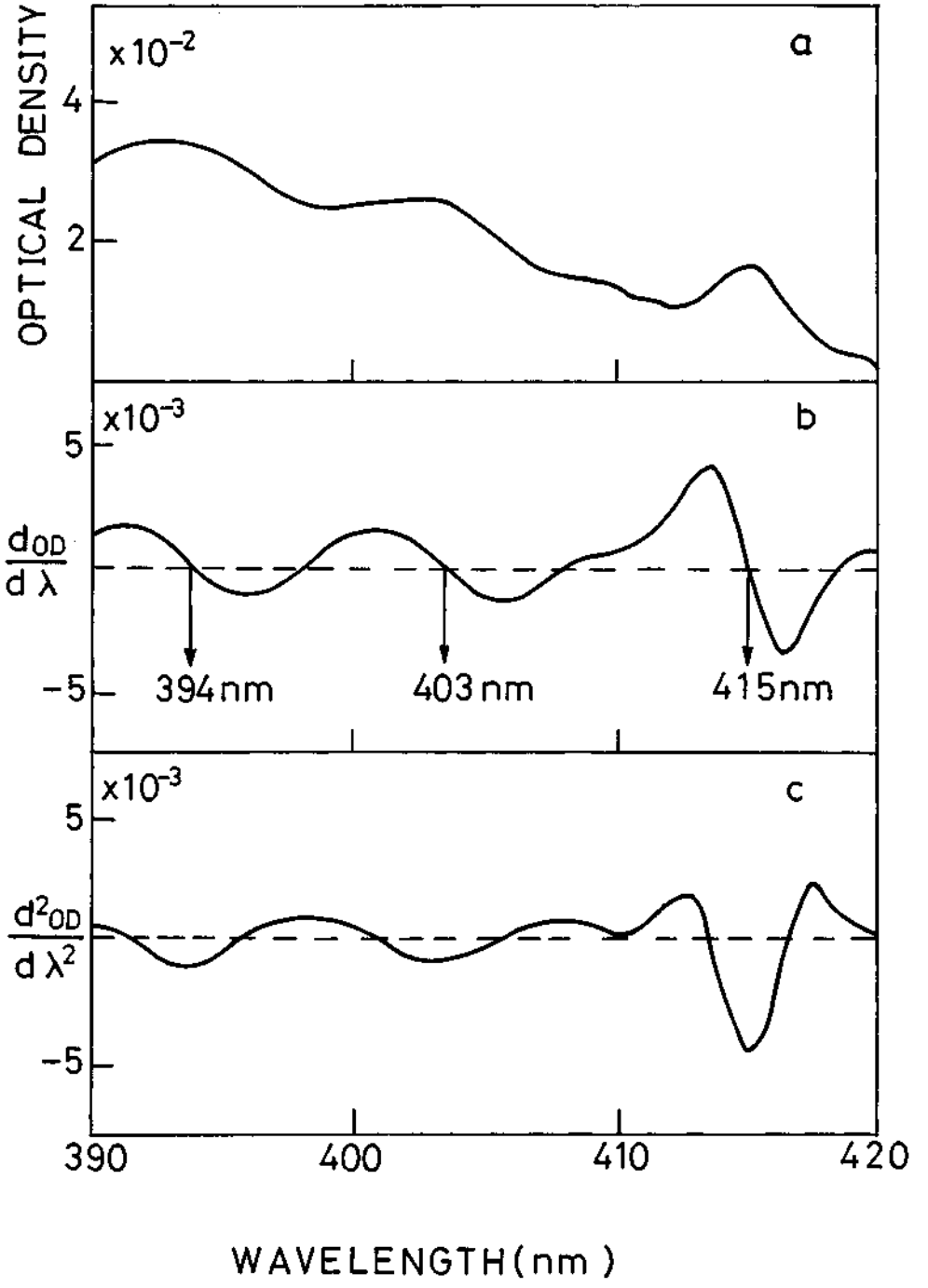

Fig. 1. a) Absorption of a (J) grade diamond at RT.
b) First derivative of the absorption spectrum (a).
c) Second derivative of the absorption spectrum (a).

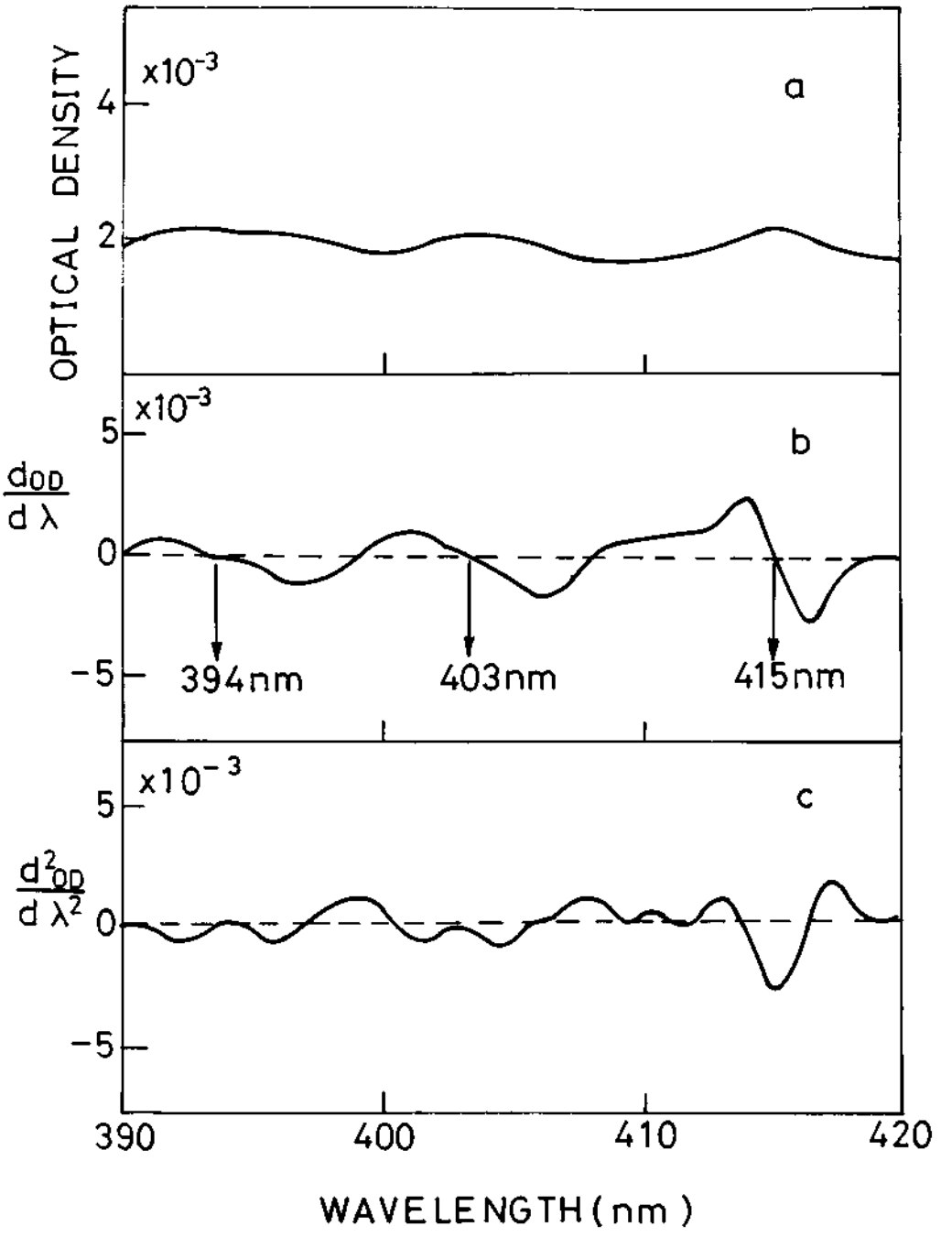

Fig. 2. a) Absorption spectrum of an (H) grade diamond at RT.
b) First derivative of the absorption spectrum (a).
c) Second derivative of the absorption spectrum (a).

point out the very good signal-noise ratio and the appearance of a richer structure in accordance with the very complex spectrum characteristic of the N3 centres and clearly observed in coloured diamond at LNT.

The good signal-noise ratio obtained allows one to apply optical absorption measurements to more transparent gems. In this line (H) grade diamonds have also been studied. Figure 2a shows the optical absorption spectrum in the 390-420 nm range obtained at RT. The same absorption bands seen in the (J) grade crystal stones are recorded again but with smaller optical density (OD about 10^{-3}). The positions of these bands are marked in the first derivative spectrum (Figure 2b), and are also coincident with those found in coloured diamonds.

The second derivative spectrum is given in Figure 2c; although the optical density is very weak, the 415 nm band is clearly observable and the second derivative spectrum can be used for detecting N3 centres in (H) grade diamonds. Looking at this last result, the lower limit in the N3 centre absorption detection could be determined, and a value of OD$\approx 10^{-3}$ appears as the lowest discernible with a spectrophotometer similar to the one used in this work. Recently, however, spectrophotometers with higher sensitivity in the optical detection (OD$\approx 10^{-5}$) have become available and so the power in the diamond optical testing can be improved by an order of two magnitudes.

In conclusion, the optical spectroscopy including derivative techniques can be useful to distinguish natural from synthetic diamonds, even in colourless samples without the inconvenience of lower temperature manipulation.

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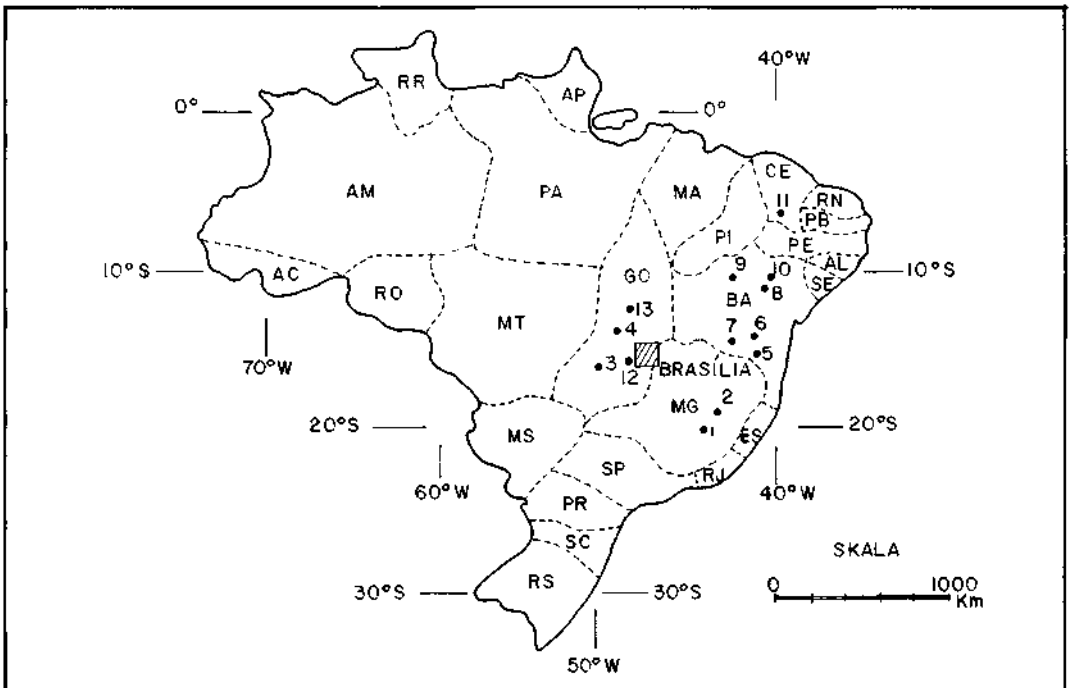
The Brazilian emeralds and their occurrences: Socotó, Bahia

Dr Dietmar Schwarz, Thomas Eidt** and Pedro A. Couto****

*German Academic Exchange Service, Gemmological Centre, Federal University of Ouro Preto, Minas Gerais, Brazil
**University of Mainz, West Germany
***CPRM, Salvador, Bahia, Brazil

1. Introduction

The mining area of Socotó is located in north-western Bahia about 25 km NE of Campo Formoso and 40 km NE of the emerald deposit of Carnaíba (Figures 1 and 2). The entrance to the Socotó mining area is reached by a dirt road from Campo Formoso. Following the dirt road north-eastwards you will pass the small villages of Vanvana (after 8 km) and Ituiutiba/Socotó (after 15 km). The area which is currently being mined belongs to the farm 'Fazenda Piabas' and was occupied by garimpeiros (freelance miners) in January 1983. A few weeks later more than 500 garimpeiros had reached the area and by the beginning of February of the same



Bahia
BA-5 Fazenda do Pombo
BA-6 Açude do Sossego
BA-7 Brumado
BA-8 Carnaíba
BA-9 Salininhas
BA-10 Socotó

Ceará
CE-11 Tauá

Minas Gerais
MG-1 Mina Belmont (Itabira)
MG-2 Santana dos Ferros

Goiás
GO-3 Fazenda das Lajes (Itaberaí)
GO-4 Santa Terezinha de Goiás
GO-12 Pirenópolis
GO-13 Porangatu

Fig. 1. The emerald occurrences in Brazil.

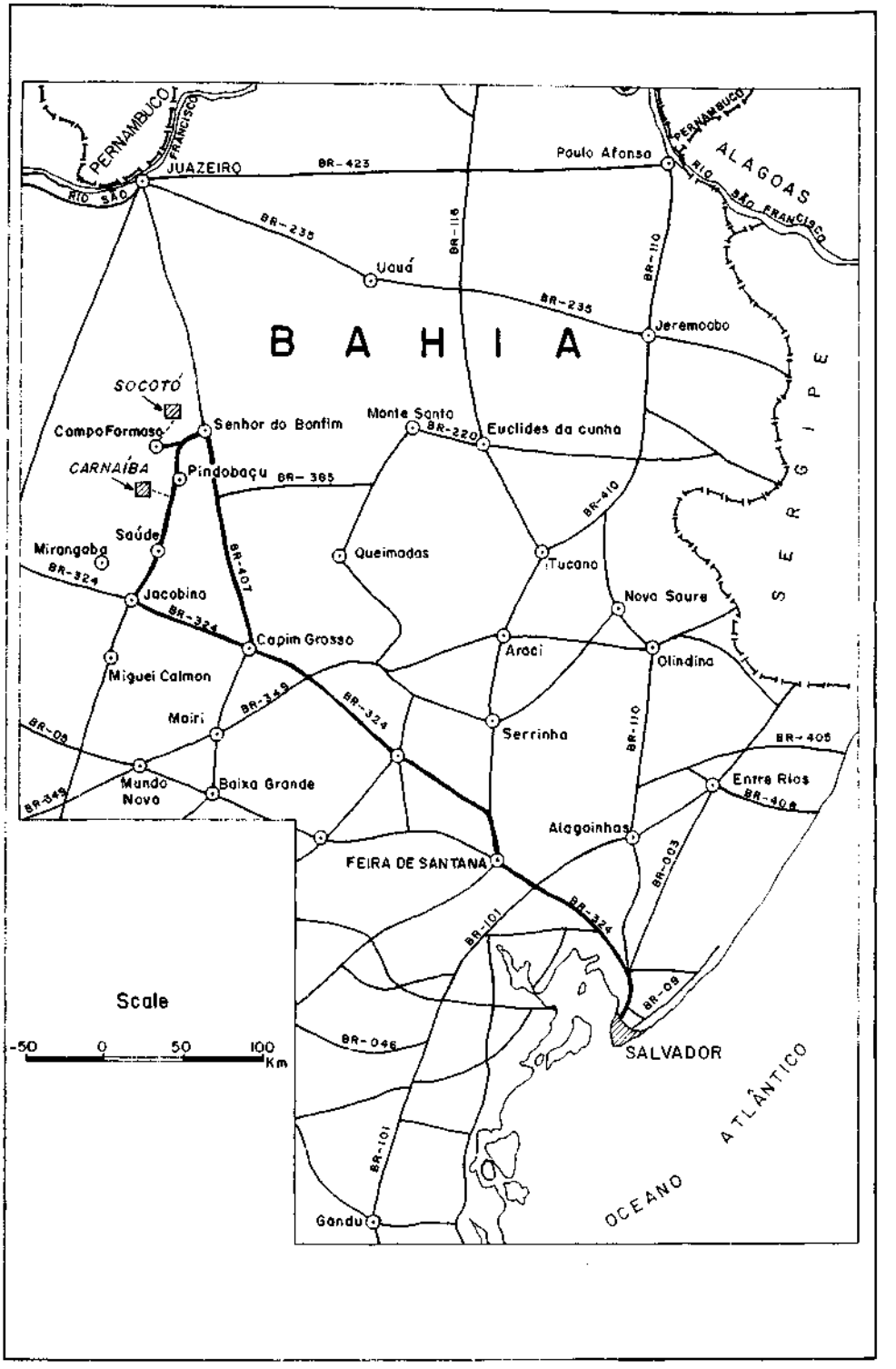


Fig. 2. Bahia state with the emerald occurrences of Socotó and Carnaíba.

Fig. 3. 'Quijillas' searching the waste material for emeralds.

year 132 grams of emeralds from 'medium to good' quality had been mined. The officially registered amounts of emeralds being mined in 1984 were 2 181.726 kilograms in Socotó and 3 459.630 kilograms in Carnaíba. The value of the mined emeralds in 1984 was estimated to be US$ 1 000 000 for Socotó and US$ 430 000 for Carnaíba (Couto, 1984).

