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The colour of Igemerald: I.G. Farbenindustrie flux-grown synthetic emerald

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ABSTRACT: Seven samples of I.G. Farbenindustrie flux-grown synthetic emerald were examined. The synthetic emeralds were grown between 1929 and 1942 at Bitterfeld, Germany, in a lithium molybdate solvent. Gemmological, chemical and spectroscopic properties are given. The colour of the samples is caused by minor amounts of chromium and nickel and, thus, the secret ingredient mentioned by Espig (1960) is identified as a nickel-bearing compound.

Introduction

Historical background

The first emerald synthesis which produced facetable crystals above one centimetre in size was performed by I.G. Farbenindustrie (literally I.G. Dye Trust) at Bitterfeld, Germany. Facetable material had been grown since 1929 (Schiebold, 1935; Espig, 1960), but samples were released to the public only after the first announcement to the press in February 1935 (Anonymous, 1935). Gemmological descriptions of this synthetic emerald were published in the same year (Eppler, 1935; Jaeger and Espig, 1935; Anderson, 1935) and mineralogical investigations of the synthetic emerald crystals, e.g. by X-ray powder diffraction, were also performed (Schiebold, 1935; Espig, 1935; Anderson, 1935). Gemmological properties of these synthetic emeralds were examined later by various authors and their results were summarized and compared with the features of the first synthetic emeralds produced in the United States by Chatham in different articles in the '50s (e.g.

Webster, 1952, 1955, 1958; Wiegand, 1952; Gübelin 1953; Eppler, 1958a,b). Regarding the growth technology used, there was only speculation until three more or less detailed papers of one of the inventors of the I.G. Farbenindustrie process were published (Espig, 1960, 1961, 1962). Before this information was available, the synthetic emeralds were considered as hydrothermally grown (Webster, 1955, 1958; Wilke 1956).

Growth technology

Espig reported that the first attempts to grow synthetic emeralds at Bitterfeld started in 1911 and that he was involved in these experiments from 1924. Crystal growth in the final stage of the technical development was performed in platinum crucibles with lithium molybdate as the solvent. A schematic drawing of the growth conditions (Figure 1) which followed closely the descriptions of Espig was published by Recker (1973). A nutrient of BeO and Al₂O₃ with lithium chromate as colour-causing dopant was placed at the bottom of a

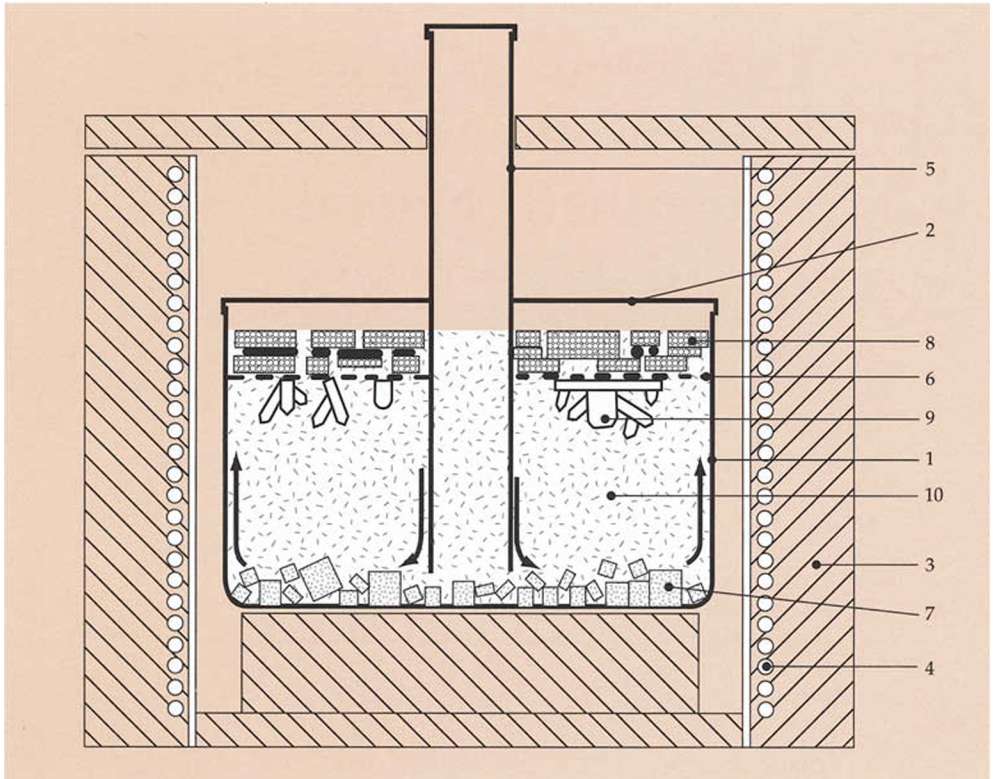


Figure 1: Schematic diagram of the process applied to flux growth of synthetic emerald by I.G. Farbenindustrie at Bitterfeld, Germany, from 1929 to 1942; Key: 1 = platinum crucible, 2 = platinum lid, 3 = insulation, 4 = heating system, 5 = central platinum tube for the addition of material to the nutrient, 6 = baffle, 7 = nutrient, 8 = quartz plates, 9 = growing crystals, 10 = lithium molybdate solvent (adapted from Recker, 1973).

platinum crucible. Subsequently, the crucible was filled with lithium molybdate and emerald seeds were positioned below a platinum baffle. Above this baffle, quartz plates of 8 to 10 mm in thickness were arranged. These quartz plates floated on top of the melt after heating the furnace to a constant temperature of about 800°C. This temperature was kept at a constant level over a growth period of 20 days, but new nutrient was added every second day by means of a central platinum tube to the material at the bottom of the crucible. After each growth period, the synthetic emerald crystals were examined and extremely impure layers of synthetic emerald material were removed. The largest crystals of prismatic habit which were obtained in about 18 growth periods during one year measured

2 or 3 cm in length (Espig, 1960, 1961, 1962). Faceted stones up to 1 ct in weight measuring 5 to 6 mm were cut from the rough.

Emeralds were produced at Bitterfeld from 1929 until 1942 in 12 furnaces (Espig, 1960), but due to the market situation for natural emeralds and the relatively high cost of crystal growth, there was no large-scale industrial production of synthetic emeralds at the I.G. Farbenindustrie (Anonymous, 1952; Wiegand, 1952). As a result, the synthetic emeralds were never sold commercially on the free market. The material was named Igemerald, standing for I.G. emerald, and was used for public relations purposes of the I.G. Farbenindustrie. In 1945, the complete platinum growth facilities were lost and production was not resumed after the war.

Colour of Igmerald

Although the basic technology of emerald production has been available to the public since 1960, a few sentences in the first of the three papers by Espig led to some speculation: 'Zwar steht in allen Lehrbüchern, daß Smaragd durch Chromoxyd gefärbt ist und in der Hauptsache trifft dies auch zu. Nachdem wir aber zum erstenmal große Kristalle erhielten, zeigte sich, daß Chrom allein ein kaltes bläuliches Grün gibt, und es waren Hunderte von Versuchen erforderlich, um diejenigen Stoffe ausfindig zu machen, die die Farbe zum warmen Grün einer Wiese im Frühling nuancierten.' [It is mentioned in all textbooks that emerald is coloured by chromium oxide, and this is generally correct. But after we obtained large crystals for the first time, we recognized that chromium alone causes a cold bluish green. Hundreds of experiments were necessary to find those compounds, which shifted the colour to the warm green of a meadow in spring.]

Another flux growth process of synthetic emerald was performed in the '20s by Professor R. Nacken in Frankfurt, Germany, using a molybdenum- and vanadium-bearing flux. Crystals up to 5 mm in size were described by Nassau (1978) and the growth technique was elucidated using Nacken synthetic emeralds from private and public collections, because no publication is available from Nacken himself describing the growth process (see also Webster, 1955, 1958). Nacken synthetic emeralds were also regarded as hydrothermally-grown synthetic emeralds until the chemical composition of a trapped molybdenum- and vanadium-bearing residual flux was established and the absence of water was confirmed experimentally (Nassau, 1978).

Knowing of vanadium as a colour-causing trace element in natural emeralds from certain sources such as Colombia, Nassau mentioned a possible co-operation of I.G. Farbenindustrie with Nacken and a possible use of vanadium as a colour-causing dopant in the I.G. Farbenindustrie growth process of Igmerald. He suggested that the secret ingredient of Jaeger and Espig may have been vanadium (Nassau, 1976, 1978,

1980; Nassau and Nassau, 1980). This assumption was accepted by other scientists (see e.g. Elwell, 1979) and seems reasonable, because synthetic green 'emeralds' which were coloured by vanadium had already been mentioned in 1926 by Bernauer (in a paper dealing with trapiche emeralds from Colombia), although the growth method of these samples was not described. This information, however, was available to the scientists involved in the growth and examination of I.G. Farbenindustrie synthetic emeralds (see Schiebold, 1935).

Materials and methods

Seven Igmeralds (I.G. Farbenindustrie flux-grown synthetic emeralds) were available from the research collection of E. Gübelin, Lucerne, Switzerland (Figure 2):

- one prismatic, slightly distorted crystal of 3.81 ct measuring 9.5 mm in length and between 6.0 and 6.8 mm in diameter;
- six faceted stones between 0.48 and 0.12 ct, all with an orientation of the table facet perpendicular to the *c*-axis.

All seven samples were tested by standard gemmological methods for optical properties, fluorescence, specific gravity and microscopic features. Inclusions were studied microscopically and identified by Raman spectroscopy with a Renishaw Raman Microscope. For a chemical characterization of the synthetic

Figure 2: Rough and faceted I.G. Farbenindustrie synthetic emeralds (left) compared to two Chatham synthetic emeralds (right). The rough crystal is 9.5 mm long (photo by H.A. Hänni).



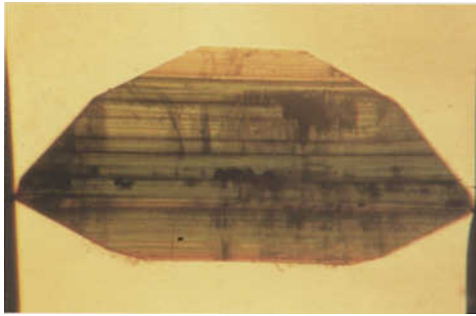


Figure 3: Growth and colour zoning parallel to the basal pinacoid in I.G. Farbenindustrie synthetic emerald. View perpendicular to the c-axis, immersion, 35x



Figure 4: Growth and colour zoning approximately parallel to the basal pinacoid in I.G. Farbenindustrie synthetic emerald; some of the growth planes are not exactly parallel to each other. View perpendicular to the c-axis, immersion, 80x

emeralds, the rough crystal and the two larger faceted samples of 0.48 and 0.26 ct were submitted to energy-dispersive X-ray fluorescence analysis (EDXRF) using a Spectrace 5000 Tracor X-ray fluorescence spectrometer with a Tracor Northern Spectrace TX-6100 software system. Spectroscopic data in the visible and ultraviolet range for all seven samples were recorded with a Leitz-Unicam SP 800 spectrophotometer.

Results

Gemmological properties

Gemmological properties, e.g. refractive indices, specific gravity, and fluorescence data (Table I), are comparable to the properties

of flux-grown synthetic emeralds of different producers, especially with those of synthetic emeralds which were grown in a solvent of lithium molybdate (see Flanigen *et al.*, 1967).

All samples revealed a characteristic growth zoning consisting of alternating

Table I: Properties of chromium- and nickel-bearing synthetic emeralds

	Chatham	Igmerald	Gilson*
Colour	bluish-green	grass-green	yellowish-green
Pleochroism parallel c	blue-green	bluish-green	intense green
perpendicular c	yellowish-green	yellow-green	yellow-green
Refractive indices n_o	1.564	1.563–1.566	1.563
n_e	1.560	1.559–1.561	1.559
Birefringence	0.004	0.004–0.005	0.004
Specific gravity	2.65	2.65–2.66	2.65
UV fluorescence long-wave	moderate red	moderate red	light yellowish
short-wave	light red	light red	light yellowish
Significant minor elements	Cr	Cr>Ni>>Fe	Cr≈Ni>(V,Fe,Cu)
Significant absorption bands	Cr	Cr>Ni	Cr≈Ni

* Schmetzer, 1989

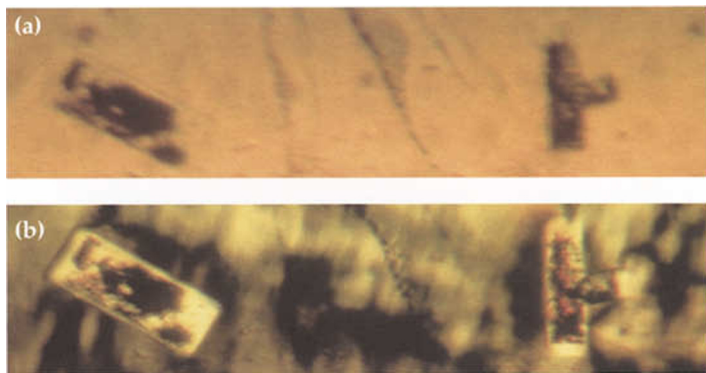


Figure 5: Inclusions of prismatic beryl crystals with orientations different from that of the host synthetic emerald; inclusions of opaque residues of the solvent have been trapped in the prismatic beryl. Immersion, (a) in plane-polarized light, 100x, and (b) in cross-polarized light, 100x.

green, yellowish-green and sometimes even greenish-yellow layers more or less parallel to the basal pinacoid (Figure 3). Some of these growth boundaries were slightly inclined to each other, i.e. not all growth lines were exactly parallel, thus representing slightly uneven undulating planes within the beryl crystals (Figure 4). The rough crystal showed also small areas with growth zoning parallel to the hexagonal prism faces ($10\bar{1}0$) and ($11\bar{2}0$), but these thin outer layers were completely removed by cutting in all six faceted samples.

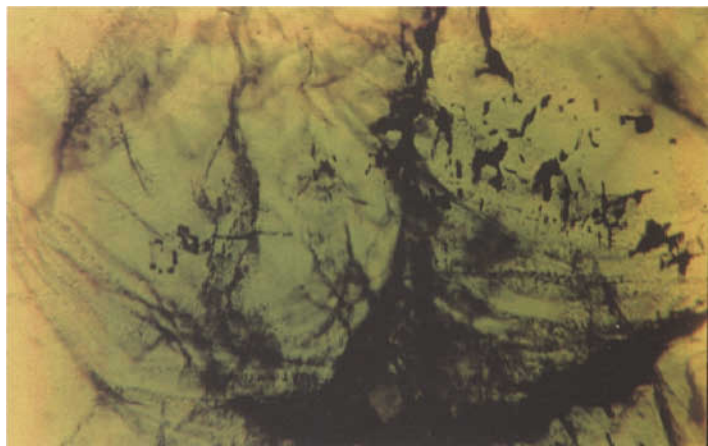
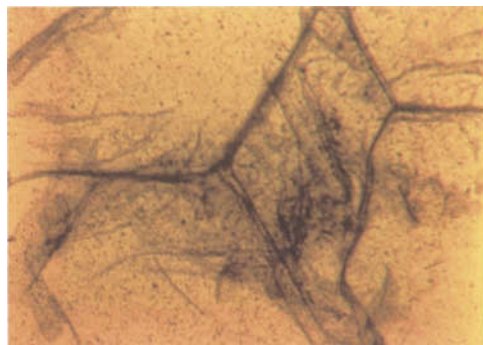
Two types of birefringent crystals were present as inclusions: the first type consisted of prismatic, elongated crystals which contained numerous small opaque inclusions, most probably of residual flux. The refractive index of these prismatic crystals was close or identical to that of

the host beryl and, thus, the single prisms were sometimes difficult to observe. Under crossed polarizers, however, these prisms always became visible due to their interference colours (Figure 5). Consequently, these inclusions were identified as beryl with an orientation different from that of the host.

The second type of birefringent inclusions consisted of colourless crystals, mostly with somewhat rounded edges with refractive indices distinctly above that of the host. These inclusions were identified by micro Raman spectroscopy as phenakite, which is a common inclusion in flux-grown synthetic emeralds from different producers (Delé-Dubois *et al.*, 1986a, b).

Figure 7: Residual flux trapped in I.G. Farbenindustrie synthetic emerald. Immersion, 60x.

Figure 6: Cellular pattern of residual flux in I.G. Farbenindustrie synthetic emerald. View parallel to the *c*-axis, immersion, 60x.



Residual flux was present in various forms in all seven I.G. Farbenindustrie synthetic emeralds examined. In views parallel to the *c*-axis, a cellular pattern of flux particles was sometimes visible (Figure 6). In other directions of view, the wispy veils typical for flux-grown synthetic emeralds were commonly observed (Figure 7).

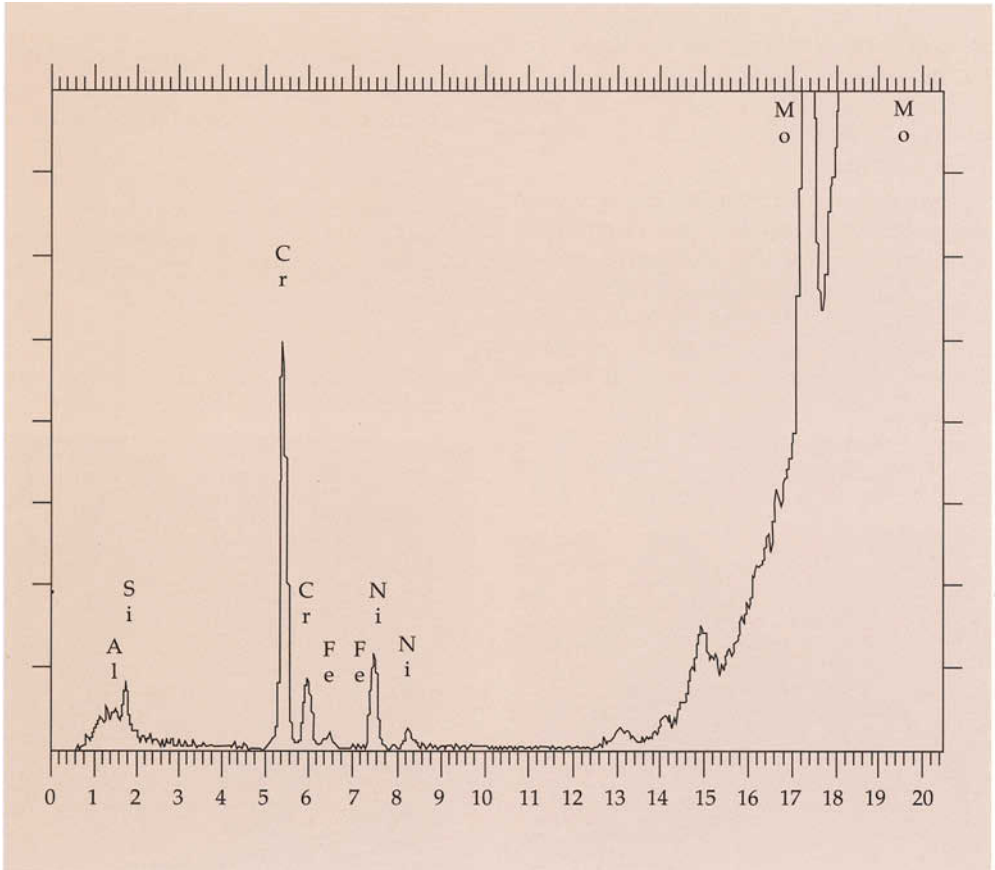
Occasionally, residual flux was also found in channels parallel to the *c*-axis. Raman spectroscopy of the compounds trapped in channels parallel to *c* indicates that at least three solid phases are present. The spectra are consistent with the Raman spectra of different polymolybdate molecules in solutions (Johansson *et al.*, 1979; Murata and Ikeda, 1983) and with the spectrum of residual polymolybdate fluxes in different

flux-grown emeralds (Delé-Dubois *et al.*, 1986a, b). In addition, the strongest Raman lines of orthorhombic molybdenum trioxide (Krasser, 1969; Py *et al.*, 1977; Delé-Dubois *et al.*, 1986a, b) were also observed.

Chemical and spectroscopic properties

The rough crystal and the two faceted samples which were examined by energy dispersive X-ray fluorescence revealed characteristic EDXRF spectra indicating the presence of molybdenum (from residual flux material), distinct amounts of chromium and nickel, and traces of iron (Figure 8). In all samples tested the relative abundances were Cr > Ni >> Fe, but the characteristic emission lines of vanadium were not found.

Figure 8: EDXRF spectrum of a faceted I.G. Farbenindustrie synthetic emerald showing distinct amounts of Cr and Ni (chromophores) and Mo (from the flux).



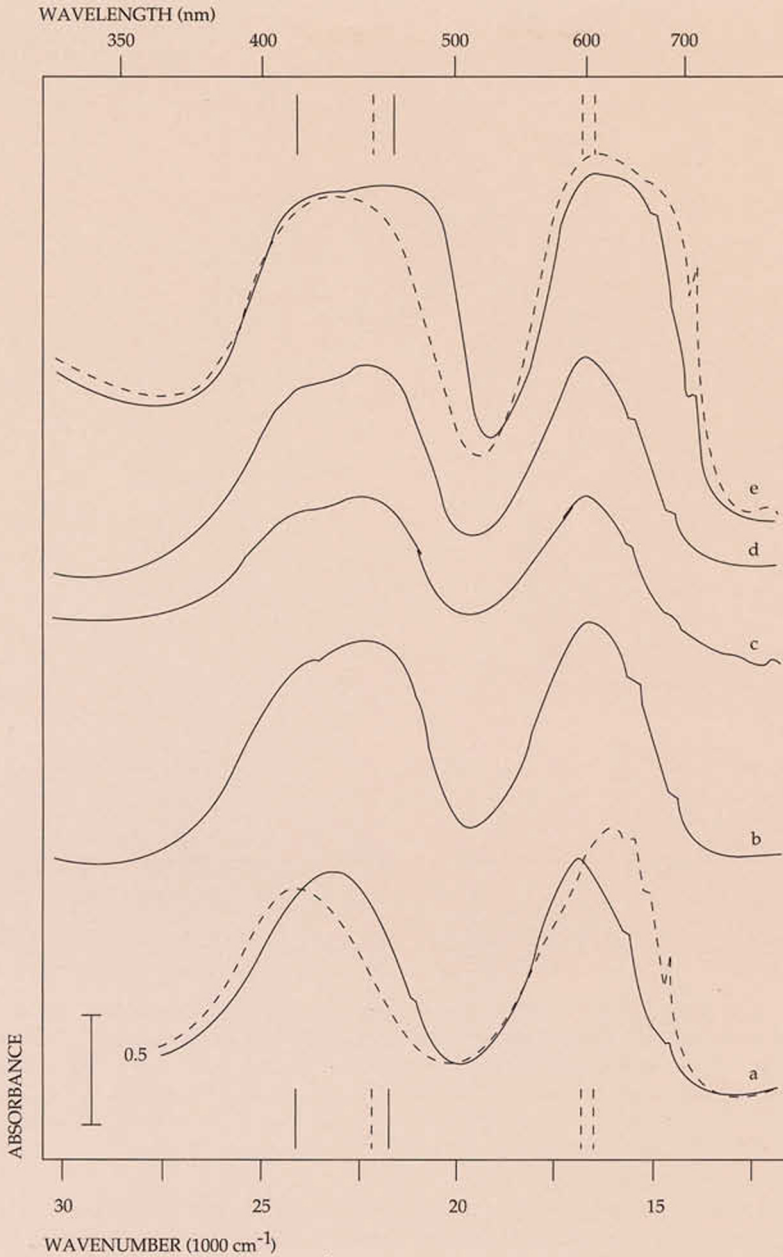


Figure 9: Absorption spectra of chromium- and nickel-bearing synthetic emeralds: (a) chromium-bearing Chatham synthetic emerald, (b) to (e) chromium and nickel-bearing I.G. Farbenindustrie synthetic emeralds; spectra (b), (c), and (d) were recorded from faceted samples with direction of the beam parallel to the c-axis, the polarized spectra (a) and (e) were recorded from faceted or rough crystals with direction of the beam perpendicular to the c-axis; the positions of nickel absorption maxima are indicated by dashed and solid lines at the bottom and at the top of the drawing; solid lines represent a polarization perpendicular to the c-axis, dashed lines represent a polarization parallel to the c-axis.

