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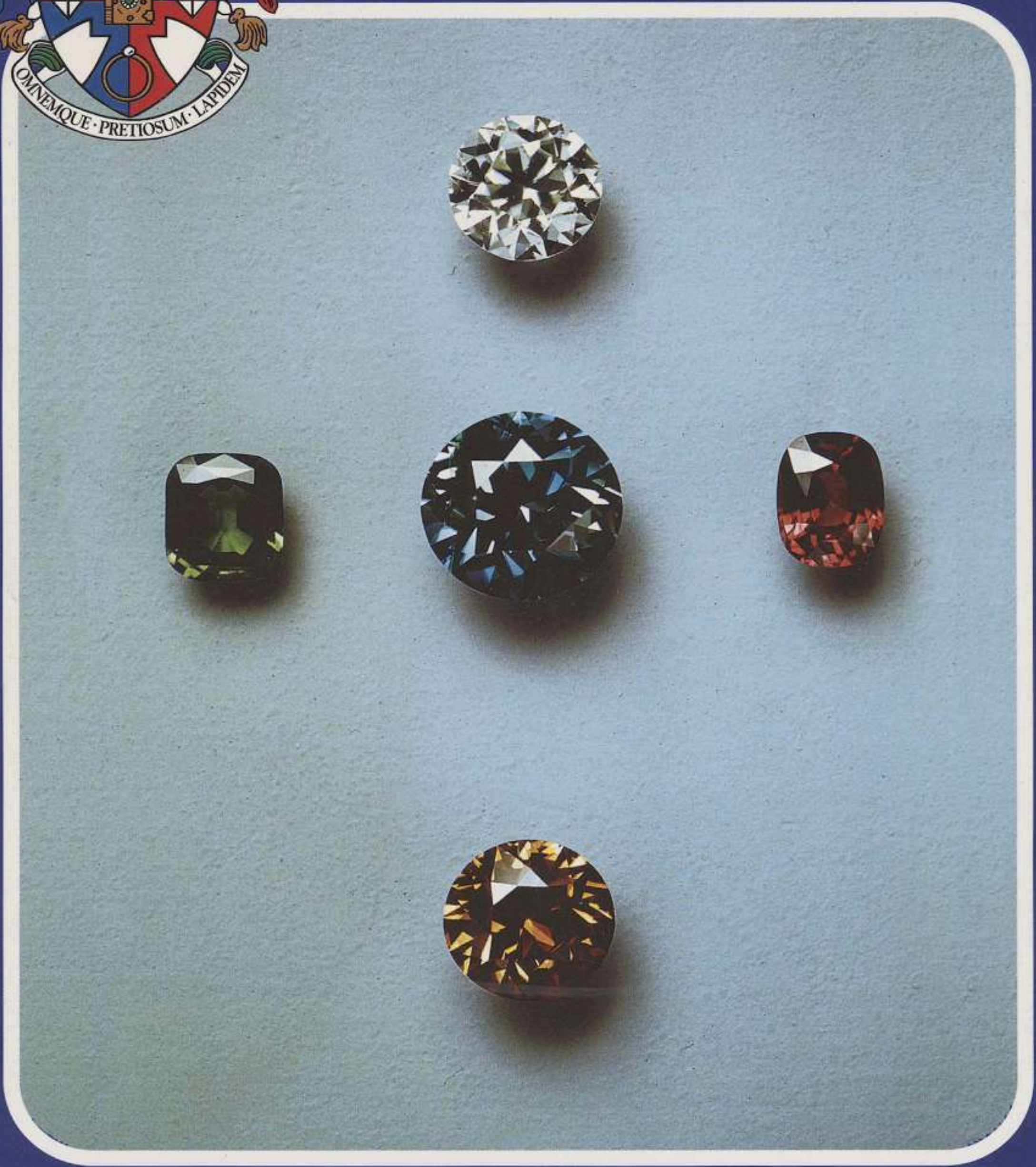

THE GEMMOLOGICAL ASSOCIATION AND GEM
TESTING LABORATORY OF GREAT BRITAIN

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Cover Picture

A series of cut zircons; the heat-treated stones are from Indo-China and weigh 21.32 ct (colourless), 33.34 ct (blue) and 27.58 ct (brownish-orange). They have been on exhibition for many decades and have not changed colour. The other stones are from Sri Lanka and are not treated; they weigh 9.85 ct (green) and 12.34 ct ('red'). All are on exhibition in the former Geological Museum, London. *Photo E.A. Jobbins.*

ISSN: 0022-1252

GAGTL ANNUAL CONFERENCE

24 October 1993

Great Western Royal Hotel,
Paddington, London

Inclusions

The theme of the Annual Conference this year is 'Inclusions' and we are pleased to announce that Dr E. Gübelin will deliver the keynote lecture. This will include newly discovered inclusions in gemstones and also a discussion on treated diamonds.

The theme will be continued with reports of recent work on Burmese and Vietnamese rubies and sapphires by Alan Jobbins, also of the range of Montana sapphires, treated and untreated, by Michael O'Donoghue. Both speakers have made recent visits to these producing areas.

Other items include lectures by Philip Sadler, who will outline the part played by gems in his investigations as a forensic scientist, and by Stephen Kennedy who will be talking about pearls and pearl fishing in the Arabian Gulf.

Throughout the day delegates will have the opportunity to view displays and participate in practical demonstrations.

GAGTL Open Day

The conference will be followed on Monday 25 October by an Open Day at the GAGTL Gem Tutorial Centre.

For further details and a booking form please contact:

Miss Linda Shreeves at GAGTL on 071 404 3334
(Fax 071 404 8843)

Zircon: a study of material donated by Mr W.C. Buckingham from various localities (mainly Indo-China)

Edinburgh Gemmological Group[1]

Introduction

In 1988 Mr W.C. Buckingham, FGA, donated his fine collection of rough and preformed zircons to the Gemmological Association of Great Britain. These zircons were to be made available to FGAs for research purposes, provided researchers complied with stipulated criteria namely:

1. the rough specimens originate from various localities, mostly Indo-China, and the research might be directed towards determining any variation in properties from the different localities. However, other research topics would be considered;
2. having carried out the research programme, the Fellow must present the results in the form of a paper which would, in the opinion of the Editor, be worthy of publication in *The Journal of Gemmology*.

This paper outlines investigations directed towards determining possible variation in properties of the zircons.

There were 12 packets of zircons which, in toto, weighed 1420.4 grams and a further 36.9 grams of selected material. The latter was mostly marked as having been worked on by Basil Anderson.

Ten stones were randomly selected from each packet. These constituted the samples. To help investigations and RI measurements windows were polished on the stones. The descriptions and results are set out in Table I.

Optical Data and Specific Gravity

Refractive indices were measured using a Rayner Diamond Table Refractometer with West's Solution as the contact liquid. Difficulties arose because of the liquid's viscous nature and toxicity. Table II details results, each of which is the sample average. Samples 2, 5, 7 and 12, had been heat-treated once. Samples 3, 4, 8, 10 and 11 had been heat-treated twice. Samples 1, 6 and 9 were untreated. Apart from samples 4, 5 and 12, all fell within the range for high zircon (1.925 - 1.984).

Specific gravity was determined by hydrostatic weighing. Anomalous specific gravity readings were queried and it was noted that the results had

Table I: Location and appearance of zircons tested

Packet No.	Mine & location	Notes
1	Looi mine, Kha district	Natural state as found
2	Looi mine, Kha district	Blue-coloured after initial heating
3	Looi mine, Kha district	Bleached white after second heating
4	Looi mine, Kha district	Tending to golden after initial heating
5	Hau Tek mine, Kha district	Finest. Only white after initial heating
6	Various, Champasak district	White stones after full heating
7	Various, Champasak district	Pre-heated to facilitate inspection for cracks and inclusions before main heating
8	Various, Champasak district	As above (packet 7) after final heating
9	Pailin district	Natural colour as found. Produces only white after heating
10	Looi mine, Kha district	After heating roughly shaped for faceting
11	Looi mine, Kha district	Bleached white after heating: roughly shaped for faceting
12	Various, Champasak district	After heating roughly shaped for faceting

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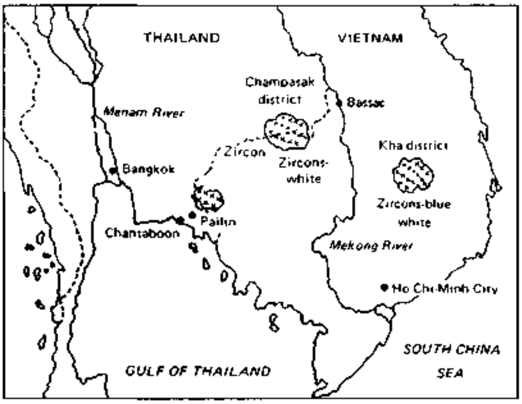
Table II: Properties of zircons from various localities in Indo-china