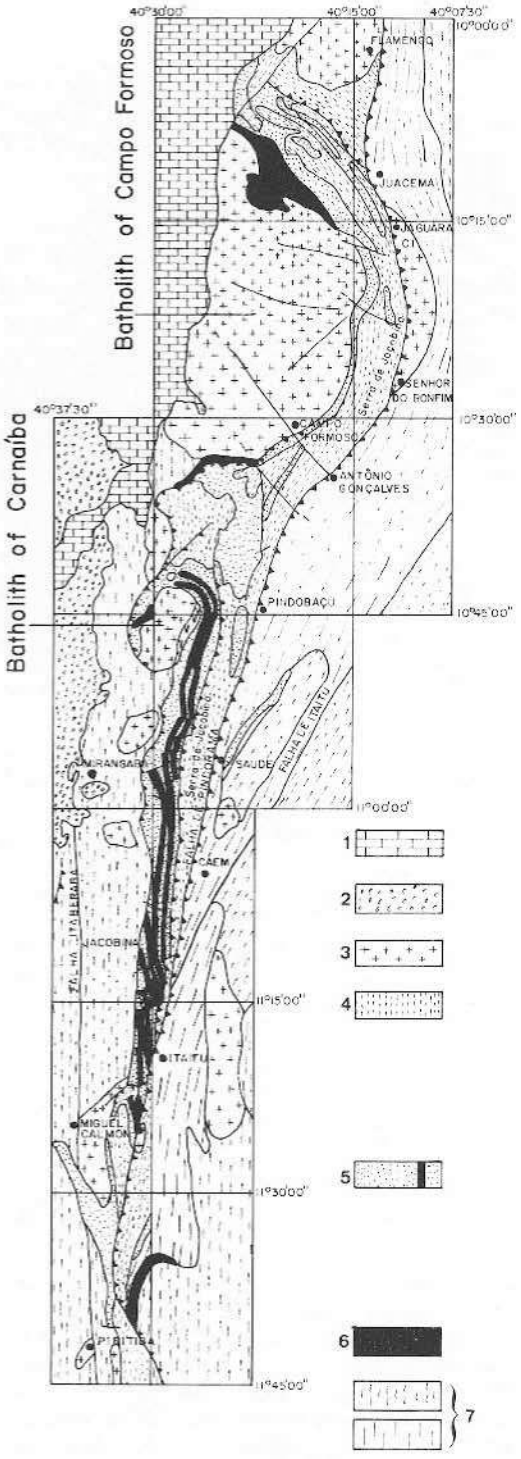
Table 1 (Couto, 1986) shows the official annual output (in kg) of emerald/green beryl of the Carnaíba area (1977-1982) and for both areas (Carnaíba and Socotó) for the years 1983 to 1986. Despite a decrease in the total amount being mined, the total value of the emeralds increased because of the steadily increasing portion of faceting grade material. The best stones are found in the Trecho Velho (Socotó) and in Formiga/Trecho Velho (Carnaíba).

Based on the similar geological setting in the mining areas of Carnaíba and Socotó extensive emerald reserves are expected at Socotó. For the first 11 months of 1985 an official output valued at 4.4 million US$ was registered in the region. According to the official statement of the Receita Federal (Government Office) about ⅔ of this had been mined in Socotó and ⅓ in Carnaíba.

With the exception of the Belmont Mine in Itabira/MG, the mining methods in the Socotó area are typical for Brazilian deposits. The emeralds are mined underground. Shafts follow the mineralization zones in 'galerias', horizontal or slightly inclined tunnels. Sometimes the tunnels are straight but mostly they are curved or they change their direction abruptly. In part, the entrance to the tunnel is made directly from the surface; normally, however, pits about 100 metres deep are used. The length of the tunnels can reach more than 300 metres.

Table 1. Annual output of emerald/green beryl in the mining area of Carnaíba (1977-1982) and Carnaíba/Socotó (1983-1986).

Year	Output (kg)
1977	18 642.3
1978	8 652.3
1979	15 302.4
1980	14 503.4
1981	8 842.1
1982	7 467.4
1983	13 371.3
1984	5 641.3
1985	4 129.3
1986	3 794.7



The mining of the vein material is by hand, mainly with primitive tools like pickers, hammers, chisels and jimmies. Use of pneumatic hammers is rare. To remove the vein rock, pushcarts are operated in the tunnels. In the pits, transportation is with the help of buckets or containers made of old car tyres operated either by hand or by electrical winches. Tunnels and pits are lined or supported by wooden beams. Entering water has to be constantly removed by pumps.

The limits of each claim ('serviço') are marked on the surface upon agreement with the landowner, who receives a percentage of the profit. Besides the actual owner of the claim, those people who raise money for starting the mining (the so-called 'capitalistas') also participate in the profit. Among the people who are directly involved in the mining, the 'cortador' (the man in charge of opening up new shafts and drifts) is the most important and best paid. He is responsible for carrying out the excavation operations.

The separation of the emeralds from the rocks is done personally by the owner of the claim in the presence of the 'cortador', the most important crew members and the financiers. Also involved in the mining operation are the 'quijillas', a group composed of elderly men, women and children who search the waste material with sieves and small hammers to find the last pieces of emeralds (Figure 3).

The Government tries to give some technical assistance to the miners and to control mining activities through the DNPM (Departamento Nacional de Produção Mineral). All garimpeiros have to be registered at the office of the 'Receita Federal'. At the end of 1986 in the Socotó area there

Fig. 4. Geological map of the Serra de Jacobina showing the batholiths of Carnaíba and of Campo Formoso (the latter with the Socotó mining region). (in Inda & Barbosa, modified after Couto *et al*, 1978).
1 – Metasediments of the Una Group
2 – Metasediments of the Espinhaço Super Group
3 – Granitic rocks
4 – Complexo Itapicuru (volcanoclastic sequence): feldsparquartzites, phyllites and schists, amphibolites, metabasites, and serpentinites. Formations Agua Branca (Tab), Serra da Alegria (Tsl), Cruz das Almas (Tca), and mica schists with aluminium silicates (Tal).
5 – Jacobina Group (clastic sequence): metaconglomerates, orthoquartzites, intercalated serpentinites. Formations Rio de Ouro (Tro) and Serra do Córrego (Tsc).
6 – Basic and ultrabasic rocks.
7 – Basement (i.e. mainly Archean migmatites and gneisses)

were 144 operating claims with about 600 garimpeiros. In the Carnaíba area there were 90 claims with about 400 garimpeiros. The total 'population' of both areas was about 4 000 persons.

2. Geology

2.1 Regional Geology

The regional geological conditions are practically identical for the emerald deposits of Carnaíba and Socotó. They are characterized by the occurrence of granite batholiths whose pegmatites penetrated rock units of the Serra de Jacobina (Figure 4) and, in contact with its chromium bearing rocks (ultrabasites) caused the formation of emerald mineralizations. The age of the granites has been dated as about 2 billion years.

Figure 5 (modified after Rudowski *et al.*, 1987) shows the outcrop pattern in the Serra de Jacobina and Figure 6 (Couto, 1984) shows a sketch of the Campo Formoso batholith in the region of Socotó. The Campo Formoso batholith, a complex of K/Na-rich rocks, covers a semicircular area of about 700 km^2. Most abundant in it are granites and variations which have been petrographically determined to be adamellites and granodiorites. In the northern part of the batholith these rocks contain, in addition to pegmatites, numerous large xenoliths. The xenoliths vary from quartzites to amphibolites and from metabasites to normally serpentinised ultrabasites. Most xenoliths have the lithologies of the Serra de Jacobina.

The emplacement of the Campo Formoso batholith as well as other plutons was in part responsible for the east-west narrowing of the Serra de Jacobina (see Figure 4). It was accompanied by folding and imbricate faulting. The formation of the intrusive granites such as the Campo Formoso batholith occurred during the Transamazonian Cycle which shows granitisation effects of regional extent. However, the intrusive character of the Campo Formoso batholith is proved by the presence of granite-apophyses which penetrate the rocks on the western edge of the Serra de Jacobina. Also, xenoliths of green quartzites belonging to the Jacobina Group occur within the granite. The intrusion of the batholith caused much faulting, in particular, in the area of the emerald deposit.

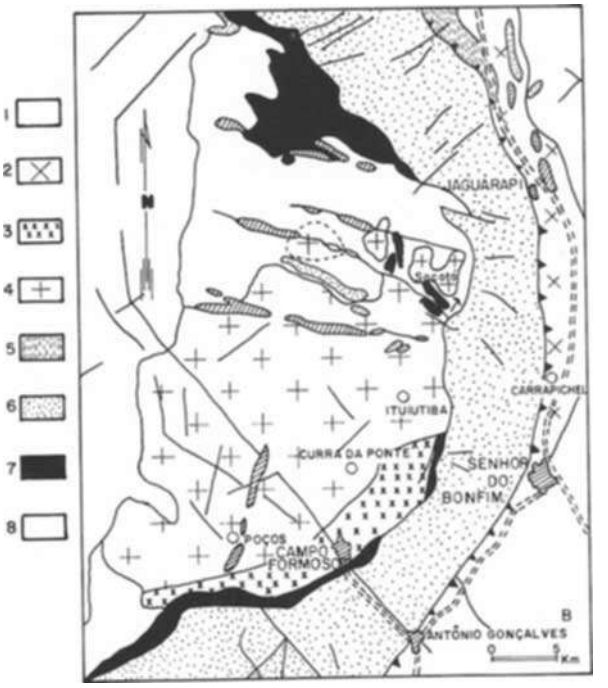
The metasediments of the Una group lie discordantly above the Campo Formoso granites in the western area. In the north and southeast, the Campo Formoso granite is in contact with rocks of the basic-ultrabasic complex. In the east it borders on the quartzites of the Serra de Jacobina.

2.2 Local geology and genetic aspects

Based on the results of detailed mapping, geologists of the DNPM/CPRM (CPRM = Companhia de Pesquisa de Recursos Minerais) have concluded that besides the area currently being worked (3.0 × 0.3 km) there are more emerald-bearing bodies which show identical structural and petrographical characteristics. Indeed, several serpentinised bodies have already been found on the northern rim of the batholith, one of them extending over more than 40 km^2. It is quite possible that mineralizations of the same types observed in Carnaíba will be found. There, the first discovered mineralized zone was situated in an ultramafic block within the granite. Only later the metamorphosed ultrabasites were discovered that are inserted in the Jacobina quartzites. The garimpo Socotó is located (as can be seen in Figure 6) in the tectonically most affected area of the whole region. Observations made in other emerald deposits have shown that – independent from the type of genesis – the mineralizations of emerald appear preferentially in areas with intensive tectonism. This is due to the easier migration in these zones of the solutions that are responsible for the transportation of the emerald components. So we can assume that the local geological conditions in the area of the Socotó garimpo were especially advantageous for the emerald mineralizations.

The ultramafite body which hosts the emerald mineralizations of Socotó has a length of 3 650 metres with an average width of 200 metres. It represents an enclave within the granitic rocks of the Campo Formoso batholith. In the centre of the main body, known as Trecho Velho and Trecho Novo, occur serpentinites, talcites, amphibolitic rocks, biotite schists, gabbros, metadiabasites and cataclastic rocks. The following petrographic types predominate: actinolite-talcite, biotite-chlorite schist, amphibolite (metadiabase) and – in the contact zones with the granite-cataclasites, muscovite-quartz schist and rocks with granodioritic composition. Besides emerald and green beryl, the occurrence of molybdenite, scheelite, powellite, phenakite, chromite, asbestos and sulphides (chalcopyrite ?) was confirmed. Locally, a lot of black tourmaline can be observed in a tourmaline-biotite schist.

Comparing the garimpo of Socotó with the mining area of Carnaíba (Eidt & Schwarz, 1988), the currently mined area is equivalent in its geological and petrographical nature to the area called Carnaíba de Baixo. It is an ultramafite body located in the middle of the granite and which is penetrated by pegmatite veins. The pegmatite veins are accompanied by metasomatically altered zones in which the emerald mineralizations occur. The area which would correspond to Socotó de Cima (the area which is characterized by the occurrence of schistified ultramafite lenses in quartzites) has not yet



1 Proterozoic superior cover

2 Jaguarari granite

3 Two-mica granite

4 Porphyroid two-mica granite

5 Chloritoschist phyllites

6 Quartzites and volcano-sedimentary formations

7 Serpentinites

8 Archean gneisses, metatexites and diatexites

Fig. 5. Outcrop pattern in the Serra de Jacobina with the Campo Formoso batholith (modified after Rudowski *et al.*, 1987).

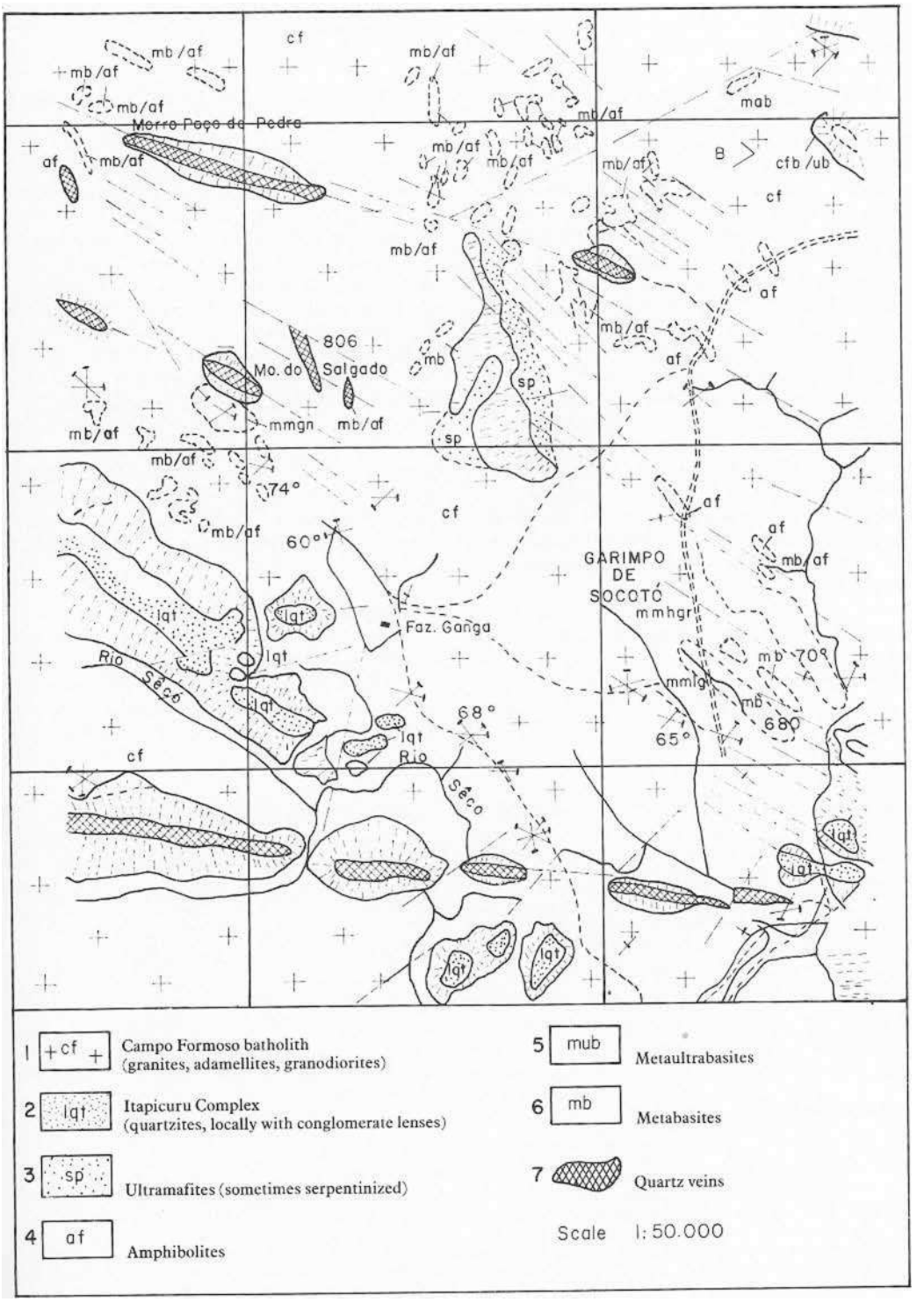


Fig. 6. Sketch of the Campo Formoso batholith in the Socotó area.

been mined.

Despite the fact that the regional geological features are practically identical in Carnaíba and Socotó, some peculiarities of the latter deposit should be emphasized. First is the considerably larger extension of the Campo Formoso batholith, which increases significantly the mineralization potential. Second, the area of Socotó shows a larger variety of tectonic structures and rock types. On the whole, these factors result in a larger range of variation in the mechanism of formation of the Socotó emeralds. It is interesting to notice that the greater variety of environments is not only observed when studying the geological and petrological conditions, but also when examining the Socotó emeralds under the gem microscope.

Like the occurrences of Carnaíba and Tauá/CE, Socotó belongs to the classic type of emerald deposit. The elements Cr and Fe derive from mafic and ultramafic rocks (or their metamorphosed derivates). The (main) suppliers for beryllium are pegmatites. The Belmont Mine at Itabira/MG is considered to represent a special type of the classic genesis and in the Santa Terezinha/GO deposit the main suppliers for beryllium are non-pegmatitic rocks (Schwarz, 1987).

3. Optical and chemical properties of the Socotó emeralds

Table 2 gives the optical data of Socotó emeralds, the measured density values range between 2.67 – 2.72 g/cm^3.

Table 2. Refractive indices and birefringence of Socotó emeralds.

n_e	n_o	Δn
1.579–1.582	1.587–1.590	−0.007–0.009

The results of the microprobe analyses performed on twenty emeralds from the Socotó mining region are compiled in Table 3.

Structural and (crystal-)chemical considerations as well as the calculated mineral formula coefficients (Table 3) indicate that – as we can see also in emeralds from other occurrences – the following substitutions dominate:

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

(b) Al^{3+}(octahedral) = $(Cr,Fe)^{3+}$(octahedral)

It is interesting, however, that in the Na-(Mg+Fe)-diagram for the mineral formula coefficients the points for most of the Socotó emeralds are distinctly shifted to the right, indicating that the $(Mg,Fe)^{\cdot}$ excess is higher than that normally observed in emeralds from other locations (Figure 7).

4. Inclusions

The first results of examinations of inclusions in emeralds from the Socotó occurrence were presented at the 33rd Brazilian Geological Congress in Rio de Janeiro (Schwarz, 1984a). Since then, further detailed studies have been made using a large

Table 3. Microprobe analyses of Socotó emeralds. Total iron as FeO. CaO-content <0.01 Wt%.