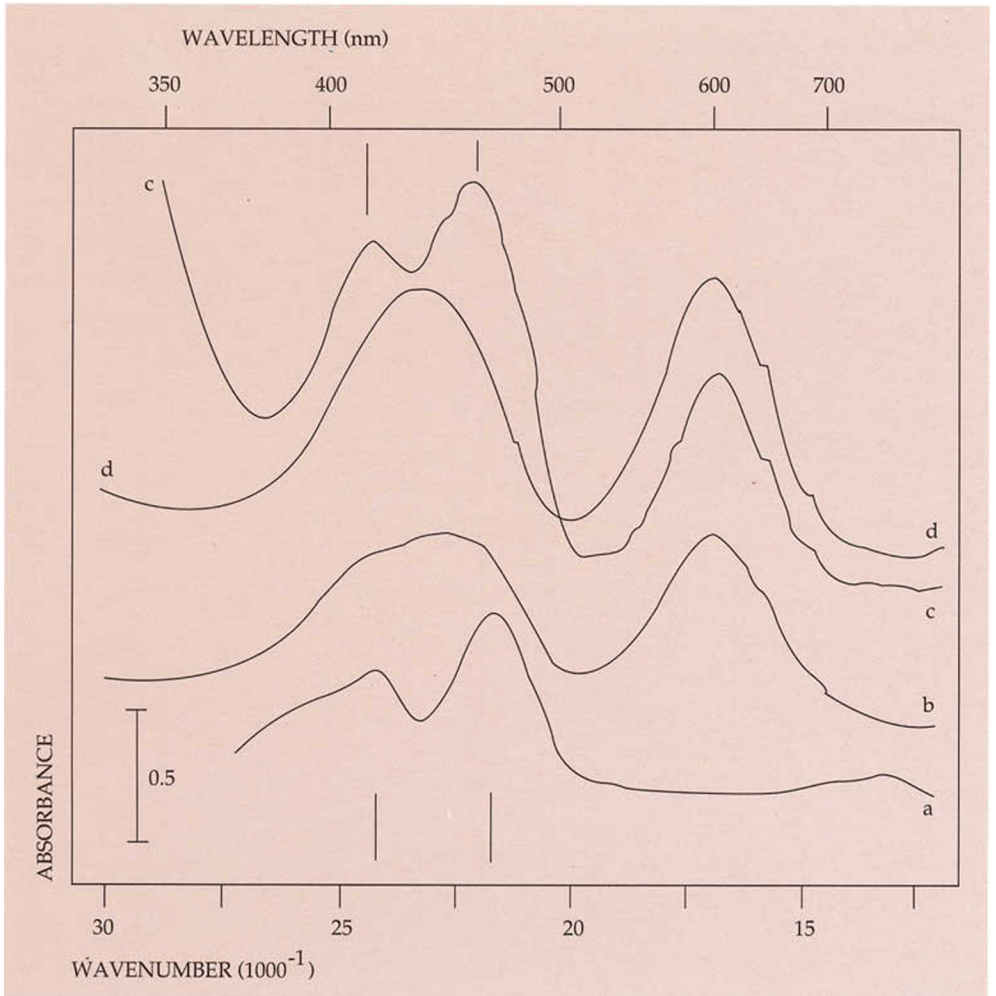


Figure 10: Absorption spectra of chromium- and nickel-bearing synthetic emeralds and nickel-bearing synthetic beryl: (a) nickel-bearing Russian hydrothermally-grown synthetic beryl, (b) chromium and nickel-bearing I.G. Farbenindustrie synthetic emerald, (c) chromium and nickel-bearing Gilson synthetic emerald, (d) chromium-bearing Chatham synthetic emerald; the positions of nickel absorption maxima are indicated by solid lines at the bottom and at the top of the drawing; all spectra represent polarization perpendicular to the *c*-axis.

Polarized absorption spectra of the rough crystal (Figure 9e) and non-polarized spectra of all six faceted samples (Figure 9b to d) where the incident beam was parallel to the *c*-axis, i.e. representing a spectrum with polarization perpendicular to *c*, consisted of the well-known absorption spectrum of chromium in beryl (see Figure 9a), superimposed by a series of nickel absorption bands. In particular, the

chromium spectrum perpendicular to *c* is superimposed by two absorption bands with maxima at 21 700 and 24 200 cm^{-1} (Figure 10) and the chromium spectrum parallel to *c* is superimposed by a doublet at 16 500 and 16 800 cm^{-1} and by an absorption band at 22 100 cm^{-1} . According to the examination of nickel-bearing hydrothermally-grown synthetic beryl and the assignments of the observed absorption bands to Ni^{2+} and Ni^{3+}

in the papers by Solntsev (1981a, b); Klyakhin *et al.*, (1981); and Lebedev *et al.*, (1986), the band at $22\,100\text{ cm}^{-1}$ is caused by bivalent nickel and the remaining bands mentioned are due to trivalent nickel, both replacing Al^{3+} in octahedral sites of the beryl structure.

It is worth mentioning that the nickel doublet at $16\,500$ and $16\,800\text{ cm}^{-1}$ had already been observed by Anderson (1935) in one of the first Igmeralds, and this was later confirmed for additional samples in the United States and Switzerland (Anonymous, 1937; Gübelin and Shipley, 1941). There was, however, no explanation for the additional absorption bands in the Igmerald spectrum at that time.

Discussion

Characteristic properties of I.G. Farbenindustrie synthetic emeralds

The most characteristic microscopic feature of Igmerald is the distinct growth and colour zoning parallel to the basal pinacoid. A rough calculation from the data given by Espig (1960, 1961, 1962) indicates a growth rate of about 0.06 to 0.09 mm per day. The growth layer obtained in a growth period of two days corresponds to the average thickness of growth layers in faceted samples, which were determined by microscopic examination. This is understandable according to the fact that the equilibrium between the different components of beryl in the solvent was abruptly changed every second day by the addition of new material to the nutrient at the bottom of the crucible. Obviously, there were different periods of growth and even dissolution (see Espig, 1962) within these growth cycles, and these caused somewhat uneven undulating surfaces on different parts of the growth layers.

The inclusions of small prismatic beryl crystals with a high concentration of trapped opaque flux material is also characteristic for Igmerald, but this feature was only observed in some of the samples. Inclusions of phenakite and various forms of trapped flux are common in flux-grown synthetic emeralds from various producers.

It is evident that the secret ingredient mentioned by Espig (1960) which was added to the nutrient for the flux growth of synthetic emeralds by I.G. Farbenindustrie at Bitterfeld was a nickel-bearing compound. From the present study, there is no evidence for the presence of vanadium in the flux or in the nutrient. Thus, our experimental data can offer no support to a possible link between Professor Nacken and the scientists who were involved at I.G. Farbenindustrie with the development of the growth process for synthetic emeralds. According to his 1962 paper, Espig was still assuming a hydrothermal technique for emerald growth by Nacken at that time. There was no reason to publish such a statement in 1962 in a description of most of the technical details of the emerald growth process by I.G. Farbenindustrie, if there really was co-operation in the '20s.

The authors are aware that nickel-free synthetic emeralds were also produced at Bitterfeld. Thus, for samples of doubtful origin or possibly mislabelled synthetic emeralds in gemstone collections, for which a distinct nickel content cannot be proven, the characteristic growth pattern and colour zoning and/or typical inclusions, e.g. prismatic beryl crystals with a high concentration of residual flux, may be appreciated as characteristic features.

It is interesting to note that the synthetic emeralds of Zerfass, which were produced at Idar-Oberstein from 1963 (Eppler, 1964) by one of Espig's former co-workers with knowledge of the I.G. Farbenindustrie process (Nassau, 1976, 1980), were coloured only by chromium and did not contain nickel. Based on investigations of several samples of Zerfass synthetic emeralds by the present authors using absorption spectroscopy and X-ray fluorescence analysis, the emeralds examined display a normal chromium absorption spectrum and contain among the minor elements only molybdenum (from the flux) and chromium.

Colour of nickel-bearing synthetic emeralds

In general, distinct amounts of nickel are present in addition to chromium, iron and



Figure 11: Chromium- and nickel-bearing I.G. Farbenindustrie synthetic emerald (left) and chromium-bearing Chatham synthetic emerald (right). The right-hand sample measures 9 x 7.3 mm (photo by H.A. Hänni)

copper in both types of Russian hydrothermally-grown synthetic emeralds which are produced commercially (Schmetzer, 1988, 1996; Koivula *et al.*, 1996). These crystals are grown in autoclaves without precious metal liners, a technique which was also proven for samples of Lechleitner hydrothermal fully synthetic emeralds (Schmetzer, 1990). These samples also contained distinct amounts of chromium, iron, nickel and copper as colour-causing trace elements. The colour of all these hydrothermally-grown synthetic emeralds is a complex function of the relative concentrations of all four transition metals.

Traces of 0.04 wt.% NiO were analyzed by Schrader (1983) in one sample of Inamori flux-grown synthetic emerald, but according to the high chromium content of this stone, an influence of nickel on the colour of this sample is unlikely.

Another nickel-to-chromium ratio was found in an extraordinary yellowish-green Gilson flux-grown synthetic emerald, which contained similar amounts of chromium and nickel (Schmetzer, 1989). Comparing the absorption spectrum of this sample with the spectra of the seven Igmeralds examined in this study, it becomes evident that the relative intensity of nickel absorption bands compared to the chromium spectrum is stronger in the Gilson sample than in the Igmerald spectra (Figure 10). In terms of the colour and pleochroism of synthetic

emeralds, increasing nickel content relative to chromium causes the pleochroic colour parallel to *c* to shift from blue-green to bluish green and green, i.e. the bluish component is reduced. The pleochroic colour perpendicular to *c* shifts slightly from yellowish-green to yellow-green, i.e. the yellow component of the green is slightly increased. In general, the overall colour shifts with increasing nickel content from bluish-green to grass-green and yellowish-green (Figure 11, Table 1).

These results are consistent with the data presented by Bukin *et al.* (1981), who found a complex relation between colour and the relative amounts of Ni²⁺, Ni³⁺ and Cr³⁺ in individual samples. According to Bukin, a nickel content above 0.1 wt.% is able to change the colour of an emerald sample. With increasing amounts of nickel, a shift of colour is mainly observed parallel to *c*, and only a minor change is found perpendicular to *c*.

Obviously, the grass-green colour of chromium- and nickel-bearing synthetic emerald was more acceptable as a 'good' emerald colour in the '30s in Germany by the producers of Igmeralds than the more bluish-green of chromium-bearing, nickel-free emerald. As a consequence of the great efforts necessary to find the appropriate mixture of compounds in the nutrient which produced this 'good' emerald colour, this recipe was not disclosed in the papers of Espig (1960, 1961, 1962) and has been kept secret until now.

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A study of Korean precious serpentine

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ABSTRACT: A precious serpentine deposit was recently discovered in Booyo County, Republic of Korea, and is the first recorded occurrence in the country. It forms along both contacts of a garnet vein intruding the serpentinite. The precious serpentine is semi-transparent and deep green with an oily lustre. It is very tough and measures about 5 on Mohs' scale of hardness. Its SG and RI are 2.57~2.58 and $N_D = 1.56$, respectively. X-ray powder diffraction analysis indicates that the precious serpentine is antigorite. The major chemical components are SiO_2 (42.49%), MgO (39.08%), Fe_2O_3 (3.85%), and H_2O (11.87%). Important trace elements include Cr (2188 ppm), Ni (1110 ppm), and Co (58 ppm). An IR spectrum and DTA/TGA thermogram are discussed and black inclusions finely dispersed through the serpentine consist of magnetite.

Keywords: precious serpentine, Booyo, Korea, antigorite, serpentine

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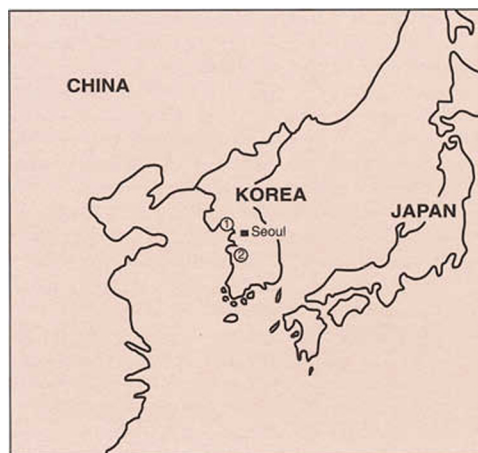
Introduction

A new gem-quality serpentine deposit was discovered in 1995 in the Booyo area, about 250 km south-west of Seoul, Korea (Figure 1), and is being mined by the Booyo Nokok (meaning green jade) Mining Company. After the Booyo material has been fashioned as rings, beads, cabochons, pendants, earrings, etc. (Figure 2), it is traded on the domestic market under the name 'Booyo precious serpentine'. The green-coloured Booyo precious serpentine has gained a high reputation in the country and is valued much more highly than the existing so-called 'Korea Jade' which is a greenish-yellow bowenite, reportedly produced from Haeju in North Korea (Figure 1).

Figure 1: Map of Korea showing two important gem-quality serpentine deposits, Haeju (1) and Booyo (2).

Occurrences

The geology of the precious serpentine deposit consists of Precambrian schist and granitic gneiss, Jurassic conglomerate



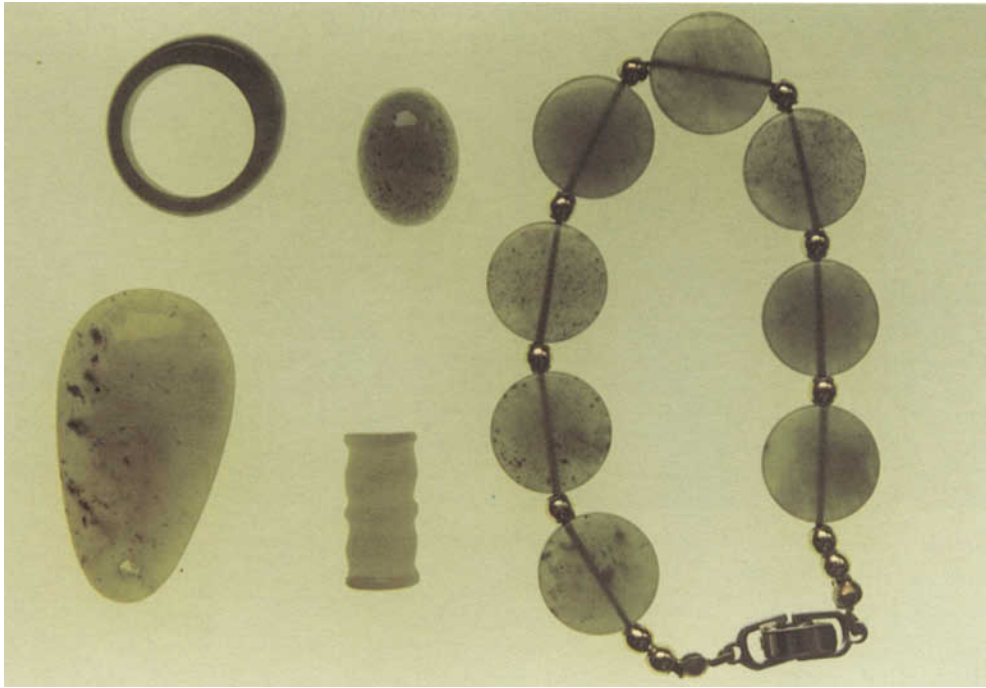


Figure 2: Precious serpentine from Booyo, Korea, fashioned as a ring, cabochon, pendant, button, and a string of beads with eye-visible black inclusions (magnetite). The semi-transparent nature of the serpentine is well demonstrated.

Figure 3: Geological map of the Booyo Nokok mine area, Korea.

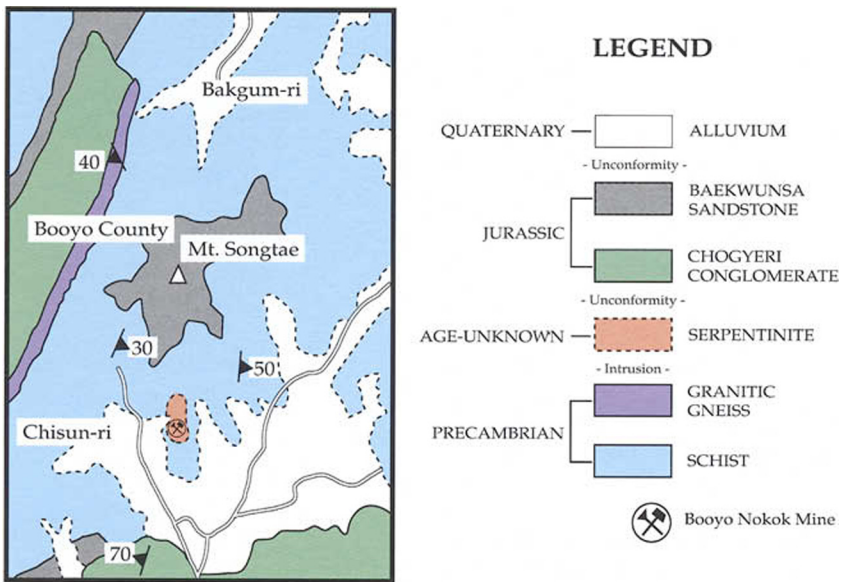




Figure 4: Non-precious serpentine extracted from the Booyo Nokok mine.

(Chogyeri Formation) and sandstone (Baekwunsa Formation), and serpentinite of unknown age (Figure 3).

The precious serpentine lies in a body of serpentinite, a part of which is characterized by well-developed igneous layers that strike N18°W and dip 50°SW. Outcrop of the serpentinite at the surface is approximately 100 m long. A grossular garnet vein, 15 cm in average width at the surface and light brown in colour, has intruded the serpentinite, striking E-W and dipping 6°N. Precious serpentine has formed along both contacts and varies in thickness between 3 and 20 cm.

At present 2 adits are open at the mine. They are at 10 metres vertical interval and are about 80 m long, to follow the garnet vein. Extracted ore materials are dumped on the ground nearby (Figure 4).

Gemmological properties

Colour, diaphaneity and lustre

The Booyo precious serpentine is deep green and colour distribution is quite uniform. The material is semi-transparent (Figure 2) and shows a resinous or waxy lustre. When heat-treated at 850°C for a few hours, its colour changes to orange-pink.

Table I: X-ray diffraction data of precious serpentine and antigorite.

1		2		h	k	l
d_o (Å)	I/I_o	d_o (Å)	I/I_o			
7.40	100	7.29	100	0	0	1
		6.43	40	—		
		5.82	40	$\bar{6}$	1	0
		5.15	40	3	1	1
4.64	25	4.64	40	0	2	0
		4.26	20	$\bar{4}$	2	0
				7	1	1
		3.99	5	9	0	1
3.68	68	3.61	80	12	0	0
2.757	69	2.794	20	11	2	1
				3	3	1
		2.667	5	15	0	1
				6	2	2
		2.596	20	12	0	2
				7	3	1
2.530	49	2.525	100	16	0	1
2.459	32	2.458	60	9	3	$\bar{1}$
		2.429	20	17	0	$\bar{1}$
				2	0	3
		2.386	20	14	0	2
		2.210	20	$\bar{1}$	4	1
				$\bar{1}$	4	1
2.113	32	2.172	60	8	3	$\bar{2}$
				9	0	1
		1.833	20	18	2	2
				8	4	2
		1.812	20	15	1	3
				1	5	1
		1.742	20	7	5	1
				20	2	2
1.710	21	1.709	5	23	2	1
				9	5	1

1. Precious serpentine from Booyo Nokok mine
2. Antigorite, JCPDS 21-963.

Mineral composition and texture

X-ray powder diffraction analysis confirmed that the precious serpentine consists of antigorite (Table I). Under the polarizing microscope, the precious

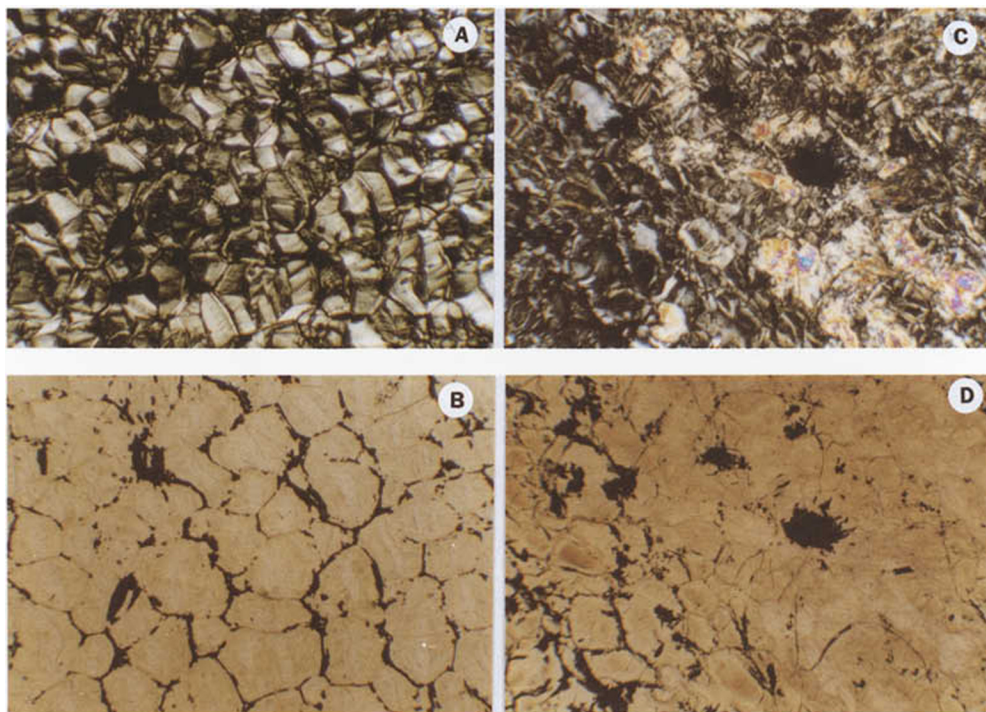


Figure 5: Photomicrographs showing textural variation between precious serpentine and ordinary serpentine: a: Precious serpentine under crossed polars. Fibrous antigorite crystals are visible. 40 x. b: Precious serpentine under plane-polarized light. Original shapes of pre-existing minerals and interstitial magnetite grains are visible. 40 x. c: Serpentine under crossed polars. Lath-shaped antigorite crystals occur with random orientation. 40 x. d: Serpentine under plane-polarized light. Original shapes of pre-existing minerals are only just detectable.

serpentine can be seen to be composed of randomly oriented fibrous aggregates (Figure 5a). The serpentine aggregates are bounded by rounded outlines that are clearly visible in plane-polarized light (Figure 5b), indicating that the serpentine was formed by alteration of olivine and pyroxene. Olivine and pyroxene remnants are rare within the matrix of serpentine minerals. The fibrous nature of the serpentine changes significantly on passing to the opaque material of the main serpentine in which blades, flakes and plates of antigorite crystals are predominant (Figures 5c and 5d); the latter is similar to the 'interpenetrating texture' described by Wicks and Whittaker (1977). Therefore, it is believed that the diaphaneity of the serpentine aggregates is related to the development of the fibrous texture.

Refractive index

Owing to the aggregated nature of the microscopically small antigorite crystals, only a single reading of about 1.56 can be obtained on a standard gemmological refractometer. This value compares well with refractive indices for antigorite ($\alpha = 1.558 \sim 1.567$, $\beta = 1.566$, $\gamma = 1.562 \sim 1.574$). It is slightly higher than the RIs of the other two serpentine polymorphs, chrysotile ($\alpha = 1.532 \sim 1.549$, $\gamma = 1.545 \sim 1.556$) and lizardite ($\alpha = 1.538 \sim 1.554$, $\gamma = 1.546 \sim 1.560$).

Hardness and toughness

The hardness was measured at about 5 on Mohs' scale and, due to the felted nature of the crystal aggregates, it is very tough.