Mine/ District	Sample No.	Colour	RI	DR	SG	Dichroism	SWUV	LWUV	Phosphor-escence	Heat-treated	Observed absorption spectrum
Looi/Kha	1	strong gold	1.923-1.983	0.060	4.670	gold - light gold	None	None	None	No	General absorption of the red and blue/violet. Two specimens displayed an absorption line near 660 nm.
Looi/Kha	2	mid blue	1.923-1.969	0.046	4.719	blue - colourless	None	None	None	Yes	Produced absorption lines in the red at 590nm and single line or pair at 653 nm. Four examples showed a line at 525nm.
Looi/Kha	3	colourless	1.923-1.984	0.061	4.657	nil	None	Mustard	None	Yes	Pairs of absorption lines at 653 nm and a single line at 600 nm. In 80% of the packet there was a line at 525 nm present.
Looi/Kha	4	golden	1.922-1.982	0.060	4.555	nil	Mustard	None	None	Yes	General absorption of the red, but also showed a vague line at 653 nm. There was also a general absorption of the blue/violet.
Looi/Kha	10	blue	1.922-1.973	0.051	4.615	sky blue - colourless	None	None	None	Yes	600 nm line and pairs or single lines at 653 nm with further absorption lines at 525 nm.
Looi/Kha	11	colourless	1.922-1.979	0.056	4.593	nil	Mustard	Mustard	None	Yes	Persistent absorption line at 600 nm. There was also a single or double line at 550 nm, 500 nm and in 5 cases a single line at 490 nm .
Hau Tek/Kha	5	gold tinged white	1.922-1.982	0.060	4.45	nil	Orange	Orange	None	Yes	Showed a line or group of lines at 653 nm, 600 nm, and 5 stones showed a line at 525 nm. There was also a general absorption of the blue/violet.
Various Champasak	6	red	1.922-1.982	0.060	4.679	red - light red	Dull orange	None	None	No	No distinct absorption lines although there was general absorption of the blue/violet.
Various Champasak	7	orangy-white	1.922-1.982	0.060	4.695	nil	None	Orange	None	Yes	Line at 653 nm and, in four specimens, general absorption of the blue/violet.
Various Champasak	8	colourless	1.923-1.983	0.060	4.654	nil	None	Orange	None	Yes	General absorption of the blue/violet region. All specimens showed a doublet at 653 nm, a single line at 660 nm and a single line at 640 nm. In addition, all samples gave a single line 600 nm in the orange and a line at 550 nm. All specimens showed a line in the green area at 525 nm but four stones showed multiple lines in that region. Two stones displayed a doublet in the blue at 475 nm while four others only showed a single line.
Various Champasak	12	colourless	1.922-1.982	0.060	4.334	nil	Orange	Orange	None	Yes	General absorption of the blue/violet region. A distinctive line at 653 nm could be seen in most specimens as well as additional lines in the red. All samples displayed a line at 600 nm in the orange and most stones showed a line at 580 nm in the yellow region. All stones gave a line at 630 nm with a few stones giving additional lines in that area. With the exception of one specimen all samples showed lines in the blue region at 465 and 470nm.
Various Pailin	9	pale brown	1.921-1.982	0.061	4.649	pale brown-faint brown	Orange	Orange	None	No	No visible spectrum



Map 1. Location of zircon mines (after Anderson, 1990).

been influenced, primarily, by the presence of adhering matrix or, to a minor extent, by inclusions. The results were within the general range for both high and intermediate zircons.

Heat treatment did not materially affect the refractive index or specific gravity of the stones.

Fluorescence and phosphorescent effects

The samples were examined in long-wave ultraviolet light (LWUV) and short-wave ultraviolet light (SWUV) to determine any fluorescent and/or phosphorescent effects. The results are compared with those in the literature and recorded in Table II.

Locality and amount of heat treatment were the only known variables. The Looi mine zircons gave mixed results. Untreated stones (sample 1) showed no fluorescence . After initial heat treatment stones that turned blue (samples 2 and 10) did not fluoresce, whilst those that turned yellow fluoresced mustard under SWUV (sample 4). Stones that had been heat-treated twice, thereby rendering them colourless (samples 3 and 11), fluoresced mustard under LWUV, whilst sample 11 also fluoresced mustard under SWUV. The effects of heat treatment and fluorescence are clearly linked.

The other Kha district stones (sample 5) were recorded as turning colourless after a single heat treatment. These fluoresced orange under both long- and short-wave UV.

Champasak district stones also showed a link between fluorescence and heat treatment. Untreated stones did not fluoresce whilst those heat-treated once (sample 7) or twice (samples 8 and 12) fluoresced orange under LWUV. Only sample 12 showed additional orange fluorescence under SWUV.

Untreated Pailin district stones showed an orange fluorescence in both long- and short-wave UV.

Some of the heat treated stones had a skin that phosphoresced bright yellow. When this was removed by grinding no phosphorescence was observed. The skin was attributed to the surface fusion of phosphorescent material during heat treatment.

These results are similar to those recorded by Anderson (1964) and Webster (1983); the varying intensity of the fluorescence influencing the colour tone.

Spectroscope results

The assignment of a band or line to an exact wavelength is not possible, given the variable resolution of the prism spectroscope. The wavelengths cited in Table II are, therefore, a combination of accurately measured values reported by Anderson (1964), Webster (1983) and O'Donoghue (1988) and those estimated by the Edinburgh Gemmological Group. The results are set out in Table II.

Zircons are known to possess some of the most varied absorption spectra of all gemstones. The most persistent line is in the red at 653.5nm and the number of lines increases with the uranium content. In his study of Ceylon (Sri Lanka) zircons Anderson (1964) noted that the breakdown of the crystal structure can be clearly followed by the gradual deterioration of the uranium absorption bands. Sharp lines displayed by normal, fully crystallized zircon are replaced by weaker and vaguer development of the same bands until, with complete structural breakdown, metamict zircon displays merely a vague band in the red near 650nm sometimes accompanied by a narrow band in the green at 520nm. The latter band is not seen in normal zircon. Heat treatment of intermediate zircons will enhance the sharpness of the spectrum lines. Samples 8, 11 and 12 exhibited similarities to the anomalous spectrum produced by heat-treated low zircons (Anderson, 1990).

Infrared spectra of zircon

Variation in the infrared spectrum of zircon correlates directly with the degree of ordering of the atomic lattice. High zircons, which are well-ordered, display several sharp absorption bands (Figure 1). The three strong, sharp absorptions at 434, 386, and 318cm^{-1} represent crystal lattice vibration while those at 980 and 902cm^{-1} represent stretching modes of the $[SiO_4]^{4-}$ anion and at 610cm^{-1}, a bending mode of the $[SiO_4]^{4-}$ anion. Metamict stones, which have poor ordering, display two broad absorption curves (Figure 1).

All IR spectra were consistent with a well-ordered atomic structure. There were, however, small but significant differences between the

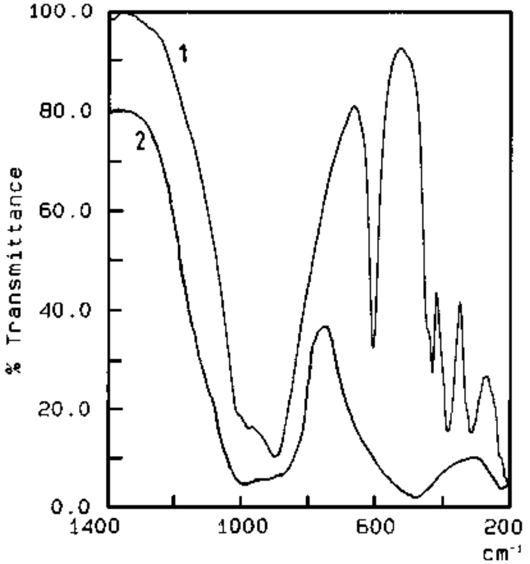


Fig. 1. 1. Infrared spectrum of zircon with well crystallized atomic structure.
2. Metamict zircon spectrum constructed from examples in the literature.

spectra of untreated and heat-treated stones.