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SiO_2	65.51	65.13	64.76	64.81	64.73	66.01	65.89	65.19	64.55	65.66	65.31	64.88	65.53	64.42	64.44	63.48	63.76	66.68	64.53	64.38
Al_2O_3	15.38	15.72	15.48	14.81	15.51	16.24	16.35	16.16	16.02	16.59	16.72	15.94	16.50	15.54	15.31	16.02	16.25	16.96	16.20	15.80
Cr_2O_3	0.36	0.16	0.30	0.30	0.22	–	0.11	–	0.11	0.11	–	0.13	–	0.25	0.41	0.18	0.25	0.75	0.34	0.35
FeO	0.96	0.88	0.95	0.91	0.89	0.53	0.66	0.79	0.76	0.75	0.58	0.76	0.67	0.87	0.91	0.77	0.49	0.51	0.67	0.77
MgO	2.55	2.28	2.39	2.63	2.24	2.27	1.91	2.05	2.06	1.81	1.88	2.42	2.05	2.58	2.50	1.89	2.12	1.56	1.98	2.15
K_2O	–	–	0.10	–	0.06	–	–	–	0.08	–	–	–	0.07	–	0.10	0.07	0.06	–	0.07	–
Na_2O	1.15	1.00	1.11	0.98	1.08	0.87	0.92	0.68	1.00	0.84	0.99	1.05	1.09	0.89	1.05	1.62	1.59	0.96	1.20	1.16
MnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CaO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	85.91	85.15	85.11	84.44	84.73	85.92	85.86	84.87	84.58	85.76	85.47	85.18	85.91	84.55	84.72	84.02	84.52	87.41	85.00	84.60

Mineral formula coefficients (normalized: Si = 6)

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Si	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.660	1.707	1.691	1.616	1.694	1.740	1.755	1.753	1.755	1.786	1.810	1.737	1.780	1.705	1.680	1.785	1.802	1.798	1.776	1.735
Cr	0.028	0.012	0.022	0.022	0.016	0.000	0.008	0.000	0.008	0.008	0.000	0.010	0.000	0.018	0.030	0.013	0.018	0.054	0.025	0.026
Fe	0.073	0.068	0.074	0.071	0.069	0.040	0.051	0.061	0.059	0.058	0.044	0.059	0.051	0.068	0.071	0.061	0.039	0.038	0.052	0.060
Mg	0.349	0.313	0.331	0.369	0.309	0.308	0.260	0.282	0.285	0.246	0.257	0.333	0.280	0.359	0.348	0.266	0.297	0.209	0.275	0.298
K	0.000	0.000	0.012	0.000	0.008	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.008	0.000	0.012	0.008	0.008	0.000	0.009	0.000
Na	0.204	0.179	0.199	0.176	0.195	0.153	0.163	0.121	0.179	0.149	0.177	0.188	0.194	0.161	0.190	0.297	0.291	0.167	0.215	0.210
Total	8.314	8.279	8.329	8.254	8.291	8.241	8.237	8.217	8.296	8.247	8.288	8.327	8.313	8.311	8.331	8.430	8.455	8.266	8.352	8.329

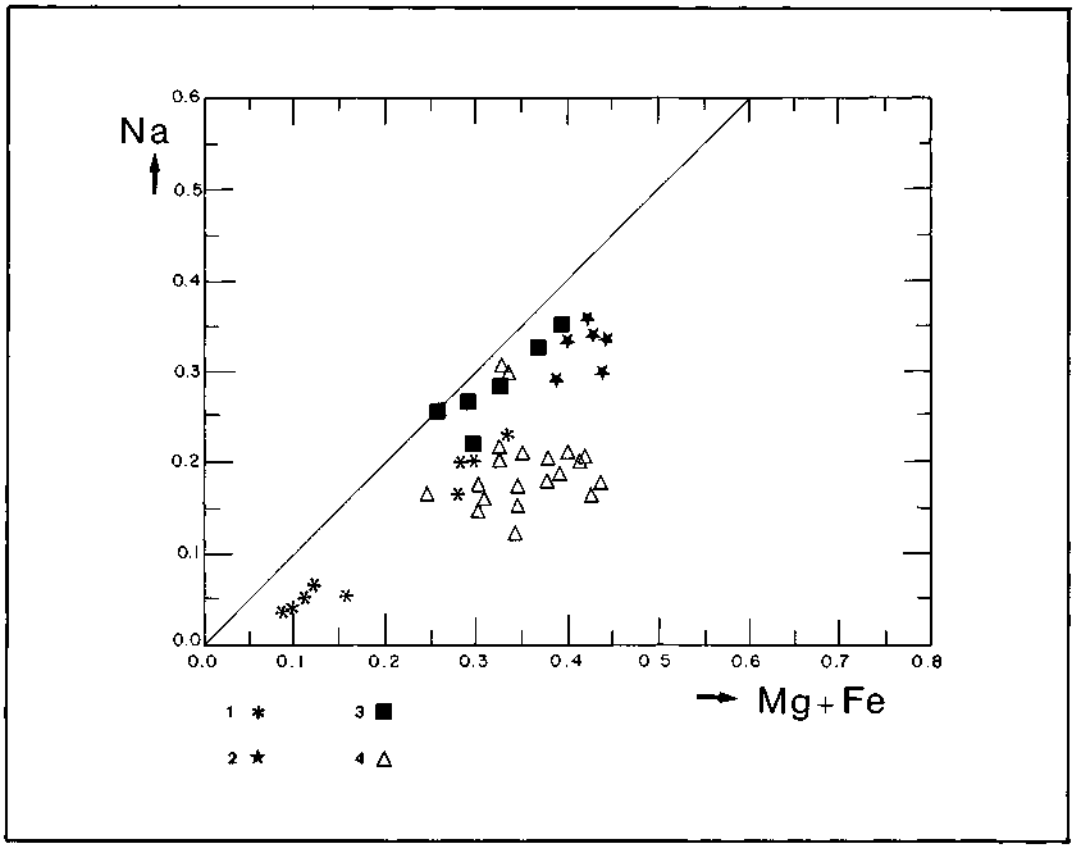


Fig. 7. Plot (Mg+Fe) over Na for emeralds from different Brazilian occurrences.
1. Itabira/MG (Hänni, Schwarz and Fisher, 1987).
2. Tauá/CE (Schwarz *et al.*, 1988).
3. Carnaíba/BA (Schwarz & Eidt, 1988).
4. Socotó/BA.

number of emeralds from the Socotó mining area (on the whole about 1000 samples were examined under the gem microscope). Following the microscope examinations, a number of selected samples were analyzed using X-ray diffraction and micro-X-ray spectroscopy techniques (microprobe).

Considering the geographic proximity and the fact that the regional geology is almost identical for the two occurrences of Socotó and Carnaíba, we expected to find that inclusion features would also be more or less identical. However, a comparative study shows that the inclusions in the Socotó emeralds are abundant and that numerous inclusions are not (or only very rarely) observed in the Carnaíba emeralds (compare Schwarz & Eidt, 1988). The emeralds from Carnaíba are characterized by the appearance of the so-called 'flocs' and 'stars' (mostly composed of minute liquid droplets or 'l-g'-two-phase inclusions), mineral inclusions are relatively rare. The most frequent inclusion mineral in the Carnaíba emeralds is a mica (member of the biotite/phlogopite series), that sometimes shows a very uncommon 'board' or 'lath'-like form that can be considered as diagnostic of emeralds from this occurrence (Schwarz, 1984b). In the emeralds from Socotó, on the contrary, a great variety of different mineral inclusions can be observed. However most of these are not very frequent.

Mica

The most common inclusion mineral in the Socotó emeralds is – as should be expected – a mica of biotite/phlogopite composition (Table 4). This is due to the fact that the largest portion of the Socotó emeralds has a biotite/phlogopite schist as its host rock. Margarite and muscovite are much rarer as inclusions.

Normally, the mica crystals occur in the form of rounded or irregular-shaped platelets. Their colour

Table 4. Microprobe analyses of mica inclusions in Socotó emeralds.

	Biotite/Phlogopite			Margarite
SiO_2	41.48	39.50	42.12	29.42
Al_2O_3	13.11	12.84	13.08	44.61
TiO_2	0.09	–	0.13	–
V_2O_3	–	–	–	–
Cr_2O_3	0.55	1.18	–	–
FeO	8.71	11.12	8.53	0.29
MnO	–	0.22	–	–
MgO	20.36	17.54	21.01	0.68
CaO	0.19	0.17	0.12	12.86
Na_2O	0.08	–	0.17	0.60
K_2O	10.32	12.43	10.41	–
Total	94.99	95.00	95.57	88.46

Table 5. Microprobe analyses of actinolite/tremolite inclusions in Socotó emeralds.

SiO_2	55.70	57.34	54.27	58.11	59.22
Al_2O_3	0.73	1.96	1.38	2.08	3.83
TiO_2	–	–	–	–	–
V_2O_3	–	–	–	–	–
Cr_2O_3	0.22	0.05	0.29	0.21	–
FeO	6.95	6.88	7.39	7.25	6.08
MnO	0.18	0.21	0.14	0.21	0.19
MgO	18.18	19.07	18.69	20.17	16.55
CaO	14.06	12.82	12.57	12.96	11.25
Na_2O	–	0.54	1.19	0.64	0.67
K_2O	–	–	0.09	0.15	0.09
Total	96.02	98.87	99.02	101.78	97.88

Table 6. Microprobe analyses of different mineral inclusions in Socotó emeralds.

	Allanite	Apatite	Chromite	
SiO_2	28.71	–	0.55	2.41
Al_2O_3	14.19	0.13	7.72	5.88
TiO_2	0.31	–	0.38	0.41
V_2O_3	1.89	–	0.43	0.73
Cr_2O_3	1.86	–	52.56	53.02
FeO	10.20	–	34.17	32.75
MnO	0.62	–	1.62	2.11
MgO	0.45	–	0.73	0.38
CaO	12.31	54.01	–	–
Na_2O	0.45	–	1.58	0.70
K_2O	–	–	–	0.08
P_2O_5	–	41.50	–	–
NiO	–	–	–	–
	~30% Ce			
Total	70.99	95.74	99.74	98.71

is generally light to dark brown; greenish brown shades are rarer. Margarite and muscovite are practically colourless. Only rarely do the mica crystals occur isolated; mostly they form agglomerations ('clouds') that can be so dense that the emerald host crystal shows a dark brown colour and appears almost opaque in these regions. Many times the mica crystals, present in a great number, reflect the formation history of the Socotó emeralds: sometimes they are oriented practically parallel to the emeralds growth striae or they contribute, through an elevated concentration in concentric 'growth rings', to the formation of a zonal structure in the emerald (see below). Sometimes, tubes (channels) of variable thickness are observed, oriented in the direction of the emeralds *c*-axis and filled with mica (Figure 8).

Talc

Talc occurs in the form of transparent, almost colourless platelets.

Chlorite

Because of their very similar appearance the separation of mica and chlorite in the gem microscope is sometimes very difficult. Chlorite, which is observed frequently together with mica, normally has a more greenish colour.

*Actinolite/Tremolite**

In the first Socotó emeralds available for inclusion studies, actinolite/tremolite was observed relatively often (Schwarz, 1984b). In the stones examined at that time it occurred with almost the same frequency as mica and often was found together with the latter. Additional examinations made on a great number of Socotó emeralds, however, showed that the importance of actinolite/tremolite as an inclusion mineral falls clearly behind that of the micas. This fact is in accordance with the observations made in the emerald mining area showing that an actinolite schist is much rarer as an emerald host rock than is the mica schist.

Actinolite/tremolite sometimes forms thick needles or rods that are practically colourless and transparent. These occur isolated or form nest-like agglomerations of numerous unoriented crystals (Figure 9). These can be restricted to certain regions of the host crystal or can be randomly distributed.

The quantity of actinolite/tremolite crystals in some of the Socotó emeralds can be so large that these can be confused, at first sight, with emeralds

* It is true that the crystals examined by micro-X-ray spectroscopy (see Table 5) are all actinolites, but we can suppose that some of the amphibolite inclusions in the Socotó emeralds are members of the actinolite/tremolite series.

Table 7. Microprobe analyses of feldspar inclusions in Socotó emeralds.

	Albite	K-feldspar	Plagioclase
SiO_2	68.39	64.23	61.60
Al_2O_3	20.21	19.47	26.02
TiO_2	–	–	–
V_2O_3	–	–	–
Cr_2O_3	–	–	–
FeO	–	–	–
MnO	–	–	–
MgO	0.35	–	0.28
CaO	0.13	–	6.59
Na_2O	10.25	–	6.92
K_2O	0.44	15.79	0.16
Total	99.77	99.49	101.57

Table 8. Microprobe analyses of carbonate inclusions in Socotó emeralds.

	Calcite	Dolomite	Breunnerite
SiO_2	1.21	–	–
Al_2O_3	0.25	–	–
TiO_2	0.28	–	–
V_2O_3	–	–	–
Cr_2O_3	–	–	–
FeO	–	2.09	15.78
MnO	–	–	0.34
MgO	0.17	19.44	35.63
CaO	56.04	29.53	0.14
Na_2O	–	–	–
K_2O	–	–	–
Total	57.95	51.06	51.89

from Sandawana (Figure 10). Normally, however, they don't have the 'hair-like' appearance of the curved tremolite crystals typical for the Sandawana emeralds. Besides the colourless-transparent crystals occur others of a greenish to light-brown colour, that sometimes show the characteristic 'bamboo'-like appearance (Figure 11.)

Allanite (Orthite)

The Ce-epidote allanite (orthite) forms prismatic crystals of a dark brown colour (Figure 12).

Apatite

Occurs as prismatic crystals that are sometimes slightly corroded and rounded. They are colourless and almost always show cleavage planes parallel to the basal face. Based on their outer appearance and on the manner of distribution within the emerald host crystal we can infer that these crystals are protogenetic inclusions (Figure 13).

Quartz

The prismatic quartz crystals show more or less distinctly developed corrosion phenomena (Figure 14).

Feldspar

The Socotó emeralds are partly found in feldspar masses and this explains the appearance of isolated feldspar crystals and of fractures filled with feldspar in the emeralds. The chemical analyses (Table 7) show that different types of feldspar are present: an almost pure Na-feldspar (albite), a K-feldspar and a plagioclase of andesine composition.

Carbonates

The presence of carbonate inclusions in the emeralds of Socotó is also not surprising because the emeralds are occasionally found in carbonate rocks.

Table 9. Microprobe analyses of tourmaline inclusions in Socotó emeralds.

SiO_2	33.79	33.63	33.45	36.72	36.13	35.44
Al_2O_3	29.41	29.76	31.31	33.88	33.73	31.98
TiO_2	0.14	0.23	–	–	–	0.16
Cr_2O_3	0.67	–	–	–	0.30	–
FeO	4.00	3.41	3.84	4.16	3.93	4.14
MgO	9.84	9.92	8.59	9.30	8.98	9.62
K_2O	–	0.08	–	–	0.09	–
Na_2O	1.95	2.24	2.36	2.62	2.31	2.37
CaO	1.98	1.64	0.78	0.91	0.80	1.54
Total	81.78	80.90	80.33	87.59	86.25	85.25

Unlike the Santa Terezinha emeralds from Goiás that often show well-developed rhombohedra, the carbonates in the Socotó emeralds are normally small, irregular shaped grains. These are, in general, concentrated in certain regions of the host crystal or fill fracture planes; rhombohedral crystals are rare. Although single crystals are practically transparent and merely show a more or less broad and dark border line when observed in transmitted light, carbonate masses in the fissures can be so thick that they appear practically opaque.

Besides an almost pure Ca-carbonate (calcite) the microprobe analyses (Table 8) revealed the presence to two other carbonate minerals: one of Ca/Mg (dolomite) and the other of Mg/Fe (= ferromagnesite or breunnerite).

Tourmaline

Tourmaline is – as is true also for the emeralds from the Carnaíba mining region – a rare inclusion mineral in the Socotó emeralds. It forms long prismatic or rod-like crystals of a dark brown colour that don't show a preferred orientation in the

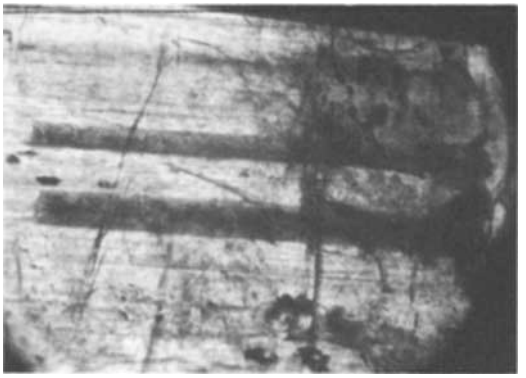


Fig. 8. Channels, oriented parallel to the *c*-axis and filled with mica. 35x

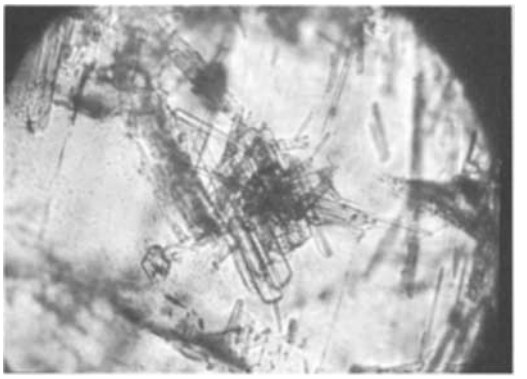


Fig. 9. Agglomeration of prismatic, colourless-transparent actinolite/tremolite crystals. 35x

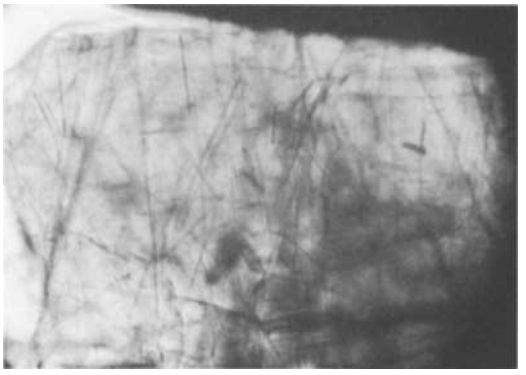


Fig. 10. Actinolite/tremolite inclusions in the form of needle-like prismatic crystals. 20x

Fig. 11. Actinolite/tremolite crystals of green-brownish colour and 'bamboo'-like appearance. 20x

Fig. 12. Dark-brown, prismatic crystals of allanite (orthite). 50x

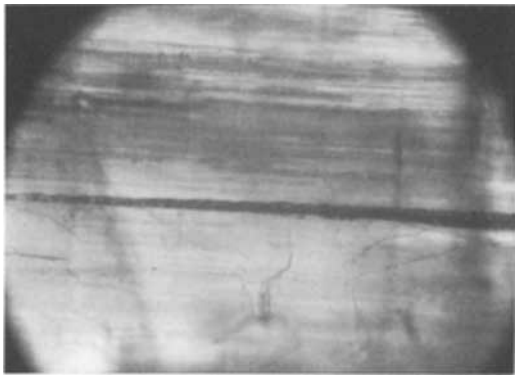


Fig. 19. Growth tube, filled with black mineral substance. 70x

emerald host crystal. According to their chemical composition they are members of the dravite-schlorite series (Table 9).

Hematite/Goethite – Limonite/Lepidocrocite

Hematite occurs as (pseudo-) hexagonal platelets (Figure 15) or as small, irregular crystals that can be found mostly within fissures or dispersed over the surface of the emerald crystals. Hematite that occurs on the emerald's surface or within fissures is almost always partially or completely altered to geothite/limonite (Figure 16). In these cases it has the appearance of black, opaque flakes or simulates ink-blots. Sometimes skeleton crystals or irregular-shaped platelets can be seen. Lepidocrocite, which is distinguished by a strong orange-red colour, is a rare inclusion mineral and forms, generally, irregular platelets or skeleton-like crystals.