Table II: Chemical analyses of precious serpentine from Korea and serpentine minerals from other sources

Wt. %	1	2	3	4	5
SiO ₂	42.49	43.1	43.60	38.04	39.45
Al ₂ O ₃	1.30	1.3	1.03	0.86	1.07
Fe ₂ O ₃	3.85	3.4	1.71	7.62	7.72
MgO	39.08	39.8	41.00	37.47	38.48
MnO	0.12		0.04	0.11	0.10
CaO	0.68		0.05	0.24	0.63
K ₂ O	0.06		0.03	0.01	0.02
Na ₂ O	n.d.		0.01	0.01	0.25
TiO ₂	0.01		0.01	0.01	0.02
Cr ₂ O ₃	*		0.02	n.d.	n.d.
NiO	*		0.16	n.d.	n.d.
P ₂ O ₅	0.06		n.d.	0.01	0.11
LOI	11.87			n.d.	11.30
H ₂ O		11.97	12.26		
Total	99.52	99.57	99.92	84.38	99.15
ppb, in serpentine from Booyo Nokok mine, Korea					
Li	2717.50	Nb	12925.19	Tb	35.92
Be	321.10	Mo	2858.60	Dy	291.25
Sc	5409.16	Cd	n.d.	Ho	47.37
Cr	2188503.91	Te	2022.68	Er	135.69
Co	58426.31	Cs	1450.91	Tm	70.57
Ni	1110853.28	Ba	22816.11	Yb	254.40
Cu	5929.28	La	1941.50	Lu	n.d.
Zn	96669.14	Ce	4302.41	Hf	n.d.
Ga	2193.34	Pr	396.02	Ta	108501.11
Rb	19809.42	Nd	1242.18	Pb	4264.71
Sr	7097.00	Sm	450.36	Bi	675.74
Y	2897.50	Eu	26.83	Th	1894.58
Zr	8995.92	Gd	601.57	U	991.02

1. Precious serpentine (antigorite) from Booyo Nokok mine, Korea

2. Antigorite, JCPDS card 21-963

3. Antigorite, Venezuela (Hess *et al.*, 1952)

4. Lizardite from Ulsan serpentinite (Park and Lee, 1955)

5. Lizardite from Ulsan serpentinite (Choi *et al.*, 1990)

* see list of trace elements

n.d. not determined

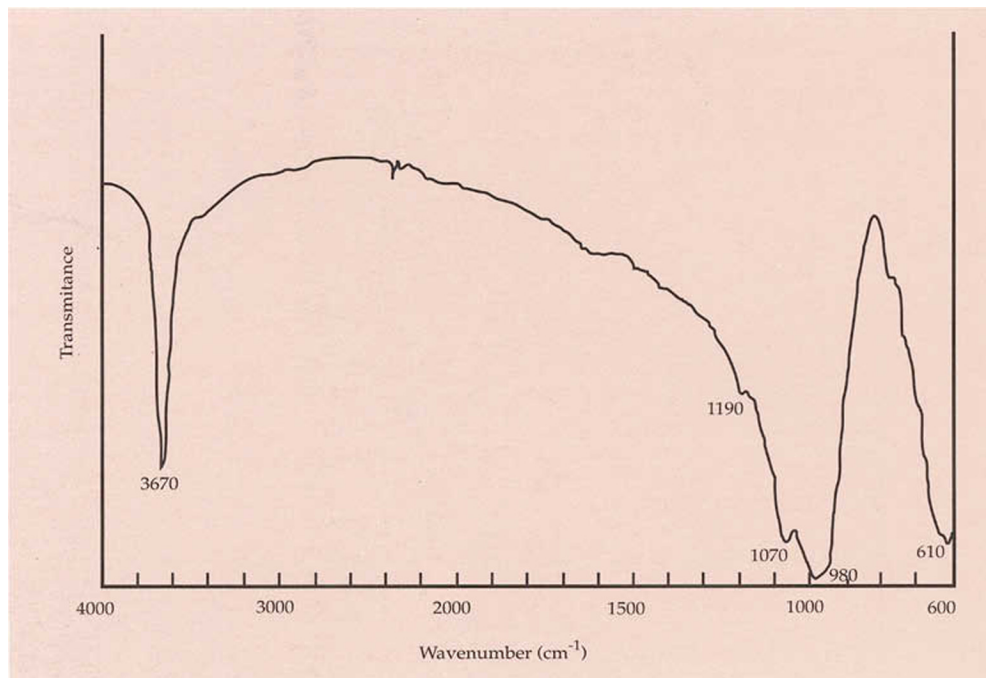


Figure 6: Infrared absorption spectrum of the precious serpentine from Booyo, Korea.

Specific gravity

The specific gravity of precious serpentine determined by the hydrostatic weighing technique ranges from 2.57 to 2.58. This value compares well with that of antigorite (2.58 ~ 2.59), but is higher than that of chrysotile (2.55) and lizardite (2.55 or lower) given by Deer *et al.* (1966). The specific gravity value of the Booyo precious serpentine, however, is considerably lower than the 2.617 reported for a bluish-green variety from South Island, New Zealand, by Webster (1994, p 370). The difference may be explained, in part, by different inclusions in the two materials but this needs further work.

Chemical composition

Chemical compositions of the precious serpentine were determined by X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) methods and are shown in Table II. Amounts of SiO₂ (42.49 wt. %) and MgO (39.08 wt. %) together with loss on ignition (LOI)

(11.87 wt. %), probably water, compare well with the ideal chemical composition of serpentine, Mg₃Si₂O₅(OH)₄. The presence of other elements including Al and Fe is attributable to the elemental substitution of Al³⁺ for Si⁴⁺, and Al³⁺, Fe³⁺, Fe²⁺, and Ni for Mg²⁺ (Deer *et al.*, 1966). Amounts of SiO₂, MgO and Al₂O₃ of the Booyo material are surprisingly similar to those of antigorite from Griffin Range, New Zealand (Table II, 2), and Caracas, Venezuela (Table II, 3). The smaller amount of Fe in antigorite from Venezuela, when compared with that from Booyo and the Griffin Range, is consistent with a higher MgO content in the material. It is interesting to note that the amount of SiO₂ (38.04%, 39.45 wt. %) in lizardite from the Ulsan serpentinite, Korea (Table II, 4–5), is significantly lower than antigorite from various sources. This deficiency may be compensated partly by its higher than normal Fe₂O₃ content.

The precious serpentine from Booyo is relatively rich in transition elements Cr (2188 ppm), Ni (1110 ppm) and Co

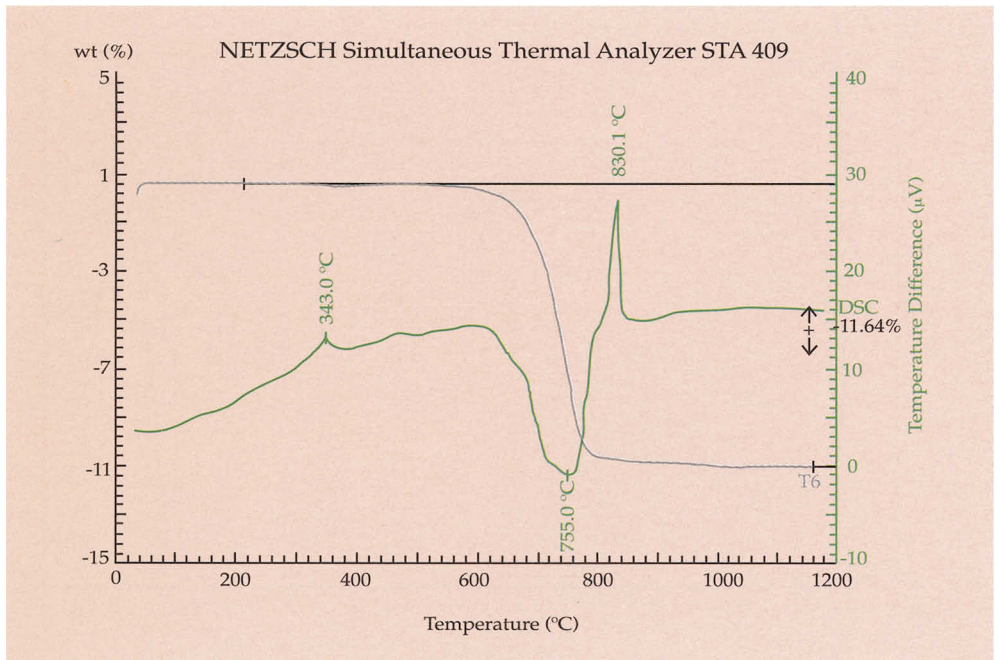


Figure 7: Differential thermal analysis and thermogravimetric analysis (DTA/TGA) thermogram of the precious serpentine from Booyo, Korea

(58 ppm) (Table II). Such a large concentration of these elements suggests that the antigorite is an alteration product of ultramafic igneous rocks whose principal constituents were olivine and pyroxene.

Infrared spectrum

The infrared absorption spectrum (Figure 6) of the precious serpentine, recorded by a JASCO IRA-1 spectrophotometer, shows characteristic absorptions at 3670, 1190, 1070, 980, and 610 cm^{-1} . The strong peak at 3670 cm^{-1} is due to OH stretching, and those at 1190, 1070, and 980 cm^{-1} are due to SiO stretching. The 610 cm^{-1} band results from an OH bending vibration (Farmer, 1974); this is consistent with absorption between 600 and 660 cm^{-1} caused by hydroxyls in the serpentine minerals reported by Pampuch and Ptak (1970). The sharpness of OH absorptions at 3670 and 610 cm^{-1} may indicate that this precious serpentine (a trioctahedral 1:1 layered silicate) has a relatively ordered structure.

Fluorescence

The precious serpentine shows no luminescence under ultraviolet light.

Differential thermal analysis and thermogravimetric analysis (DTA/TGA)

Thermal analysis data recorded by a Netzsch simultaneous Thermal Analyser STA 409 (Figure 7), show peaks at 343.0°C (exothermic), 755.0°C (endothermic), and 830.1°C (exothermic). The peak at 755.0°C (green line) corresponds to the decomposition of the mineral by expulsion of the structural water (Deer *et al.*, 1966). According to Smykatz-Kloss (1974) the decomposition temperature is influenced by the Fe-content in the structure, and can vary between 760 and 800°C for Fe-free serpentines and between 600 and 650°C for Fe-rich varieties. The strong exothermal peak at 830.1°C (green line) is related to the structural change of antigorite to olivine, which is supported by X-ray diffraction data of precious serpentines both before and after heat

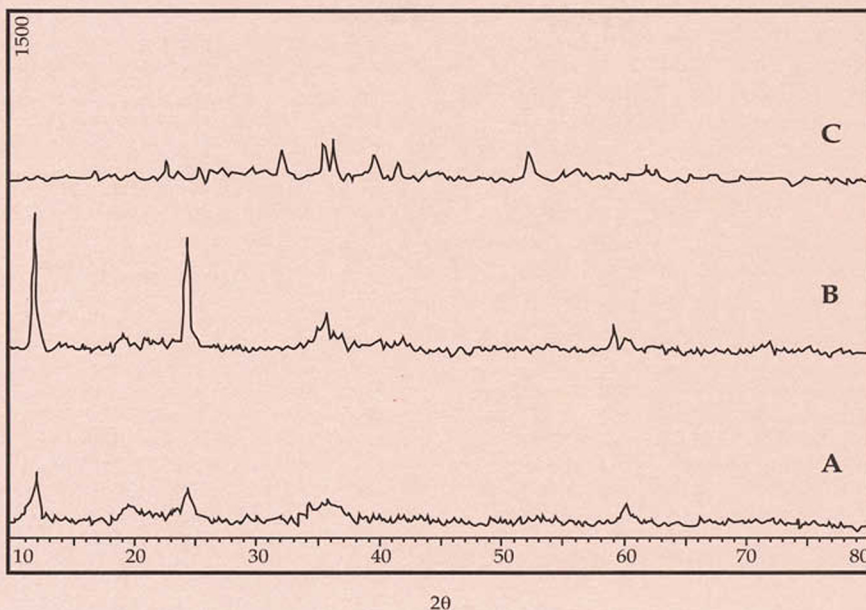
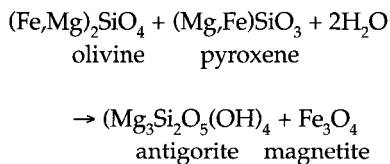


Figure 8: X-ray diffraction data for the precious serpentine from Booyo, Korea. Antigorite structures of precious serpentine, A: untreated, B: after heat treatment at 600°C. C: Olivine structure is developed after heat treatment at 850°C.

treatment at 850°C (Figure 8). A total weight loss of water in association with this reaction is 11.64% (see red line and blue indicators in Figure 7); this corresponds very well with the chemical data (loss on ignition of 11.87 wt. %). The exothermic reaction at 343.0°C (green line) may possibly be caused by a polymorphic transformation of antigorite.

Inclusions

The precious serpentine from Booyo contains numerous fine black inclusions which are concentrated in the interstices of the former olivine or pyroxene grains (Figure 5b). These opaque inclusions were identified as magnetite by X-ray diffraction using 114.6 mm Gandolfi X-ray camera. During the serpentinization process, much of the iron contained in the olivine and pyroxene may go to form magnetite because of the relatively low preference for iron in the serpentine structure (Wicks and Whittaker, 1977). Formation of magnetite can be represented by the following equation:



Conclusion

The Booyo precious serpentine is now being cut, polished and sold exclusively by the Nokokwon (meaning green jade garden) Company in Seoul.

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Distinction of taaffeite and musgravite

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ABSTRACT: Problems associated with the identification of taaffeite and musgravite are discussed. Due to an overlap of gemmological properties, time consuming mineralogical research techniques (quantitative chemical analysis, X-ray diffraction) are needed for a determination of both species. However, recently micro-Raman spectroscopy has been found to be useful as a quick non-destructive routine technique for identification of both species.

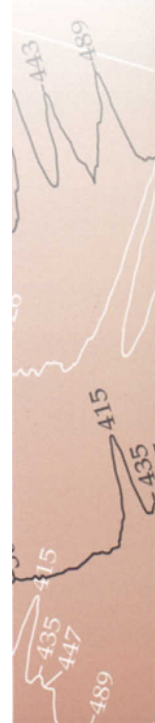
The structurally related Be-Mg-Al-oxides taaffeite, $\text{BeMg}_3\text{Al}_8\text{O}_{16}$, and musgravite, $\text{BeMg}_2\text{Al}_6\text{O}_{12}$, were originally regarded as polytypes of one single mineral. Chemical and structural examinations, however, proved the existence of two independent species with different chemical formulae, unit cell dimensions, space groups and crystal structures. In both minerals a certain amount of isomorphous replacement of Mg by Fe, Zn and Mn may be observed, thus leading to a more complex formula of $\text{Be}(\text{Mg},\text{Fe},\text{Zn},\text{Mn})_3\text{Al}_8\text{O}_{16}$ for taaffeite and to a formula of $\text{Be}(\text{Mg},\text{Fe},\text{Zn})_2\text{Al}_6\text{O}_{12}$ for musgravite (Schmetzer, 1983, a,b; Nuber and Schmetzer, 1983).

For almost half a century since the discovery of the first taaffeite as a cut gemstone in 1945, faceted and rough taaffeites were known predominantly from Sri Lanka, a few rare samples were also mentioned from Myanmar (Kampf, 1991; Demartin *et al.*, 1993). In 1993, however, two faceted 'taaffeites' from Sri Lanka were identified as musgravites by means of X-ray single crystal diffraction (Demartin *et al.*, 1993) and, just recently, a third faceted musgravite was determined by X-ray

powder diffraction (Johnson and Koivula, 1997). In this third stone, major amounts of zinc and iron were detected by qualitative EDXRF analysis.

Because the difference in BeO content between taaffeite and musgravite is only 1.56 wt. %, similar physical properties such as refractive indices and specific gravity are observed for both mineral species. In detail, a complete overlap has been found for the properties of the three faceted musgravites described so far (n_o 1.725–1.728, n_e 1.719–1.721, SG 3.62–3.69) and for high zinc- and iron-bearing faceted taaffeites from Sri Lanka (n_o 1.724–1.730, n_e 1.719–1.726, SG 3.61–3.71; Schmetzer and Bank, 1985; Ponahlo, 1993). Consequently, neither the determination of physical properties such as refractive indices and specific gravity in the range given above nor qualitative chemical analyses with the determination of zinc and iron in major amounts are useful in deciding whether taaffeite or musgravite is present.

Thus, an unequivocal distinction between taaffeite and musgravite has so far only been possible by quantitative chemical analysis or by X-ray diffraction (powder or single crystal techniques). These methods, however, are



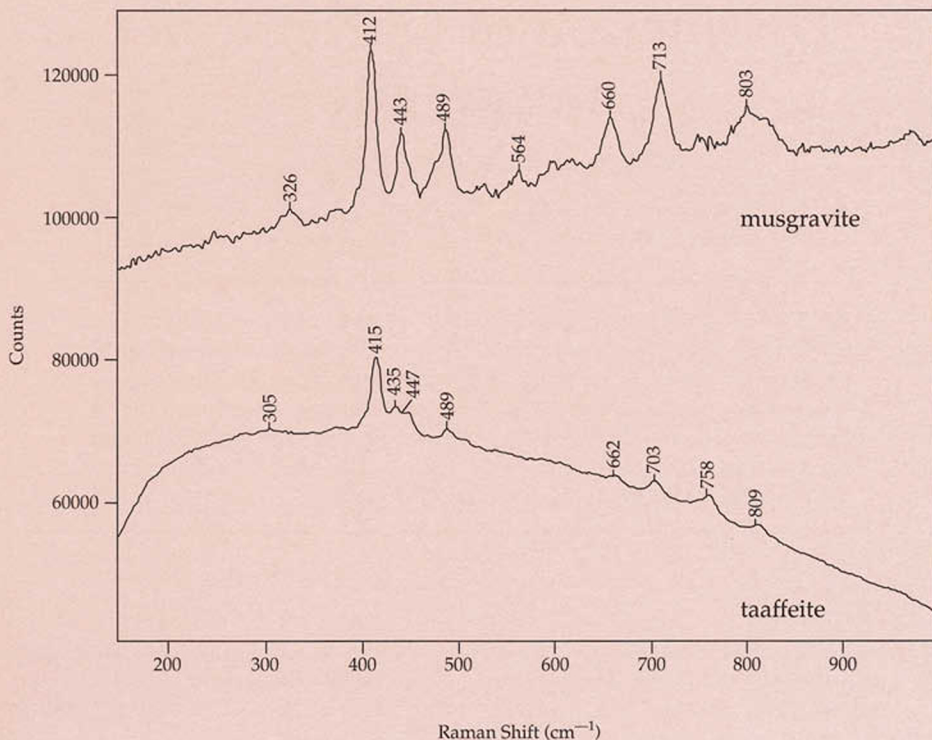


Figure 1: Raman spectra of taaffeite, Sri Lanka, and musgravite, Antarctica.

time-consuming research techniques and not routine methods in gemmology. In addition, for the preparation of an X-ray powder diffraction pattern, a small amount of substance has to be scraped from the girdle of a faceted stone, which is not always wanted or allowed by the owner of a sample to be identified.

With this background, the authors tested the applicability of micro-Raman spectroscopy for the distinction of musgravite and taaffeite. At the end of the '90s, an increasing number of Raman microscope facilities are available at the major gem-testing laboratories around the world and are used as routine instruments for various problems in gem testing (Hänni *et al.*, 1997). To evaluate possible determinations of taaffeite and musgravite by micro-Raman spectroscopy, six taaffeites

(five faceted and one rough gem-quality) from Sri Lanka were examined. Small musgravite crystals were available from the Musgrave Ranges, Australia (type material) and from Casey Bay, Antarctica. For all samples quantitative chemical analyses were performed to identify them as taaffeites or musgravites and for most of them X-ray single crystal and/or powder diffraction data were also available. Raman spectra were recorded using a Renishaw Raman Microscope facility.

As a result, we observed a unique type of Raman spectrum for all taaffeites examined, as well as another Raman spectrum for the musgravites (Figure 1). The six strongest Raman lines were recorded as 415, 435, 447, 703, 758 and 809 cm^{-1} for taaffeite and at 412, 443, 489, 660, 713 and 803 cm^{-1} for

musgravite; broad peaks for musgravite are schematically indicated by wavenumbers 564 and 803. It is notable that although there are small differences in peak intensities related to orientation of the specimen, the overall pattern of the spectrum (in terms of peak positions and peak shapes) of taaffeite is distinctly different from that of musgravite. Consequently, Raman spectroscopy is useful as a non-destructive routine technique for rapid distinction of taaffeite and musgravite.

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Identification of polystyrene in impregnated jadeite

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ABSTRACT: Fourier transform infrared transmission and X-ray photoelectron spectroscopy have proven to be useful spectroscopic techniques used to detect the presence of wax and polymers in jadeites, thus enabling the discrimination between A and B jades. This paper reports the results of Fourier transform infrared transmission and X-ray photoelectron spectroscopic studies done on a sample of polymer-impregnated jadeite. The polymer used for the impregnation of this sample has been previously reported (e.g. Fritsch and McClure, 1993) to be present in impregnated jadeite. Using the above two spectroscopic techniques, this polymer has been identified as polystyrene.

Keywords: Fourier transform infrared spectroscopy, impregnation, jadeite, polymers, polystyrene, X-ray photoelectron spectroscopy

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Introduction

Since at least 1989, the jade market in many parts of Asia has been infiltrated by many jade pieces which have been bleached then polymer-impregnated (Hurwit, 1989; Anon, 1991a and b). The gem is soaked in acid to take away the brown spots (iron oxides) present on the surface of the jadeite and these cracks and holes are then filled up with polymers. This ensures that the jadeite does not have visible flaws on its surface and enables it to fetch a higher price. It has been well established that the simple gemmological tests like measurement of refractive index, specific gravity and fluorescence under ultra-violet light cannot reliably detect impregnation (Fritsch *et al.*, 1992; Tan *et al.*, 1995; Quek and Tan, 1997). The impregnation is also not detectable under the optical microscope (Hurwit, 1989). Now, detection methods like Fourier transform infrared transmission spectroscopy (Fritsch and Stockton, 1987; Fritsch *et al.*,

1992), X-ray photoelectron spectroscopy (Tan *et al.*, 1995) and diffuse reflectance infrared Fourier transform spectroscopy (Quek and Tan, 1997), have been found useful in the detection of impregnated jadeite. Using a scanning electron microscope, evidence of damaged crystal structure was found in impregnated jadeites (Tay *et al.*, 1993) but this method cannot be used to determine the chemical composition of the substance of impregnation.

Though many detection methods have been used in jadeite testing, an exact identification of the polymers present in jadeite has not been carried out. The focus has been mainly on the identification and discrimination of A and B jade. In 1992, Fritsch *et al.* found that two polymers in impregnated jadeites had Fourier transform infrared transmission spectra very similar to an Opticon-like polymer and to a compound of the class of phthalates. In this study, we use similar methods to positively identify

another polymer found in impregnated jadeites. Knowledge of the type of polymers used in jadeite impregnation is useful in many ways, and can be used in supplementing further gemmological studies on impregnated jadeites.

Methods and tests

A sample of jadeite which was shown earlier to be impregnated with polymer was used for this study. For the testing of the jadeite sample, a Bomem DA3.002 Fourier transform infrared transmission spectrophotometer (Tan *et al.*, 1995) was used. The resolution of the spectrophotometer used was 2 cm^{-1} . Spectra were taken of the jadeite sample only from 2000 to 5000 cm^{-1} as the infrared light used cannot pass through the sample beyond these frequencies.

The sample was further tested using a VG ESCALAB MkII X-ray photoelectron spectrometer using an MgK X-ray source (1253.6 eV photons) at a reduced power of 120 W (12 kV and 10 mA) (Tan *et al.*, 1995).

Results and discussion

As commonly known, infrared light is absorbed by different functional groups in organic compounds and, thus, each compound has a characteristic infrared spectrum. Comparison of infrared spectra can thus unambiguously identify a particular compound.

Figure 1a shows the Fourier transform infrared transmission spectrum of a piece of Grade A jade which has been only wax-buffed, something that is done very often by jewellers to improve the shine of the jade (Ehrman, 1958; Crowningshield, 1972). This does not affect the quality of the jade. Note that relative to the characteristic absorption of jadeite between 3800 – 3200 cm^{-1} , the peaks from the wax at 2920 cm^{-1} and 2852 cm^{-1} are much weaker, showing that the concentration of the wax is quite low.