Between 340cm^{-1} and 260cm^{-1} heat-treated stones showed a series of subtle absorptions of variable intensity superimposed upon the fundamental absorptions seen in untreated stones (Figure 2). This was attributed to crystal lattice absorption effects resulting from enhanced ordering following heat treatment. The subtle absorptions occurred at 330, 320, 308, 294 and 284cm^{-1}. Confirmation of heat treatment of colourless, blue and red zircon is not normally attempted, it being automatically assumed that such material has been heat-treated (Nassau, 1984). The IR spectrum of zircon provides confirmatory evidence of heat treatment in the absence of the anomalous visible spectrum described by Anderson (1990).

Inclusions

Tension fractures form the major internal feature of all the zircons. In many cases these were filled with secondary iron oxide staining which, in one specimen where the staining reached the surface and could be removed, was identified by X-ray diffraction as goethite. Curved and healing fractures were also common.

Colour zoning parallel to the prism faces {100} and {010} was only rarely seen (Figure 3) and only in untreated stones.

A dark brown inclusion extending to the surface proved, on X-ray analysis, to be ferrian spinel (specimen 2/10) (Figure 4). A specimen from the Looi mine was broken in order to expose a similar opaque inclusion. Unexpectedly, this revealed a

Fig. 2. Infrared spectra of: 1. heat-treated zircon from the Looi Mine; 2. untreated zircon from the Looi mine.

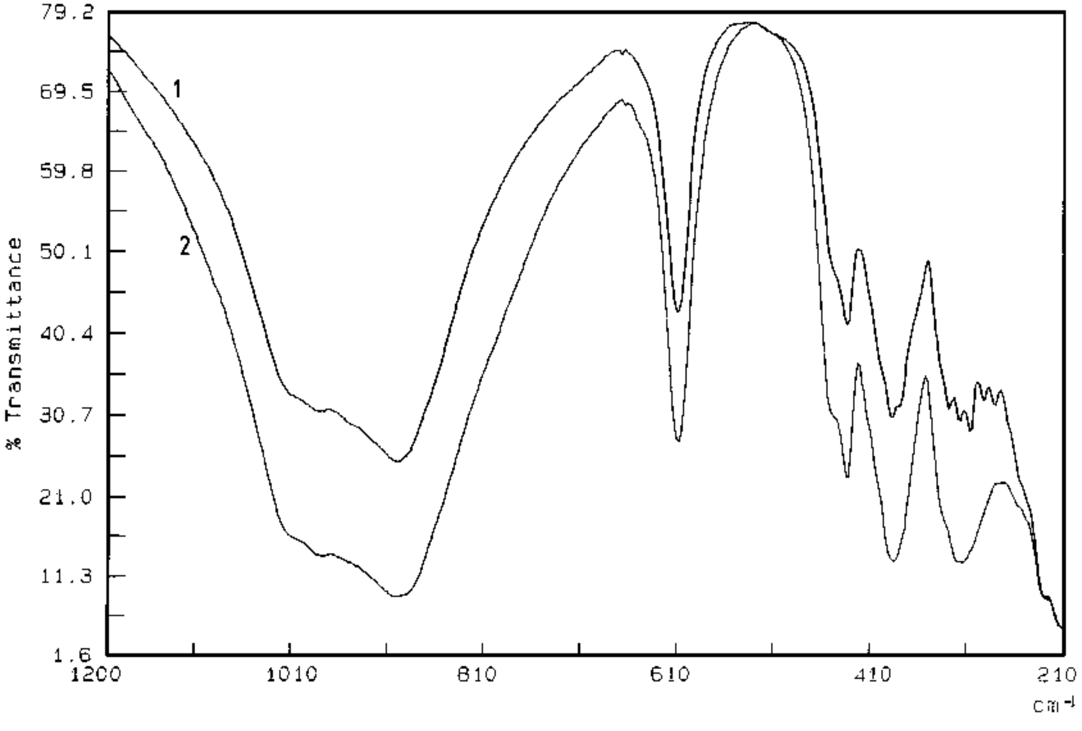


Fig. 3. Colour zoning intersecting at 90°.

Fig. 4. Distorted crystal of ferrian spinel in highly fractured blue zircon.

cavity the walls of which were covered by a dark coating. Inside, partially filling the cavity, was a dark grey mineral debris* (Figure 5). Spot analyses of the debris gave varying ratios of iron, aluminium and silicon which could not be assigned to any particular mineral species. Several grains (100µm to 150µm) contained only zirconium and therefore thought to be baddeleyite (ZrO_2). The baddeleyite occurs close to the zircon host and suggests a possible reaction phenomenon. High magnification of the dark-grey mineral debris revealed a sponge-like matrix,the voids of which contained light coloured partial-spheres <1µm across (Figure 6). Analyses*, detailed in Table III, could not be readily assigned to any known mineral and it is possible that more than one phase may be present. A search of an interactive mineral identification program (MinIdent-PC) using the matrix analysis in Table III gave 85.6% and 83.8% probability match for

Fig. 7. Heat-treated zircon showing bubbles around thermally decomposed inclusion.

Fig. 5. Scanning electron microscope (SEM) photograph of debris-filled cavity in fractured zircon.

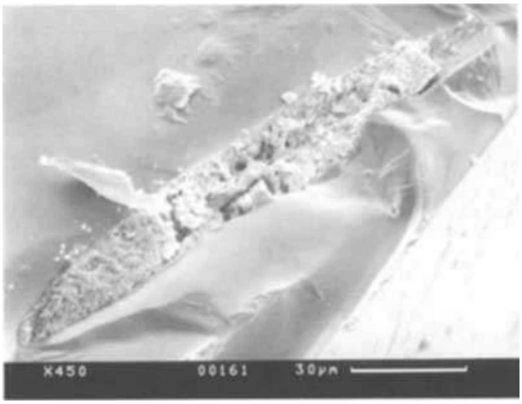
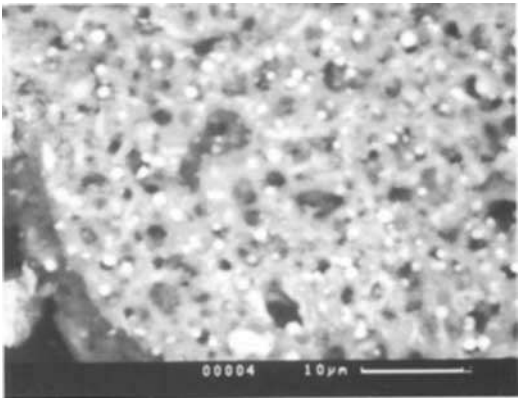


Fig. 6. Scanning electron microscope (SEM) photograph of the groundmass showing sponge-like form with white spheres.



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* Analysed using a Link Systems AN100000 system with energy dispersive Si(Li) detector on a CamScan scanning electron microscope (SEM).

Table III: Analyses of inclusion material

	Partial-spheres	Spongiform matrix
SiO_2	13.12	47.65
TiO_2	00.98	03.16
ZrO_2	00.00	00.00
Al_2O_3	13.69	37.69
Cr_2O_3	00.05	00.23
FeO*	62.49	08.89
CaO	00.18	00.69
K_2O	00.05	00.21
P_2O_5	09.15	01.41
Cl	00.28	00.07
-O=Cl	0.06	0.02
Total	99.93	99.98

* The valence state of iron is assumed be 2+

cordierite and minerals in the cordierite-sekaninaite [$Mg_2Al_4Si_5O_{18}$-$(Fe,Mg)_2Al_4Si_5O_{18}$] series respectively. The partial spheres could not be identified with confidence. The frothy, sponge-like appearance of the dark grey matter suggested the emission of gases. This supports the view that there has been a reaction between the inclusion and the host zircon probably brought about by thermal decomposition during heat treatment. The elements present in ferrian spinel and zircon are also those contained in baddeleyite and cordierite-sekaninaite. Such reaction features (Figure 7) can show bubbles around the inclusion.

Other inclusions were black, distorted hexagonal plates of biotite and apatite crystals.

Conclusions

Application of the various tests failed to establish the existence of locality specific criteria.

Whilst there is evidence to support a correlation between fluorescence, locality and degree of heat treatment, the anomalies dictate that caution should be exercised. Fluorescence should be used neither as a clear-cut test for locality assignment nor, because of the anomaly shown by sample 9 under LWUV, as categorical evidence of heat treatment. Fluorescent effects of zircons from other localities would also have to be examined before refining views on fluorescence as a potential locality or heat treatment indicator.

Whilst the extent of heat treatment on the Indo-China samples clearly influenced the absorption spectra (colourless stones showing the strongest spectra), no correlation between spectra and location could be established. There was no discernible difference in the absorption spectra between the Indo-China zircons and those described by Anderson (1964) from Sri Lanka..