Molybdenite

Molybdenite, which belongs to the group of the rarer mineral inclusions in the Socotó emeralds, forms hexagonal platelets that are distinguished by a strong silvery-grey metallic lustre in incident light (Figure 17).

Pyrite and chromite

Other opaque mineral inclusions are pyrite (generally as cube-like crystals) as well as a black mineral that strongly resembles the picotite inclusions so frequently seen in the Santa Terezinha emeralds. It almost always forms small grains that occur isolated or in cloud-like, more or less compact agglomerations. The microprobe analyses (Table 6) show that these are crystals of chromite, a member of the spinel group.

Emerald/Beryl

Among the most interesting mineral inclusions in the Socotó emeralds are crystals of emeralds/beryls. Generally, these are not fragments or chips, as were described, for example, in emeralds from Colombia (Gübelin, 1974) or from Carnaíba (Schwarz, 1984b), but well developed, prismatic crystals. These can be oriented parallel to the *c*-axis of the host emerald or be present without showing a preferred orientation.

During a superficial examination in the gem microscope, emerald/beryl inclusions can be easily overlooked, because their colour is practically identical to that of the host crystal. But when using crossed polarizing filters, they become distinctly visible because their extinction position is generally different from the extinction position of the host crystal. Sometimes they can be easily recognized because they are covered on their surface by another material or because they contain so many inclusions that they clearly contrast with their surroundings.

Among the most striking inclusion features in the Socotó emeralds are some phenomena whose formation is directly related to the growth process of the emerald host crystal. These phenomena show a variety that has never been observed by the authors in emeralds from other occurrences:

Growth tubes and channel-like cavities

The growth tubes observed in Socotó emeralds show a surprising variety with regard to form, size, colour and tube fillings. Some of them are elongated cavities that are sometimes empty but, in general, present a one or two phase filling. The cavities can be arranged in parallel strings (in direction of the *c*-axis) causing a 'silky' or 'milky' turbidity-effect that can also be observed in many Brazilian aquamarines and in the emeralds from the Belmont mine near Itabira/MG. Emeralds with numerous inclusions of this type sometimes show – when cut as cabochon – a chatoyancy effect.

Another type of tube forms larger, frequently slightly flattened, channels that generally traverse the emerald host crystal in its total length. These channels are mostly concentrated in irregularly delineated zones that clearly reflect the hexagonal symmetry of the host crystal ('central core', see Figure 18). As a rule, the channels have a two phase filling ('l-g'-type); others are filled with mineral material (Figure 19).

The larger growth tubes normally traverse the full length of the emeralds (Figure 18), but sometimes they end abruptly in the interior of the host crystal and then they look as if they had been cut by a pair of scissors. This fact suggests that the growth environment suffered abrupt changes. Sometimes groups of growth tubes can be seen that start from fracture planes. Other tubes (channels) present a hexagonal cross-section and are of an intensive brown colour. At higher magnifications in the gem microscope these tubes are not homogeneous but show a somewhat granular aspect, i.e. their walls are coated with grains and platelets of a brown mineral. The microprobe analyses show that this material is mica.

Zones with an elevated density of inclusions

We previously described an inclusion type showing the concentration of growth tubes or channels that results in a more or less sharply delineated 'central-' or 'core-zone'. The zoning based on an elevated inclusion density can be caused also by different mineral inclusions (Figures 20 and 21). Generally, these are mica, carbonate(s), or feldspar; sometimes other minerals also occur. The concentration of the inclusion minerals can be so high that their volume is larger than that of the surrounding

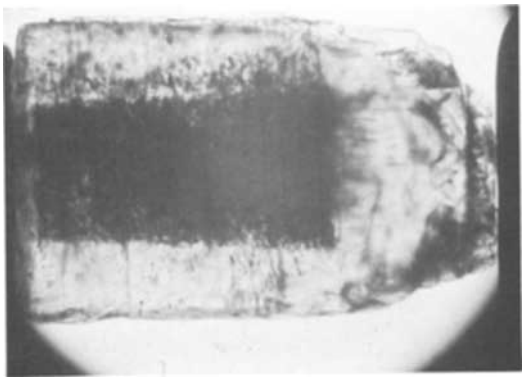


Fig. 20. Sharply delineated 'core-zones', formed by the concentration of numerous mineral inclusions (principally mica, feldspars and carbonate(s). 20x

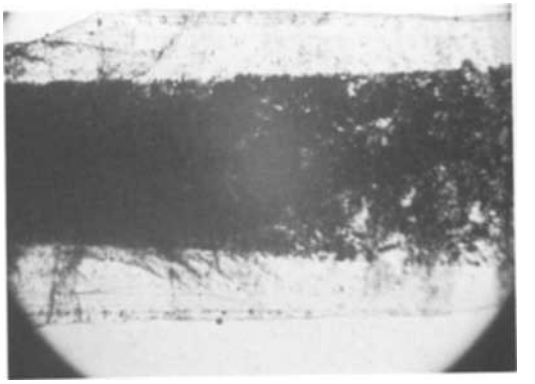


Fig. 21. Sharply delineated 'core-zones', formed by the concentration of numerous mineral inclusions (principally mica, feldspars and carbonate(s). 20x

Fig. 22. Growth layers parallel to the basal face, formed by a high concentration of mineral substance or of growth tubes. 35x

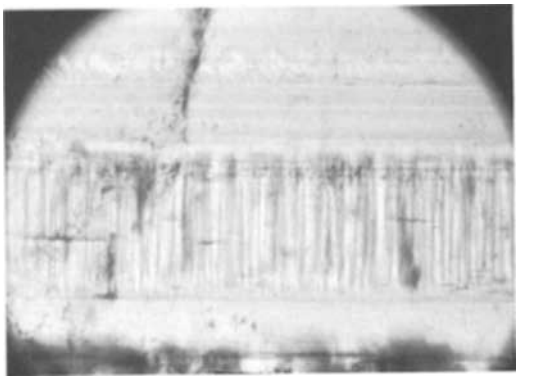


Fig. 23. Internal structure of a growth layer resulting in a somewhat diffuse aspect. 50x

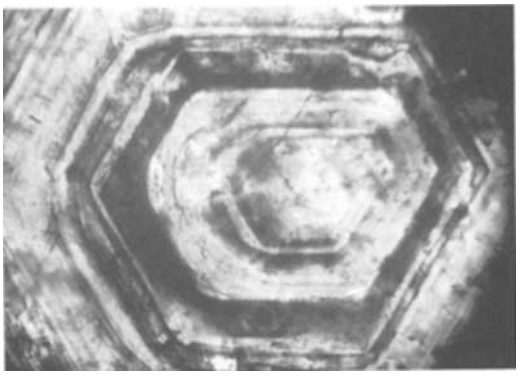


Fig. 24. Concentric colour zoning (looking parallel to the *c*-axis). 50x

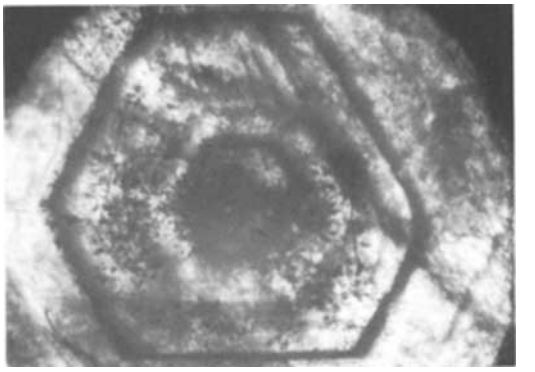


Fig. 25. Enrichment of mineral substance in concentric 'growth-rings'. 35x

Fig. 13. Apatite in the form of prismatic crystals showing corrosion phenomena and cleavage planes parallel to the basal face. 70x

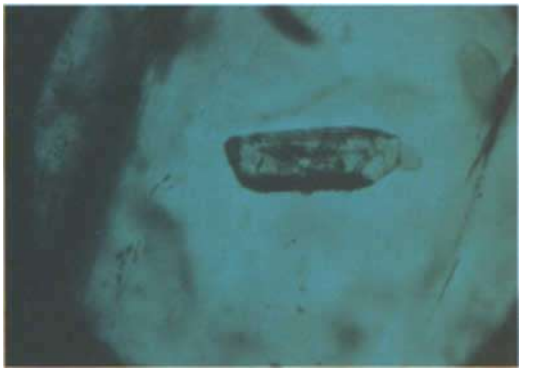


Fig. 14. Partially corroded quartz crystals. 50x

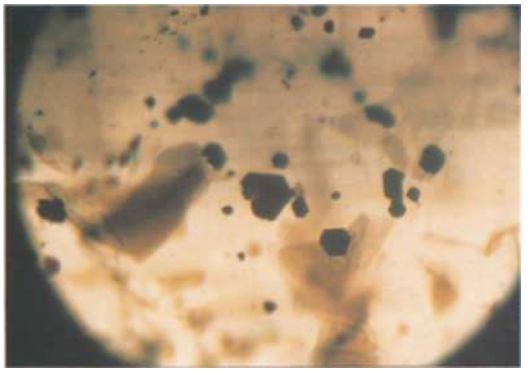


Fig. 15. (Pseudo-)hexagonal hematite platelets and brown mica crystals. 20x

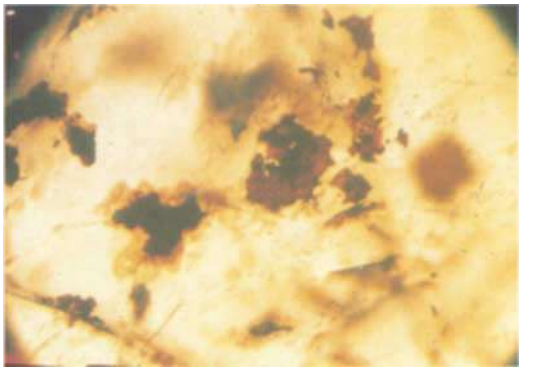


Fig. 16. Hematite is often partially or completely altered to goethite or limonite/lepidocrocite. 20x

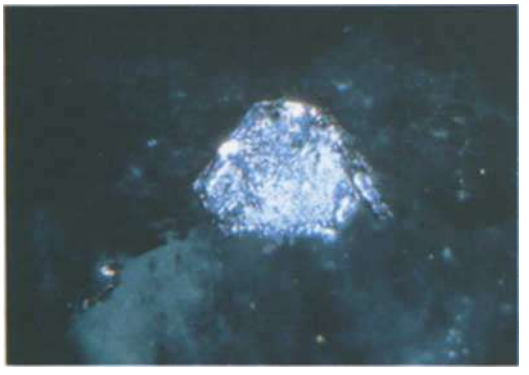


Fig. 17. Hexagonal platelet of molybdenite showing a strong silvery-grey metallic lustre. 50x

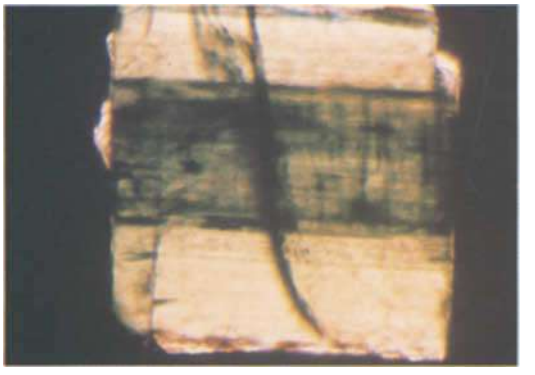


Fig. 18. 'Core-zone', formed by a high concentration of growth tubes that are present through the full length of the emerald. 20x

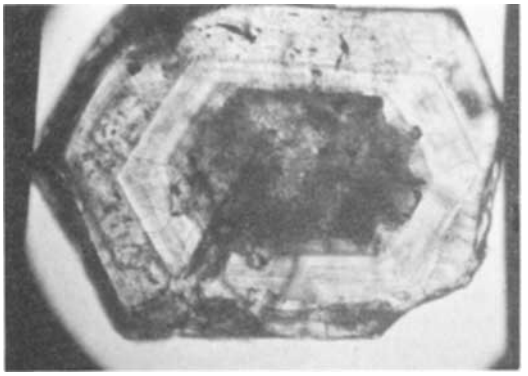


Fig. 26. Concentric colour zoning and 'central core' (caused by the enrichment of growth tubes), reflecting the hexagonal symmetry of the host crystal. 20x

Fig. 27. Three phase inclusion ('s-l-g'-type) with birefringent crystal. 50x

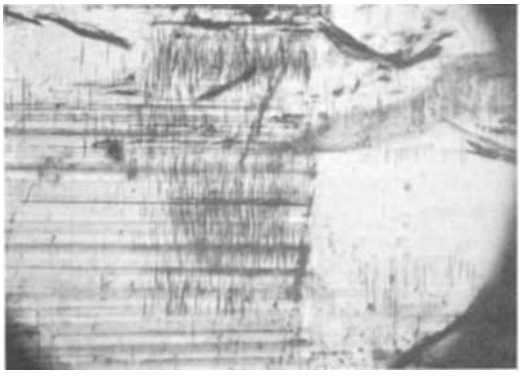


Fig. 28. Swarm of fine, disc-like fissures, oriented parallel to the emerald basal face. 35x

emerald. As a rule, the 'core-zone' traverses the host crystal in its full length. Sometimes, however, it is fairly sharply delimited, ending in its interior. The presence of the core-zones as well as the growth layers described below, show that the growth history of the Socotó emeralds is characterized by repeated abrupt alterations of the environment.

Besides the concentration of growth tubes and mineral inclusions in the core-zone, frequently, enrichment of these inclusions can be observed in layers parallel to the basal plane (Figure 22). Like the core-zones these layers are composed mostly of mica, carbonate(s), feldspar and of growth tubes showing different sizes. As a consequence of the presence of these layers many Socotó emeralds break easily along these layers, i.e. parallel to the basal face. The fracture planes show a strong glass- or nacreous lustre and simulate a good cleavage of the emerald.

As in the Carnaíba emeralds an internal structure of the growth layers can frequently be seen also in the stones from Socotó. This gives rise to a somewhat diffuse aspect of the growth layers (Figure 23), difference from the regular and sharply delimited growth layers generally seen in synthetic emeralds.

Colour striae/colour zoning

A large portion of the Socotó emeralds shows a distinctly developed colour zoning that can express itself both in a strongly coloured central zone with paler border zones, and in a paler central area with darker (i.e. greener) border zones. Other crystals show a sequence of darker and paler 'growth rings' (Figure 24).

The concentric colour zoning is frequently accompanied by the concentration of inclusions (growth tubes, mineral inclusions) in concentric rings (Figure 25) or in certain, generally well delineated, domains of the host crystal (Figure 26). Rarer than the concentric colour zoning are colour striae running parallel to the emerald's *c*-axis.

Fluid inclusions and fractures

Besides the above described mineral inclusions and growth phenomena can be found two phase inclusions of the 'l-g'-type (within the growth tubes or in rectangular cavities). Three phase inclusions (the solid phase is birefringent!; Figure 27) and multiphase inclusions are rarely seen.

More frequent are fractures that generally have no orientation and that are mostly unhealed. Other fractures have a disc-like shape and form swarms oriented parallel to the emerald's basal plane (Figure 28).

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Note

All photographs were taken using an immersion liquid. All photographs by D. Schwarz.

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The Pharaohs' forgotten emerald mines

O. Grubessi, C. Aurisicchio**, and A. Castiglioni****

*Dipartimento di Scienze della Terra, Universita 'La Sapienza', Roma, Italy
**C. S. Mineralogia e Petrologia delle formazioni Ignee.C.N.R., Roma, Italy
***Via Morazzone 2, 21100 Varese, Italy

Introduction

The aim of latest expedition to Djebel Sikeit and Djebel Zabarah by the brothers Angelo and Alfredo Castiglioni was the re-discovery of the Pharaoh's emerald mines.

The Castiglioni expedition was successful in the re-discovery of these forgotten ancient mines and has collected samples and documents on these famous deposits of precious stones, providing emerald specimens of great interest to gemmologists and archaeologists, as will be revealed in this paper.

Historical notes

While there are scientists who believe that emeralds were already in use in Egypt during the 12th dynasty, 2000-1788 BC (Ball, 1931), they were certainly widely diffused during the Ptolemaic (304-30 BC) Roman (30 BC-395AD) and Byzantine period (395-640AD) and the mines were fairly intensely exploited until 1237 during the reign of Sultan Al-Kamel.

The problem of dating the first appearance of the emerald is complicated by some confusion caused by the word that the ancients used for emerald. Apparently, the Egyptian word 'mafek' or 'wed' and the Greek word 'smaragdus' were freely used for all the green stones which were or appeared to be emeralds.

On this matter, Lucas (1934) who is undoubtedly an authority on the nature and use of ancient Egyptian materials, points out that the Egyptian mines were '...probably of the Greek-Roman period. There is, in fact, no evidence that they were exploited during the reign of Amenopsis III, as Wilkinson (1890) affirms; on the contrary it is certain that beryl has not been used in Egypt before the Ptolemaic period: all the stones examined by author from before that time, were not beryls but amazonite or other greenish materials.'

According to Lucas this was due to several archaeologists who, examining various collections, had classified a lot of green stones as emeralds or under the vague term of 'mother-of-emerald', even if they were not.

Previous explorations

In the following centuries, it seems that the mines may have been exploited by the Turks. However, around 1750 all activity stopped and the decline began, eventually reaching the point at which all records of the location of the mines was lost and it became as if they had never existed.

The first man to revive interest in these mines was a French explorer and archaeologist F. Cailliaud, who, commissioned by the Viceroy of Egypt, Ali Mohammed Pascha, in 1816, went back along the caravans path which led from the Nile to the mining areas of Djebel Zabarah and Djebel Sikeit. For several years his initiative aroused treasure hunting by travellers and scientists such as Belzoni in 1820 and Brocchi in 1823.

The latter (1841) described the fundamental geology of the area and provided some mineralogical information on the various minerals associated with the emerald. From 1841 until the end of the last century, these areas were again forgotten.

In 1899 McAlister made an extensive geographical and geological description of the mining area.

In 1911 a Frenchman, J. Couyat, visited the region and provided a brief mineralogical description of the emeralds. He described, in fact, only the colour, the morphology of the crystals and their occurrences. He affirmed, particularly, that the colour varies with the locality: 'deep green at Djebel Sikeit and bluish green at Djebel Zabarah and Abou Reched.' He also suggested, with great insight, that the different colours might be the reason that the ancients used different names for the same mineral.