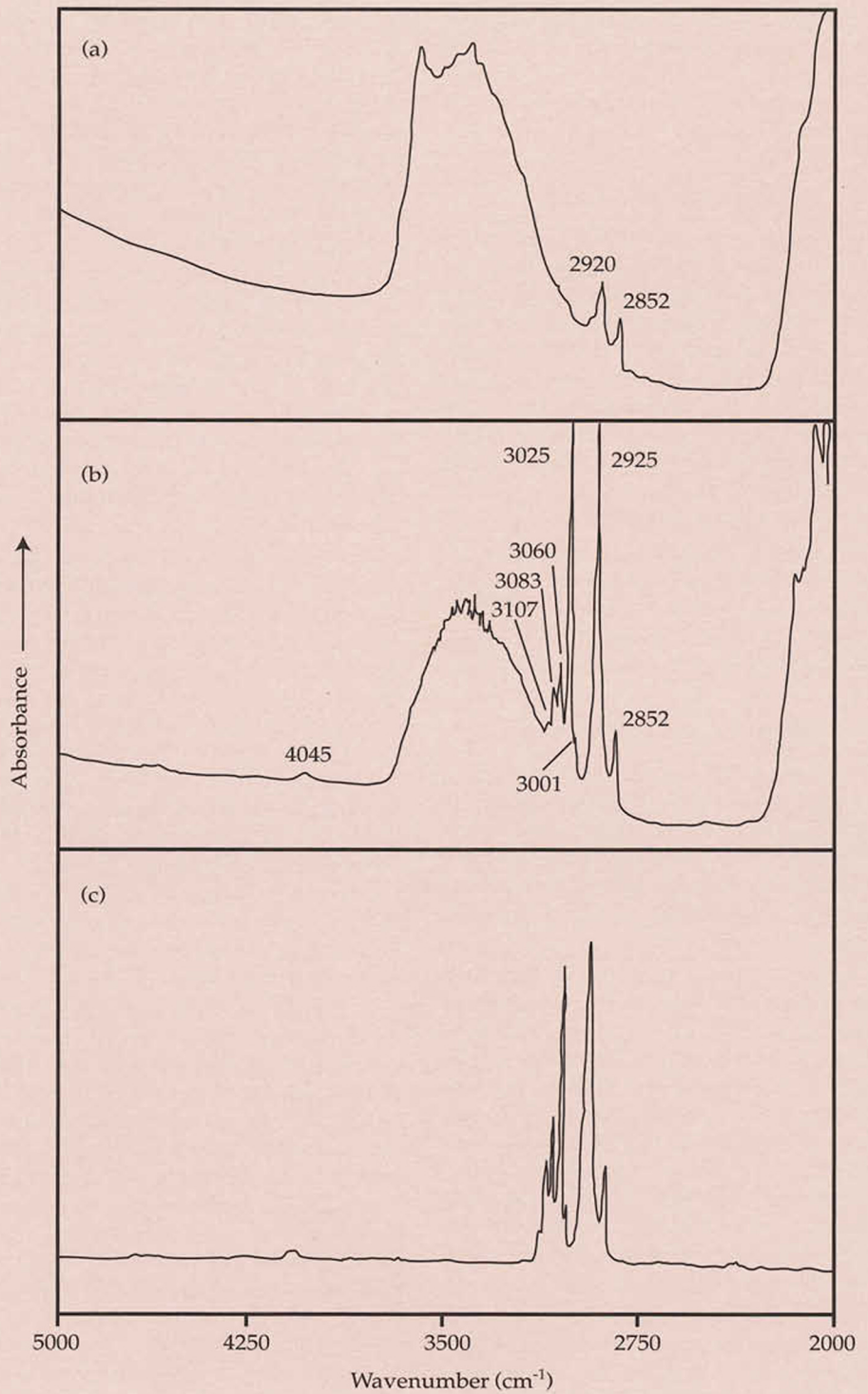
Figure 1b, in comparison, shows the spectrum of the piece of bleached and polymer-impregnated jadeite examined in the present study. New absorption peaks are

shown in comparison with Figure 1a at 4045 cm^{-1} , 3107 cm^{-1} , 3083 cm^{-1} , 3060 cm^{-1} , 3025 cm^{-1} , 3001 cm^{-1} , 2925 cm^{-1} and 2852 cm^{-1} . Fritsch and McClure (1993) also obtained a Fourier transform infrared transmission spectrum with identical peaks compared to Figure 1b, and both spectra match polystyrene's Fourier transform infrared transmission spectrum above 2000 cm^{-1} shown in Figure 1c.

Polystyrene is made of two main parts: an aliphatic component (CH_2) and an aromatic component (C_6H_5). The aromatic component comes from a single benzene ring occurring in every monomer unit. The monomer of polystyrene is styrene, named systematically as phenylethene. A clearer chemical formula is $[-\text{CH}_2=\text{CH}(\text{C}_6\text{H}_5)-]_n$, which indicates quite clearly the arrangement of atoms in polystyrene.

The two peaks at 2852 cm^{-1} and 2925 cm^{-1} correspond to the symmetric and asymmetric C–H stretches of the CH_2 group in polystyrene respectively. These strong peaks are superimposed on the wax absorption peaks if there is any wax present. The CH_2 is the aliphatic group in the polymer, and the two peaks correspond to the normal 2960 – 2850 cm^{-1} absorption frequency of aliphatic C–H bonds. Aromatic C–H bonds, however, reveal an absorption in a region of slightly higher wavenumber, between 3100 cm^{-1} and 3000 cm^{-1} and the absorption peaks at 3107 cm^{-1} , 3083 cm^{-1} , 3060 cm^{-1} , 3025 cm^{-1} and 3001 cm^{-1} in the polystyrene spectrum are attributed to this cause.

For further confirmation of the identity of the polymer, the X-ray photoelectron spectrum of the jadeite sample was collected at low and high resolutions. Many of the functional groups in organic compounds shift the value of the primary C 1s chemical shift from its standard position at 285.00 eV . This shift can be accurately measured and thus, the functional groups in the compound can be determined. In our study, the range of binding energies between 280 eV to 295 eV was scanned to show the C 1s chemical shift in the jadeite sample. This was also compared against standard spectra to confirm the identification of the polymer. It



was found that the ratio of the C 1s peak to the Na 1s peak in the low-resolution spectrum is more than 40, a positive identification for polymer impregnation in jadeite reported in Tan *et al.* (1995).

Figure 2a shows the high-resolution X-ray photoelectron spectrum of the impregnated jadeite sample from 280 to 295 eV. There is an extremely intense peak at 285 eV composed of both aliphatic and aromatic carbons, which, because of their great similarity in eV values, are superimposed as one peak. The small peak at 287 eV corresponds to the C–O group. This peak is present because the jadeite samples were cleaned with highly volatile propanol (propyl alcohol) before spectra were collected, and some of the propanol is still present as an impurity. This peak is not seen in Figure 2b, which shows the high-resolution X-ray photoelectron spectrum of polystyrene. The peak due to the C–OH group in propanol is not seen on the infrared spectrum because the C–O group absorbs infrared light at wavenumber 1300–1000 cm^{-1} and the O–H bond absorbs infrared light at wavenumber 3550–3230 cm^{-1} . In these two regions jadeite absorbs infrared light very strongly, and thus, the C–OH peaks due to propanol are obscured.

However, the most distinguishing feature of the high-resolution X-ray photoelectron spectrum (Figure 2a) is the ‘shake-up’ feature between 292 and 295 eV. This is caused by the conjugation between the 2p orbitals of the carbon atoms in the phenyl group resulting in a π orbital being formed. The ‘shake-up’ is characteristic of aromatic and unsaturated systems, and this particular pattern of ‘shake-up’ is characteristic of polystyrene (Figure 2b) (Beamson and Briggs, 1992). This shows clearly that the polymer present on the jadeite surface is polystyrene.

Properties of polystyrene and polystyrene impregnated jadeite

The properties of polystyrene which make it suitable for jade impregnation are as

follows: it is hard, cheap, readily available, has low moisture absorption, is easy to fabricate and has surface smoothness and clearness (Sprouse and Hansen, 1987). All these characteristics make it easy for impregnation to be carried out, yet make detection extremely difficult, especially when only small amounts of the polymer are used.

As mentioned before, polystyrene was reported as an unidentified polymer (Polymer 5) in Fritsch and McClure (1993). The jadeite samples at that time were reported to ‘sweat’ when tested with the Temperature Reaction Tester (TRT) and float in methylene iodide (specific gravity 3.32). This is consistent with the physical properties of polystyrene, which has a glass transition temperature of 100°C and is thus expected to cause the jadeite sample to ‘sweat’ easily. In addition, polystyrene’s relative density of 1.047 would result in a significant decrease in the specific gravity of jadeite treated with polystyrene and cause it to float in methylene iodide.

Another important point to note is that polystyrene degrades under ultra-violet light and this could be the reason why some treated jadeites turn dark and have a greyish colour after some time, a feature reported by Fritsch *et al.* (1992).

Conclusion

In this paper, we have made use of two spectroscopic techniques to study a sample of bleached and impregnated jadeite and have identified the polymer used in the impregnation to be polystyrene; a substance that is cheap and commonly available, and yet has many characteristics which make it effective in jadeite impregnation. Further studies on the identification of polymers would be useful when looking for alternative methods of discrimination between Grade A and B jadeites.

Figure 1: (a) Fourier transform infrared transmission spectrum of a sample of wax-buffed jadeite. (b) Fourier transform infrared transmission spectrum of the bleached and polymer-impregnated jadeite sample used for this study. (c) Fourier transform infrared transmission spectrum of polystyrene

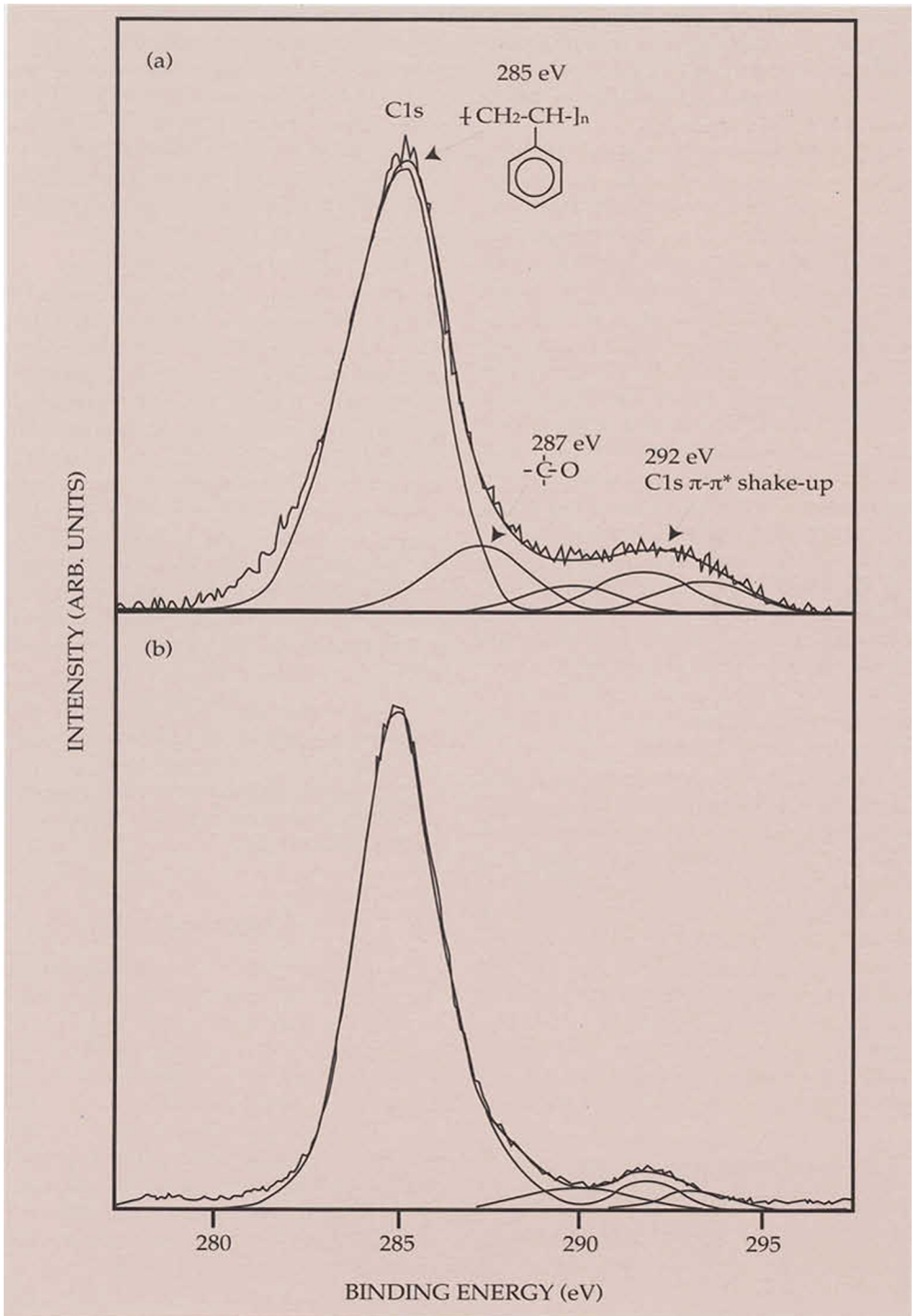


Figure 2: (a) High-resolution X-ray photoelectron spectrum of the bleached and polymer-impregnated jadeite sample (from 280 to 295 eV). (b) High-resolution X-ray photoelectron spectrum of polystyrene.

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Emeralds from Sandawana, Zimbabwe: the use of Raman microspectroscopy in identification of their solid inclusions

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ABSTRACT: For the first time, Raman microspectroscopy has been used as a tool to identify mineral inclusions in emeralds from Sandawana, Zimbabwe. Spectra of emerald, actinolite, cummingtonite, albite, apatite, calcite, Mn-Fe-bearing dolomite and quartz are presented and discussed. Correct characterisation and identification of solid inclusions in Sandawana emeralds could not be carried out by Raman microspectroscopy alone, but is effective in conjunction with chemical analysis by electron microprobe. By these means, inclusions of chromium-rich ilmenorutile have been identified; this variety has not been known and described before.

Keywords: Raman microspectroscopy, Sandawana, solid inclusions, chromian ilmenorutile

Introduction

Zimbabwe's Sandawana mines have been an important producer of emeralds for 40 years. The emerald deposits are located 65 km south of the village Mberengwa (or 68 km east of West Nicholson), in the Mweza greenstone belt. The mining lease and claim holdings cover a 21-km-long strip along the southern slope of the Mweza Hills, on which three mines, named Zeus, Aeres and Orpheus, are currently producing. The name 'Sandawana' refers to the entire mining area, and the emeralds mined there.

The Archaean Mweza greenstone belt consists of a series of intensely deformed and moderately metamorphosed ultramafic-to-mafic volcanic rocks and metasediments. It

also contains numerous relatively small pegmatite bodies that intruded mostly the southern limb of the belt, during a main deformation event in the area, around 2.6 billion years ago. Emeralds occur near the pegmatites at the contact with (ultra)mafic lavas; they are concentrated in pockets at sites where the pegmatite is tightly folded and/or the rocks are sheared.

Mining at the largest mine (the Zeus mine) is done underground, with the ore processed in a standard washing/screening trommel plant. Since the Sandawana mines came under new ownership in 1993, consistent production of emeralds has been established. In addition to the small sizes for which Sandawana is best known, more polished stones up to 1.50 ct have been produced.

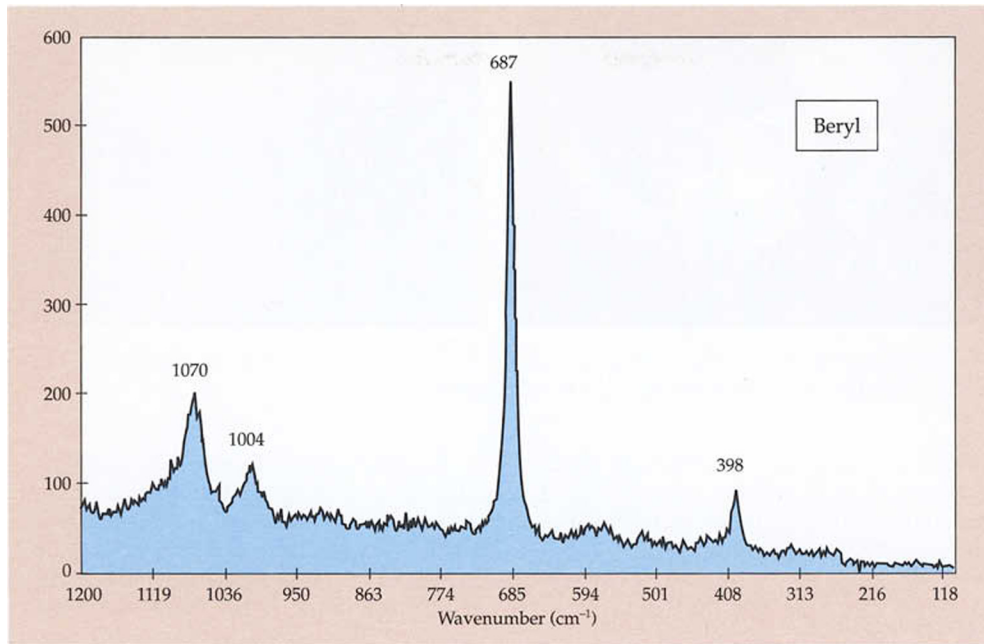


Figure 1: Raman spectrum of emerald with characteristic peaks at 1070 and 687 cm^{-1} .

Because of their relatively constant properties Sandawana emeralds can be readily separated from emeralds from other localities worldwide. They have high refractive indices and specific gravities, and chemically, they have very high chromium and sodium contents. Two amphiboles, actinolite and cummingtonite, are abundant inclusions; albite and apatite are common. Also found are remnants of fluid inclusions.

Soon after their discovery, characteristics of Sandawana emeralds were described by Gübelin (1958), while much later Böhme (1982) described the paragenesis of the emerald and the geology of the Sandawana area. Anderson (1978) gave information on the occurrence and mineralogy of emeralds in Zimbabwe, with additional data on Sandawana emeralds. An update and overview of the geology, mining, physical properties and chemistry of emeralds from Sandawana, brief descriptions of the most common inclusions in them, and a comparison with properties of emeralds from other occurrences, are given in Zwaan *et al.* (1997). This paper gives more

information on the solid inclusions (especially the rarer ones) and also aims to evaluate to what extent non-destructive identification of these inclusions could be carried out with the aid of a Raman microprobe.

Raman microspectroscopy in gemmology

The Raman technique and its instrumentation is thoroughly described in McMillan and Hofmeister (1988), McMillan (1989) and Williams *et al.* (1994). McMillan (1989) gives an overview of applications of Raman spectroscopy, which include applications in structural studies of silicate glasses and melts, study of dissolution mechanisms of volatiles (H_2O , CO_2 , H_2) in aluminosilicate melts and glasses, study of the structure of aqueous fluids and liquids, study of geochemical fluids at high temperatures and high pressures, studies of phase-transitions in solids, and micro-Raman analysis of fluid inclusions which has been used successfully for qualitative and

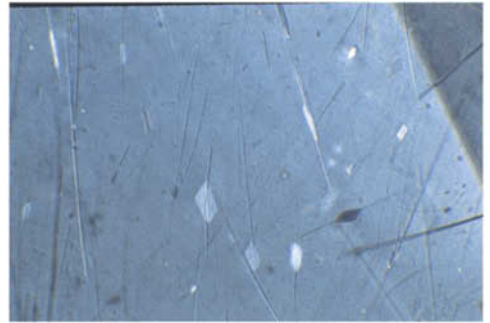
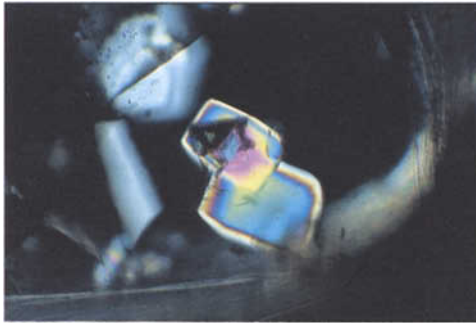
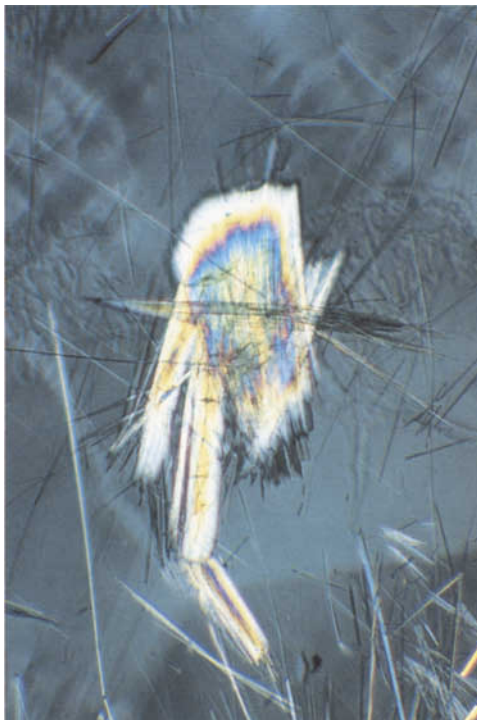


Figure 2a and b: Emerald inclusions in emerald, in transmitted light between crossed polarising filters. Magnified 100x. Photomicrographs by J.C. Zwaan.

quantitative analyses of molecular species, such as CO₂, CO, CH₄, N₂, H₂, O₂ and H₂S (e.g. Burke and Lustenhouwer, 1987; Van den Kerkhof, 1988; Burke, 1994).

Figure 3: Actinolite (large long prismatic crystal) and cummingtonite (long prismatic crystal on the left, showing twinning) are common amphiboles in emeralds from Sandawana. Transmitted light, magnified 10x. Photomicrograph by J.C. Zwaan.



Applications of Raman spectroscopy in identification of minerals and gems and solid inclusions in them are described by e.g. Dhamelincourt and Schubnel (1977), Delé-Dubois *et al.* (1980), Nassau (1981), Griffith (1987), Schubnel (1992), Pinet *et al.* (1992), Lasnier (1995) and Hänni *et al.* (1997). One of the earliest applications of Raman microspectroscopy to the identification of solid inclusions in emeralds was carried out by Rosasco and Roedder (1979). This paper presents another application, which shows advantages but also limitations of this technique.

Materials and methods

For this study, 68 emerald specimens were examined in detail, of which 36 were polished. Almost all the rough material was transparent and suitable for cutting. Inclusions were identified using a standard gemmological microscope (Super 60 Zoom Gemolite Mark VII), a polarisation microscope (Leica DMRP Research microscope) and a laser Raman microspectrometer (Dilor S.A. model Microdil-28®). Polished thin sections were prepared from 11 samples, and semi-quantitative and quantitative chemical analyses on the inclusions were carried out with EPMA (Electron Probe Micro Analysis, JEOL model JXA-8800M). Both Raman and EPMA analyses were performed at the Faculty of Earth Sciences, Vrije Universiteit Amsterdam.