Infrared spectra could not be used to provenance the zircons although its use in heat treatment determination may prove useful.

It was not possible to assign particular inclusions to any specific locality.

Acknowledgements

The authors would like to thank Mr W. C. Buckingham and the Gemmological Association and Gem Testing Laboratory of Great Britain for allowing us to work on the specimens and their patience during the course of this study. Thanks are also due to Mr Paul Wilthew of the Conservation and Analytical Research Laboratory of the National Museums of Scotland for all SEM and analytical work. Karl Bank is thanked for his contributions at an early stage in the work.

Note

1. The Edinburgh Gemmological Group (EGG) is an informal group of FGAs who meet to discuss and investigate gemmological topics. The EGG members who collaborated in the preparation of this paper are: James 'Mac' Heatlie, Yvonne Holton, Brian Jackson, Alistir Tait, Euan Taylor, James Walker, Margery Watson and Tom Watson.

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[*Manuscript received 1 January 1993*]

Flux-grown synthetic rubies from Russia

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Introduction

Russia and some other states of the former Soviet Union are well known as producers of various synthetic stones, e.g. synthetic amethyst, emerald, alexandrite, spinel and diamond. Synthetic ruby was first mentioned by the authors in 1990. The dark red synthetic material (Figure 1) showed an aggregate-like, grained texture with few homogeneous parts which are facetable. The largest piece of rough weighed 30 ct. Microscopical studies yielded black bubble-like residues of the flux (Figure 2).

The existence of synthetic rubies of Russian production permitted the supposition that gem quality material would come up very soon. Finally in 1992, the first cut synthetic rubies from Russia were observed. Peretti and Smith (1993a) mentioned faceted specimens up to 1. 69 ct. and reported that the synthetic rubies were hydrothermally-grown. A detailed description of that material together with the chemical and physical properties was published by the same authors (Peretti and Smith, 1993b). Also in 1992, the authors of this article saw a faceted synthetic ruby said to be flux-grown from Russia and in January 1993 they received two rough crystals of synthetic ruby. The supplier, a colleague from the Academy of Sciences of Novosibirsk, where the synthetic specimens are produced, stated that the synthetic rubies were produced by using a flux technique.

The present article summarizes the properties of these flux-grown synthetic rubies of Russian production and emphasizes the important distinguishing features from natural rubies.

General appearance

The two rough crystals of synthetic ruby are quite different in visual appearance in both crystal habit and colour.

Type 1 (Figure 3) has an elongated, tabular prismatic habit and weighs 63.8 ct. The colour is pale red with a high homogeneity.

Type 2 (Figure 4) possesses a rhombohedral crystal habit, weighs 22.6 ct. and has a dark red colour.

Crystallographic description

The type 1 synthetic ruby crystal (tabular prismatic) shows a well-developed second-order hexagonal prism *a*$(11\bar{2}0)$ and less distinct positive rhombohedron *r*$(10\bar{1}1)$ and basal pinacoid *c*(0001).

The rhombohedral type 2 synthetic ruby shows well-developed crystal faces with the positive rhombohedron *r*$(10\bar{1}1)$, second-order hexagonal prism *a*$(11\bar{2}0)$, second-order hexagonal bipyramid *n*$(22\bar{4}3)$ and basal pinacoid *c*(0001).

Chemical composition

Chemical analyses carried out by EDAX-eds system fitted on a scanning electron-microscope proved the two synthetic ruby crystals from Russia to contain aluminium oxide and chromium oxide as main components. The tabular prismatic type 1 synthetic crystal shows 99.72 wt. % Al_2O_3 and 0.28 wt. % Cr_2O_3 and the rhombohedral type 2 synthetic ruby 98.48 wt. % Al_2O_3 and 1.52 wt. % Cr_2O_3.

Refractive indices, birefringence and density

Using a standard gemmological refractometer, the refractive indices have been determined for both type 1 and type 2 synthetic ruby: type 1: n_e=1.760 and n_o=1.768; type 2: n_e=1.762 and n_o=1.770. The birefringence of both specimens is 0.008. The optic sign is uniaxial negative.

The density has been measured by using a hydrostatic balance. The data determined vary between 3.98 and 4.01 g/cm³. It must be remembered that the inclusions (flux residues) substantially influence the values of the density.

Absorption spectrum and pleochroism

The synthetic ruby crystals of Russian production show typical absorption spectra of Cr^{3+}. The

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Fig.1. Aggregate-like, polycrystalline synthetic ruby from Russia, first described in 1990 (weight of the large piece 28 ct).

Fig.4. Rhombohedral synthetic ruby crystal of Russian production (type 2), weighing 22.6 ct.

Fig.2. Black, bubble-like flux residues in the polycrystalline synthetic Russian ruby material. x20.

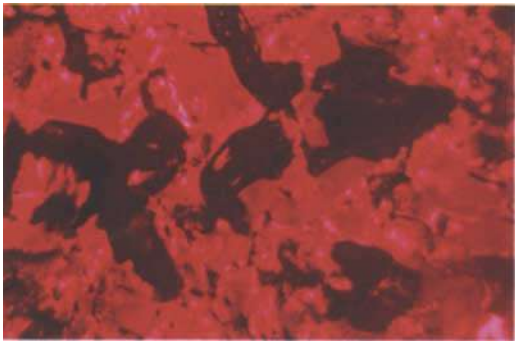

Fig.3. Elongated, tabular prismatic synthetic ruby crystal (type 1) from Russia, weighing 68.8 ct .

Fig.5. Black, opaque flux residues in a synthetic ruby from Russia. x10.

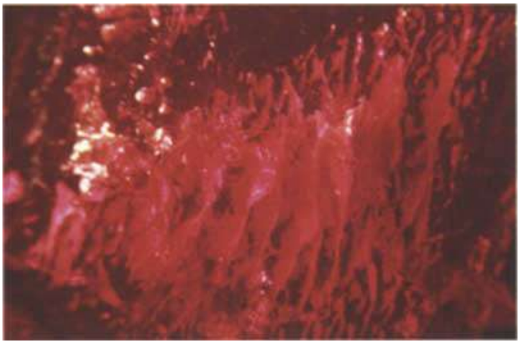

Fig.6. The flux residues of Figure 5 under darkfield illumination.

Fig.7. Flux residues in a synthetic ruby from Russia. x15.

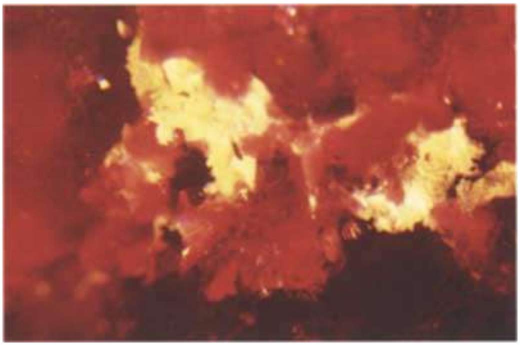

Fig.8. Yellow residues of the lithium tungstate flux at the surface of the type 2 synthetic ruby crystal from Russia. x10.

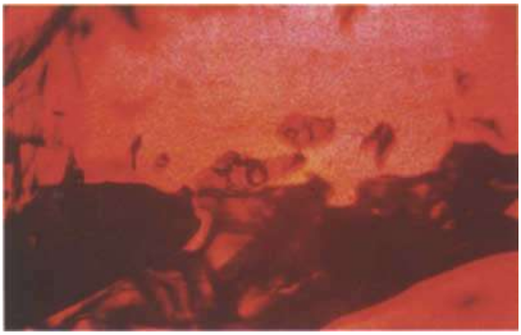

Fig.9. Cavities filled by flux residues. x20.

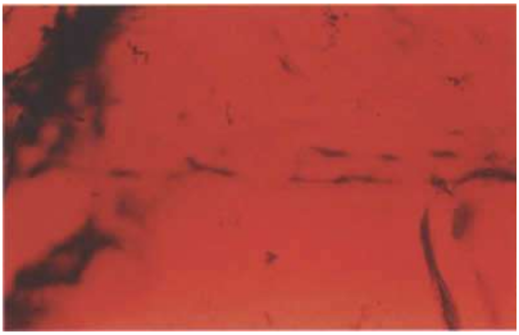

Fig.10. Tiny triangular platelet as a residue from the crucible (probably platinum). x30.