In 1934 another Italian geologist, A. Stella, visited the area and stayed for a while by the Djebel Umm Kabu mine, which is the third and smallest mine in the area. Stella was the first to suggest that the berylliferous mineralization might be due to pneumatolytic or hydrothermal impregnation in the crystalline schists of the Etbai. He therefore suggested, using geological data, that there was a genetic analogy with the beryls from the Urals (USSR), Habachtal (Austria) and Leysdorp (South Africa).

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In 1957 Basta and Zaki re-explored the region and produced the first mineralogical information on the beryls from Wadi Sikeit and Djebel Sikeit. They reported occurrences, paragenesis, refractive indices, inclusions and X-ray powder patterns. On the basis of refractive indices they indicate the 'presence of about 15% alkalies.'

The expedition

To approach Mount Zabarah, the emerald mountain, the Castiglioni brothers used IVECO 75 PC 4×4 lorries equipped with advanced technological instrumentation called 'Satellitale' which could give at any time the exact latitude and longitude of their position. However, in spite of the sophistication of the computer, their personal experience and the old camel tracks proved to be their main aids in facing a journey bristling with difficulties.

The expedition set off from Alexandria, heading south and near the city of Edfu they left the fertile Nile valley and headed on into the desert and the barren mountains by the Red Sea. The valleys are often dominated by high peaks, some of which have old dry-stone pyramids on them, which are thought to have been ancient sign posts.

Thousands of years of caravan traffic have scattered the desert with caravanserais, of which today only the great dry stone walls remain. They were used to enclose the wells and thus protect them from the sand. The remnants of these wells reveal the perfection of their construction. The Bir Hammet well, found approximately 90 km from the Nile, on the Quseir road, octagonal in shape, more than 25 m deep, with a diameter of almost 4 m, was accurately surveyed by the Castiglioni brothers. The walls are compact, built with large blocks, perfectly fitted together without a single crack.

Slightly beyond this well one finds the Uadi Hammamat gorge and then the 'Green breccia' quarries, where huge abandoned blocks given evidence of a very ancient exploitation. Among the masses of broken blocks and piles of stones, it is possible to distinguish the form of a sarcophagus, which has lain there, forgotten for 25 centuries (Figure 1).

All around are remnants of simple dwellings, several heiroglyphic inscriptions and the remains of signal towers from the Roman period. In addition, practically everywhere are the constantly recurring symbols of the god Min, 'the divinity of the Eastern desert', who is represented with his head surmounted with huge feathers, his left arm raised, and his virile organ always erect (Figure 2).

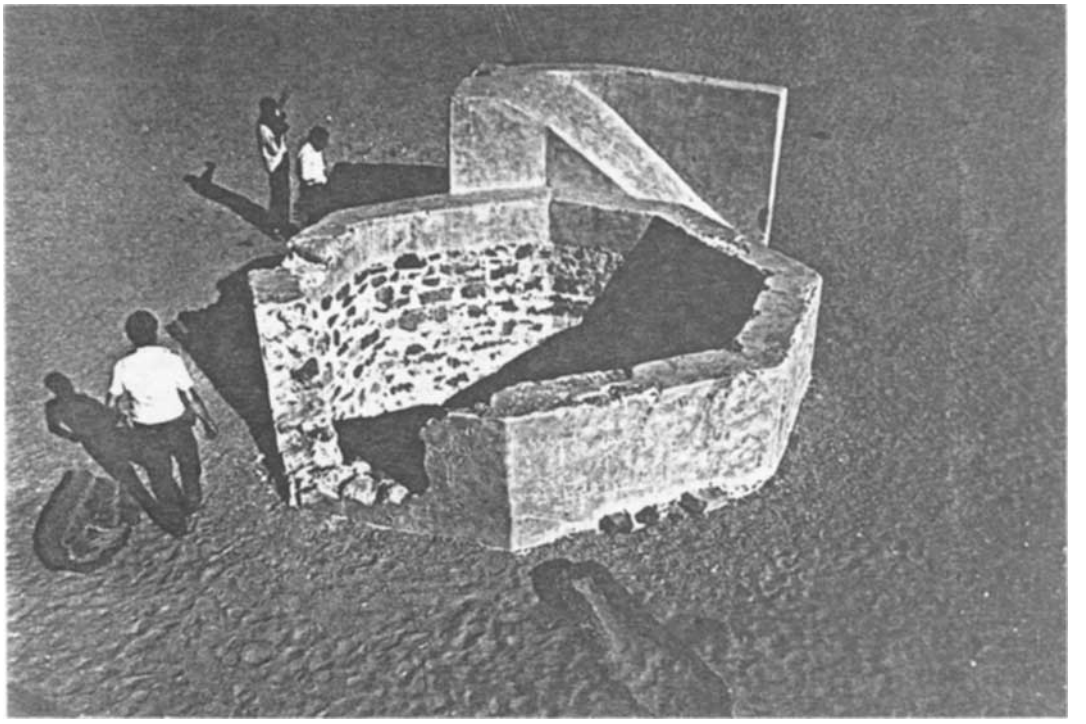

Fig. 1. The Great Bir Hammat well. Located 90 km from the Nile, on the Quetseir road, this well was for centuries an important stop for the caravans, which were going towards or were coming from the Red Sea. A few sarcophagi, broken during the transport and left on the sand, confirm the ancient time of construction of this spot of water.

Fig. 2. The God Min. 'The lord of the region', his image used to be frequently crafted on the rocky walls of the Uadi Hammamat. His head surmounted by large feathers, his left arm stretched up and his virile organ always erect.

Fig. 3. The ancient residences of Sikeit miners. The ruins of the houses are scattered on two sides of the mountains which flank the valley. The constructions show a great accuracy of execution: the stones, without mortar, are accurately selected in order to fit in one another to form a compact, smooth and exactly vertical wall.

Fig. 4. The temple at Sikeit. Opened in the middle of the mountain, this ancient place of worship, which thousands of years have eroded, still shows its attractive architectural beauty.

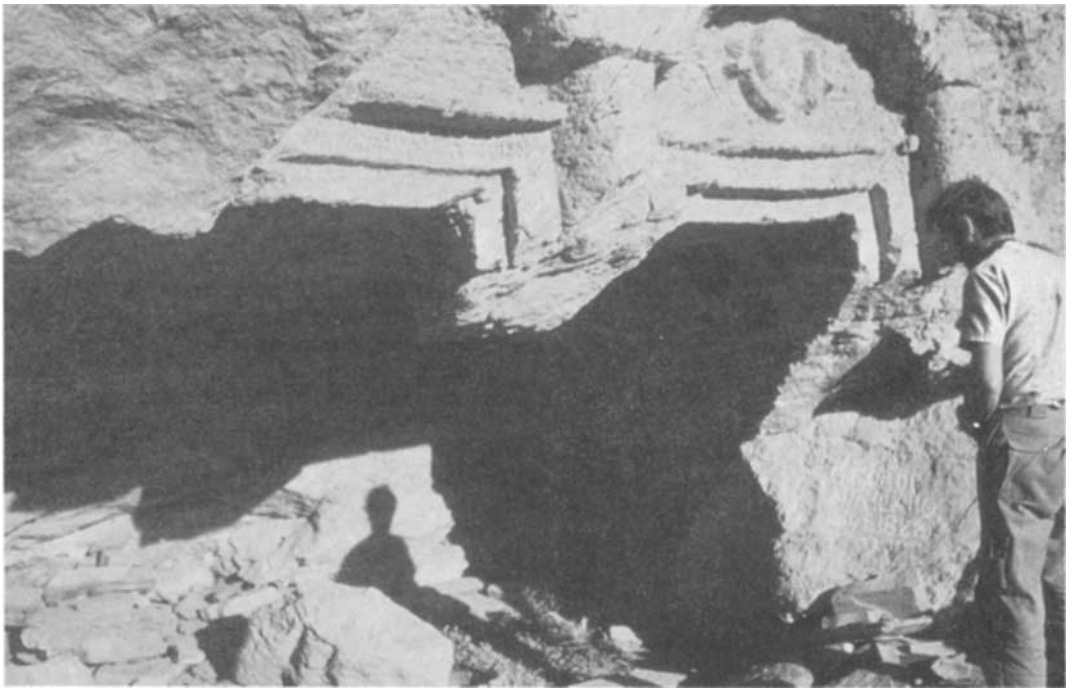

Fig. 5. Another temple at Sikeit. This second, smaller, temple at Sikeit is important for the Greek inscriptions crafted on the arches and for the solar symbols, surrounded by two snakes, which surmount the architrave. This high-relief allows dating of the temple as Ptolemaic in age.

Fig. 6. The entrance of the Pharaohs' emerald mine.

Fig. 7. Some of the members of the Castiglioni expedition in the emerald mine at Djebel Zabarah. On the walls the marks made centuries ago by thousands of blows, using diorite wedges, bronze chisels, iron tools for crushing quartz, are still visible.

The ancient city of the miners

The first sign of the forgotten mines is a low, dry stone building, the home of the Blemmis, the Sikeit miners, who supplied emeralds to the Ptolomans and to the Romans. The remnants of the house show that they were constructed with considerable accuracy; they are scattered along the sides of the mountains which flank the valley, and are furnished with stone benches and niches in the walls (Figure 3).

Zabarah, the emerald mountain

After leaving the Sikeit valley, other buildings were observed by the travellers arranged in lines, built in a very simple and modern way, that made up the miners' village of the past. Piles of quartz splinters lay inside and outside the houses together with small bright green fragments of emerald. A little farther on, the valley narrows and there are the ruins of ancient cemeteries, piles of debris and at last the mountains pock-marked with holes which indicate the entrance of the ancient mines.

Fig. 8. Emerald from Djebel Zabarah mine.

The temples of Sikeit

Sikeit also includes traces of two ancient temples. One is a tiny construction almost entirely in ruins, while the other larger one is in the middle of the mountain, its elegant slender columns carved out of the living rock. One of the internal columns is broken; without its central part it seems to challenge the laws of gravity, because the upper capital and part of the column shaft are still hanging from the ceiling, while one would expect to find them shattered on the floor of the temple. Only on closer inspection is it revealed that all columns are part of the same single piece, painstakingly carved out of the rock (Figures 4 and 5).

The mines

The entrance is normally a narrow corridor, carved out in the mica-schist, which suddenly opens into a chasm from which at various heights very narrow cavities start (Figure 6).

To explore these cavities, made by generations of miners, following the irregular path of emerald-rich quartz and feldspar veins, proved to be extremely difficult.

The space is restricted and breathing was made difficult due to a kind of very fine talc, thrown up by mere footsteps. The humidity increases as one

descends to the lower levels. The result is an irritating yellowish-white crust that gradually covers the body, damp with sweat, that vividly reminds one of the sufferings of the men who were forced to work for hours in the pale light of torches or terracotta lanterns. These would have burnt up the oxygen making the situation even worse, and all this for the glory of the Pharaohs. The rocks, blackened by the smoke of thousands of torches, still clearly show the efforts of those men.

The columns and stone arches found at various points were used to tie ropes on to, that allowed men to go down the shaft or to pull up baskets of material (a few pieces of hemp are still hanging in these shafts (Figures 7 and 8).

Among the other dangers there were the scorpions (*Androctonus australis*), who tend to build their nests in the entrance of the caves.

But were the emeralds of Zabarah really worth all dangers, efforts and sufferings?

For the ancient Egyptians the answer was yes, because they considered the emerald to be the symbol and purest essence of eternal life, and thus every sacrifice to obtain it was justified; this stone symbolized rebirth in the after life and had the colour of the life that flourishes on the banks of the Nile, after the fertilizing flood.

The emeralds from Djebel Zabarah

The characterization of the emeralds from Djebel Zabarah, the larger and historically most important of the three Egyptian mines, is strictly speaking, more a geo-archeological contribution than a gemmological one.

The emeralds are often '....pale green in colour, cloudy and exhibit considerable inclusions' as Cailliaud described them, or '...fairly clear, irregularly coloured and affected by several hairline fractures' as Stella said, although one can find clear crystals varying in colour from yellowish-green to bluish- and dark green.

The rough material examined occurs as large beryl crystals enclosed in a quartz mica-schist matrix consisting of plagioclase (oligoclase $Ab_{84.7}An_{15.3}$), mica (phlogopite), chlorite, (analyses reported in Table 1), quartz and calcite.

Carefully selected emerald fragments exhibiting few or no incusions have been analysed using the traditional first level gemmological analysis (Table 2), followed by second level analysis (chemical

Table 1: Analysis of associated minerals (electron microprobe)

	Plagioclase	Phlogopite	Chlorite
SiO_2	64.79	41.66	30.77
Al_2O_3	22.15	15.61	18.37
FeO	–	11.14	14.38
MnO	–	–	0.20
MgO	–	18.39	23.76
Cr_2O_3	–	0.24	0.32
TiO_2	–	1.14	–
CaO	3.25	–	0.23
Na_2O	9.93	0.50	–
K_2O	–	9.71	–
Total	100.12	98.39	88.03

Table 2: Properties of Djebel Zabarah mine emerald

Lustre	: Vitreous
Density	: 2.75 g/cm^3
Colour	: Medium green
Hardness	: 7.5
Refractive index	: $N_o = 1.596 - N_e = 1.590$
Birefringence	: − 0.006
Pleochroism	: N_o = light/dark green N_e = yellow
Ultra-violet fluorescence	: none
Inclusions	: Colour zoning, veils, fractures, two-phase inclusions, hair fine primary growth tubes in parallel alignment, growth hillocks. Negative crystals. Solid inclusions of mica and beryl.

analysis, X-ray diffraction and infrared spectroscopy).

Gemmological properties

Chemical analyses

The chemical analyses of the emerald and the associated minerals of the matrix were performed by the electron microprobe analyzer JEOL JXA-50A, equipped with the LINK SYSTEM 860 energy dispersive spectrometer (EDS). Be and Li were analyzed by a PERKIN ELMER 5000 spectrometer equipped with a graphite crucible. The weight-loss determination was carried out by thermo-gravimetric analyses on a PERKIN ELMER TGS-2 (Table 3).

In Table 3 are reported the analyses of the emeralds from some known mines like St Teresiña (Brazil), Habachtal (Austria), Muzo (Colombia) and Urals (USSR) for comparison (Aurisicchio *et al.* 1988) together with the sample from the Zabarah mine.

The Djebel Zabarah beryl reveals a large substitution of the Al in the octahedral site and therefore it is classified in the octahedral series (Aurisicchio *et al.*, 1988, see Figure 9 this paper).

It is worth stressing that the prevailing substitution for Al is by Mg ions as it is for the emeralds

Table 3: Chemical analyses of emeralds

		St Teresiña 31*	Zabarah E	Habachtal 23*	Muzo 10*	Urals 26*
SiO_2		64.36	64.78	63.60	65.34	65.14
Al_2O_3		13.99	14.84	14.54	16.51	17.72
FeO		1.11	0.72	0.38	0.31	0.24
MgO		2.68	2.36	2.27	0.87	0.44
Cr_2O_3		0.32	0.11	0.35	0.37	–
V_2O_5		–	–	–	0.64	–
TiO_2		0.22	–	–	–	–
BeO		13.03	13.11	13.01	13.37	13.46
Li_2O		0.05	0.04	0.04	–	0.05
Na_2O		2.03	1.64	1.72	0.49	0.51
K_2O		–	0.07	–	–	–
Cs_2O		0.33	–	–	–	–
L.O.I.		2.00	2.01	2.60	2.40	2.30
Total		100.13	99.89	98.51	100.30	99.86
		Number of ions on the basis of 18 oxygens				
Si	T′site	6.016	6.033	6.025	6.025	6.001
Al	O site	1.541	1.628	1.623	1.794	1.924
Fe^{3+}		0.009	0.008	–	–	–
Fe^{2+}		0.077	0.048	0.030	0.024	0.018
Mg		0.373	0.328	0.320	0.119	0.060
Cr		0.024	0.008	0.026	0.027	–
V		–	–	–	0.047	–
Ti		0.015	–	–	–	–
Be	T″site	2.925	2.932	2.960	2.960	2.978
Li		0.019	0.015	0.015	–	0.018
Na	Rf	0.368	0.296	0.316	0.088	0.091
K		–	0.008	–	–	–
Cs		0.013	–	–	–	–
Total		11.367	11.304	11.315	11.084	11.090

L.O.I. = loss on ignition; dash = below detection; Fe^{3+} by charge balance; * = these numbers refer to the samples reported in the reference, Aurisicchio *et al.*, 1988. T′site = tetrahedral site; T″site = different tetrahedral site; O site = octahedral site; Rf = alkali ions; Me = divalent metals.

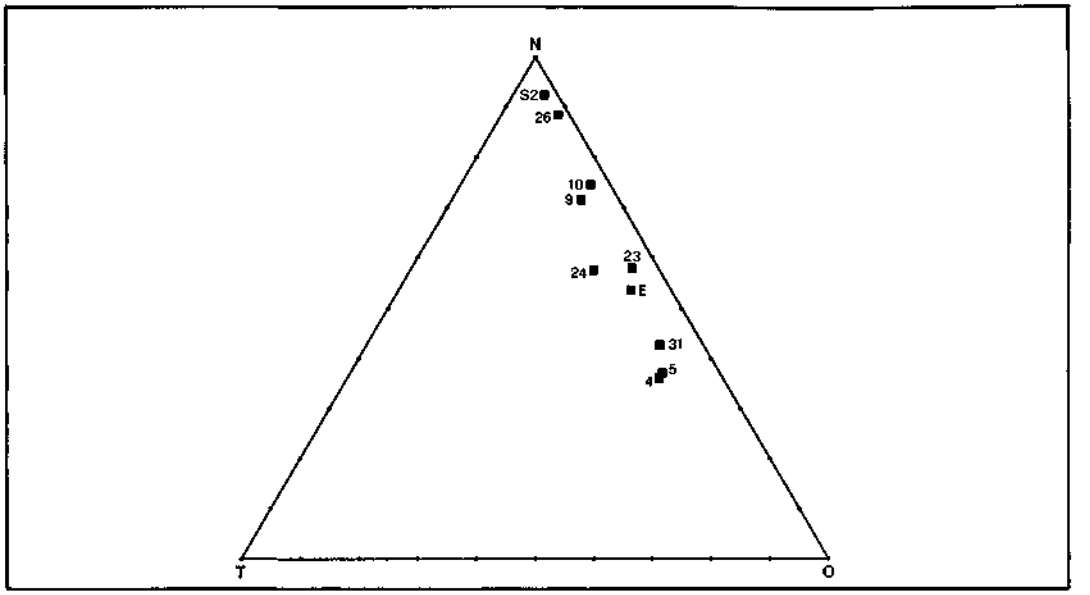

Fig. 9. Ternary diagram based on end members: 'Normal' beryl = N. $Al_2Be_3Si_6O_{18}.zH_2O$; 'Tetrahedral' beryl = T. $Rf+Al_2Be_2LiSi_6O_{18}.zH_2O$; 'Octahedral' beryl = O. $Rf+AlMe^{2+}Be_3Si_6O_{18}.zH_2O$. Drawn from figure 6 of the work Aurisicchio *et al.*, 1988.

from St Teresiña and Habachtal, the only other beryls showing Mg enrichment. From this point of view then, the beryls shown in Table 3 all have their genesis in an Mg-rich environment so it would be very useful to know the kind of conditions controlling the substitution in the pattern shown.