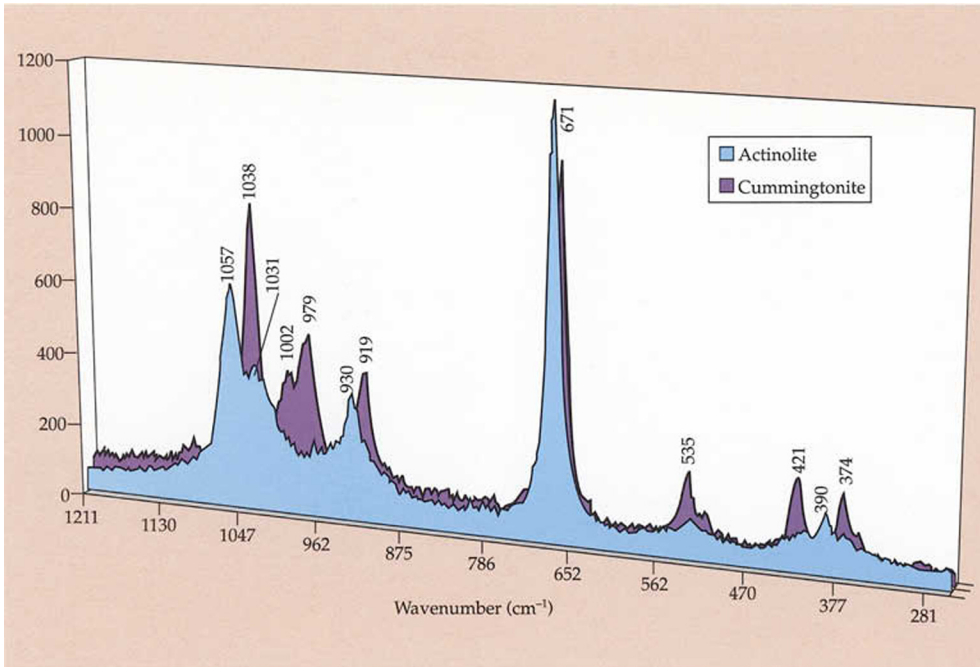


Figure 4a: Raman spectra of actinolite and cummingtonite, both clin amphiboles, which show a characteristic peak near 670 cm^{-1} .

Results

Emerald

Emeralds from Sandawana show a Raman spectrum of beryl (Figure 1) with characteristic peaks at 1070 and 687 cm^{-1} . In addition to these peaks, Pinet *et al.* (1992) showed others at 1011 , 526 , 400 and 325 . Our spectra showed only additional peaks near 1004 and 398 cm^{-1} . In some emeralds, emerald inclusions occur as crystals with a very low relief and a slightly different orientation, which can be viewed best between crossed polarising filters (Figure 2). The inclusions and the host show the same Raman spectrum of beryl.

Amphiboles

The most common and well known inclusions in the emeralds from Sandawana are acicular amphibole crystals. In this study two amphiboles were identified, actinolite and cummingtonite (Figure 3). Both minerals are equally abundant and occur as fibres as well as long-prismatic crystals.

Figure 4b: Raman spectra of the OH stretching modes of actinolite and cummingtonite.

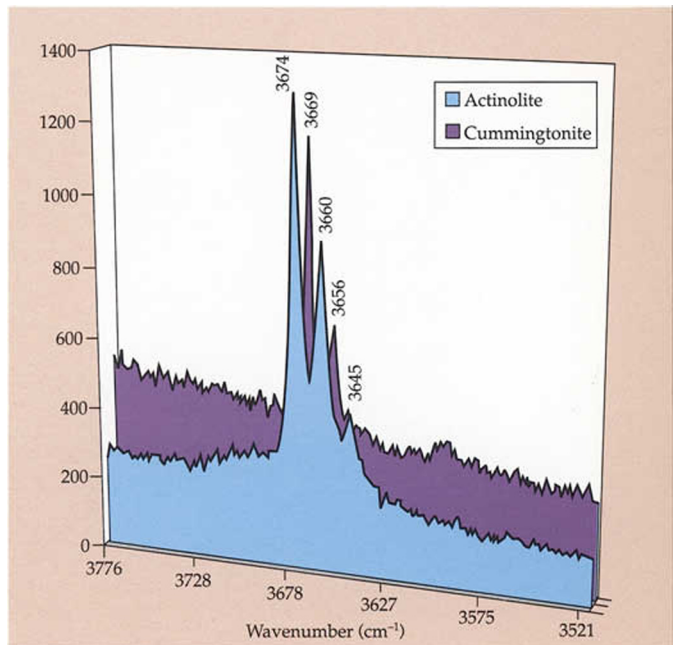


Table I. Chemical analyses of the actinolite and cummingtonite crystals, of which Raman spectra are shown in Figure 4.

Oxides (wt. %)	Actinolite	Cummingtonite	
SiO ₂	54.1	56.4	
TiO ₂	0.05	-	
Al ₂ O ₃	2.91	0.45	
Cr ₂ O ₃	0.31	0.13	
FeO	8.40	15.8	
MnO	0.41	0.66	
MgO	18.3	22.7	
CaO	11.9	0.61	
Na ₂ O	0.96	0.19	
K ₂ O	0.06	-	
H ₂ O*	2.01	2.11	
F	0.13	-	
Total	99.55	99.05	
Cations based on 22 O and 2 (OH,F,Cl).			
	Minimum Fe ³⁺	Maximum Fe ³⁺	
Si	7.67	7.59	8.00
Al IV	0.33	0.41	0
T site	8.00	8.00	8.00
Al VI	0.16	0.08	0.07
Fe ³⁺	0	0.20	0
Ti	0.01	0.01	0
Cr	0.04	0.04	0.01
Mg	3.87	3.83	4.79
Fe ²⁺	0.94	0.79	0.12
M1, 2, 3 sites	5.00	5.00	5.00
Fe ²⁺	0.06	0	1.75
Mn	0.05	0	0.08
Ca	1.81	1.79	0.09
Na	0.08	0.21	0.05
M4 site	2.00	2.00	1.97
Na	0.19	0.06	0
K ⁺	0.01	0.01	0
A site	0.20	0.07	0
OH	1.90	1.90	2.00
F	0.10	0.10	0
Anion	2.00	2.00	2.00

- not detected

* calculated

All ferrous formulae for both amphiboles are permitted, for cation sums are not too high. Thus formula were calculated based on a minimum Fe³⁺ estimate = 0.000 (Compare Leake *et al.*, 1997). For an explanation of the actinolite formula based on a maximum Fe³⁺ estimate, see the text.

Table II. Chemical analyses of two large albite (NaAlSi₃O₈) grains*. Albite is the only feldspar that has been identified in emeralds from Sandawana.

Oxides (wt. %)	ALB 1	ALB 2
SiO ₂	66.8	67.3
Al ₂ O ₃	20.2	20.4
FeO	0.01	0.18
CaO	0.84	0.91
Na ₂ O	11.3	11.3
K ₂ O	0.04	0.03
Total	99.19	100.12
Cations based on 8 O.		
Si ⁴⁺	2.95	2.95
Al ³⁺	1.05	1.05
Fe ²⁺	0	0.01
Ca ²⁺	0.04	0.04
Na ⁺	0.97	0.96
K ⁺	0	0
Number of cations	5.01	5.01

*ALB 1 is feldspar I in Figure 6.

Cummingtonite may be distinguished from actinolite by its higher relief and lamellar twinning, which was seen under a microscope in transmitted and polarised light. However, both amphiboles are often intergrown and with a normal gemmological microscope it is in most cases not possible to

Figure 5a: A large grain of feldspar (feldspar I in Figure 6) turned out to be albite. The lozenge-shaped crystal underneath it is identified as cummingtonite. Transmitted light, magnified 100x.

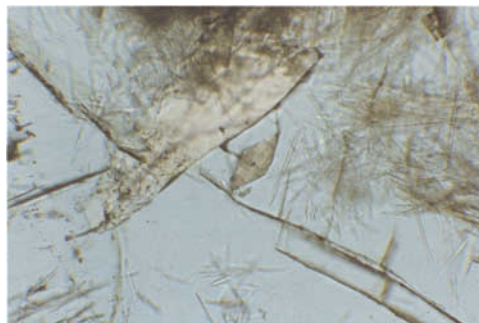




Figure 5b: Small idiomorphic albite crystals frequently occur in emeralds from Sandawana. The Raman spectrum of this crystal is shown in Figure 6 (feldspar II). Transmitted light, magnified 175x.

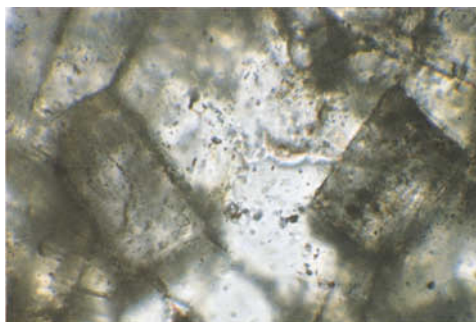


Figure 5c: Two slightly brownish to white crystals of albite, surrounded by minute inclusions, mostly also albite. The Raman spectrum of the crystal on the left is shown in Figure 6 (feldspar III). Transmitted light, magnified 175x. Photomicrographs by J.C. Zwaan.

make a distinction. Raman spectra of the two amphiboles are shown in Figure 4a and b.

Both actinolite and cummingtonite show a very strong peak at 671 cm^{-1} , which is characteristic for all clin amphiboles (e.g. Pinet *et al.*, 1992). Various peaks are recorded near 1000 and 3650 cm^{-1} . The identities of actinolite and cummingtonite were confirmed by chemical analysis (Table I).

Feldspar

Feldspar is very common in emeralds from Sandawana and shows various morphologies. It may occur as large tabular fragments, as small idiomorphic to slightly rounded, colourless crystals or as whitish to slightly brownish crystals surrounded

Figure 6: Raman Spectra of feldspars with different morphology. The spectra show the same peaks, which all correspond to the spectrum of albite feldspar.

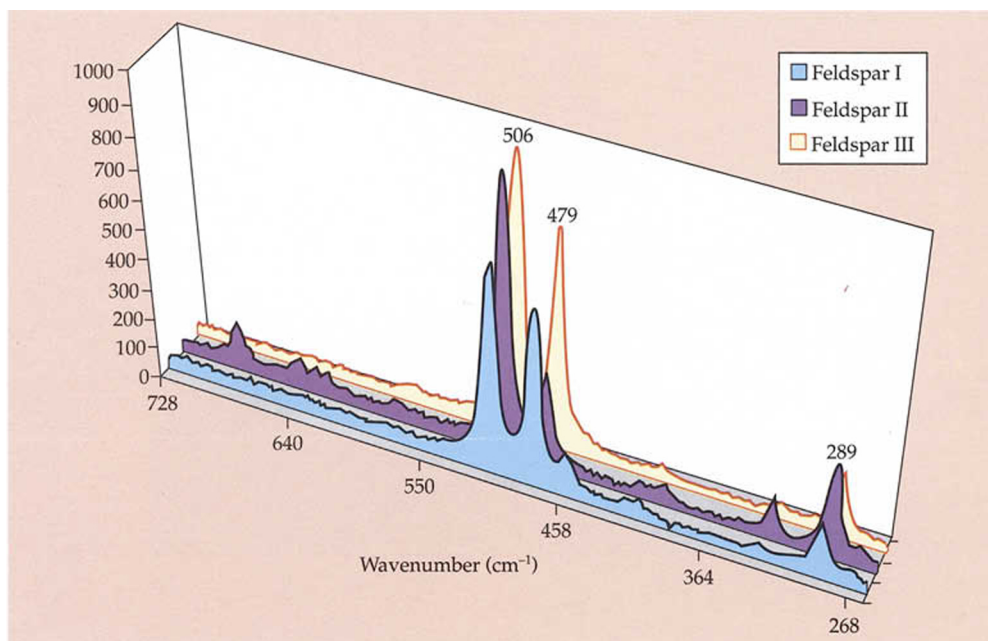




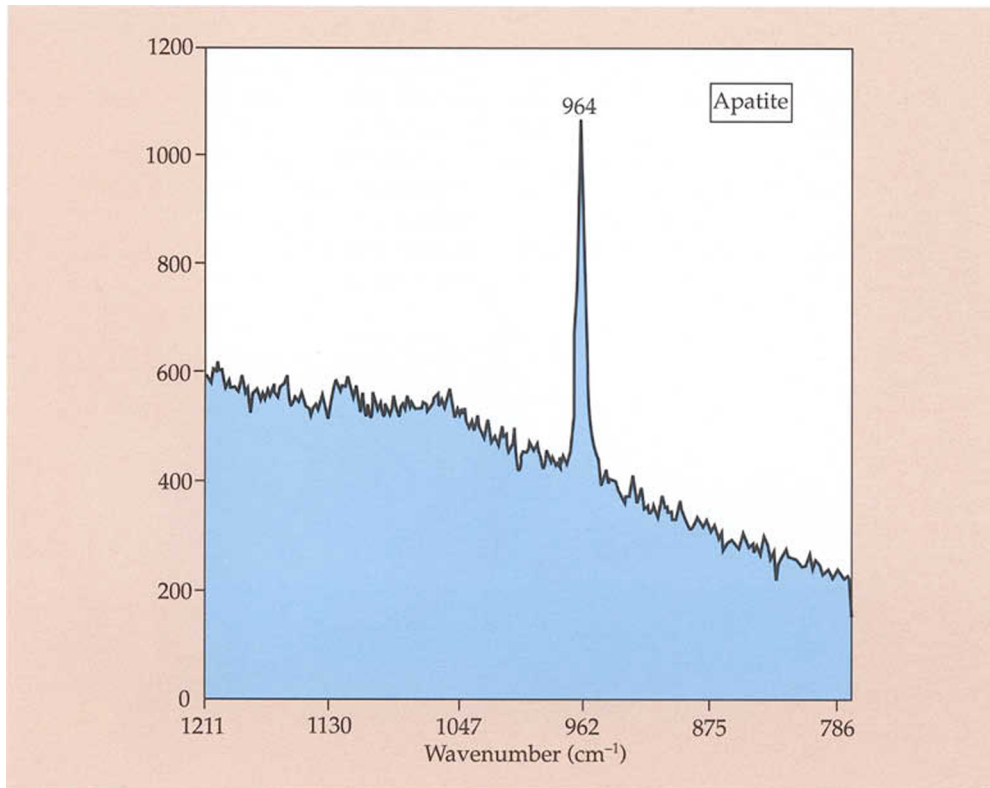
Figure 7: Idiomorphic apatite inclusion in Sandawana emerald; its Raman spectrum is shown in Figure 8. Transmitted and conoscopic light, magnified 175x. Photomicrograph J.C. Zwaan.

by minute inclusions (Figure 5a, b and c). The Raman spectra of the three habits are shown in Figure 6.

The spectra of the feldspars with different habits are very similar. Although the intensity of the peaks may vary, due to different crystallographic orientations of the inclusions, they are all in the same positions. The most important peaks that were recorded are at 506, 479 and 289 cm^{-1} .

These similar spectra indicate that the various crystals represent just one particular kind of feldspar. Compared to the spectra of feldspars published by Pinet *et al.* (1992) and Hänni *et al.* (1997), our spectra corresponded mostly to the spectrum of albite, which was confirmed by chemical analyses as $\text{Ab}_{96}\text{An}_4$ (Table II).

Figure 8: Raman spectrum of apatite, with one diagnostic peak at 964 cm^{-1} , and an increasing background towards higher wavenumbers due to fluorescence.



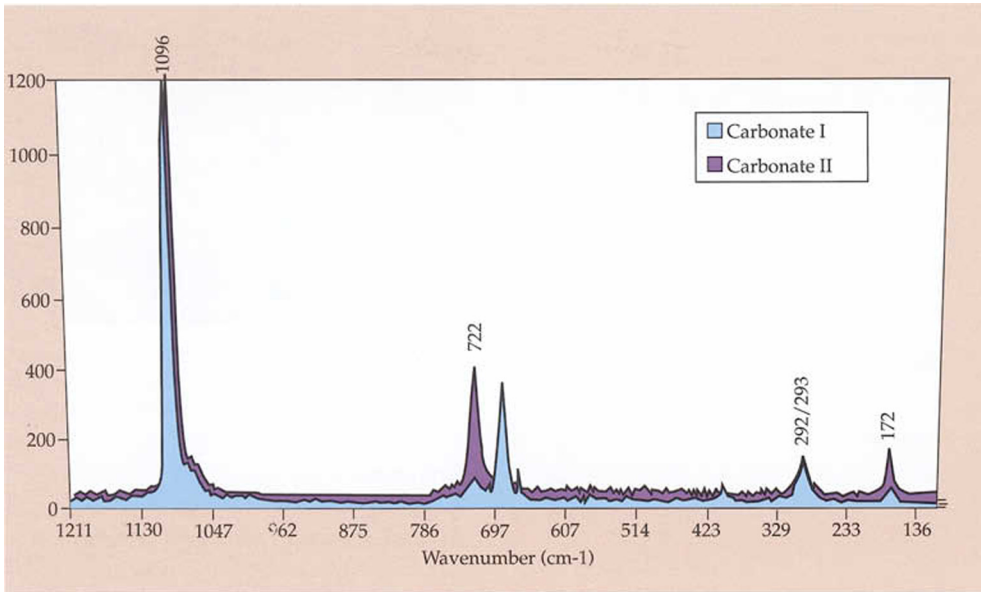


Figure 9: Different grains of a common carbonate in Sandawana emeralds produced similar spectra. Chemical analysis of the carbonate shows it to be a dolomite. The peaks at 687 and 399 cm^{-1} are caused by emerald.

Apatite

Like albite, apatite frequently occurs in emeralds from Sandawana, and also shows various morphologies. It occurs as transparent, often colourless idiomorphic crystals, either isolated or in clusters, and as rounded crystals with more irregular surfaces (Figure 7). The apatite and albite crystals can appear very similar, although most apatite

inclusions are very small. The Raman spectrum of apatite is characteristic with a peak at 964 cm^{-1} (Figure 8) and therefore provides a quick and reliable identification.

In fact, the Raman spectrum of apatite was so prominent (it caused abundant fluorescence), that it was not possible to analyse inclusions in apatite crystals, which occur in emerald-bearing amphibole schist at Sandawana.

Table III. Published and previous recorded Raman spectra of carbonates

Mineral	Recorded peaks (cm^{-1})				Reference
Dolomite	1097	725	299	176	a
	1099		300	175	b
Magnesite	1094	738	329		a
Ankerite	1091	720	284		c
Calcite	1085	711	283	156	a
	1086	712	280	153	b
Aragonite	1089	710	209	152	a
	1085	702	206	151	b

a) Burke, 1994.

b) Pinet *et al.*, 1992

c) reference sample Free University, Amsterdam (W. Lustenhouwer)

Table IV. Spot analyses of Carbonate I, a manganese-iron bearing dolomite.

Oxides (wt. %)	1	2
CaO	27.9	28.3
SrO	0.04	0.03
FeO	8.56	7.50
MnO	3.66	3.01
MgO	12.9	14.2
CO ₂ *	46.9	47.0
Total	99.96	100.04
Cations based on 6 O.		
Ca ²⁺	0.96	0.96
Sr ²⁺	0.00	0.00
Fe ²⁺	0.23	0.20
Mn ²⁺	0.10	0.08
Mg ²⁺	0.62	0.67
C ⁶⁺ *	2.05	2.04
Number of cations	3.96	3.95

* C was not measured: CO₂ has been calculated at 100%.

Figure 10: Mn-Fe dolomite is a common carbonate in emeralds from Sandawana, normally as very small and irregular grains, but also as larger elongated grains such as shown here. Between crossed polarising filters this grain shows high order interference colours characteristic for a carbonate. Magnified 100x. The Raman spectrum of this particular grain is shown in Figure 9 (carbonate I). Photomicrograph by J.C. Zwaan.

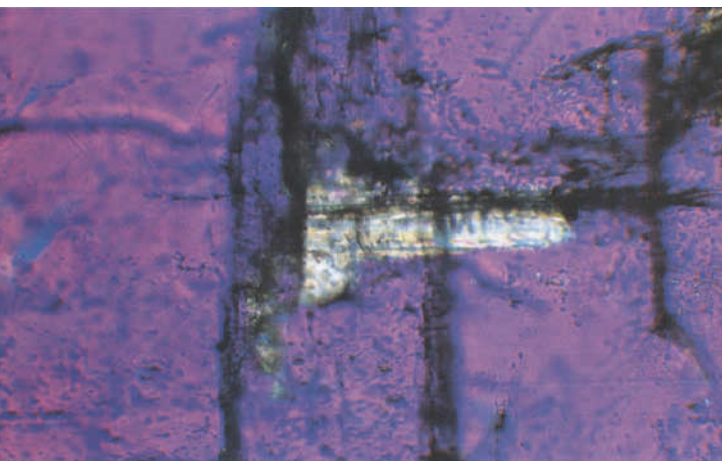


Figure 11: Elongated and parallel quartz crystals occur in some emeralds from Sandawana. Magnified 100x, photomicrograph by J.C. Zwaan.

Carbonates

Two carbonate minerals were identified: calcite and another carbonate which showed ambiguous Raman spectra. Calcite is present in very small grains, which showed characteristic Raman peaks at 1086 and 282 cm⁻¹. The spectra of two other carbonate grains, which show peaks at equal positions, are presented in Figure 9. Both carbonates show peaks at 1096, 722, 292–293, and 172 cm⁻¹.

Comparing these spectra with the published values (Table III), they lie between the spectra of dolomite-CaMg(CO₃)₂ and ankerite-CaFe(CO₃)₂. Chemical analysis proved that the carbonates are Mn-Fe bearing dolomites (Table IV).

Dolomites with similar chemical composition were regularly encountered in Sandawana emeralds, not only as small grains, like calcite, but also as larger, elongated grains (Figure 10). Three dolomites which were chemically analysed contained on average 12.6 wt% MgO, 7.70 wt% FeO, and 3.35 wt% MnO.

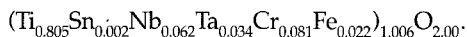
Quartz

Quartz occurs in emeralds from Sandawana as small isolated and rounded grains, and as elongated and tube-like crystals with low relief, which are orientated parallel to the *c*-axis (Figure 11). Because these grains are small and most are not close to the surface, it was not easy to get reliable Raman spectra; however, diagnostic peaks at 466 and 207 cm⁻¹ were obtained from several grains.

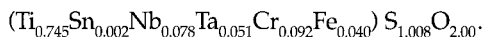
Ilmenorutile

Opaque minerals are rare in Sandawana emeralds but black crystals with submetallic lustre up to 0.7 mm were present in one polished stone (Figure 12). Reliable Raman spectra of these crystals cannot be obtained. Although Raman analysis is in principle non-destructive, the risk of instant oxidation is considerable when one tries to analyse opaque inclusions.

Chemical analysis proved these crystals to be a chromium-iron-niobium-tantalum-titanium oxide (ilmenorutile). From Table V (spot analyses 1–5) and Figure 13 it can be seen that this grain shows a rather homogeneous composition with a very high chromium content. The whitish area at the upper side of the grain shows even higher Cr, but also higher Nb, Ta, Fe and lower Ti (analysis 6). Based on analyses 1–5 the average chemical formula could be written as:



For the whitish area in Figure 13 the formula would be:



The average atomic ratio Nb/Ta is 1.82 (whitish area: Nb/Ta = 1.53). Because the atomic ratio Nb/Ta > 1, this mineral may be

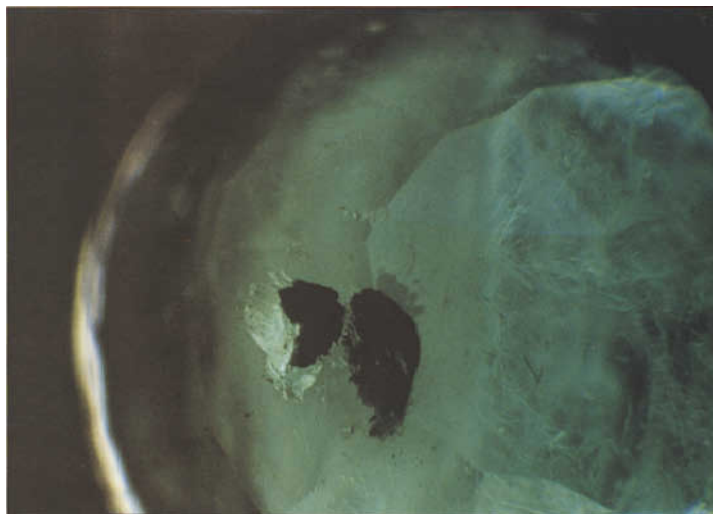


Figure 12: Extremely rare crystals of Cr-ilmenorutile were found in a polished Sandawana emerald. Magnified 60x. Photomicrograph by J.C. Zwaan.

called niobian rutile (preferred by Flinter, 1959 and Cerny *et al.*, 1964) or ilmenorutile (Siivola, 1970), a name which has been used since its discovery in 1854 (if Nb/Ta < 1 the name would be tantalian rutile or strüverite). Other phases that were identified in the analysed grain (Figure 13) are ilmenite and chromite; one grain of probable

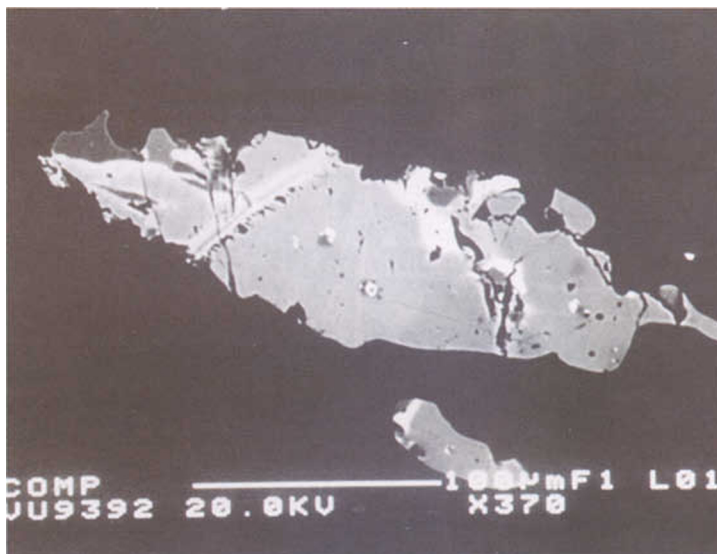


Figure 13: Electron photomicrograph of a chromium rich ilmenorutile grain in Sandawana emerald. The whitish area at the upper side of the grain indicates a lower Ti concentration (and higher Cr, Nb, Ta and Fe concentrations). Other phases include ilmenite (the very dark grey part on the upper left side), chromite (the dark grey part next to it) and tantalite/columbite (the small white speck in the middle of the grain). Photomicrograph by W.J. Lustenhouwer.