Table 1: Properties of flux-grown synthetic rubies from Russia

		Type 1	**Type 2**
Crystal habit		Tabular	Rhombohedral
Chemical composition (wt.%)	Al_2O_3	99.72	98.48
	Cr_2O_3	0.28	1.52
Colour		Pale red	Dark red
Pleochroism	o	Violet-red	Purplish-red
	e	Yellowish-red	Orange-red
Absorption spectrum		Typical Cr^{3+} -spectrum Cr^{3+}-absorption line: 692 nm Cr^{3+}-absorption bands maxima: E // c: 545 and 409 nm E⊥c: 554 and 400 nm	
Refractive indices	n_e	1.760	1.762
	n_o	1.768	1.770
Birefringence		0.008	0.008
Density (g/cm^3)		3.98	4.01
UV luminescence			
long-wave UV		Strong red	
short-wave UV		Weak red	
Internal features	Black, opaque residues of the flux (tungsten oxide has been determined as a component of the flux by chemical analyses), cavities partly filled with a flux bubble (the flux material has contracted during the cooling of the synthetic ruby crystals), small triangular residues from the crucible (probably platinum), distinct growth structures.		

Cr^{3+} absorption line is located at 692 nm. The pleochroic absorption bands are in the green and violet spectral range and possess maxima at 554 and 400 nm for E⊥c and 545 and 409 nm for E//c.

The pleochroism is distinct: violet-red (o) and yellowish-red (e) for type 1 and purplish-red (o) and orange-red (e) for type 2.

Ultraviolet luminescence

When exposed to ultraviolet (UV) radiation the synthetic ruby crystals both show strong red fluorescence under longwave-UV and weak red under short-wave UV.

Internal features

Microscopic investigations showed black, opaque residues of the flux (Figures 5,6,7). Chemical analyses of residues at the surface of the synthetic ruby crystals (Figure 8) proved the flux to contain tungsten as a main component. According to information from the producer, the synthetic rubies are produced in a lithium tungstate melt (Li_2O-WO_3) at temperatures of 1100°C . Flux residues are also found as residual fillings of cavities (Figure 9). Triangular residues of the crucible material (probably platinum) are also found as typical inclusions of flux-grown synthetic rubies (Figure 10).

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Notes from the Gem and Pearl Testing Laboratory, Bahrain – 2

A. Bubshait, FGA, and N.P.G. Sturman, FGA, DGA

Pressed amber

In our first Bahrain Laboratory notes (in Scarratt, 1992, 223-4) we made reference briefly to characteristic strain patterns normally associated with some forms of pressed amber. The strain patterns referred to were those sometimes observed between crossed polars and typical of materials subjected to some form of internal structural strain.

Interestingly, shortly after the publication of this article, a yellow heart-shaped cabochon (Figure l) was submitted for a verbal opinion. The properties of the cabochon indicated that it was amber: it floated in brine, had an RI of 1.54 (direct and distant vision) and when a hot point was used extremely carefully, it gave off a characteristic resinous odour. However, unlike the necklace in our first report, when examined between crossed polars the cabochon displayed strain patterns typical of some forms of pressed amber (Figure 2). Microscopic examination revealed clear boundaries between some of the individual amber pieces making up the cabochon and the fluorescence exhibited under short wave ultra-violet light, although weak, was a patchy chalky whitish green colour. On closer examination the uneven fluorescence appeared to be related to the different fluorescent characteristics of the amber pieces within the cabochon.

Fig. 1. The pressed amber cabochon.

Fig. 2. The interference colours exhibited by the cabochon seen in Fig. 1, when examined through a polariscope.

Surface colour enhanced amber

A string of 'worry beads' comprising 45 spherical, one cylindrically-shaped and two disc-shaped yellow brown beads was submitted recently with a request to check that the beads were amber. The usual testing procedures used on materials suspected of being amber all indicated that samples from the beads were amber, but the colour of the beads looked 'odd' when examined through the microscope. This oddity took the form of transparent lighter yellow patches of various sizes, scattered across the mainly darker orangish brown surface of the beads (Figure 3). These lighter areas

Fig. 3. One of the lighter yellow areas acting as a 'window' to reveal the underlying colour of the beads.

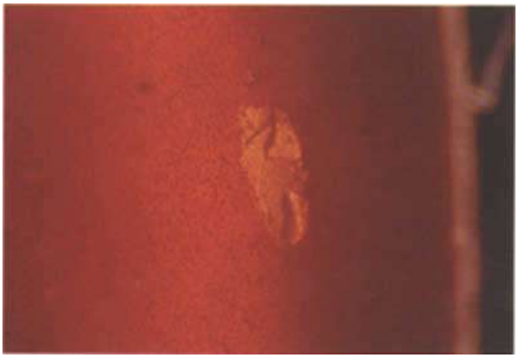

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Fig. 4. The spangles observed in some beads.

appeared to resemble gaps in an uneven coating of some type (rather like a decorator painting a wall but missing small areas), but no signs of any coating could be detected. Higher magnification showed that many of the lighter areas were slightly raised above the surface. In order to check that these areas were not due to spots of some separate substance which had been dropped onto the surface and solidified, we very carefully levelled one with a knife. This showed that the underlying colour was still a lighter yellow and that the raised area was not formed from another substance. As an extra check, the underlying area revealed by the knife and the top of another raised area which had not been examined previously were lightly touched with a thermal probe. Both gave a resinous odour typical of amber.

At this point we began to note the similarities between these beads and those examined in our first 'Note from the Bahrain Laboratory' (in Scarratt, 1992, 223-4). In UV radiation the darker coloured surface areas of the beads fluoresced a weak chalky orange, whilst the small lighter yellow areas within the darker body showed a distinct moderate to strong whitish/blue fluorescence. Pursuing this relationship between colour and fluorescence further, we gently scraped away the darker surface colour of one bead in a small inconspicuous area. Not only did the underlying colour of this particular area turn out to be light yellow, but when this previously dull orange fluorescent area was examined with UV light once more, a strong whitish-blue fluorescence was observed. It would appear that the body colour of the beads, in both this necklace and that described in the previous 'Note' (1992), is pale yellow and gives rise to whitish- blue fluorescence. The greenish-brown fluorescence of the more strongly coloured areas in the faceted bead necklace and the orange fluorescence of the necklace just described, probably indicate either slightly different starting materials or different degrees of heating.

Numerous spangles seen in some of the beads (Figure 4) are typical of some examples of clarified amber (Fraquet, 1987) and add credence to the idea that the beads have been heat-treated.

Surface cavity filled natural rubies

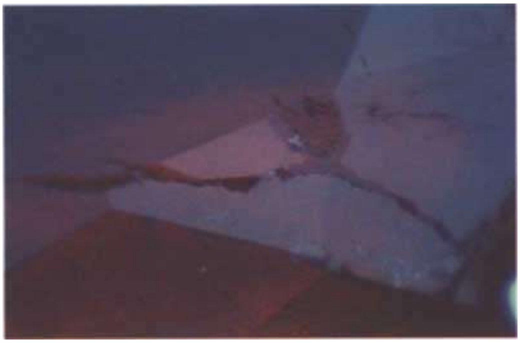
Today, gemmologists are not only faced with identifying a wide range of gemstones, but also a wide range of treatments used to improve the colour, clarity and, hence, the apparent value of these stones.

One of the most frequently encountered treatments is the artificial filling of cavities and fractures in natural rubies and, to a lesser extent, natural sapphires (Hughes, 1990). Figures 5 and 6 show the type of filling that the gemmologist needs to be aware of. These features were observed in two natural Thai rubies that were mounted in a necklace containing 32 oval faceted rubies of approximately 0.60 - 0.70ct each. Three more rubies in the necklace revealed narrow fillings in deeper fractures.

Stones with shallow filled surface cavities may be repolished to remove the material, but if, as in this case, any of the material present is in a deep fracture or feather the potential of the stone is not so good, as no amount of repolishing will remove all the material.

Fig. 5. The larger filled surface cavity in a ruby.

Fig. 6. Surface-reaching fracture in another ruby showing that part of the stone (top right) is filled.



Waxed filled cavities in coral

'Worry beads' are a part of Bahraini life and as such are used as a fashion accessory. Because of their popularity we inevitably see a large number pass through the Laboratory for examination. Figure 7 shows some 'worry beads that were tested recently. The concentric/radial branch-like structure of the beads and the other gemmological properties proved them to be coral, but what was more interesting was that some cavities and surface-reaching fractures appeared to have been filled. The material filling the surface features became very apparent under reflected light (Figure 8), as the lustre of the filler was notably different from the surrounding coral. In addition to the difference in lustre, some filled areas contained one or more bubbles, were easily marked with a metal pointer and flowed when a hot-point was placed near them. All this evidence led us to believe that the material used to fill the cavities was probably wax that had been used in part to improve the surface appearance of the beads by hiding the cavities.