On the basis of the reported analyses therefore, and as hypothesized by Stella (1934) from geological evidence, the Zabarah emerald shows a close chemical analogy with the Habachtal emerald. This similarity is supported in the ternary diagram of Figure 9 in which the Ural emerald (26) lies close to the 'Normal' apex and the St Teresiña emerald (31) with 2.68% MgO substituting for Al_2O_3 lies closer to the 'Octahedral' apex. For further details the reader is referred to the work of Aurisicchio *et al.*, 1988.

X-ray diffraction

The unit cell parameters of the emeralds studied were obtained by the powder method with an automatic SEIFERT MZIV diffractometer. Si powder was used as internal standard (Table 4).

The synthetic emerald S2, obtained by flux fusion, was produced in our laboratory (Flamini *et al.*, 1983).

The *c/a* values in the range 0.991 – 0.996 put in evidence the trend corresponding to the 'octahedral' beryls; 'normal' and 'tetrahedral' beryls show *c/a* values in the range 0.997 – 0.999 and 1.000 – 1.003.

Table 4: Lattice parameters *a* (Å), *c/a* ratio, cell volume of some natural and synthetic emeralds.

	a	*c*	*c/a*	V
31 St Teresiña, Brazil	9.263	9.196	0.9927	683.7
4 Mingora, Pakistan	9.263	9.199	0.9931	683.6
E Djebel Zabarah	9.253	9.166	0.9938	679.6
5 Val Vigezzo, Italy	9.257	9.201	0.9940	682.8
23 Habachtal, Austria	9.249	9.200	0.9947	681.6
4 Morrua, Zambia	9.237	9.190	0.9950	679.0
9 Carnaíba, Brazil	9.226	9.192	0.9963	677.0
10 Muzo, Colombia	9.218	9.189	0.9969	676.2
26 Ural Mts., USSR	9.217	9.197	0.9977	676.7
S3 Gilson	9.217	9.197	0.9978	676.8
S2 Flux-fusion sint.	9.205	9.195	0.9989	674.8

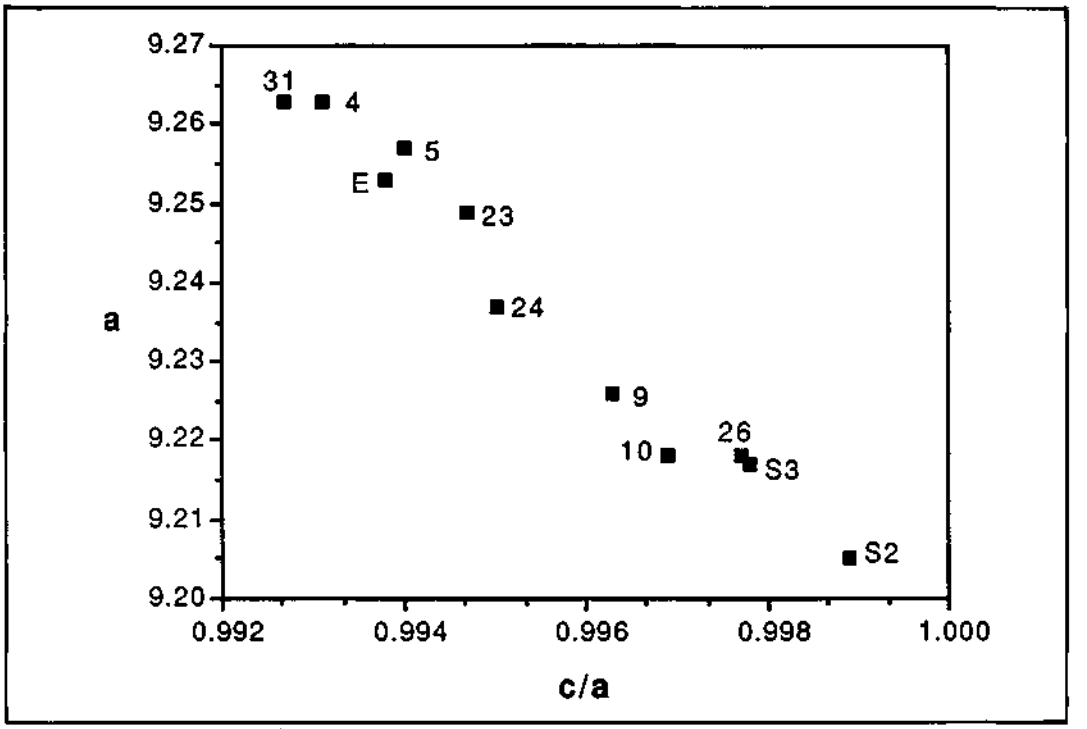

Fig. 10. The lattice parameter *a* (Å) vs. the *c/a* ratio. The trend corresonds to 'octahedral' beryls. Aurisicchio *et al.*, Fig.7, 1988.

In Figure 10 the unit cell-edge of the studied emeralds is plotted against the *c/a* ratio. The Djebel Zabarah beryl falls just on the line of the 'octahedral' beryls, confirming its behaviour.

Infrared spectroscopy

IR spectra were performed with a double beam PERKIN ELMER spectrometer with diffuse reflectance attachment, in the range 4000 – 250 cm^{-1}.

The IR spectrum is a powerful tool for studying cut and rough gem-materials. It can give us basic information about the structure, chemical composition, isomorphic substitutions, water and CO_2 content and space organization of the molecules in the channels. The Djebel Zabarah emerald shows the spectrum of Figure 11 which also shows the IR patterns of the St Teresiña and Muzo emeralds which show a different degree of octahedral behaviour. From a detailed examination of the spectra and a comparison with our data bank of emeralds and beryls from various world wide localities, it appears that the spectrum of the Egyptian emerald is made up of three main parts: the first in the range around 4000 – 2500 cm^{-1} where the characteristic water absorption is located; a second zone in the middle with CO_2 stretching and water bending vibrations; the third part down to 1300 cm^{-1} shows the structural bands of the beryls due to the vibrational frequencies of each bond.

Aurisicchio *et al.* (1988) describe the good correlation between structural data (the parameter of the cell) and band shifting (520 cm^{-1} vibration) with increasing Al substitution. Here, in Figure 12, we report the trend of the a parameter versus the position of the band located at about 520 cm^{-1} for the mentioned emeralds. This peak is due to the vibrations of the octahedral bonds and shifts its position notably as Mg, Fe, and other ions enter in to this site. The Zabarah emerald lies on the trend given for the emeralds or generally for 'octahedral' beryls.

Conclusions

With the aid of the non-destructive analyses used in this work it has been possible to characterize entirely the Zabarah emerald confirming its structural, chemical and genetic affinity with the Habachtal emerald whose use as gemstone in ancient times was not known (Sinkankas, 1981).

It should be desirable, therefore, to carry out comparisons with ancient gemstones assumed to be of Egyptian origin to verify if the used methodologies could give some help to the historians and archaeologists.

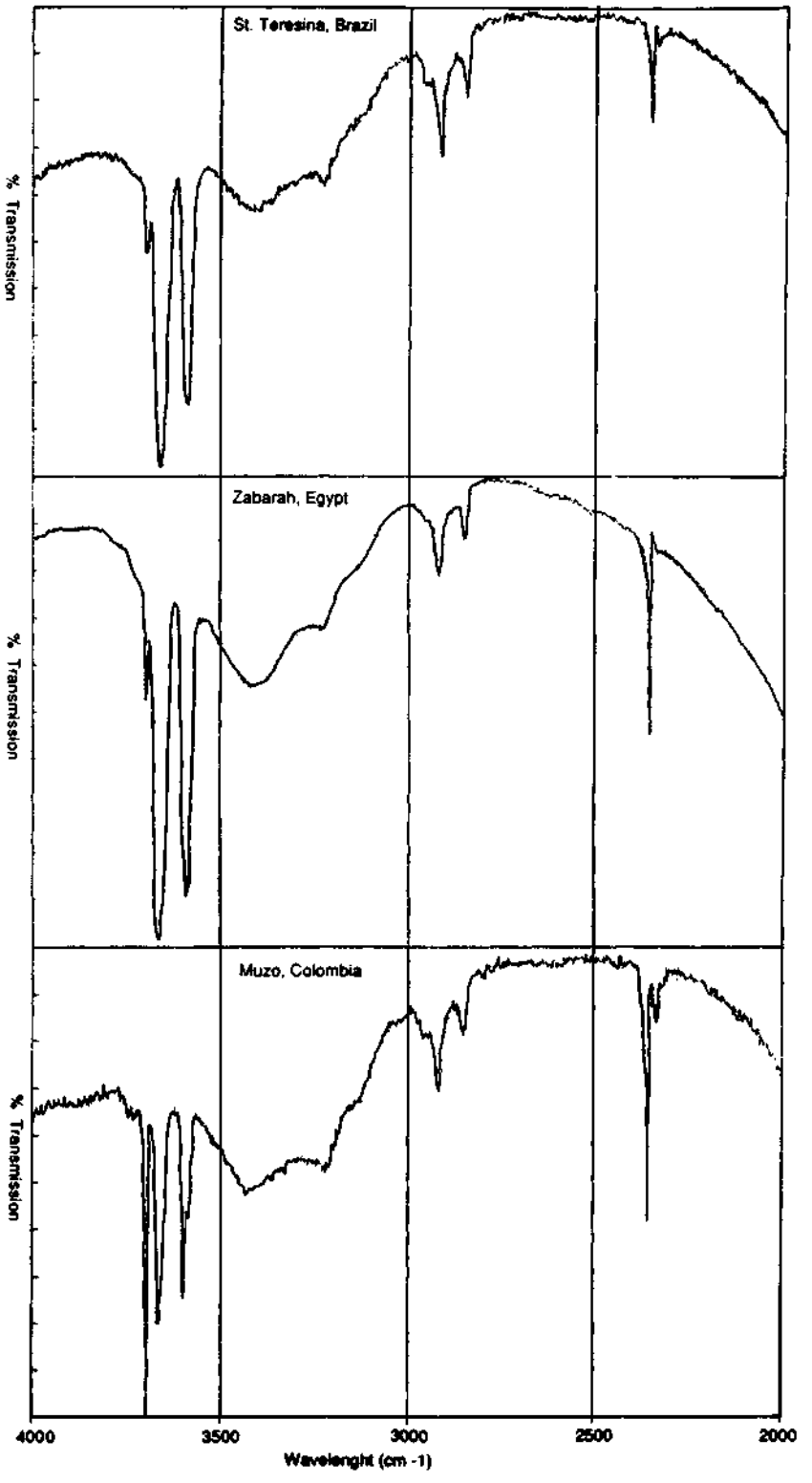

Fig. 11a Infrared spectra of emeralds from St Teresiña, Muzo and Zabarah at the temperature of liquid nitrogen.

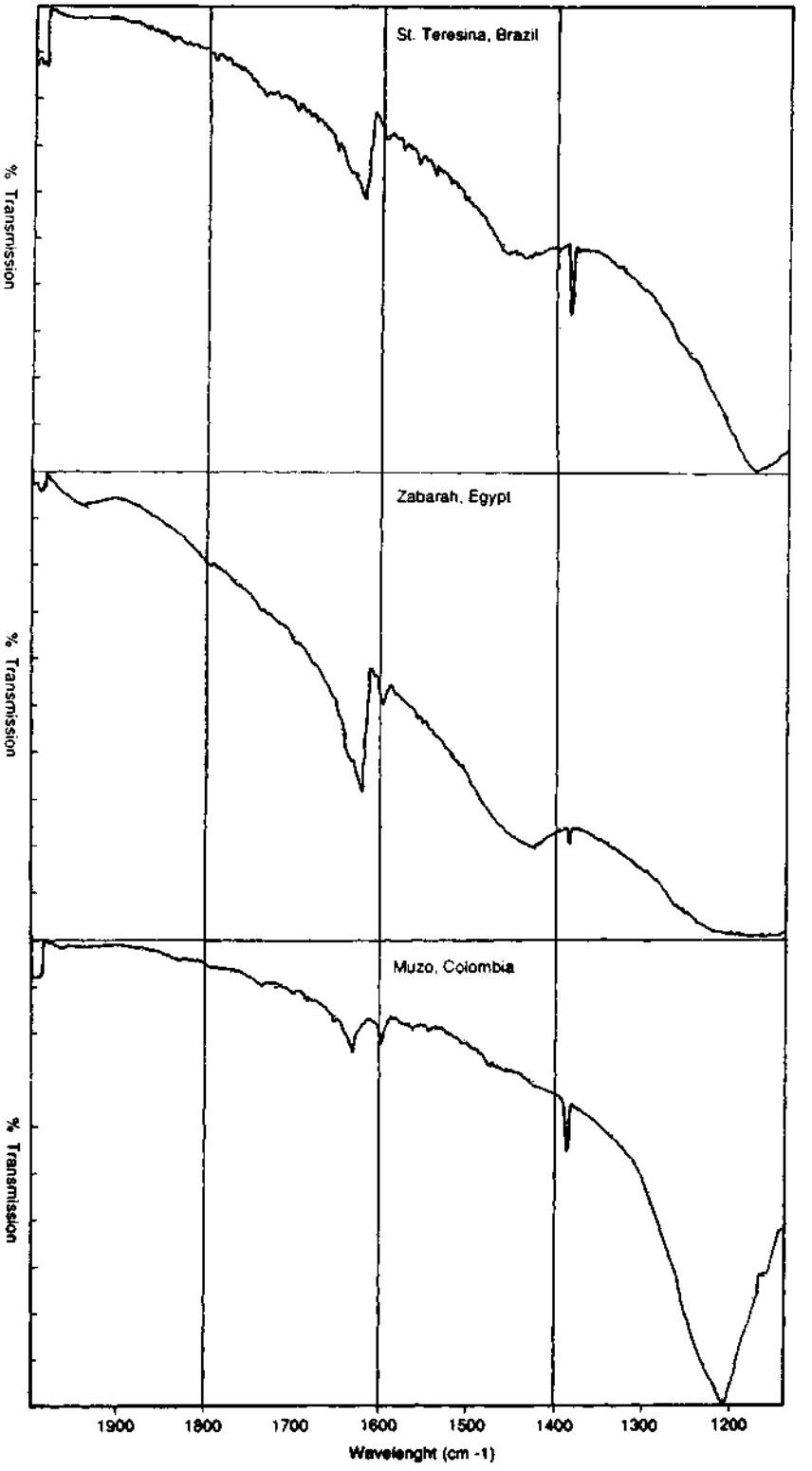

Fig. 11b Infrared spectra of emeralds from St Teresina, Muzo and Zabarah at the temperature of liquid nitrogen.

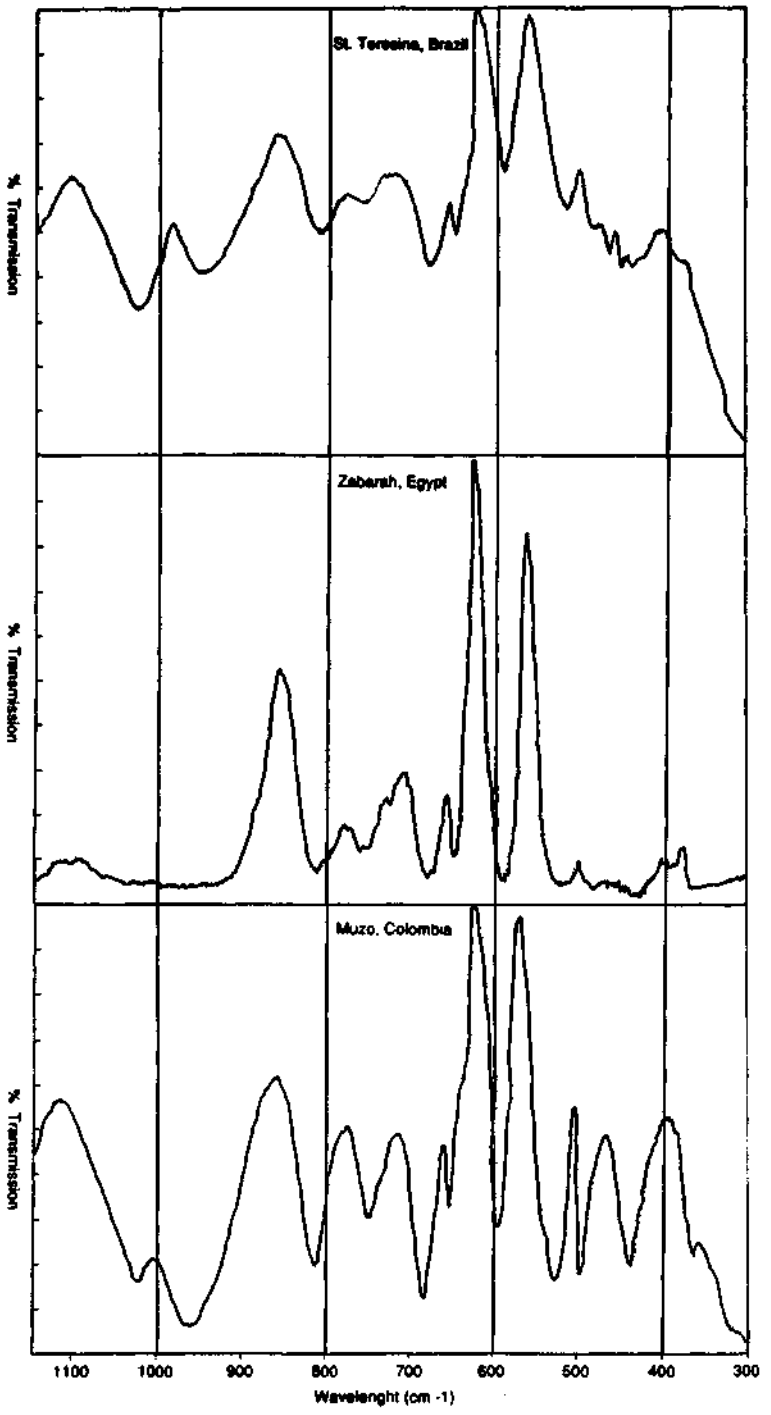

Fig. 11c Infrared spectra of emeralds from St Teresina, Muzo and Zabarah at the temperature of liquid nitrogen.