Table V. Spot chemical analyses of a chromium-rich ilmenorutile inclusion in emerald from Sandawana.

Oxides (wt.%)	1	2	3	4	5	6
TiO ₂	72.1	71.7	70.3	70.1	70.7	63.7
SiO ₂	0.07	0.07	0.07	0.08	0.07	0.09
SnO ₂	0.38	0.42	0.45	0.45	0.32	0.34
Nb ₂ O ₅	8.81	8.93	9.25	9.39	9.32	11.1
Ta ₂ O ₅	8.23	7.79	8.41	8.15	8.67	12.1
Al ₂ O ₃	0.05	0.04	0.05	0.05	0.05	0.06
Cr ₂ O ₃	6.64	6.85	7.03	6.83	6.62	7.45
FeO	1.80	1.53	1.66	1.75	2.05	3.07
MnO	–	–	–	–	–	–
MgO	–	–	–	–	–	–
CaO	0.02	0.03	0.03	0.03	0.02	0.01
Total*	98.10	97.36	97.25	96.83	97.83	97.92
<i>Cations based on 2 O</i>						
Ti ⁴⁺	0.810	0.810	0.800	0.800	0.801	0.745
Si ⁴⁺	0.001	0.001	0.001	0.001	0.001	0.002
Sn ⁴⁺	0.002	0.003	0.003	0.003	0.002	0.002
Nb ⁵⁺	0.060	0.061	0.063	0.064	0.063	0.078
Ta ⁵⁺	0.033	0.032	0.035	0.034	0.036	0.051
Al ³⁺	0.001	0.001	0.001	0.001	0.001	0.001
Cr ³⁺	0.078	0.081	0.084	0.082	0.079	0.092
Fe ²⁺	0.023	0.019	0.021	0.022	0.026	0.040
Ca ²⁺	–	–	0.001	0.001	–	–
Number of cations	1.008	1.008	1.009	1.008	1.009	1.011

– not detected

* low totals are due to conductivity which was not optimal

tantalite/columbite is too small for microprobe analysis.

Discussion

The acicular amphibole crystals in the emeralds from Sandawana were previously described by various authors (e.g. Gübelin, 1958; Böhmke, 1982; Gübelin and Koivula, 1992) as tremolite needles or fibres. From results in our study, it became apparent that the amphiboles present are actinolite and cummingtonite but not tremolite.

The particular actinolite of which the Raman spectrum is shown, is magnesium-rich; the analysis (Table I) shows a Mg/Mg + Fe²⁺ ratio = 0.79, which is slightly higher than the maximum ratio of 0.74, which was previously indicated (Zwaan *et al.*, 1997). The indicated ratio is based on a minimum ferric estimation. In order to define the range of possible formulae and possible names for this particular amphibole (as recommended by Leake *et al.*, 1997), the formula for the maximum ferric estimate has also been calculated (Table I). From this

calculation the $\text{Mg}/\text{Mg} + \text{Fe}^{2+}$ ratio = 0.83, which is still consistent with naming the amphibole actinolite.

Unfortunately, very few Raman spectroscopic investigations of amphiboles have been reported (e.g. Wang *et al.*, 1988) and it should be noted that many amphiboles show strong fluorescence, which generally masks their Raman spectra. It is therefore difficult to obtain good Raman spectra and to interpret them correctly.

In *Figure 4a* the strong peak at 671 cm^{-1} is caused by the Si–O–Si bonds, but the peaks near 1000 cm^{-1} are difficult to interpret (Pinet *et al.*, 1992). The peaks near 3650 cm^{-1} (*Figure 4b*) are caused by the OH stretching vibrations. These spectra are used to study the cation distribution in amphiboles (Wang *et al.*, 1988). In this region, the recorded peaks of actinolite (3674 , 3660 and 3645 cm^{-1}) and cummingtonite (3669 and 3653 cm^{-1}) closely correspond to the positions of the peaks, published by Wang *et al.* (1988). Some other peaks published by them were not recorded in this study, probably due to the variability of peak intensity with crystal orientation. Because the resolution of these spectra is not high enough, it is at present not possible (even with the use of the most sophisticated Raman spectrometers) to positively identify a particular clin amphibole solely on the basis of positions of the peaks caused by OH (see also Wang *et al.*, 1988). Therefore chemical analysis on the surface of a sample is still needed to confirm the identity of a particular amphibole.

Considering the spectra of nearly pure albite, peaks were recorded at 506 , 479 and 289 cm^{-1} . According to Pinet *et al.* (1992), albite should show peaks at 510 , 482 and 294 cm^{-1} , while Hänni *et al.* (1997) reported peaks at 505 , 477 and 288 cm^{-1} in this region.

Apatite shows a characteristic Raman spectrum, but may produce such fluorescence that identification of its inclusions by Raman spectrometry is not possible. Both apatite and albite have not been reported as inclusions in Sandawana emerald by previous authors, although Gübelin (1958) and Anderson (1978) mentioned the presence of 'decomposed

feldspar' and Böhmke (1982) mentioned the presence of plagioclase feldspar and apatite in the ore-zone.

Mn–Fe bearing dolomite has not been reported before in Sandawana emerald. Raman spectra of this particular dolomite (peaks at 1096 , 722 , 292 – 293 , and 172 cm^{-1}) are distinctly different from the previously published spectra of (normal?) dolomites (see *Table III*). These spectra may be difficult to distinguish from spectra of ankerite, another member of the dolomite group. A solid solution series exists between dolomite– $\text{CaMg}(\text{CO}_3)_2$, ankerite– $\text{CaFe}(\text{CO}_3)_2$ and kutnohorite– $\text{CaMn}(\text{CO}_3)_2$. Naturally occurring dolomite deviates somewhat from $\text{Ca}:\text{Mg} = 1:1$ with the $\text{Ca}:\text{Mg}$ ratio ranging from $58:42$ to $47.5:52.5$ (Klein and Hurlbut, 1993). The $\text{Ca}:\text{Mg}$ ratio of carbonate I (*Table IV*) varies between $60:40$ and $59:41$; which is very close to the ratios of dolomite. The slightly lower magnesium content is compensated by the presence of iron (ankerite component) and manganese (kutnohorite component). The chemical formula of the analysed Mn–Fe bearing dolomite in *Table IV* can be written as $\text{Ca}_{0.96}(\text{Mg}_{0.645}\text{Fe}_{0.215}\text{Mn}_{0.09})(\text{C}_{1.023}\text{O}_3)_2$.

The presence of ilmenorutile as a rare inclusion in Sandawana emerald was mentioned earlier by Böhmke (1982). While Mn-rich ilmenorutile is known from Uzumine, Japan (Kawai, 1960), a chromium-rich variety of ilmenorutile, such as encountered in our study, has not been reported before (see e.g. Cerny *et al.*, 1964; Siivola, 1970). Chromium is not present in ilmenorutile from other localities. Only in ilmenorutile from the type locality in the Ilmen mountains, Urals, Russia, chromium is possibly present in concentrations of $<0.009\%$ (Cerny *et al.*, 1964). While intergrowths of ilmenorutile with ilmenite and columbite are quite common (e.g. Sosedko, 1939; Ando and Nitta, 1941; Noll, 1949; Cerny *et al.*, 1964; Siivola, 1970), the association of ilmenorutile and chromite in Sandawana emerald is the first of its kind.

From this study it appears that in order to identify solid inclusions in gem material correctly, it is still generally necessary to get a (semi-)quantitative chemical analysis of the

inclusions, as support for the initial identification from Raman spectra, or simply as an alternative (e.g. in the case of phlogopite, which was identified in Sandawana emerald by optical microscopy and chemical analysis). In this context the restrictions of the Raman method, as mentioned by e.g. Van den Kerkhof (1988), are still valid: spectra of solids are not easy to interpret, Raman peak intensities are strongly dependent on the crystallographic orientation due to different polarisations of the light in different directions, which means that these intensities cannot be quantified; no direct quantitative information on the composition of the mineral can be obtained, some minerals are strongly fluorescent and some are not or are only weakly Raman active. Consequently, not only a huge database is needed, as indicated by Hänni *et al.* (1997), but also more theoretical understanding of the interaction of light and crystalline material (crystal lattice) is required to make the most of applying Raman microspectroscopy in identification of minerals.

Conclusion

Raman spectroscopy is a useful non-destructive technique to identify not only fluid but also solid inclusions in gemstones. An important advantage of this technique is that it enables us to not only identify inclusions at the surface but also underneath it. However, it also has its limitations. In this study, it appeared that amphiboles and carbonates are difficult to identify correctly, and that opaque minerals may be burnt, which means that in some cases the method might turn out to be destructive. Apatite may produce a fair amount of fluorescence, such that inclusions in it cannot be identified. It became apparent that Raman spectra of dolomites which contain some iron and manganese are distinctly different from the previously published spectra of dolomites. These spectra may be difficult to distinguish from spectra of ankerite, another member of the dolomite group.

Rare large opaque inclusions at the surface of a polished emerald could not be

analysed by Raman but were identified with electron microprobe as chromian-ilmenorutile. This variety has never been reported before, and can thus be considered as extremely rare.

It is concluded that in order to identify solid inclusions in gem material correctly, in many cases it is still necessary to get a (semi-) quantitative chemical analysis of the inclusion, as a backup for the obtained Raman spectrum, or just as an alternative. In order to make the most of applying Raman Microspectroscopy in identification of minerals it is necessary to gain more theoretical understanding of the interaction of light and crystalline materials, and to build a reliable database.

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Diamonds

Pacific Coast diamonds – an unconventional source terrane.

W.D. HAUSEL. *Geology and ore deposits of the American Cordillera: Geological Society of Nevada symposium Proceedings, Reno/Sparks, NV, 2, 1996* 925–34.

Several hundred diamonds have been found along the Pacific Coast of the United States in California, Oregon, Washington and Alaska, for which no known source rock has been identified. The Pacific Coast is an atypical terrain for diamonds and is not considered favourable for the emplacement of diamondiferous kimberlite or lamproite. The postulated source is an obducted ophiolite or alpine peridotite interpreted to have been tectonically emplaced during plate collision. Similar diamond occurrences have been identified at several other collision zones along plate margins in the world. Being derived from an organically-rich oceanic slab, such deposits could be extremely high grade, although relatively small. W.D.H.

The diamond deposits of Myanmar.

U.T. HLAING AND T.T. WIN. *Australian Gemmologist*, 19(11), 1997, 445–7, 1 map, 4 tables.

The three diamond occurrences previously reported in the *Australian Gemmologist* (volume 17, p. 278) are now known as the Theindaw, Toungoo and Momiek deposits. The authors describe the occurrences of the three diamond deposits, their mineral associations and the general features of diamonds. P.G.R.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(3), 1997, 220–30, 13 illus. in colour.

Assessments carried out on the lamproite pipe near Murfreesboro for its economic potential as a diamond mine proved the average diamond content to be 0.005 ct

per ton of ore. This is not enough to support commercial mining so the pipe will remain as a tourist attraction. J.J.

First occurrence of strontian K-Cr loparite and Cr-chevkinite in diamonds.

M.G. KOPYLOVA, R.S. RICKARD, A. KLEYENSTUEBER, W.R. TAYLOR, J.J. GURNEY AND L.R.M. DANIELS. *Russian Geology and Geophysics*, 38, 1997, 405–20. [Proceedings of the sixth International Kimberlite Conference, Vol. 2, Diamonds.]

Strontium-bearing K-Cr loparite and Cr-chevkinite, both Ti-bearing minerals, are identified as radioactive inclusions in diamonds from the River Ranch kimberlite pipe in the Limpopo Mobile Belt, SE Africa. Both minerals are partially replaced by secondary phases. The exotic titanates may indicate metasomatism genetically associated with kimberlite formation processes. M.O'D

Gem Trade Lab notes.

T.H. MOSES, I.M. REINITZ, AND S.F. MCCLURE. *Gems & Gemology*, 33(3), 1997, 212–18, 15 illus. in colour.

A pair of black opaque cabochons (3.55 and 3.56 ct) were proved to be diamonds by a hardness test. It was the first time diamonds have been seen cut as cabochons. A rare fancy vivid faceted diamond was reported to be from South Africa. In the rough it appeared brown with only a hint of orange. It was a type IIa diamond. Recently fracture-filled diamonds have been seen when the flash colour effect was less pronounced due to reheating. A diamond had transparent droplets on the surface possibly caused by the subsequent reheating of the diamond after filling causing the filling to boil over. J.J.

Geothermometry and oxygen barometry of coexisting iron-titanium oxides of Majhgawan diamondiferous pipe, Madhya Pradesh.

A. MUKHERJEE, K.S. RAO, D. BANDYOPADHYAY, G. ROY AND A.K. CHATTERJEE. *Journal of the Geological Society of India*, 49(1), 1997, 55–60.

Abstractors

R.K. Harrison R.K.H.
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R.A. Howie R.A.H.
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J. Johnson J.J.
B.E. Leake B.E.L.
M. O'Donoghue M.O'D.
G. Raade G.R.

P.G. Read P.G.R.
R.E. Samson R.E.S.
E. Stern E.S.

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

Geothermometry of the coexisting magnetite-ilmenite pair from this diamondiferous pipe indicates a T of 1150°C. The values of f_{O_2} , T and P fall in the equilibria field defined by iron-wüstite and wüstite-magnetite, indicating depth of sampling of ~155 km and P 46 kbar. The Majhgwan pipe is the only diamond-producing primary source in India and has an annual capacity of 29 000 ct. R.A.H.

Petrology and geochemistry of kimberlite pipe 11 of Chigicherla area, Anantapur district, Andhra Pradesh, south India.

D.S.N. MURTHY, A.M. DAYAL, R. NATARAJAN, V. BALRAM AND P.K. GOVIL. *Journal of the Geological Society of India*, 49(2), 1997, 123–32.

This kimberlite pipe contains two generations of olivine with phlogopite, spinel, perovskite and melilite. A comparative study with other kimberlite pipes in the area indicates that Zr–Hf, Nb–Ta and Th–U have a high degree of correlation; the ratios of Ba/Nb (< 10), Zr/Hf (~ 50) and Nb/Zr (> 0.5) are similar to those of group-I kimberlites). The chondrite-normalized REE pattern of pipe 11 is similar to that of other kimberlites and shows enrichment of LREE. The incompatible trace elements indicate similarity with OIB or other types of alkaline intraplate volcanic rocks. The major element chemistry and Ce/Yb and La/Yb ratios suggest that the formation of kimberlite was due to a low degree of partial melting of an ultrabasic source along with an earlier subducted oceanic lithosphere. R.A.H.

Fifty years of the Diamond Research Laboratory.

C. OWERS. *Industrial Diamond Review*, 57(575), 1997, 109–11, 9 illus.

The author traces the history of De Beers Diamond Research Laboratory from the laying of its foundation stone by Sir Earnest Oppenheimer in March 1947 to its 50th anniversary celebrations attended by the outgoing Chairman of De Beers, Julian Ogilvie Thompson and his successor Nicky Oppenheimer.

During its first half century of operation, the laboratory, through its mineral processing division, developed technology for the mining, extraction and sorting of diamond using surface characteristics, X-rays, colour and thermal properties. Although diamond for industrial use was initially limited to grit produced from the crushing and processing of boart, when the synthesis of diamond was achieved in the '50s, the laboratory, through its synthesis division, was also in the forefront of that research. Although its actual formal success in diamond synthesis followed the scientific breakthroughs by ASEA in Sweden and GE in the USA, it became one of the leaders in the development of a range of natural and synthetic abrasive products. P.G.R.

Trace element analyses of fluid-bearing diamonds from Jwaneng, Botswana.

M. SCHRAUDER, C. KOEBERL AND O. NAVON. *Geochimica et Cosmochimica Acta*, 60(23), 1996, 4711–24.

Trace element analyses using INAA are reported for 13 fibrous diamonds previously examined by EPMA and Fourier-transform IR spectroscopy. Concentrations of incompatible elements (K, Na, Br, Rb, Sr, Zr, Cs, Ba, Hf, Ta, Th, U and the LREE) are higher in the water- and carbonate-rich fluids in microinclusions than are those of primitive mantle, mantle-derived melts or melt inclusions in low- P peridotites. Cr, Co and Ni are similar in abundance to those of primitive mantle. Minerals in equilibrium with the fluids must have already been enriched in K, Ti and many incompatible elements, and the fluids were not derived by partial melting of common peridotites or eclogites. The major and trace element compositions of the trapped fluids in fibrous diamonds confirm that at P compatible with those of the diamond stability field, carbonatitic and hydrous fluids can be efficient carriers of incompatible elements, and such fluids are common in the mantle. R.K.H.

Geology of the Sturgeon Lake 01 kimberlite block, Saskatchewan.

B.H. SCOTT SMITH, J.P. LETENDRE AND H.R. ROBISON. *Exploration & Mining Geology*, 5(3), 1996, 251–61.

This kimberlite, found by heavy mineral sampling and shown to be diamondiferous but not economic, was the first to be discovered in Saskatchewan. The body, a 98 m.y.-old glacially-transported megablock, occurs within glacial sediments overlying Cretaceous bedrock shale. Marine shale of a similar age occurs adjacent to the kimberlite and appears to represent a separate glacial block. The kimberlite is typical of Group 1, containing two generations of olivine, macrocrysts of ilmenite, garnet, spinel and mica together with ground-mass mica, spinel, perovskite, apatite, carbonate and serpentine. R.E.S.

The origins of Yakutian eclogite xenoliths.

G.A. SNYDER, L.A. TAYLOR, G. CROZAZ, A.N. HALLIDAY, B.L. BEARD, V.N. SOBOLEV AND N.V. SOBOLEV. *Journal of Petrology*, 38(1), 1997, 85–113.

Major, trace and REE mineral chemistry of clinopyroxenes and garnets (pyrope, grossular, almandine), C isotopes in diamonds, Rb–Sr, Sm–Nd, Re–Os and O isotopes have been determined on ultrabase minerals and rocks from eclogites in the Udachnaya, Mir and Obnazhennaya kimberlite pipes in Yakutia, Russia. The results show that the eclogites were formed in a variety of ways, both within the mantle and from oceanic crustal residues. The Udachnaya eclogites lack chemical zoning in the minerals have unradiogenic Sr and lack O, S and C isotope variation relative to the mantle. They, and most of the Obnazhennaya samples, correspond with the Group A eclogites from elsewhere (probably true mantle cumulates), have not been re-cycled, and were derived from typical depleted mantle except for a few samples derived from either enriched, or very depleted, mantle. The Mir eclogites are more typical of other eclogites worldwide and have convincing evidence of a recycled oceanic crustal affinity. B.E.L.

Kinetics of Ib to IaA nitrogen aggregation in diamond.

W.R. TAYLOR, D. CANIL AND H.J. MILLEDGE. *Geochimica et Cosmochimica Acta*, **60**(23), 1996, 4725–33.

High-*P* and high-*T* experiments with aggregation state determination by IR microspectrometry are used to re-evaluate Ib → IaA aggregation kinetics and the sector dependency of the aggregation state. Diamonds with N₂ impurities as singly-substituted C centres (Ib) are rare because Ib N₂ atoms aggregate to form A centres (type IaA) during 500–3000 m.y. upper mantle residence times. The results show that cube sectors have an activation energy Ib → IaA conversion (E_a) = 6.0 ± 0.2 eV compared to E_a = 4.4 ± 0.3 eV for the octahedral sectors. Sector dependency is ascribed to different mechanisms of N₂ migration. Application to Kokchetav microdiamonds indicates that their aggregation state is consistent with peak *T* of 950°C and a burial to exhumation of ~17 m.y. Yellow diamond cubes and diamond 'coat' from Yakutia with ~20% Ib grew ≤ 7 m.y. before kimberlite eruption for mantle *T* ≥ 950°C, but did not grow directly from the transporting kimberlite magma. R.K.H.

Alexandrite chrysoberyl from Dowerin, Western Australia: revisited.

A. BEVAN AND P. DOWNES. *Australian Gemmologist*, **19**(11), 1997, 460–3, 1 illus. in black-and-white, 5 illus. in colour.

In the form of a preliminary report, the authors describe the geology and mineralogy of the Dowerin deposit, an area in Western Australia where small crystals of gem-quality chrysoberyl (including a few showing the characteristic alexandrite colour change) were first discovered in 1930. These workings have recently been reopened and small cut stones have been produced from the alexandrite rough. P.G.R.

A miscellany of organics

G. BROWN. *Australian Gemmologist*, **19**(12), 1997, 503–6, 16 illus. in colour.

Identifying features are given of some of the rarer organics that have appeared in the author's laboratory reports over the last decade. Among these are kukui nuts, imitation ox-blood coral, apple coral and imitation black pearls. P.G.R.

Gems and Minerals

A donation of Archbishop Nil to St Petersburg University.

G.F. ANASTASENKO. *World of Stones*, **12**, 1997, 24–7, illus. in colour.

Some gem mineral crystals are included in the gift made in 1874 by Archbishop Nil of Yaroslavl' and Rostov [secular name Nikolai Fedorovich Isakovich] to the University of St Petersburg. Many specimens are from Russian deposits. M.O'D.

Two zincian rarities.

M. BURFORD. *Canadian Gemmologist*, **18**, 1997, 108–10.

Taaffeite and gahnospinel [the latter not a distinct species but a specimen with composition on the series between spinel and gahnite] are described with a table of properties and notes on occurrence and inclusions. Some constants (for both materials) are slightly outside figures usually cited. M.O'D.

500 Jahre Edelsteinregion Idar-Oberstein (1497–1997).

H. BANK. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 129–52, 10 photographs, 2 maps, 1 table, bibl.

Although apparently the Romans had mined agates in Idar-Oberstein, there is no written evidence before the year 1497. From then on there are numerous mentions in various documents (the article reproduces one mention of chalcedony and rock crystal in 1606). The industry was fairly small (in 1825 200 cutters and 70 miners were working) till some emigrants went to Brazil and found similar material there and started to export these agates back to Idar. The industry grew, so that during the period between 1890 and 1930 there were up to 2328 lapidaries working including 325 engravers. Before the Second World War up to two thousand goldsmiths were employed. Apart from Germany, the industry delivered goods to France, England, Russia, USA and the orient. Many cheaper articles were sold to the African and Arab countries and Freemasons were supplied. Cameos were fashionable in the late nineteenth century and this art was brought to perfection. E.S.

Kingsbridge: an early quarrying district on Manhattan Island.

L.H. CONKLIN. *Mineralogical Record*, **28**, 1997, 457–73, illus. in colour, 1 map.

Attractive and apparently gem-quality crystals of dark red rutile and yellow-brown uvite, with well-crystallized diopside, pyrite and other minerals are described from the long built-over Kingsbridge marble quarry in the north of Manhattan Island, New York City. M.O'D.