Nineteen rows of mixed natural and non-nucleated cultured pearls

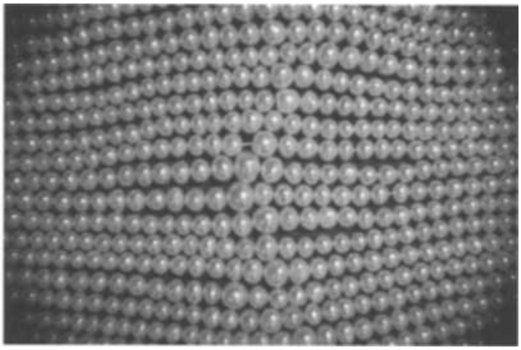


Fig. 9. Nineteen rows of pearls containing a mixture of non-nucleated cultured pearls and natural pearls.

Nineteen graduated single rows of pearls were recently submitted for a sample test and the largest pearls (up to 8.0 mm) are shown in Figure 9. We were informed that the pearls were thought to come from the Gulf and, since being found, had been sent to India for drilling, sorting and stringing. Gulf pearls have been sent to India to be incorporated in Bombay bunches for hundreds of years, so this account came as no surprise. The pearls were duly tested, and, when the radiographs of the pearls were examined, it became clear that the rows contained a mixture of natural and non-nucleated cultured pearls. Ever since the introduction of non-nucleated cultured pearls in the late 1950s, those dealing in natural pearls have had to be wary of this type of cultured pearl. These rows show just how careful dealers have to be, especially with the improved techniques used to culture pearls today. Nowadays, most of the non-nucleated cultured pearls no longer have a 'Rice-Crispie' shape, hitherto so characteristic of the freshwater culturing method, and many pearls resulting from freshwater and marine culturing methods may closely resemble natural pearls in external appearance.

Although these mixed rows are not the first to have been tested by the Bahrain Laboratory, they have proved to be the most mixed seen to date. In most previous rows we have examined, the non-nucleated cultured pearls have been small to medium sized, whereas the non-nucleated cultured pearls illustrated in Figure 9 are of numerous sizes, including many that are large. We know of no commercial cultured pearl farming in the Gulf so, although the natural pearls may well have a Gulf origin, the non-nucleated cultured pearls must come from elsewhere.

Two pearls with interesting drill-holes

In February 1993 a customer brought us two button-shaped pearls for testing. It was not their radiographic structure that interested us, but rather how they were drilled. The drilling methods used on each pearl were different, as the radiograph in Figure 10 shows. One showed the 'Chinese-drilling' method where two part-drilled holes are angled to meet one another to form a 'curved' drill-hole and the other showed a very large part-drilled hole in the base with a separate

Fig. 10. Radiograph and diagram of the two pearls showing the drilling methods applied to each. 15 minutes exposure, short development.

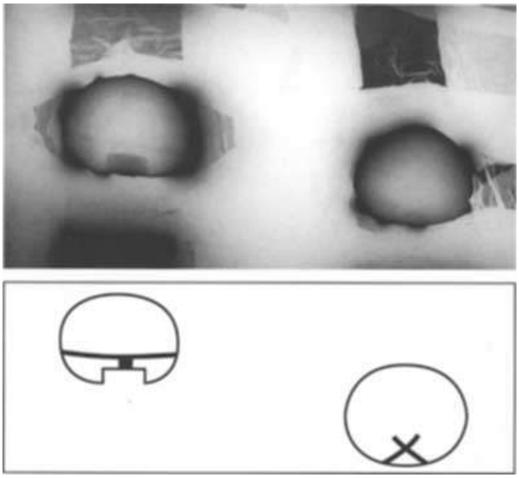


Fig. 7. The coral 'worry beads'.

drill-hole at right angles, running across the diameter of the pearl.

Both methods of drilling are often associated with natural pearls and, in our experience, a pearl with either form of drilling often proves to be natural. That this is not always the case is demonstrated by the pearl with the 'T' drilling which proved to be cultured. Such drilling clues, therefore, cannot be taken as proof of identity.

Chinese-drilling was so named because the Chinese often drilled pearls in this way for use as buttons and decorations on Mandarins' clothes (J. Taburiaux, 1985).

Acknowledgements

The authors acknowledge with thanks the assistance of both the Bahrain and London Laboratory staff.

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[*Manuscript received 7 March 1993*]

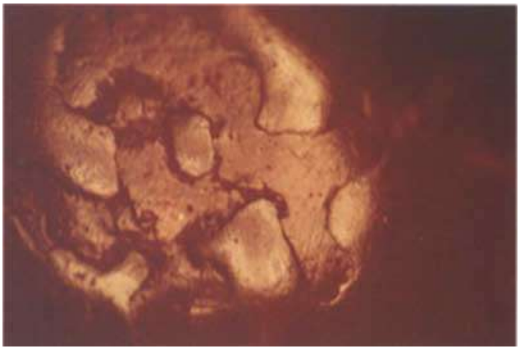

Fig. 8. The difference in surface lustre seen when a filled area is examined by reflected light. Note the dull lustre of the soft wax and the brighter lustre of the coral.

Emerald mineralization of Barang, Bajaur Agency, Pakistan

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Abstract

This is the first account of emerald mineralization from Barang, Bajaur Agency, NW Pakistan. Emerald mineralization is associated with talc carbonate host of the Indus suture ophiolitic melange. The mineralization is pneumatolytic and hydrothermal, late to post tectonic and structurally controlled. For the first time it is being recognized and proposed that the source of beryllium bearing fluids responsible for emerald mineralization are the Tertiary minor granites of S-type occurring in the area. This is contrary to the already held views that beryllium fluids emanated from a trench or arc source. The colour of Barang emerald varies from light bluish-green to deep green and the crystals range from minute to 2.5cm. This paper for the first time presents cell dimension of emerald from Pakistan by using an advanced computer program and four cycles of refinement.

Introduction

A variety of gemstones including emerald, ruby, pink and golden topaz, bi-colour tourmaline and aquamarine are being mined in northern Pakistan, mostly by the public sector. Amongst them, the top quality Swat emeralds are considered to be among the best in the world. For long these had been sold in the world market as 'Afghanistan' emeralds. The recent efforts of the Gemstone Corporation of Pakistan have introduced this emerald in the world market and because of its properties it is in great demand nowadays.

The main emerald-producing areas in the Swat district are Mingora (Gübelin, 1968, 1982; Jan, 1968, Jan *et al.*, 1981; Kazmi *et al.*, 1984, 1986) and Gujar Kili (Hussain *et al.*, 1982). Khazana (Shamozai area) is a newly discovered locality in Swat, the potential of which is still to be ascertained.

Emerald from Amankot, Bajaur Agency (longitude 71° 36.68′ and latitude 34° 39.25′), has been produced by the locals since early 1970s. The location of the area is given in Figure 1. Because of the tribal and hostile attitude of the locals, no outsider could visit the mining areas of this agency and hence nothing was reported about the nature of these deposits. After protracted efforts, it became possible to carry out investigations of the Amankot emerald mines in 1984.

A brief account of the geology and emerald mineralization of Amankot mines in Bajaur Agency is given below.

Geology and petrography of the host rocks of emerald

The geological map of the area is given as Figure 2. The lithostratigraphic sequence and broad tectonic units of the area are as follows:

Kohistan sequence	Amphibolite, etc.	Cretaceous
	----- Main Mantle Thrust (MMT, Indus suture) ------	
Indus suture melange	Talc carbonate Ultramafics Gabbro Green schist/stone Amphibolite Metasediments	Cretaceous to Palaeocene
	---------- Thrust ----------	
Indian Plate	Carbonatite Minor S-type Granite	Tertiary
	Graphitic schist Garnetiferous-calcareous rock Quartzite/quartz-mica schist	Precambrian
	Granite gneiss	Proterozoic

Talc carbonate blocks which host emerald mineralization in Barang, Bajaur Agency, are part of the Indus suture melange which marks the line of closure of the Tethys. This tectonic melange occurs between the Indian plate composed mainly of Precambrian metasediments and S-type granite gneisses cut at places by Tertiary garnet and tourmaline bearing leucogranites of S-type and associated beryl bearing pegmatites to the south and the Kohistan island arc complex of Creto-Tertiary age to the north.