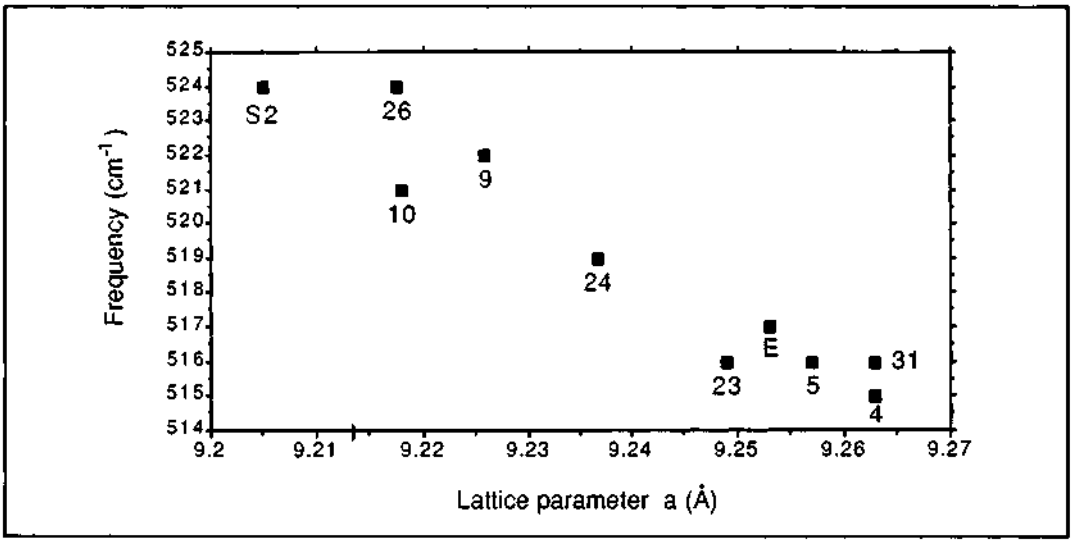

Fig. 12. The lattice parameter a (Å) vs. the 525 cm^{-1} mode shift for Zabarah and other known emeralds. The trend corresponds to 'octahedral' beryls.

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[*Manuscript received 7 July 1989.*]

Gemmological Abstracts

BANK, H., HENN, U., 1990. Untersuchung eines im Flussmittelverfahren hergestellten synthetischen roten Spinells aus der UdSSR. (Examination of a flux-grown red spinel from the USSR.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 45-8, 6 figs.

The red synthetic spinel from the USSR was a 1..5cm long crystal weighing 13.14 ct. It is an octahedron with level faces allowing reading the RI which was 1.716. SG 3/62/ Absorption spectra analysis showed the stone to be coloured by Cr^3. The microscope showed tension cracks causing undulous extinction and some black particles, probably residues of the flux. E.S.

BANK, H., HENN, U., BANK, F.H., PLATEN H.v., HOFMEISTER, W., 1990. Leuchtendblaue Cu-führende Turmaline aus Paraiba, Brasilien. (Brilliant blue Cu-containing tourmalines from Paraiba, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 3-11, 5 figs, 2 tables, bibl.

The brilliant blue tourmalines come from a new occurrence near Salgadinho in the State of Paraiba, Brazil. RI 1.615-1.632 to 1.620-1.640. DR 0.0117-0.020. SG 3.04-3.07. A microprobe showed the stones to be elbaites, relatively rich in Mn, containing CuO and Bi_2O_3. The bright blue colour is due to absorption bands of Cu and Mn. At temperatures of about 600°C the colour changes to greenish-blue. E.S.

BANK, H., HENN, U., 1990. Ein Beitrag zur Unterscheidung natürlich blauer und durch künstliche Bestrahlung blaugefärbter Topase anhand von Thermolumineszenzuntersuchungen. (A contribution to the differentiation between natural blue topaz and those coloured blue through artificial irradiation with the help of examination by thermoluminescence.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 65-72, 5 figs, 1 table, bibl.

The authors describe method of differentiating between natural and artificially coloured (by gamma-, electron-and neutron-irradiation) blue topaz by using thermoluminescence. The apparatus is described in detail. Natural blue topaz shows intensive thermoluminescence between 250-350°C, while the irradiated stones thermoluminesce between 400-550°C, those that have been treated with gamma rays requiring the higher range of temperatures, and those treated with electrons the lower ones. E.S.

BRIDGES, C.R., GRAZIANI, G., GÜBELIN, E., 1990. A Kenyan gemstone of the feldspar family; further observations. *Australian Gemmologist*, **17**, 5, 177-83, 11 figs in colour.

Describes in detail delicate blue and green albite cabochons from Kioo Hill, Kenya, which are identified as peristeritic. RI α1.531 and γ1.539, with slight variation; weakly pleochroic; spectrum confused; whitish weak fluorescence under LUV. R.K.M.

BROWN, G., KELLY, S.M.B., 1990. Knischka-created rubies. *Australian Gemmologist*, **17**, 5, 199-204, 14 figs in colour.

Study Club report on recently produced ebauchated crystal, a well-formed crystal and cut stone, which gives the history of Professor Knischka's clever synthetic and its gemmological properties in some detail. A useful paper. 'Ebauche' is French for 'rough-hewn', which describes the serrated, file-like appearance of this multiple crystal rather well. R.K.M.

FAULKNER, M.J., SHIGLEY, J.E., 1989. Zircon from the Harts Range, Northern Territory, Australia. *Gems and Gemology*, **25**, 4, 207-15, 8 figs in colour.

Zircon from this remote central region is largely pale, brownish-purple, pink, yellow and some which can be made almost colourless by heating but no blue or golden shades, and is remarkable for its low content of radio-active uranium or thorium. Location, access, geology and gemmological properties are described. RI well above 1.81, SG between 4.62 and 4.72, H 7 to 7.5. Absorption showed 653nm most prominently but other lines at 535, 590, 657 and 689 were weak; confirmed by spectrometer. Spectra varied slightly with crystallographic direction. Mr Faulkner provides notes on cutting and polishing this material. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., HARGETT, D., 1989. Gem Trade Lab notes. *Gems and Gemology*, **25**, 4, 236-42, 17 figs in colour.

A large mass of orange, white, yellow and brown rough, sold as amber in Tahiti, proved to be plastic, probably polyvinyl chloride. An almandine-pyrope inclusion in diamond is described and illustrated. A bi-colour yellow and white marquise diamond fluoresced blue in its white centre and chalky yellow at its yellowish tips, followed by a weak chalky yellow phosphorescence over entire stone. Another diamond contained a colour-change garnet, red-purple in incandescent, and saturated green in fluorescent light. A large pear-shaped green diamond was radio-active, probably from radium salts treatment early this century; report advises against its use in jewellery. An irradiated octahedron, one of several treated crystals seen, was a superficial blue concentrated mainly in the crystal edges; lines at 415.5, 498/504 and a weak 594nm were seen, rather as expected. [One wonders why crystals are treated in this way? Cutting would surely eliminate most of the surface colour?]

Sample beads of jadeite purported to be 'before' and 'after' versions of a new treatment, but both types were found to have been impregnated with plastic, probably polyacrylate.

A seemingly solid natural pearl in a bezel-set ring was found to consist of two parts when unset, probably worked from two blister pearls, the join was obscured in an X-radiograph by the bezel of the ring. A black cultured pearl from a three strand necklace, represented as natural coloured, was sectioned and showed the presence of black dye, probably silver, in the nacreous outer layer; the two pearls examined were inert under LUV, where a naturally coloured black cultured pearl [or a natural black pearl for that matter] would have fluoresced brownish-red.

An attractive untreated Burma ruby in a ring came back some weeks later for a damage report. The stone had been ruined by sudden temperature change, the result of re-tipping a prong [claw] without unsetting the ruby! A 26.11 ct faceted purple scapolite is said to be unusual in such a size; illustration suggests that it was slightly cloudy; much such Burmese material is cut as cat's-eyes. A fine 15.18 ct violet-blue tourmaline from a new mine at San Jose Baltalha, Paraiba, Brazil, resembled tanzanite, a new colour for tourmaline and unusually large for this mine; the absorption was strong and unusual. A pair of earrings offered as zirconia, in a real estate presentation, proved to be paste (RI 1.57) and foiled. R.K.M.

HARDER, H., 1990. Klare und trübe Korunde als Rohsteine für wärmebehandelte Saphire aus Sri Lanka. (Clear and opaque corundums as raw material for heat treated sapphires in Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 73-87, 6 photographs in colour, 2 tables, bibl.

Common corundum which lend themselves to heat treatment into sapphires occur in Sri Lanka. This raw material can be clear or opaque. Locally the clear varieties are known as Ural and Ottu, the opaque as Geuda and Dot. Ural refers to clear colourless corundum with a small intensely blue concentration. Ottu are those clear corundums with bluish-green parts, blue lines in the crystal or on the surface. Geuda are the opaque stones or those somewhat translucent, milky with a lot of silk. Dot are opaque with a white shimmer, milky with a lot of silk. The potential value of these rough stones can be estimated according to hints on the content of iron and titanium. The content of iron can be guessed from some blue lines or dots or from some greenish to brownish weathering coloration. Reducing conditions in flames lead to the best quality colours in sapphires depending on quality of rough stones. X-ray fluorescence tests of the highly evaluated Ottu qualities show similar content of iron and titanium as cornflower blue, untreated sapphire of good quality. The relationship between iron and titanium in corundum is not only the key for untreated sapphires, but also for various qualities of corundum which can be heat treated into blue sapphires. E.S.

HENN, U., BANK, H., 1990. Blaue Saphire aus Malawi. (Blue sapphire from Malawi.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 89-92, 7 figs (1 in colour), 1 table, bibl.

Previously cuttable rubies and padparadshas from Malawi have been described. Now some gem quality sapphires have come onto the market. RI 1.762-1.770, DR 0.008,. SG 3.97-3.99. The blue colour is caused by absorption bands of Fe^2/Ti^4 charge transfer and Fe^3, FeO, TiO and Cr_2O_3 have been found by analyses. Lamellar twinning, boehmite, rutile and zircon have been found under the microscope. E.S.

HUNSTIGER, C., 1990. Darstellung und Vergleich primärer Rubinvorkommen in metamorphen Muttergesteinen. Petrographie und Phasenpetrologie. Teil II. (Representation and comparison of primary ruby occurrences in metamorphic rocks. Petrography and petrology. Part 2.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 49-63, 8 figs (3 in colour) 4 tables, bibl.

The second part of the thesis deals with rubies in gneises. The characteristic of these rocks seems to

be a complete absence of quartz whenever rubies are present. The excess of SiO_2 first combines to Al-Silicates before corundum is formed. The occurrences which are described in detail are the rubies of Azov in the USSR in the east of the Crimean peninsular, those in Froland, Norway, near Arendal, south Norway, rubies found in Alipur, Mysore, India, and those in the Hida metamorphic belt in Japan. There is a comparison of mineral analyses of ruby carrying gneises and a short note on the petrology of gneises. E.S.

KAMMERLING, R.C., KOIVULA, J.I., KANE, R.E., 1990. Examination of an interesting cultured blister pearl. *Australian Gemmologist*, 17, 5, 174-5, 5 figs in colour.

Report on a blister pearl in a fresh-water shell depicting the goddess Kwan Yin. Most such inserted images are metal but this one was transparent to X-rays and was probably of moulded plastic with similar X-ray characeristics to those of the shell. R.K.M.

KANE, R.E., KAMMERLING, R.C., MOLDES, R., KOIVULA, J.I., MCCLURE, S.F., SMITH, C.P., 1989. Emerald and gold treasure of the Spanish galleon Nuestra Senora de Atocha. *Gems and Gemology*, 25, 4, 196-206, 12 figs in colour.

Bullion, coins, gold and emerald treasure has been found near the wrecks of galleons sunk between Cuba and Florida almost 350 years ago. Some of the gold and emerald jewellery from the Atocha was examined by the GIA Gem Trade Laboratory. Most emeralds had lightly frosted surfaces, presumably etched by long exposure to sea-water. Gold work had been cast in almost pure gold; chains made from drawn wire; missing beads in a rosary chain thought to have been wood which disintegrated in water. Some items had probably been decorated with enamel or with niello. Emeralds probably Colombian. Craftsmanship described as superb, mainly produced by a lost wax process; in the soft gold, setting and engraving were exceptionally skilled. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Gem news. *Gems and Gemology*, 25, 4, 244-51, 13 figs in colour.

Diamonds

An earlier statement that glass filler could not be completely removed from diamond was shown to be wrong. Australian and Canadian companies are jointly exploring for diamonds at Pilbara, W Australia, about 650 miles from the Argyle project. Diamond output in Botswana is to be increased. Ghana may privatize mines. Diamond cutting in Mauritius is to expand. Diamonds are being mined from the sea on two concessions on west coast of South Africa.

Coloured stones

Myanmar (Burma) gold mines have contracted for Yugo Slav technology. Adularescent violet-blue chalcedony found in Mojave desert. A rare star chrysoberyl from Sri Lanka is illustrated. Psilomelane and basalt were among black gem materials seen. Quench crackled green-dyed quartz sold as 'green amethyst' without mention of dyeing. A 40kg double terminated sapphire crystal found at Rakwana, Sri Lanka, had gemmy bluuuuuue arreas and others which might heat to blue. Sapphires have been found in Burundi. Gold, sapphire and ruby mines are re-opening in Vietnam, following the withdrawal of troops from Cambodia. Laos and Cambodia are calling for similar investment arrangements with the Thais. Drought followed by severe flooding has hit gem production in Sri Lanka, terrorism adds to the problems. Small poor quality emeralds have been found in SE Sri Lanka, colour of one crystal seen was very dark. A new find of attractive green zircons, and an exceptionally fine hessonite are also reported from the island. Paraiba, Brazil, green to blue tourmalines show strong absorption centres at 700nm possibly due to copper. A high cabochon green tourmaline had a thin blue base which changed the colour of the stone to blue when lit vertically from below.

Synthetics and simulants

George Bosshart of Switzerland alerts trade to 'water-worn crystals' of ruby and sapphire bought in Sri Lanka, which proved to be flame fusion synthetics shaped to long barrel habit with lateral stepped striations and other convincing features cut onto the 'prism' faces; striations were not parallel, and optic axes were 30° out of line; curved colour banding and fluorescence confirmed synthesis. A 'hydrothermal' red synthetic spinel from Russia was found to be flux-grown; irregular flux inclusions were seen but a stone cut to exclude these would be virtually identical to a natural stone. A new man-made 'garnet' from Switzerland, called oolongite, is made in colourless, blue, bluish-green and lilac shades: RI 1.93 to 2.00, SG 6.7 to 7.0, H 7.5 to 8. Chemical composition is not quoted. R.K.M.

LINTON, T., BROWN, G., 1990. A dark-field illuminator for gemmological microscopes. *Australian Gemmologist*, 17, 5, 171, 3 figs.

A Japanese accessory which is given full marks for ease of installation and use, but some parts reflect confusingly. R.K.M.

MCAUGHTRIE, G., 1990. A preliminary assessment of the gem identification system (GIS) software. *Australian Gemmologist*, 17, 5, 172-3.

System was found to have low success rate due to lack of flexibility in constants and other testing factors. So far these computorised systems do not seem to compete very well with normal gemmological methods. R.K.M.

MALONE, F.J., HANCOCK, D.A., JEFFRIES, B., 1988. The Western Australian pearling industry. *Australian Gemmologist*, **17**, 5, 184-92, 1 map.

Abstracts from the report of the Pearling Industry Review Committee, Fisheries Management paper No. 17. Fisheries Department of Western Australia. Reviews and reports on pearl-shell industry and more particularly on recent growth of the cultured pearl industry around Broome and the neighbouring coast of W. Australia. Future would seem to be tied in with production in Indonesia and the Philippines. The industry seems to be largely Japanese dominated. R.K.M.

MARTIN, F., MERIGOUX, H., ZECCHINI, P., 1989. Reflectance infrared spectroscopy in gemology. *Gems and Gemology*, **25**, 4, 226-31, 6 figs in colour.

A non-destructive laboratory test which identifies gem minerals with comforting certainty; even distinguishing between some natural stones and their synthetic counterparts. Only Type II diamond will not respond because it is transparent to the infrared wavelengths used. Use of reflectance rather than transmission makes the test far simpler. Some 64 infrared spectra are illustrated in bar-graph form, an unfamiliar representation of a spectrum region which is unknown to most gemmologists. The reflecting unit is illustrated but a more detailed explanation would help the ordinary gemmologist to understand the test better. [The full apparatus is costly.] R.K.M.

MITCHELL, R.K., 1990. A letter. *Australian Gemmologist*, **17**, 5, 208.

An attempt to put right confusion between 'profilated' (Webster) and 'proliferated' (Brown). when describing extended bubbles in some synthetic spinels. The attempt is foiled by a characteristic printer's error which turns my quote of Grahame Brown's 'proliferated' into 'profilerated', an even greater abomination. The correct expression for such bubbles is surely 'profiled', although the new word 'profilated was coined by Anderson long before Webster copied it in his book *Gems*.

(Author's abstract) R.K.M.

NASSAU, K., LEWAND, E.A., 1989. Mildly radioactive rhinestones and synthetic spinel and glass triplets. *Gems and Gemology*, **25**, 4, 232-5, 2 figs in colour.

Certain greenish-yellow peridot-like pastes and synthetic spinel and glass triplets were found to be slightly radio-active due to the use of uranium glass, but are thought to present no health hazard. Authors express wonder that this glass is still used since the colour can be obtained by other means. R.K.M.

PHILLIPS, G., BROWN, G., 1990. Mtorolite. *Australian Gemmologist*, **17**, 5, 205-7, 3 figs in colour.

This is the natural chrome-coloured chalcedony which so closely resembles the chrome-*stained* product which imitates natural chrysoprase so badly that one wonders whether there can be a market for the natural product. The sharper one band spectrum at 680nm differs from the vague three band effect seen in some of the stained material. R.K.M.

ROBERT, D., 1990. Emeraldolite. *Australian Gemmologist*, **17**, 5, 196.

A short report on a new coated beryl made by depositing a thin layor of flux-grown emerald crystals onto a colourless natural beryl 'seed'. SG is that of natural beryl and RI low, as for flux emerald. Used as scintillating green rough or as cut, carved or polished specimens in a variety of forms. R.K.M.

SCHWARZ, D., 1990. New aspects of the emerald workings in Colombia. *Australian Gemmologist*, **17**, 5, 168-70, 1 map.