Characteristics of violet jade from Turkey.

M.A. DIGENNARO, C. TROSSARELLI AND C. RINAUDO. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 169–74, 6 photographs, 1 table, 1 graph, bibl.

Violet jade from Turkey has an RI of 1.65–1.66, SG 3.10, and an inert reaction to UV. The samples are composed of jadeite, quartz, feldspar, muscovite, pyrite, Mn and Fe oxides. Various concentrations of some of these minerals are responsible for varying colours of violet. Jadeite is the preponderant mineral and the rock should be defined as impure jade. E.S.

A mineralogical and structural study of red corundum, $\text{Al}_{1.98}\text{Cr}_{0.02}\text{O}_3$, from Froland, Norway.

B. ESTIFANOS, K. STÄHL, P.-G. ANDRÉASSON, G. BYLUND AND L. JOHANSSON. *Norsk Geologisk Tidsskrift*, 77(2), 1997, 119–22.

The crystal structure of red corundum, $\text{Al}_{1.98}\text{Cr}_{0.02}\text{O}_3$, from Froland has been refined from X-ray powder diffraction data by Rietveld analysis. Space group a 4.7597 (4), c 13.0013(9) Å. The substituting Cr-atoms do not take the site of Al-atoms, they depart 1.04 Å in the direction of the vacant octahedral interstices. A SEM (EDS) study revealed microphases of diaspore; one of the reasons for gem quality being lost. The reaction $\text{Al}_2\text{O}_3 + \text{H}_2\text{O} \rightleftharpoons 2\text{AlO}(\text{OH})$ occurred in the late stage of the metamorphic history of the Froland region. G.R.

Raman spectra of various types of tourmaline.

B. GASHAROVA, B. MIHAILOVA AND L. KONSTANTINOV. *European Journal of Mineralogy*, 9(5), 1997, 935–40.

From an investigation of 25 tourmalines in the spectral range 150–1550 cm^{-1} , classified chemically into three main groups buergerite-schorl, elbaite-type and dravite-buergerite-uvite, it was found that they can be similarly classified on the basis of their Raman spectra. R.A.H.

Les saphirs du nord de Madagascar.

E. GONTHIER. *Revue de gemmologie*, 132, 1997, 14–17. illus. in colour.

Description of blue sapphires found in the northern part of the Malagasy Republic with notes on local geology and usages of the people in whose territory the sapphires occur. M.O'D

Origin and formation of agate-bearing spherulites: the Thuringian Forest, Germany.

G. HOLZHEY. *Australian Gemmologist*, 19(11), 1997, 452–9, 24 illus. in colour, 1 map.

In the Thuringian Forest of Central Germany agate occurs in many locations, mostly as spherules within rhyolites that form a low volcanic mountain chain covered by the forest. These agate-bearing spherulites were formed epigenetically by silica-mineralizations which occurred in two distinct phases to produce hollow spherulites and wall-banded and horizontally layered agate plus macrocrystalline quartz. P.G.R.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(3), 1997, 220–30, 13 illus. in colour.

Prospecting for beryl in Saudi Arabia found epidote and not emerald in the Hadiyah area. Between Riyadh and the Red Sea some gem-quality aquamarine was found. Radioactive cat's-eye chrysoberyls have been sold in Bangkok. More fine Russian demantoid garnet is on the market, reportedly from the Nizhniy Tagil area. Namibia is also producing commercial quantities of demantoid garnets. A large yellow cabochon and two other pieces from the Kuruman District in South Africa were found to

represent the ettringite group of minerals and were probably sturmanite. Brownish-yellow and greenish-yellow bicoloured grossular garnet has been found in Mali; the RI varies according to which colour zone is being tested. A piece of opal rough had inclusions in the form of thin tubes which did not affect the play of colour and were therefore thought to be older than the aggregation of opal spheres. 'Pink geuda' sapphires are being sold in Vietnam. Most are opaque and cloudy with a pronounced milkiness, but it was found that with heat treatment some of the stones were improved enough to be cut into low-quality cabochons. J.J.

Multicoloured bismuth-bearing tourmalines from Lundazi, Zambia.

M.L. JOHNSON, C.Y. WENTZELL AND S. ELEN. *Gems & Gemology*, 33(3), 1997, 204–11, 7 illus. in colour, 2 tables.

These multicoloured tourmalines have an unusually high content of bismuth and recently have been mined in the Kalungabeda area of the Lundazi district. Colours include pink, orange, green and yellowish-green with cut stones containing two or more colours. They occur in alluvial gravels associated with granitic pegmatites, which were intruded into gneiss and schist basement of the Mozambique Belt. Much of the rough is susceptible to cracking during sawing, so to keep the multicoloured appearance it was noted that the green rind must be retained as it imparts a physical stability to the stone. The most distinctive features of these tourmalines are growth bands, straight, wavy or angular. Unexpectedly the inclusions show no signs of bismuth minerals. EDXRF showed the highest concentration of bismuth to be in the pink centres and the lowest in the green rims, with one pink stone containing 0.49 wt% Bi_2O_3 . J.J.

Neuer Rauchquarzfund aus dem Pendeli bei Athan, Griechenland.

H. KIRCHNER AND E. KOFLER. *Mineralien Welt*, 8(6), 1997, 59–60, illus. in colour, 2 maps.

Fine crystals of gem-quality smoky quartz are reported from Pendeli, near Athens, Greece, where they occur in the Penteli marble. M.O'D

Emerald mineralization and metasomatism of amphibolite, Khaltaro granitic pegmatite-hydrothermal vein system, Haramosh Mountains, northern Pakistan.

B.M. LAURS, J.H. DILLES AND L.W. SNEE. *Canadian Mineralogist*, 34(6), 1996, 1253–1286.

Emerald mineralization occurs in 0.1–1 m thick hydrothermal veins and Tertiary pegmatites cutting amphibolite in the Nanga Parbat-Haramosh massif, N Pakistan. The emerald in quartz and tourmaline-albite veins, and more rarely in pegmatite; the Cr_2O_3 and Fe_2O_3 contents, respectively, of the emeralds decrease systematically from emerald (>0.20, 0.54–0.89 wt.%), to pale blue beryl (≤ 0.07 , 0.10–0.63 wt.%). EPMA results are reported for tourmaline, biotite, muscovite and beryl, together with major and trace element analyses of the amphibolite and leucranites.

Oxygen isotope analyses of igneous and hydrothermal minerals indicate that a single fluid of magmatic origin with $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ 8‰ produced the pegmatite-vein system and hydrothermal alteration at 550–400°C. The introduction of HF-rich magmatic-hydrothermal fluids into the amphibolite caused hydrogen ion metasomatism, releasing Cr and Fe into the pegmatite-vein system. R.A.H.

Benitoite from the New Idria District, San Benito County, California.

B.M. LAURS, W.R. ROHRT AND M. GRAY. *Gems & Gemology*, 33(3), 1997, 166–87, 29 illus. in colour, 2 tables.

Benitoite ($\text{BaTiSi}_3\text{O}_{10}$) is only produced in commercial quantities from the Benitoite Gem Mine in the San Benito County; it was first discovered in 1907. These strongly dichroic stones are typically violet-blue; rare stones are pink or colourless. Orange stones have been produced by heat treatment. Benitoite is found exclusively in blueschist bodies within serpentine and thought to have originated when Ba and Ti were released by the alteration of blueschist in the presence of Mg- and Ca-rich fluids generated by regional metamorphism. Gem-quality benitoite is found in veins and usually coated in natrolite. The crystals are normally triangular with dominant π (011) faces being frosted and the m faces being smooth. Colour zoning is common with colourless cores and blue rims. Non-gem-quality benitoite has abundant fibrous inclusions. Sizes range up to 2–3 ct. Details of the history, mining and production are given together with details of the various local claims. J.J.

Neues Vorkommen von Demantoid in Namibia.

T.H. LIND, U. HENN, A. HENN AND H. BANK. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 46, 1997, 153–60, 6 photographs, 3 tables, 2 graphs, bibl.

The demantoid occurrences in Namibia are in the central part of the Damara-Orogen, a flat land surrounded by mountains consisting of intrusive rocks. Some demantoids have been picked up from the ground and sieved, others cut out of the rockface. The RI cannot be read on a standard refractometer, SG 3.81–3.85. Chemical analyses show the andradite to be pure with a low content of Cr_2O_3 (0.02–0.13%). Absorption spectra show bands of Fe^{3+} and Cr^{3+} . Distinct growth zoning is visible under magnification in addition to as yet unidentified ore-like inclusions. No chrysotile inclusions have been found. E.S.

Minerali e pietre figurate della discarica di Candeli (Firenze).

R. MELI. *Rivista Mineralogica Italiana*, 22, 1997, 369–76, illus. in colour, 1 map.

Fine landscape-like patterning occurs on some limestones found on railway tunnelling spoil dumps in the Candeli district, Firenze, Italy. Patterning arises from the presence of Fe and Mn hydroxides. M.O'D.

Gem Trade Lab notes.

T.H. MOSES, I.M. REINITZ, AND S.F. MCCLURE. *Gems & Gemology*, 33(3), 1997, 212–18, 15 illus. in colour.

A faceted semi-transparent green stone with a sharp 'cat's-eye' was identified as an emerald. A polymer impregnated jadeite carving showed some interesting features, with near-colourless areas of exceptional transparency surrounding isolated green grains of jadeite. The infrared spectrum showed polymer peaks so strongly that the typical jadeite spectrum was dwarfed. A jadeite carved urn had the appearance of nephrite as the colour distribution showed a typical cloudy effect.

Two faceted purple beads showed typical quartz properties as well as a peak in the infrared absorption at 2900 cm^{-1} similar to that seen in polymer impregnated materials. It was assumed that the beads had been quench-cracked and dyed, but the cracks made it impossible to determine whether they were synthetic or natural. Topaz fashioned to look like diamond rough were identified as topaz especially with occurrence of tourmaline and chlorite inclusions. Trigons had been carved and were raised above the surface and not depressed. J.J.

Die 'opal pineapples' von White Cliffs in New South Wales.

G. NIEDERMAYR AND G.M. PEARSON. *Mineralien Welt*, 8(4), 1997, 51–5, and 8(5), 1997, 1997, 48–53.

Assemblages of precious opal taking a pineapple shape are described from the White Cliffs opal field, New South Wales, Australia. The relationship between opal, glauconite, gaylussite and ikaite is discussed. M.O'D.

Le saphir 'padparadscha'.

F. NOTARI. *Revue de Gemmologie*, 132, 1997, 24–7, illus. in colour.

Chemical composition and spectra of a large number of orange-pink sapphires is presented to show what may or may not be the padparadscha variety. A Cr content of between 0.04 to 0.8% is needed to produce the colour as well as the presence of undefined colour centres. Sri Lanka is the only known producer. M.O'D.

Jadeite – K-feldspar rocks and jadeites from northwest Turkey.

A.I. OKAY. *Mineralogical Magazine*, 61(6), 1997, 835–43.

Blueschist-facies rocks with jadeite-K-feldspar-lawsonite paragenesis occur as exotic blocks in Miocene debris flows in the Bektablar region of NW Turkey. The jadeite-feldspar rocks are very fine-grained and retain a relict porphyritic volcanic texture; nepheline microphenocrysts are pseudomorphed by jadeite and K-feldspar, and relict magmatic aegirine has rims of jadeite. In some rocks jadeite amounts to > 60% of the rock; EPMA results show the jadeite, K-feldspar and lawsonite to have essentially pure end-member compositions. P - T estimates for these rocks are 8 ± 2 kbar, $300 \pm 50^\circ\text{C}$. The preserved volcanic texture, relict aegirine and bulk rock composition indicate that these rocks represent metamorphosed phonolites; it is considered that jadeite – K-feldspar is a stable mineral pair in blueschist-facies P - T conditions. R.A.H.

New chrysoberyl deposits from India.

J. PANJIKAR AND K.T. RAMCHANDRAN. *Indian Gemmologist*, 7(1/2), 1997, 3-7, illus. in colour.

Chrysoberyl of gem quality from the states of Madhya Pradesh, Orissa and Andhra Pradesh originates from very similar geological environments. In Madhya Pradesh alexandrite is reported from Latapara and Matrapara in Raipur district where it occurs in pegmatites intruding granite. In Orissa pale yellow to green chrysoberyl, sometimes chatoyant, occurs in pegmatites at Jerapani, Surjapalli and Dakalguda: alexandrite is found at Ranchipura where it occurs in the contact zone between pegmatite and peridotite. Green tourmaline, yellow chrysoberyl, green beryl and garnet are found in association. In Andhra Pradesh large chrysoberyl deposits occur in the Narsipatnam area of Vishakhapatnam region which forms part of the Eastern Ghat Supergroup.

The Orissa alexandrite occurred as small brownish-green crystals with a moderate colour change while chatoyant material was a bright yellow with attractive sheen. Andhra Pradesh alexandrite occurred as pale to dark green crystals, some with a pronounced colour change while chatoyant material was a pale yellow with a whitish sheen. Alexandrite from Madhya Pradesh was a dark green with a strong colour change while the yellow chrysoberyl had a slight greenish tinge. Sillimanite, quartz, mica and rutile have been generally observed as inclusions while flattened apatite crystals are found only in the material from Andhra Pradesh. M.O'D.

Tugtupit-kamień ozdobny końca XX wieku.

T. SOB CZAK AND N. SOB CZAK. *Mineralogia Polonica*, 27, 1996, 99-103.

Review of the occurrence, mineralogy and recovery of tugtupite which was first reported in 1960. A table gives the chief properties of tugtupite together with those of the similar-appearing species stichtite, sogdianite, sugilite, jadeite and eudialyte. M.O'D.

Gemmological features of rubies and sapphires from the Barrington volcano, Eastern Australia.

G. WEBB. *Australian Gemmologist*, 19(11), 1997, 471-5, 13 illus. in colour, 1 map, 1 table.

Although Australia is an important source of sapphires, ruby remains a rare gemstone among the country's corundum deposits. However, among the few ruby occurrences, the best gem-quality stones originate from alluvial deposits derived from the Barrington volcano in New South Wales. Ruby and pink sapphire can form 50 per cent of the weight of sampled gem corundum concentrate in this area. Two distinct suites of sapphire accompany the rubies, one of which relates to the ruby, while the other is typical of eastern Australian sapphires. Gemmological features of these rubies and sapphires are described by the author. P.G.R.

Gemstone occurrences in British Columbia.

B.S. WILSON. *Canadian Gemmologist*, 18, 1997, 74-83.

Descriptive list of the gem species found in British Columbia with notes on the volcanic rocks, high-grade

metamorphic rocks, felsic plutonic rocks with associated granite pegmatites, and skarns, all of which provide hosts to gemstone mineralization. M.O'D.

Canadian tourmaline: a new discovery.

B.S. WILSON. *Canadian Gemmologist*, 18, 1997, 107.

Gem-quality tourmaline, mostly pink and brownish-pink and identified as elbaite, is reported from miarolitic cavities at the Stargazer claims near O'Grady Lake in the Mackenzie Mountains, Northwest Territories of Canada. M.O'D.

Instruments and Techniques

Fourier transform-Raman spectroscopy of ivory: a non-destructive technique.

H.G.M. EDWARDS, D.W. FARWELL, J.M. HOLDER AND E.E. LAWSON. *Studies in Conservation*, 43, 1998, 9-16, 10 figures.

This paper presents the results of a comprehensive, non-destructive, Fourier transform-Raman spectroscopic study of elephant ivory, bone and tooth. Samples tested ranged from museum specimens to modern tusks. The principles of FT-Raman spectroscopy are described and the characteristic vibrational features identified which distinguish elephant ivory from tooth and bone. Another important result is the ability of this technique to characterize ivory from the woolly mammoth, African and Asian elephants, which may help in attributing ivories to different species. The use of a remote-sensing Raman probe on inlay is also described. M.E.H.

The Gem Kit.

T. LINTON, S. SULTMAN AND J. PETERS. *Australian Gemmologist*, 19(11), 1997, 448-51, 3 illus. in black-and-white.

The portable gem testing kit described is a product of NM Australia Pty Ltd, and is contained in a black leatherette carrying case the size of a small laptop computer. The kit contains the basic gem testing instruments (refractometer, spectroscope, polariscope, dichroscope, Chelsea filter, triplet loupe, tweezers and light sources, together with a Leveridge gauge and accessories) and is available in three versions depending on the mix of instruments purchased. P.G.R.

A new technique for detecting synthetic yellow sapphire.

T. LINTON. *Australian Gemmologist*, 19(12), 1997, 509-11, 3 illus. in colour.

The problems experienced by gemmologists and valuers when confronted with a large yellow sapphire that does not contain obvious inclusions can be overcome by using a test procedure developed for identifying flame-fusion synthetic yellow sapphire. The technique described used a Nelson M17 Gemstone Cooling Unit which is filled with liquid nitrogen to rapidly cool the sapphire under test. The gem is then irradiated with UV. If the sapphire is a flame-fusion yellow corundum coloured by nickel and

chromium this produces a fluorescent line at 693.5 nm (not visible at room temperature) in the gem's visible absorption spectrum. In addition to this spectroscopic analysis, details are given of other UV fluorescent tests which can also be applied. P.G.R.

Meiji Technico model GF-252 refractometer-polariscope.

T. LINTON, S. SULTMAN AND G. PETERS. *Australian Gemmologist*, 19(12), 1997, 513-14, 2 illus. in colour.

Two of the most often used gemmological instruments, the refractometer and the polariscope, have been combined together in the same case in the Meiji Technico unit checked by the GAA Instrument Evaluation Committee. The internal light source for both the refractometer and the polariscope is a low wattage filament lamp which provides yellow-rich illumination suitable for the refractometer's yellow interference filter. A control at the side of the instrument's case enables the interference filter to be moved out of the refractometer's light path so that an external white light or sodium light can be used as alternative sources of illumination. P.G.R.

Synthetics and Simulants

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(2), 1997, 142-52, 23 illus. in colour.

At the 1996 Diamond Conference in Tours, France, one of the topics discussed was the use of diamond thin films and their industrial uses. Also discussed was the high pressure/high temperature synthetic mono crystals manufactured in Japan. Some have coloured centres caused by cobalt used as a solvent during growth; these are yellow stones types Ib and IaA, and showed cobalt-related fluorescence. They are also grown with phosphorus for electronic appliances. Thin films of synthetic diamond have been used in jewellery; they are transparent and can appear grey due to the light scattering from the tiny diamond crystals.

On examination in methylene iodide of a piece of rough and two faceted stones of vanadium-bearing Russian synthetic green chrysoberyl, showed strong bands of curved zoning. A cat's-eye effect was obtained from a Russian hydrothermal synthetic emerald when the stone was cut as a cabochon and the original rough base was retained. Imitation Zambian emerald crystals have been sold to the unwary. They are composed of fragments of quartz crystal glued together with green epoxy resin and another type was a quartz crystal coated in a bluish-green plastic. All have matrix that covers up the glue and the plastic coating. A quench-cracked synthetic ruby had an extensive fracture system that made it difficult to observe the fine Verneuil banding. Flux grown red spinels from Russia have been found to contain dendritic inclusions only seen before in the synthetic blue spinels. J.J.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(3), 1997, 220-30, 13 illus. in colour.

Three native-cut purple sapphires supposedly from a new locality in Afghanistan were found to be synthetic. Since 1995 new colours of GGG have become available in various shades of pink, blue, red, lilac, etc. All are easily identifiable, but the blue GGG had a much lower SG than normal as it contained calcium and zirconium. J.J.

Taurus hydrothermal synthetic sapphires doped with nickel and chromium.

V.G. THOMAS, R.I. MASHKOVITSEV, S.Z. SMIRNOV AND V.S. MALTSEV. *Gems & Gemology*, 33(3), 1997, 188-202, 17 illus. in colour, 4 tables.

Hydrothermally grown synthetic sapphires have been produced for the last forty years, but until recently the manufacture of blue hydrothermal synthetic sapphires has been unsuccessful due to the uneven colour distribution within the stones. The researchers of the Taurus joint venture have developed the technology to overcome this problem, by using nickel (Ni^{2+}) as a dopant and this has resulted in 'sky' blue synthetic sapphires. This technique has also produced different coloured synthetic sapphires by varying the concentrations of (Ni^{2+}) (Ni^{3+}) and chromium (Cr^{3+}), together with varying the controls on the oxidation-reduction environment. The authors give detailed descriptions of the growing techniques together with the materials and methods used. Synthetic sapphire grown from a hydrothermal solution resembles more closely the natural counterparts than would corundum grown by flux or melt growth techniques. There are diagnostic features such as swirl-like patterns (common); a red reaction to UV radiation of the greenish-blue synthetic sapphires due to Cr; crystalline copper inclusions; and five small peaks between 2500 and 2000 cm^{-1} in the infrared spectrum. The Ni-doped synthetic greenish-blue sapphire absorption spectrum includes three intense bands at 377, 599 and 970 nm and two weak bands at 435 and 556 nm. J.J.

Synthetisch 'Phantomquarze', 'Herkimer' und bestrahlte 'Rauchquarz'.

S. WEISS. *Lapis*, 22(11), 1997, 38-49, illus. in colour.

Among specimens seen at a recent Germany mineral fair were synthetic phantom quartz and Herkimer-type crystals, as well as synthetic 'rough' quartz. M.O'D.

Hydrothermal growth of diamond in metal-C-H₂O systems.

X.Z. ZHAO, R. ROY, K.A. CHERIAN AND A. BADZIAN. *Nature*, 385(6616), 1997, 513-15.

From spectroscopic XRD and microscopy, evidence suggests that aggregates (tens of mm in size) of diamond crystals can be grown in a hydrothermal environment from a mixture of C, H₂O and metal (usually pure Ni). New diamonds are distinguished from the diamond seeds added to nucleate the new growths. The diamonds were grown using 3 wt.% powdered Ni (99.7% pure) with 95 wt.% glassy C, 2 wt.% diamond seeds (0.25 mm) and H₂O 50-100 wt.% of the glassy C, all sealed in gold tubes in conventional Roy-Tuttle bombs. R.K.H.

Book Reviews

The nature of diamonds.

G.E. HARLOW (ED.), 1997. Cambridge University PRESS, Cambridge. pp x, 278. Hardback £55.00, ISBN 0 521 62083X; paperback £19.95, 0 521 62935 7.

In this comprehensive, large-format book, published in association with the American Museum of Natural History, a dozen or more experts on the geology, mineralogy, gemmology and social-economic aspects of diamonds cover every facet of this mineral.

After an introductory chapter, the nature of colour in diamonds is discussed (E. Fritsch), and this is followed by a chapter on the origin of diamonds and the involvement of relatively cool harzburgite keels at the base of the thickest, oldest parts of the Earth's crust (M.B. Kirkley), later subduction of basaltic oceanic crust resulting in some portions of it adhering to the bases of the continental keels and recrystallizing there as eclogite. The basaltic crust contained carbon (some of organic origin) and recrystallized as diamond; heating or fluid infiltration of this continental keel caused kimberlite to form, which under the right conditions ascended rapidly to the Earth's surface.

After a brief chapter (Harlow, Shatsky and Sobolev) outlining the collision and return of ultra-high-pressure terrains, permitting formation and preservation of diamonds in the continental crust, there is a detailed chronological and geographical account of the discovery of diamond sources (Levinson). This chapter presents many fascinating insights into diamond production, firstly in India which was the sole source until around 1730, when diamonds were found in Brazil; then from around 1870 to the present day, with South Africa, Namibia, Botswana and some ten other African countries, followed by the Russian kimberlite sources mainly in Siberia (mining started in 1957), the Australian development in the lamproite of the Argyle mine (from 1979), China, and currently the active exploration in the Lac de Gras region of the North West Territories of Canada. This account is accompanied by numerous production statistics, but it is not always easy to compare production in terms of weight of carats produced with the value of diamonds mined, there being wide variations in the proportions of gem-quality diamonds in the different deposits: thus in 1995 the Argyle mine produced about 38% of the world's diamonds on a weight basis, but only about 6% on a value basis.

Sandwiched in the middle of the book is a chapter on the world's great diamonds, but here unfortunately two colour plates have been transposed relative to their legends, making the Koh-i-Noor appear in the Imperial State Crown! This is followed by various chapters outlining the history of diamonds as gemstones, their place as regal ornaments

through the centuries, their value in English literature, diamond jewellery in Russia, Hollywood and the rest of the world, and into the twentieth century.