A general north-south stretching Indus suture ophiolitic melange comprising lenses and blocks of greenstone, talc carbonate, gabbro, serpentinized peridotite, amphibolite, calcareous rock and

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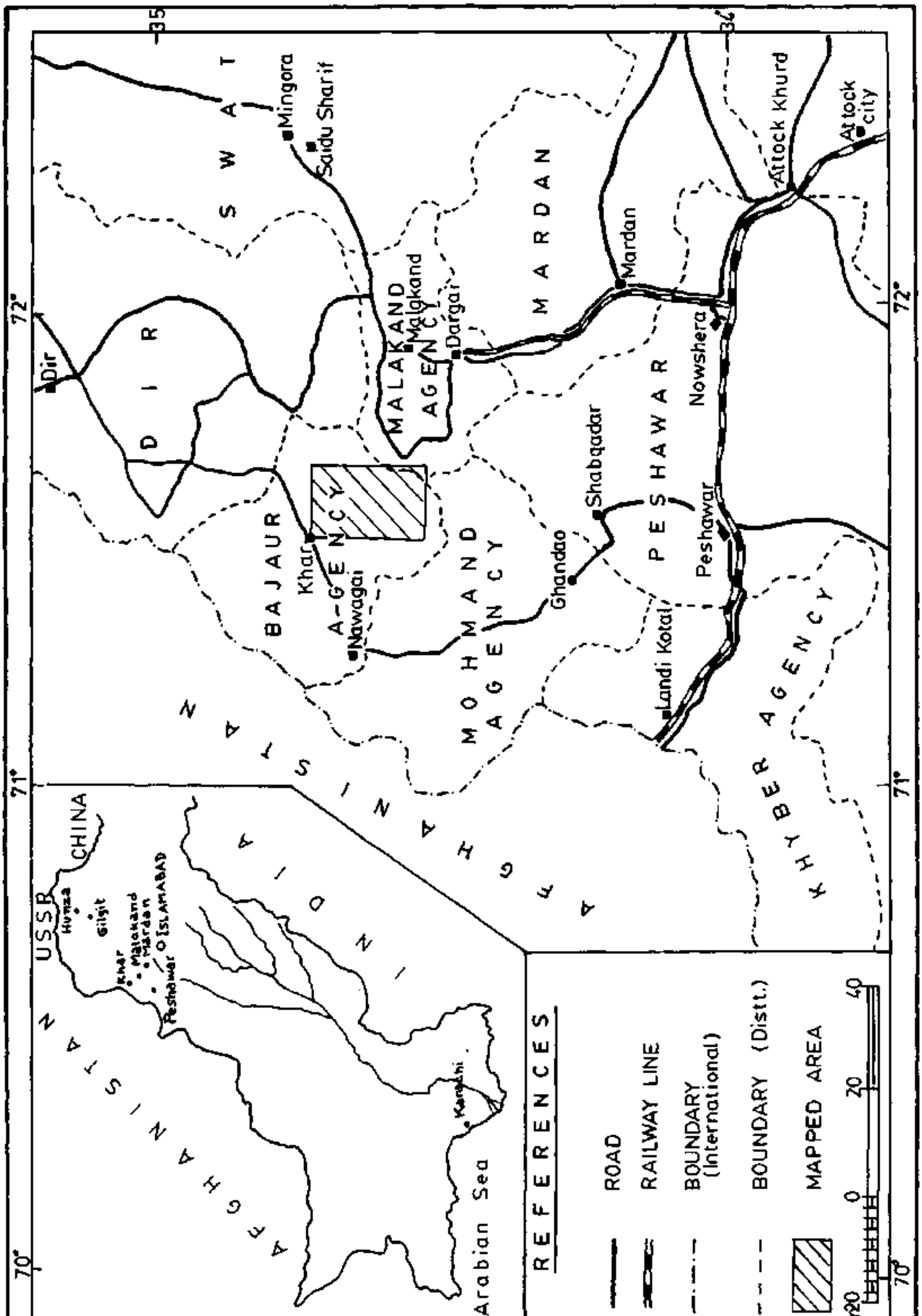

Fig. 1. Location map.

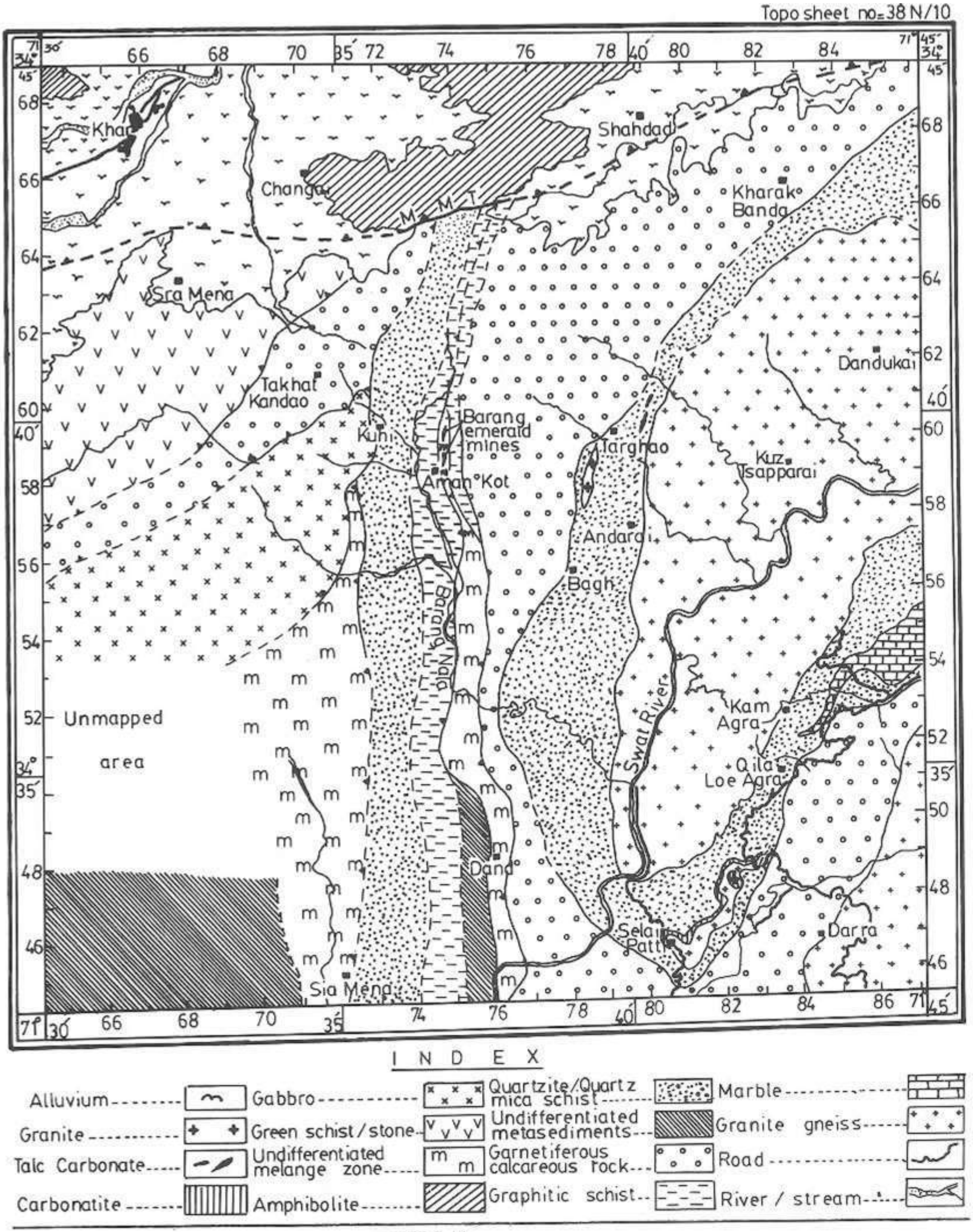

Fig. 2. Geological map of Barang-Turghao area, NWFP, Pakistan.

metachert has been briefly described by Hussain *et al.* (1984).

The larger outcrops of talc carbonate, greenstone and gabbro melange have been shown on the map (Figure 2). The melange with smaller unmappable blocks has been shown as undifferentiated melange (Figure 2). Towards the north it is truncated by Indus suture or Main Mantle Thrust (MMT). Ophiolitic melange has been emplaced along a number of faults which are usually marked by talcose rocks.

Rocks of the melange zone have an angular relationship with overlying older calcareous schists. The rock fragments or blocks in the melange zone vary in size usually from a few metres to thousands of metres across. These rocks have been subjected to deformation resulting in the formation of tight folds, fractures and faults. Talc carbonate rocks which host emerald mineralization are described below. The other rock types in the melange have been excluded since they are not directly related to the emerald mineralization.