Deposits were exploited by Muzo and Chibcha Indians long before arrival of the Spanish Conquistadores, and highly regarded by Incas, Mayas and Aztec cultures. Mining was always open-cast, more recently with modern machines moving enormous masses of overburden are creating serious environmental problems. Now Coxeminas and Tecminas are tunnelling to emerald bearing calcite which is then extracted with greater care by hand methods. Other mines are expected to follow. Guerilla activity interferes with production and several mines are inactive. New mine at Yacopi, south of Muzo, is producing quantities of pale, clear emerald. Drift (tunnel) mines are displacing thousands of 'guaqueros' who formerly fossicked among tailings and rubble for missed emeralds. Vast social problems are expected, especially with the association with drug traffic. Most emerald is smuggled out of the country despite government control of mines. R.K.M.

SEGNIT, E.R., 1990. The XXII International Gemmological Conference. *Australian Gemmologist*, **17**, 5, 193-5.

A report on the conference held at Lake Como and visiting various other Italian centres, as seen by Australian representatives. R.K.M.

Book reviews

BENNETT, D., MASCETTI, D., 1989. *Understanding jewellery*. Antique Collectors' Club. pp.386. Illus. in black-and-white and in colour. £29.95.

Unlike other jewellery books this one starts with a substantial section of some 40 pages on gem identification. This includes descriptions of all the gemstones likely to be encountered in commercial jewellery, followed by very helpful sub-sections on the various materials used to simulate each gemstone. There are 36 colour plates in the section, largely of inclusions in gems from the excellent Gübelin/Koivula *Photoatlas of Inclusions in Gemstones*, but also including good pictures of gems in jewellery and typical cuts for diamonds. This preliminary section should serve as a precautionary warning to those in the antique trade who imagine that the identification of gemstones is straightforward and without pitfalls.

The principal chapters of the book begin with the jewellery of the period 'From the late 18th century to the 1820s' with following chapters describing the jewellery of the succeeding 20 year periods up to '1920-1940'. The last chapter is entitled 'The 1920s and the Post-war years'. The outstanding feature of these chapters is the provision of over f1565 excellent colour photographs of a very considerable range of jewellery (including tiaras, parures, earrings, necklaces, brooches, pendants, bracelets and rings) selected from the vast library of Sotheby's auction operations. The designers have been very successful in marrying text with illustration – usually on the same page spread.

The reasons for the development of the various styles of jewellery are examined in some detail and include the influence of wars, revolutions, patronage, politics, economics and the development of new technologies – all of which influence fashion and, of course, jewellery. The book concludes with a reasonable bibliography and a very useful guide to approximate values of all the items illustrated at the start of 1990. This is a fascinating book, beautifully illustrated and marketed at a very economical price when one considers the cost of colour printing. Thumbing through the pages is, at once, informative, aesthetically pleasing and, for some of us, nostalgic. E.A.J.

KELLER, PETER C., 1990. *Gemstones and their origins*. Van Nostrand Reinhold, New York, USA. pp. 144. Illus. in black-and-white and in colour. US$49.95.

This is a volume that many geologists/gemmologists might wish they had written; it has been needed for years. It is a superbly illustrated book and at first sight it might appear to be yet another gemmological 'coffee table' production; it is far more than that. The principal photographers are the well-known Van Pelts of Los Angeles and two eminent gemmologists, Dr E. Gübelin and Peter Keller himself; both are doubly qualified to combine artistic excellence with geological competence. The photographs and the text are well married by the easily understandable narrative style. The gemstone occurrences are described under four principal modes of origin with typical examples of each category being dealt with in some detail. The groups are:

(1) gemstones deposited by water on the Earth's surface – the gem gravels of Sri Lanka and the opals of Australia;

(2) gemstones of igneous or hydrothermal origin – the emeralds of Colombia, the gem pegmatites of Minas Gerais, Brazil, and the ruby deposits of Chantaburi/Trat, Thailand;

(3) gems formed by very high temperatures and pressures – the ruby deposits of Mogok, Burma, and the jadeites of Tawmaw, Burma; (4) gemstones formed at great depths – the Zabgargad peridot deposits in the Red Sea and the Argyle diamonds of Australia.

The text is not just pure geology (which is, however, treated in very understandable terms with excellent diagrams) but also includes history, mining techniques, concession rights and, most spectacularly, a series of Van Pelt photographs illustrating famous gems both set in jewellery and as stunning crystals with their associated matrix minerals. Field and mining processing photographs are contributed by Edward Gübelin (many of localities no longer accessible), by Keither Proctor who knows the Brazilian deposits so well and, of course, the author himself who has visited so many 'difficult of access' gem occurrences around the world. This is not a dry academic textbook; its easy style will help the reader to understand the processes of natural gem formation and should assist in distinguishing natural stones from their synthetic counterparts. The clear accounts of the selected deposits are followed

by excellent bibliographies for the interested reader, whether amateur or professional, to follow up the whetted appetite. This book is beautifully produced and this reflects the painstaking care with which it has been researched, written and illustrated. For a quality product the price is reasonable and it is recommended reading for all gemmological aficionados, since it is probably the first of its kind in the English language. E.A.J.

MERCER, I.F., 1990. *Crystals*. British Museum (Natural History), London. pp. 59. Illus. in colour. £4.95.

Forming one of a series of popular earth science guides (the other titles are *Gemstones*, *Agates* and *Britain's offshore oil and gas*), this is a beautifully-produced and very well written introduction to the world of crystals. Frequent references are made to the occurrence of crystals in everyday life (in the freezer and fur in kettles) as well as to the basic rules of crystal symmetry and a lucid introduction to the way in which crystals grow. M.O'D.

O'DONOGHUE, M., 1990. *The pocket guide to rocks and minerals*. Dragon's World. pp.224. Illus. in colour. £6.95.

This is a small (19 x 13cm) spirally-bound book, printed in Singapore, with very good (if small) colour illustrations of rocks and minerals. It is presumably aimed at the amateur collector, but could interest a wider readership. The book starts with a brief explanation of the nature of rocks with some good photographs which actually look like rocks in the hand in contrast with many other texts. The general introduction on minerals, including classification, crystal morphology and properties, growth of crystals, crystals and light, collecting, conservation and cleaning, takes up some 50 pages. These sections are generally well presented and understandable to the beginner, but the reviewer takes issue with the author when he gives details (albeit with warnings!) on the use of hydrofluoric acid and sodium cyanide for cleaning specimens. These are highly dangerous chemicals in inexperienced hands.

The mineral descriptions, comprising some 150 pages, are generally good and the illustrations excellent – some could well be photographs of micromounts. Some of the species included in the descriptions are very rare and it seems doubtful if most amateurs will ever encounter them. There are, of course, a number of minor errors, including the allocation of dolomite to the pyroxene group on page 107, but these should not be allowed to detract from the overall pleasant presentation.

This book has a cheaply produced, but probably robust, binding and the photographs and general appearance are good. It will be a very good introduction for the beginner and a first reference book for the more advanced amateur. It is cheap enough to be purchased by interested but impecunious young people. E.A.J.

ROBERTS, W.L., CAMPBELL, T.J., RAPP, G.R., 1990. *Encyclopedia of minerals*. 2nd edition. Van Nostrand Reinhold, New York. pp. xxiii, 979. Illus. in black-and-white and in colour. £75.00.

The previous edition of the *Encyclopedia* in the mid-1970s was a brave and successful attempt to provide mineralogists with a comprehensive mineral encyclopedia whose entries gave brief but vital details of all minerals known at the time. It also gave a most valuable 'best reference in English' and contained a section of beautiful colour pictures of micromounts (diamond in particular). The new edition has been fortunate to have Wnedell Wilson as its Photo Editor and 400 new species have been added with 1000 entirely new entries. The total number of species described is 3200 and though the book is expensive serious mineralogists will need to have it on their desks along with Fleischer's *Glossary of mineral species*, Deer, Howie and Zussman's *Rock-forming minerals* and the Natural History Museum's *Chemical index of minerals* – the present book, by its topicallity, helps to remedy the long wait for a new edition of the latter. To replace the pictures of micromounts this edition has a centre section of megnificent colour photographs, many the work of Wendell Wilson. Mineral pictures seem to get better year by year and it is hard to imagine there being much room for improvement!

One of the values of this book to the mineralogist, apart from its comprehensiveness, is the noting of species belonging to groups, whose significance is increasingly appreciated with the developing links between mineralogy and chemistry. M.O'D.

WILSON, W.E. (ED.), 1990. *Goldschmidt's world mineral locality index*. Mineralogical Record, Tucson. pp. 44. US$12.00.

Victor Goldschmidt's *Atlas der Krystallformen* (1913-1923) will probably be familiar only to academic gemmologists. The nine volumes of text are accompanied by nine volumes of crystal drawings which Goldschmidt took from every possible printed source. Until now it has not been possible to access the 23,606 drawings by locality but this simply-produced book enables this to be done. This is a very high achievement indeed and most welcome to anyone working on old localities. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARIES

Robert Arend

This account of Robert Arend, a Dutchman who emigrated to Toronto, Canada in 1956, was delayed first by an advising letter from Mr Paul Leonard of Coburg, Ontario, which was sent to an office I had left more than ten years before and had to be returned to be readdressed care of the Association, and then by a lack of biographical information which has taken several months to fill.

Bob Arend was a correspondence course student of mine in 1959, taking his Diploma with Distinction in the following year. I obtained an impression that he was an intelligent and ambitious young man with great determination to succeed, one who believed implicitly in his own abilities. This was confirmed when he came to see me some years later in my Holborn office.

Back in Toronto Arend continued his gemmological interests, eventually taking over D.S.M. Field's classes at George Brown College, and going on to serve as President of the Canadian Gemmological Association. Details are not available, but he evidently ran a successful business of his own in down-town Toronto.

But despite preoccupation with the gem trade, there is no doubt at all that Arend's real enthusiasm was for flying, and he was known to side-track from gemmology to talk about this greater interest. A fully qualified commercial pilot, he excelled in aerobatics and in 1975 became Canadian Advanced Champion in that type of flying. Among other exploits he had raced from London, England, to Victoria, British Colombia, in a light plane, and had toured America and Canada in aerobatic displays. An island hopping trip to Venezuela and back gave him the idea for what was to prove to be his last flight.

His childhood hero was Colonel Charles Lindberg, and Arend planned to emulate the latter's solo flight in 1927 from New York to Paris. With that object in mind he spent several years planning and adapting a 17 year old fabric covered single engined plane for the attempt. Navigation aids, radios and extra fuel tanks were fitted and the engine largely rebuilt. Meanwhile he was talking of extending the trip to a circumnavigation of the world in 36 days. For some reason he elected to start the venture from Victoria B.C., with the idea that the 30 hour flight to St John's, Newfoundland, would serve as a test run for the Atlantic crossing. Unfortunately the heavily laiden plane failed to make it across the Rockies and crashed in flames on 24 June 1989 near the town of Hope, less than one hundred miles from its starting point.

Robert Arend was 56 and leaves a widow and two sons. His epic flight was to have been made in aid of the Canadian Cancer Society and other charities.

The writer very deeply regrets that this story has to be an obituary and not an account of great triumph. A brave and remarkable man, an excellent gemmologist, who perhaps had too much faith in his ability to achieve. Not many of us go out quite so spectacularly. R. Keith Mitchell

Speranza Cavenago Bignami Moneta

It is with regret that we record the death of the celebrated Italian gemmologist Senora Cavenago Bignami. Born in Milan in 1902, she moved with her family in 1927 to Brazil where she spent four years involved in singing and piano playing and began her gemmological studies at the University of Sao Paolo. In 1931, on her return to Italy, she opened the first Italian gemmological laboratory at a Milan pawnbrokers and continued to manage it until 1948. During this period she initiated studies into the testing of pearls using X-rays and investigated many other problems. In 1948 the publishers Hoepli commissioned her to write a 'gemmology manual' which was published in 1959 as *Gemmologia*. It became a classic and encyclopedic work developing into three massive volumes and is now in its fourth edition.

In 1952 she began lecturing and demonstrating in Valenza and these activities developed into the establishment of the Public Precious Stone and Pearl Control Department. The Milan Chamber of Commerce opened its testing laboratory in 1966

and Cavenago Bignami directed both laboratories until 1973. She has a strong combative spirit and was always enthusiastic and endowed with exceptional communication skills and power of oratory.

* * *

Mr Roy Lucas, FGA (D.1930), Hadley Wood, Barnet, died on 19 May 1990.

Mr Donald F. Rossiter, FGA (D.1948), Jersey, Channel Islands, died on 9 April 1989.

Mr E. Trillwood, OBE, FGA (D.1929 with Distinction), Rickmansworth, died on 15 April 1990.

MEMBERS' MEETINGS

London

On 2 May 1990 at the Flett Theatre, Geological Museum, Exhibition Road, London SW7, Mr Peter Read FGA gave an illustrated lecture entitled 'An update on gem instruments'. Following the lecture, Peter Read, assisted by Dr Jamie Nelson and Mr Roy Huddlestone, displayed and demonstrated a number of the instruments.

Midlands Branch

On 16 March 1990 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr Jim Porter gave an illustrated talk on his trip earlier in the year, to Thailand and the Chanthaburi mines. On 20 April 1990 at the Society of Friends, the Annual General Meeting was held at which Mr David Larcher, FBHI, FGA, was elected Chairman and Mr John R. Bugg, FGA, re-elected Secretary. The AGM was followed by a talk by Carol Gibbs who recounted her years as a trader in the Gilbert Islands, with a particular interest in tortoiseshell.

North West Branch

On 16 May 1990 at Church House, Hanover Street, Liverpool, Mr Peter Read gave a lecture on the Presidium Duotester.

EXECUTIVE MEETING

At a meeting of the Executive Committee held on 10 May 1990 at Saint Dunstan's House, Carey Lane, London EC2V 8AB, the business transacted included the election to membership of the following:

Fellowship

De Crecenzio, Alejandro, Amsterdam, The Netherlands. D.1989
Hapugaskumbura, Asanga W.W., Kandy, Sri Lanka. D.1989
Karkkulainen, Kari J., Oulu, Finland. D.1989
Onozawa, Katsumi, Tokyo, Japan. D.1979
Phillips, Jean M., The Peak, Hong Kong. D.1982
Schat, Ellen M., Schoonhoven, The Netherlands. D.1989
Shigeoka, Mayumi, Tokyo, Japan. D.1989
Turner, Susan E., Hong Kong. D.1989

Ordinary Membership

Bedwell, Victoria L., London.
Bensimon, Colette, London.
Bhonsle, Uday S., Gloucester.
Brown-Greaves, Rosemary L., Horsham.
Chin Chao, Dick, Taipei, Taiwan.
Collins, Stephanie, New Malden.
Costa, Georgia M., London.
De Goutiere, Anthony, Victoria BC, Canada.
Desai, Suryakant C., Nairobi, Kenya.
Eggleston, Avrina, London.
Gademsetty, Subba Rao, Chigwell.
Georgiou, Stavros, London.
Gordon, Mark I., London.
Harmsen, Harmanus P.D., Brenhelen, The Netherlands.
Henry, John M., Bolton.
Katz, Edwin S., Houston, Tex., USA.
Kyriakidis, Dimitrios K., Hamburg, W. Germany.
Lee, Tom L., Grand Rapids, Mich., USA.
Lees, John A., Waterford, Va, USA.
Liden, Ulf, Lycksele, Sweden.
Liontos, Theodoros, Chania, Crete.
Li-Ran, Dorit, Nairobi, Kenya.
Michel, Isabelle, Los Angeles, Calif., USA.
Mildenhall, Caroline, Brighton.
Mistry, Dharmesh, London.
Mitchell, Beverly J., London.
Montonati, Cristina, Portalbera, Italy.
O'Shea, Anthony L., Ruislip.
Park, Myoung O., Seoul, Korea.
Paskou, Thomas, Waukesha, Wis., USA.
Rothewicz, Jack, Bogota, Colombia.
Semenov, Steven, London, Ont., Canada.
Share, Stella, Harrow Weald.
Shearman, Jean D., Happy Valley, Hong Kong.
Smith, Michael H., Edinburgh.
Spencer, Riitta M., Horsham.
Stanuell III, Stewart, Houston, Tex., USA.
Stassinopoylos, Elias, London.
Sundin, Stig E., Hylkje, Norway.
Walker, Averil L., London.
Webster, Robin G.S., Macclesfield.
Wilkinson, Cleotilde S., Farnham Common.
Zaidi, Masud, London.

AUSTRIAN GEMMOLOGICAL RESEARCH INSTITUTE

On 17 April 1990 the Austrian Institute (EÖGG) moved to new premises. The address is now Schwedenplatz 2/33c, A-1010, Vienna, Austria. Telephone (222) 535 6246 or (222) 533 5823. Fax (222) 535 6245.

THE JOURNAL OF GEMMOLOGY BACK ISSUES

A member of the Association has various back issues of the *Journal* for sale, dating from 1948. Enquiries to Mary Burland at the Gemmological Association of Great Britain, 27 Greville Street, London EC1N 8SU.

Letter to the Editor

From Dr W.D. Ian Rolfe
Keeper of Geology, National Museums of Scotland

Dear Sir,

EXPORT OF NATURAL HERITAGE SPECIMENS

The recent near-loss from this country of an outstandingly important fossil, the earliest known reptile, has clarified the position regarding the export of such material. Natural science material, and in particular geological specimens, are not covered by the Export of Goods (Control) Order 1989, and therefore all such material, no matter how significant, is free for sale abroad. This is markedly at variance with the position regarding the man-made heritage, where export controls have long been in force for outstanding artefacts.

Prompted by this current issue, the Reviewing Committee on the Export of Works of Art has been asked by the Minister for the Arts to consider this problem and to make recommendations. It is anticipated that such outstanding natural heritage items would only rarely come before any such body for consideration, say perhaps once every ten years. It would help us considerably in presenting our case to the Committee to have case histories of previous losses of such specimens, or brief accounts of material saved from such loss, to inform the Committee's deliberations. Would anyone knowing of any such cases therefore please send brief details to any of the following: Dr W.D. Ian Rolfe, Keeper of Geology, National Museums of Scotland, Chambers Street, Edinburgh EH1 1JF; Dr L.R.M. Cocks, Keeper of Palaeontology, Natural History Museum, Cromwell Road, London SW7 5BD; Dr Paul Henderson, Keeper of Mineralogy, Natural History Museum, Cromwell Road, London SW7 5BD.

Yours etc.,
W.D. Ian Rolfe

4 June 1990
National Museums of Scotland, Chambers Street, Edinburgh EH1 1JF.

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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

Historical Note

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

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

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

Notes for Contributors

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

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

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

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