The final three chapters deal with the processing of diamonds from the Earth to fashioned objects (Harlow), diamonds as gemstones (Shigley and Moses) and the synthesis of diamonds and their applications in modern technology (Collins). The production figures are interesting, being 100 tons per year (500 million carats) of which 80% is represented by the production of synthetic diamond grit for industrial use; mined natural diamonds amount to 100 million carats per year of which 25 million are used in the gem trade.

Altogether, this is a fascinating book, covering almost all aspects of diamonds from the aesthetic to their possible use in supercomputers, and from their discovery in the frozen wastes of Siberia to their synthesis by chemical-vapour deposition. The presentation is excellent, with many clear diagrams and sketch-maps. Almost my only regret (apart from the mis-labelling of plates mentioned above) is that surprisingly there is no mention, either in the chapter on famous diamonds or in those concerned with colour in diamonds, of the wonderful Williamson 54.50 ct pink diamond (23.60 ct after cutting) presented to H.M. Queen Elizabeth II to celebrate her Coronation. R.A.H.

Gemstone buying guide.

R. NEWMAN, 1998. International Jewelry Publications, Los Angeles. pp 148, illus. in colour. Softcover US\$19.95. ISBN 0 929975 25 1.

With colour on almost every opening few could resist this book whether or not they were in the gemstone and jewellery trade or were gemmologists. Here the reader is given all the information needed to show the customer what a stone is, interesting facts about particular species and advice on cleaning and conservation. Some properties have to be given but they are introduced before the stones are described. Since this is not a gem testing book but an introduction to appraising gemstones, we are shown how to evaluate cuts, styles, colour, inclusions - all with a view to establishing a specimen within an acceptable order of value, as far as this is possible. Treatments, phenomenal stones and synthetic stones are also described.

The book should be on the counter or by the bedside (or both). Beautifully produced with fresh photographs of a high standard, it could be sold to the customer along with their gemstone or jewellery purchase. Students can learn a lot from it and it would make an excellent introduction to a gemmology course, for which an imaginative stimulus of this kind is a pre-requisite. M.O'D.

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

PHOTOGRAPHIC COMPETITION

The 1998 Photographic Competition on the theme 'Gems in Fashion' produced an interesting selection of photographs illustrating gem-set jewellery typical of many periods. After careful deliberation by the judges, the prizes have been awarded as follows:

We are pleased to announce that the prizes were sponsored by Quadrant Offset Ltd, and the GAGTL is most grateful to them for their generosity. The prizes were presented and the winning entries exhibited at the Reunion of Members held on Monday 29 June.

First Prize

Bob Maurer, FGA, DGA, London
Coral Buddha brooch by Stephen Webster
(see front cover)

Third Prize

John S. Harris, FGA, Cumbria
Cameo of peridot set in gold enamel with pearls,
19th century.

Second Prize

Petri Tuovinen, FGA, Finland
Ear ornament of faceted opal from Lightning Ridge
set in 14 carat yellow and white gold.
Opal cut by Marita Lempinen,
ornament designed and set by Petri Tuovinen



GIFTS TO THE ASSOCIATION

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

Mrs Susan M. Anderson, Perth, WA, Australia, for 33 parcels of various mineral specimens including small opal pieces and an opal in matrix.

Mr Dennis M.C. Chen, Taipei, Taiwan, for 14 pieces of coral of different colours and three books, *A Chinese treasure - the coral of Lucoral Museum*, *Wish gems* and *The rockhounds*.

Mr John R. Führbach, Amarillo, Texas, USA, for samples of the current production from Zambia of garnet (almandine) and amethyst; four specimens of oligoclase feldspar (three rough and one cut); a collection of peridot and related minerals of various colours from the Kilbourne Hole, New Mexico, USA.

Dr U. Henn and Dr C. Milisenda, Deutsche Gemmologische Ausbildungszentrum, Idar-Oberstein, Germany, for two pieces of dianite (potassium richterite, albite and augite).

Mr John Kessler, London, for emeralds (10.42 ct) from a new and as yet undisclosed source in Brazil.

Mr Kamel Kothari, Jaipur, India, for four emeralds, six rough sapphires and 17 rough rubies.

Mr Jan Sluis, Rotterdam, The Netherlands, for 132 stones including beryl, moonstone, quartz, topaz, turquoise and synthetic sapphire.

Thomson (Gems) Ltd., London, for 176 onyx cabochons that had faded.

Mrs J. M. Ward, FGAA, West Perth, WA, Australia, for the book *The Lure of the pearl* by B. Aquilina and W. Reed, presented by the authors through Joyce Ward.

OBITUARY

Mrs Tuija Nurminen, FGA (D.1985), Helsinki, Finland, died on 24 January 1998.

MEMBERS' MEETINGS

Trips and Tours

The fourth GAGTL trip to Idar-Oberstein, Germany, was held from 19 to 25 April. The group enjoyed tours of museums, workshops, showrooms and a mine, as well as a visit to the German Gemmological Association. A full report was published in the June issue of *Gem and Jewellery News*.

A trip to Scotland was held during the weekend of 29 to 31 May. The event included a tour of the mineral and gem galleries at the National Museums of Scotland, Edinburgh, followed by a lecture by Brian Jackson on the gemstones of Scotland, and a field trip to the Campsie Fells where attractive jasper and quartz was found. A report will be published in the September issue of *Gem and Jewellery News*.

London

On 22 April 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Christianne Douglas gave a talk entitled *Pearls - a fashion opportunity*.

On 13 May at the Gem Tutorial Centre Dr Roger Harding exhibited and described some of the rare and interesting specimens contained in the gem and mineral collections donated to the Association over the years.

The Annual General Meeting was held on Monday 29 June, followed by the Reunion of Members and a Bring and Buy Sale. A full report will appear in the October issue of the *Journal*.

Midlands Branch

On 19 April the subject for the Gem Club was *Bragging pieces - collectors' stones*. The day gave members an insight into gemmology in practice; keen observations, few instruments and a fount of knowledge.

On 24 April at the Discovery Centre, 77 Vyse Street, Birmingham, the Annual General Meeting

FORTHCOMING EVENTS

- 16 September** North West Branch. Gem collection with anecdotes. John Pyke Snr.
- 3 October** Trade Dinner. To be held at the Café Royal, Regent Street, London. Guest speaker: Geoffrey C. Munn.
- 21 October** North West Branch. Silversmith of Williamsburg 1780. Martin Connard.
- 1 November** Annual Conference. Gems in Jewellery. To be held at the Barbican Centre, London. A full programme of lectures, demonstrations and displays is being planned and full details will be published in the September issue of *Gem and Jewellery News*.
- 2 November** Tours of jewellery and gemstone galleries at two London museums.
- 18 November** North West Branch. Annual General Meeting.

For further information on the above events contact:

London and Trips:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

of the Branch was held at which David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected President, Chairman, Secretary and Treasurer respectively. A President's jewel had been commissioned during the year and was presented to the President. The AGM was followed by *A mosaic of gemmological tessera*.

Pre-examination seminars for Diploma and Preliminary students were held on 26 April and 3 May respectively.

North West Branch

On 20 May at Church House, Hanover Street, Liverpool 1, Brian Dunn of Garrard's, London, gave a talk entitled *Time-bomb or fun?* which included advice on how to avoid 'time bombs' when valuing watches.

Scottish Branch

On 29 March a visit to the Creetown Gem Rock Museum was arranged.

The Annual General Meeting and Conference of the Scottish Branch was held at Peebles from 8 to 10 May. At the AGM Alan Hodgkinson, Brian Jackson and Gillian O'Brien were re-elected President, Chairman and Treasurer respectively, and Catriona McInnes was elected Secretary. A report of the Conference will appear in the September issue of *Gem and Jewellery News*.

On 7 June a trip was arranged to Ruby Bay to collect the garnets of the area known as 'Elie Bay rubies'.

ANNUAL REPORT

The following is the report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for 1997.

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. The President, Professor R.A. Howie, and the Vice Presidents E. Bruton, A.E. Farn, D.G. Kent and R.K. Mitchell,

continued in office and the company also benefits greatly from the contributions of the Members' Council, the Trade Liaison Committee and the Board of Examiners. Dr G. Harrison Jones continued as chairman of the Board of Examiners, and Dr M. Newton was appointed to strengthen the diamond examination team. C. Winter continued to chair the Members' Council; K. Penton and I. Roberts retired from the Council and thanks are due to them for their contributions over the past four and seven years respectively. D. Gann completed his two-year term as chairman of the Trade Liaison Committee and T.M.J. Davidson was elected to the position with J. Monnickendam elected Vice-Chairman.

Overall, the GAGTL can report a financially better year in 1997 than 1996. Careful monitoring of expenditure, introduction of new courses and some hard earned orders in Gemmological Instruments Ltd, have contributed to a gratifying increase in turnover and reserves. In the laboratory, continued investment in promotion of the London Diamond Report is running parallel with a 28 per cent increase in revenue for diamond grading. This contrasts with a less financially rewarding position for coloured stones and pearls and efforts to improve this situation are in hand.

The nine-month diploma in gemmology course continues to thrive with a full complement having started in September. A new four-month Gem Diamond Diploma course started in October with 18 students and the classes in the expanded evening programme are nearly full. New correspondence course tutorials have started successfully drawing students from overseas as well as the UK to practise observation and instrumental measurements on gems and improve their examination technique. Both education and laboratory staff are involved in practical tuition in daytime and evening classes.

The exam entries in 1997 were 16 per cent down on the 1996 figure, at first sight disappointing but over 20 years such figures have fluctuated markedly and there were signs of a recovery for the 1998 examinations. The Tully Medal for 1997 was awarded to Ms Li Liping of Wuhan, Peoples Republic of China, who also received the Anderson-Bank Prize. The Diploma Trade Prize went to Ms M.I. Garland of London, Ontario, Canada, the Anderson Medal for the best candidate in the Preliminary Examination was awarded to Miss M.V. Ng of London, and the Preliminary Trade Prize went to Mr S.R. Millard of Corsham, Wiltshire.

At the Presentation of Awards held in Goldsmiths' Hall the guest of honour was Professor Chen Zhonghui of Wuhan University, accompanied by his wife, Professor Yan Weixuan. Professor Chen presented the diplomas and prizes to successful candidates from nine countries and then handed over to Eric Bruton to make the first presentation of the Bruton Medal, struck in his honour. The medal was awarded to Ms R. Tsang of Hong Kon for excellence in diamond studies.

Further improvements to the Preliminary course notes were completed in May and translations have been made into Chinese and Swedish. Development continued of Diploma supplements prior to production of a new Diploma course and practical manual. New Allied Teaching Centres (ATCs) have started in Singapore and Taipei and whilst gemmology taught at some UK colleges has declined, other centres are active.

A full programme of tutorials, practical workshops and update courses was conducted at the Gem Tutorial Centre and there were more enquiries for personal tuition and instruction than previously. Travelling tutorials were held in Chicago, USA, Sweden, and at cities in the UK, including the Earls Court International Jewellery Show.

The spring tour to Idar-Oberstein has now become an annual feature – again very successful – and in September 12 participants ventured even further afield to Kenya and Tanzania for a fourteen-day conducted tour of gem sites.

The Federation for European Education in Gemmology (FEEG) examinations were held for the first time in Britain at the Gem Tutorial Centre; the candidates that passed are now entitled to call themselves European Gemmologist (EG).

The new GAGTL website was established in May and by the end of the year had been visited more than 30 000 times (www.gagtl.ac.uk/gagtl).

Laboratory staff continued to provide a very professional service in diamond grading and in gem and pearl identification. The number of London Diamond Reports increased in 1997 compared with 1996, and CIBJO Diamonds Reports continued to make up about 20 per cent of grading activity. In coloured stones, the pattern of work was broadly similar to that of 1996, with increases in coloured diamonds and treated rubies and a decrease in emeralds reported on. Pearl testing was down compared with 1996 but there are an increasing number of pearls whose natural or cultured origin is difficult to determine. Work with trading standards organizations was continued both in the laboratory and in the high street. Two visits were made to different regions to

tour areas with a concentration of jewellers and survey the descriptions of their displayed goods. Where incorrect or insufficient labels were encountered, discussions were held with the jeweller to improve the information available to the public.

The Trade Luncheon was again a success at the Langham Hilton Hotel, where members and guests were addressed by Mr R. Buchanan-Dunlop, CBE, Clerk of the Worshipful Company of Goldsmiths.

Overall, membership increased to 3673 – small decreases in direct subscribers and laboratory members were countered by encouraging recruitment of ordinary members and laboratory members. At our branches in Birmingham, Liverpool and Edinburgh, and in our London centre, varied programmes of seminars, lectures, update courses and field trips covered a wide range of topics. Sadly a stalwart of the North West Branch, Joe Azzopardi, died in 1997 and we miss his enthusiasm. The members again provided a wide range of entries on the theme *Collectors' Gems* for the 1997 Photographic Competition. The winners' names and their entries were published in the *Journal of Gemmology* and additional images were selected for the 1998 calendar – again designed by Rod Coleman of Quadrant Offset Ltd.

The Annual Conference was held for the first time at the Barbican Centre in London. The theme was *Collectors' Gems* and the speakers were Ludek Hubrt (Prague), Monica Price (Oxford), David Thomas (London), Lisbet Thoresen (Los Angeles), Gabi Tolokowsky (Antwerp) and Eleni Vassilika (Cambridge). Each presented their individual views of important aspects of collections or collectors' stones to an audience of over 120 from 18 different countries. Some delegates combined their visit with attendance at a symposium on Cartier organized jointly by the Society of Jewellery Historians and the British Museum held the previous day.

Midway through the year, Council was very pleasantly surprised by news of a bequest from Mrs Jeanne Maud Herbert Towers, daughter of G.F. Herbert-Smith, a past President of the Association. It was decided to use this money to inaugurate a property fund with the ultimate aim of buying a building. Council would also like to thank all those benefactors of gems, instruments, books and documents for their generosity, enthusiasm and support for the aims and well-being of the GAGTL. Donations have come in from all over the world and checking and curation for entry on a database is going ahead. Details of the books in the GAGTL library have now been entered on a database and Council would like to thank M.J. O'Donoghue who has brought all his skill and experience to carrying out this task.

During the year, sixteen papers were published in the *Journal of Gemmology*, with such topics as colour change effects, Raman microscopy, New Zealand copal resin, marcasite, and a history of synthetic gems. Totals of 191 abstracts and 48 book reviews were produced and Council would particularly like to thank the Assistant and Associate editors for their generous help in maintaining the high standards of the *Journal*. The design of the *Journal* has been actively developed while costs of production have been kept steady.

Four issues of *Gem and Jewellery News* were published during the year - the first highlighting the new equipment developed by De Beers to counter any difficulties caused by synthetic diamonds. The GAGTL's new website was outlined in the June issue. Meanwhile discussions about a new design were under way and Volume 7 No. 1 published before Christmas was the first issue with the fresh image.

Gemmological Instruments Ltd is a wholly owned subsidiary of the GAGTL. In 1997 sales of instruments, books and students' stones all increased over 1996 levels and the turnover was enhanced by two particularly large orders. The new dichroscope for students launched in 1996 is selling well. Its design is similar to that of the Chelsea Colour Filter (CCF) and marks the continuing commitment to develop and supply practical affordable gem testing instruments. The good results in GI Ltd are a result of staff commitment and professionalism and it is a pleasure to report that now the company is a significant contributor to GAGTL finances.

The GAGTL was represented at the CIBJO conference in Las Vegas and on the committee examining nomenclature for a revised *Blue Book* of standard terms and policy statements. The Association was also represented at the biennial International Gemmological Conference held in Idar-Oberstein, Germany.

The Council of Management would like to thank all the staff, the Committee and Council members, and the helpers in the education and collections spheres who have worked so hard to make the gemmology scene interesting and successful.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 25 March 1998 the business transacted included the election of the following:

GEM TUTORIAL CENTRE

27 Greville Street, London EC1N 8SU

A COLOURFUL DAY

16 September

A rainbow of opportunity - Why and how do we see colour in gemstones?

A day spent looking at the uses and importance of colour in gems.

This is the ideal workshop for both students and enthusiasts.

Price £42.55 + VAT (£50.00) – includes a sandwich lunch

DIAMONDS TODAY

7 October

A valuable and concentrated look at all aspects of diamonds: rough and cut stones, treated (laser drilled and filled), synthetic and imitation materials.

Price £104 + VAT (£122.20) – includes a sandwich lunch

EVERYDAY LIFE – TREATMENTS AND SYNTHETICS

28 October

This one-day course will look at the synthetic, imitation and treated materials encountered in the jewellery trade today. The course will concentrate on emerald, ruby, sapphire and diamond, emphasizing observation techniques.

Price £80 + VAT (£94.00) – includes a sandwich lunch

STUDENT WORKSHOPS

Preliminary Workshop	21 October
Preliminary Theory Review	9 November
Three-day Preliminary Workshop	9 to 11 November
Diploma Theory Review	23 November
Four-day Diploma Workshop	23 to 26 November
Weekend Diamond Grading Revision	12 and 13 December
Two-day Diploma Practical Workshop	9 and 10 January 1999

For further details contact the GAGTL Education Department

Tel: +44 (0)171 404 3334

Fax: +44 (0)171 404 8843

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Diamond Membership (DGA)

Balzan, Cortney G., Fairfax, Calif., USA. 1998

Tang Yun Hing, Frances, New Territories, Hong Kong. 1998

Wong Ti Yin, Heather, Hong Kong. 1998

Diamond Membership and Fellowship (FGA/DGA)

Allardyce, Tony, Birchington, Kent. 1970/1971

Hepburn, John Alexander, Orpington, Kent. 1986/1987

Fellowship (FGA)

Anderson, Elizabeth A., Peacehaven, East Sussex. 1998
Liao Yang, Guilin, Guangxi, P.R. China. 1997
Luo Xia Ying, Guilin, Guangxi, P.R. China. 1997
Millard, Simon R., Corsham, Wiltshire. 1998
Qin Hong Yu, Guangxi, P.R. China. 1997
Rowntree, Josephine, Knaresborough, North Yorkshire. 1998
Tinnyunt, Emma J., Kensal Green, London. 1998
Tupper, Michael I., South Holmwood, Surrey. 1998
Wang Yi Fei, Guilin, Guangxi, P.R. China. 1997
Wang Yi Long, Guilin, Guangxi, P.R. China. 1997
Xie Yu Jun, Guilin, Guangxi, P.R. China. 1997
Yu Pink, Guilin, Guangxi, P.R. China. 1997
Zhang Wansong, Guilin, Guangxi, P.R. China. 1997
Zhou Wei Ning, Guilin, Guangxi, P.R. China. 1997

Ordinary Membership

El Attar, Waleed, Cairo, Egypt
Feroldi, Luca, Milan, Italy
Kinnaird, Judith, Anstruther, Fife
Rohrbach, Tanya, Dorchester, Dorset

Transfer from Diamond Membership to FGA, DGA

Lodge, Tim, Muswell Hill, London

Transfers from Fellowship to FGA, DGA

Lu Yung Ching, Taipei, Taiwan, R.O.China. 1998
Marolla, Marianna, Athens, Greece. 1998
Mitchell, Susannah, Newton by Tattenhall, Cheshire. 1998
Renard-Richard, Joelle M., Ruislip, Middlesex. 1998
Seligman, Dominic, Southfields, London. 1998
Slater, Richard M., Radstock, Bath, Avon. 1998

Transfers from Ordinary Membership to FGA, DGA

Iannicelli, Marco, Salerno, Italy. 1998
Andaluz I. Sanchez, Maria, Peckham, London. 1998
Boccard, Jean-Marie, Geneva, Switzerland. 1998
Britton, Andrea L., Woking, Surrey. 1998
Draper, Zoe S., Upper Abbeywood, London. 1998
Holt, Judith A., Darwen, Lancs. 1998
John, Victoria A., Agar Grove, London. 1998
Lin Chief R., Kaohsiung, Taiwan, R.O. China. 1998
Pancratz, Mark, Weybridge, Surrey. 1998

Transfers from Ordinary Membership to DGA

Gandhi, Amar A.A., Stanmore, Middlesex. 1998
Kemp, Margaret A., Backwell, Somerset. 1998
Liile, Çigdem, Ankara, Turkey. 1998
Webster, Paul T., Greenford, Middlesex. 1998

Laboratory Membership

Trafalgar Jewellers, Newcastle upon Tyne, NE1 5AN
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Diamond Membership and Fellowship (FGA/DGA)

Hu Chin-Ching, Taiwan, R.O.China. 1998/1998

Fellowship (FGA)

Gini, Aspasia, Athens, Greece. 1990
Hsieh Evelyn Pao Lien, Shatin, NT, Hong Kong. 1998
Jacquat, Stéphane, Geneva, Switzerland. 1998
Kiefert, Lore, Basel, Switzerland. 1998
Krzemnicki, Michael Stanislaus, Basel, Switzerland. 1998
Marsh, Leona Claire, Harare, Zimbabwe. 1992
Nazos, Konstantinos, Athens, Greece. 1998
Tin Hlaing, Taunggyi, Myanmar. 1998
Tong Tao, Guilin, Guangxi, P.R. China. 1998
Wang Chao, Ning Bo, Zhe Jiang, P.R. China. 1998
White, Joanne Clare, North Sheffield, South Yorkshire. 1997
Wu Shi Zhou, Guilin, Guangxi, P.R. China. 1998
Zhao Yan Zeng, Guilin, Guangxi, P.R. China. 1998
Zheng Zi Zi, Guilin, Guangxi, P.R. China. 1998

Ordinary Membership

Borg, David, Paola, Malta
Carver, Elizabeth Mitchell, Arundel, West Sussex
Henry-Stogdon, Sarah Anita, Sutton, Surrey
Ohhara, Reiko, Ashiya City, Hyogo, Japan
Sison-Jones, Maria, London
Stimler, Harvey Jacob, Mill Hill, London
Zylberman, Nicolas, Saint Maur des Fossés, France

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GIA SYMPOSIUM: CALL FOR POSTERS

The Gemological Institute of America will host the 1999 International Gemological Symposium in San Diego, California, on 21-24 June. As well as technical sessions and panel discussions on the theme 'Meeting the Millennium' there will be an open Poster Session featuring original presentations (details of which were published in the *Journal of Gemmology*, 1998, 26 (1), 56).

To be considered for this event please submit a preliminary abstract (no more than 250 words) to one of the Poster Session organizers by 1 October 1998. For further information on the Poster Session contact Dr James Shigley at 760-603-4019 (Fax 760-603-4021, e-mail jshigley@gia.edu) or Ms Dona Dirlam at 760-603-4154 (fax 760-603-4256 or e-mail ddirlam@gia.edu). For information on the Symposium, contact Carol Moffatt at 760-603-4406, e-mail cmoffatt@gia.edu).

ISLAND OF GEMS

The exhibition on gems and the gem industry of Sri Lanka is to be held for the third successive year from 29 to 31 October 1998 at Leigh Place, Baldwin's Garden, London EC1N 7AB. This exhibition is organized by D.H. Ariyaratna, FGA, DGA, FGS. The main objective of the exhibition is to give a wider publicity to Sri Lanka's gem industry in Europe. All visitors are given a chance to examine some typical Sri Lankan gemstones using many gem testing instruments, and there will be a section to give particular help to gemmology students and collectors. Visitors will receive either a souvenir brochure or a Sri Lankan gemstone on arrival. For further details contact D.H. Ariyaratna, c/o Sri Lankan Gems, P.O. Box 1837, Tottenham, London N17 9BW. Telephone/fax: 0181 808 4746.

CORRIGENDUM

On p.93 above, second paragraph, for '1,2-dibromomethane' read '1,2-dibromoethane [C₂H₄Br₂]

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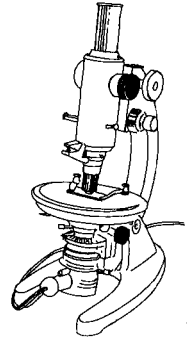
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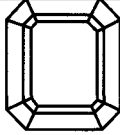
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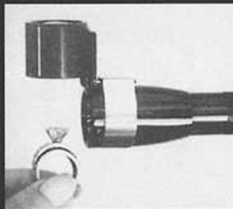
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