Talc Carbonate Rocks

Field and laboratory studies indicate that these rocks are the altered ultrabasics. They occur as lenses, patches and sheets of various sizes and are composed of talc, carbonates (mainly magnesite), quartz, actinolite, iron ore, etc.

The schistosed zones are talc-rich and exhibit tight drag folding. Talc carbonate schists contain almost equal quantities of talc and carbonate. Soapstone is also associated with talc carbonate schist. Massive rocks are carbonate (dominantly magnesite) with a small quantity of talc. These are well jointed and contain abundant quartz and calcite veins. Lenses and nodular quartz veins and stockwork are sometimes lined by chlorite and fuchsite.

Talcosed rocks may contain phacoids (concordant lenses) of green schist. Actinolite is developed in talc carbonates at their contacts with metasediments. At these places talc carbonates appear to be metasomatically altered. This is indicated by the presence of feldspar which is not strongly altered. Some of the altered bodies are highly feldspathic with chlorite, actinolite, muscovite and quartz as accessory or minor minerals. These patches are up to a few metres across in size.

Emerald mineralization is found in talc carbonate rocks towards the north of Amankot. Silicification of these rocks is observed and emerald has been mineralized in the silicified parts. These quartz schorl and somewhat feldspathized quartz schorl rocks are closely associated with the talc carbonates in the mine area of Amankot. The silicified and metasomatized areas (quartz-schorl-feldspar and quartz-schorl rocks) may contain tiny beryl crystals.

In Barang-Turghao area both S-type Proterozoic granite gneiss and younger anatectites (Tertiary in age and associated with the Himalayan orogeny) are present. The small acid minor bodies of Tertiary age are late to post tectonic.

Kot granite gneiss and Agra-Turghao granite gneiss of the surrounding area are S-type. Both these bodies have younger (Tertiary) acid minor bodies. They also include beryl- and tourmaline-bearing pegmatites. The beryl is bluish-green in colour.

Emerald mineralization

About an 80 metre wide zone in talc carbonates to the north of Amankot village has emerald mineralization. The talcose rocks are emplaced along a fault within graphitic schists.

The Amankot mineralized area consists of three emerald mines over a linear extension of about 0.80km. The emerald mineralization noted in these mines is described below:

1. Hydrothermal veins, consisting mainly of quartz with a small quantity of carbonates, in places contain emerald crystals. Talcose rocks adjacent to these veins are also mineralized. The quality of this emerald, especially in the host talc carbonates, is the best. The emerald crystals are usually well developed, inclusion free and have good transparency.
2. Tourmalinized meta-cherts overlying the mineralized talc carbonates are cut by pneumatolytic/hydrothermal veins. Sometimes these veins contain small sized, poor to medium quality emerald crystals. The host tourmalinized meta-cherts may also be mineralized with the same quality emeralds.
3. Silicification of the talc carbonates has taken place over smaller areas up to a few metres across. Occasionally these contain sporadic emerald crystals. The quality of these emeralds is also not good.
4. Sheared zones are developed along the faults in talc carbonate rocks. Hydrothermal veins have filled some of these weak zones. Within such zones emerald crystals are found in pockets as well as disseminations.

Optics and chemistry of emerald

The colour of emerald crystals of Amankot area is bluish-green, green, grass green and deep green. Some crystals are light greenish-blue with green edges. Transparency varies from poor to excellent. High quality emeralds of the Amankot area are bluish-green, clear and transparent.

Single crystals are usually well developed, hexagonal and may have small sized inclusions. The size of emerald varies from 1mm to a maximum of 2.5cm in the longer dimension. The largest stones weigh up to 150 carats.

The RIs of Amankot emeralds are higher than those of pure beryl due to a high quantity of iron and chromium. The values are comparable to the emeralds of Bucha, NW Pakistan (Rafiq *et al.*, 1985) but higher than those of Mingora emeralds, Swat, due to higher FeO.

Absorption bands and refractive indices of one beryl and two emerald crystals from Amankot are listed in Table I, together with similar data for Bucha (Mohmand) beryl and emeralds (Rafiq *et al.*, 1985) as well as Mingora (Swat) emerald (Gübelin, 1982). The RI values were determined by immersion method on powdered grains. The listed values are accurate to ± 0.002. The absorption spectra of emeralds contain distinct chromium absorption lines in the red region at 682.7-683.9 nm for beryl and 682.5-683.8 nm for emeralds. There are also weak broad bands for Fe absorption for both beryl and emeralds in the yellow region between 585-584 nm. These are due to significant Fe contents. Optically the emeralds of Amankot area, Bajaur Agency, are very similar to the Bucha emeralds, Mohmand Agency, reported by Rafiq and Jan (1985).

Two chemical analyses of Amankot emeralds and one analysis of beryl for the same area are given in Table II. In addition to major elements, the amounts of Cr_2O_3, MnO, CuO and NiO have also been determined. For the sake of comparison the analyses of Amankot, Bucha (Rafiq *et al.*, 1985) and Swat emeralds (Gübelin, 1982; Schrader, 1983) and Barang emeralds and green vanadium beryls of Gandao (Snee *et al.*, 1989; Hammerstrom, 1989) have been arranged as Table II.

The analyses of Barang and Gandao emeralds have been discussed by Snee *et al.* (1989) and Hammerstrom (1989). However, they have wrongly grouped these analyses with Mohmand as constituting a single district. This grouping is erroneous since host rocks in the case of Barang (Bajaur Agency) are different from that of Gandao (Mohmand Agency) and the two deposits are separated by a considerable distance. The main Mohmand deposit occurs in meta-limestone whereas the host rock in case of Barang is talc-carbonate.

Schrader (1983) has suggested that the green colour in emeralds may be due to Cr, Mn, Ni, V and Fe. A comparison of the chemical analyses of emerald of the Amankot area with beryl of the same area shows that the values of Mn, Fe, Ni and V are similar. The only colouring factor may, therefore, be Cr. This fact has been pointed out by Rafiq and Jan (1985) for Bucha emeralds.

Cell dimensions of bluish-green emerald from Amankot (analysis 3 in Table I) were determined. The diffraction pattern was obtained on Ragaku automated powder X-ray diffractometer (Model D-MAX/IIA). The cell dimensions were calculated by using the advanced programme of Benoit (1987). Four cycles of refinement were used. The cell dimensions are:

$$a = 9.2548 \pm 0.0036$$
$$c = 9.1905 \pm 0.0075$$

This is the first determination of cell parameters of emeralds from Pakistan using an advanced computer program.

Paragenesis

Talc carbonates host emerald mineralization not only in Barang, Bajaur Agency (this account), but also in Mingora, Swat (Gübelin, 1968, 1982; Jan, 1968; Jan *et al.*, 1981, and Kazmi *et al.*, 1984, 1986). Talc carbonates also host emerald mineralization in

Table I: Physical properties of Amankot, Bucha and Swat emeralds

Specimen	Absorption (in nm)	Strength of absorption	Chelsea Colour Filter	Refractive Indices ε	ω	Inclusions
Light pale green beryl (Amankot)	682.7 683.9 585.0	Weak to moderate Weak broad bands	Light brownish-red	1.576	1.586	Fluid inclusions mica and Fe-oxides
Bluish-green emeralds (Amankot)	682.6 683.8 584.0	Strong Weak broad bands	Deep brownish-red	1.592	1.604	Fluid inclusions, talc fibres, mica plates, Fe-oxides
	682.5 683.7 585.0	″	″	1.592	1.604	″
Light green beryl (Bucha)*	682.8 683.9 585.0	Weak to moderate Weak broad bands	Light brownish-red	1.575	1.583	Fluid inclusions, feathers of Fe-oxides, siderite, tremolite/mica
Bluish-green emerald (Bucha)*	682.8 683.9 585.0	Strong	Dark brownish-red	1.590	1.600	Fluid inclusions, talc fibres, mica plates
Emerald (Swat)**	683-680 662, 646, 637	Strong Distinct to strong	red to pink	1.588 to 1.593	1.595 to 1.600	Two phase inclusions, colour banding and zoning, calcite, dolomite
	477, 472 472	Weak				

* Rafiq and Jan, 1985

** Swat emerald values cover the range for seven stones (for details, see Gübelin, 1983)

Table II: Analyses of beryls, emeralds and green vanadium beryls from Pakistan.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	63.74	–	62.41	63.05	–	–	64.2	63.7	–	N.D.	–	63.8	N.D.	63.1	62.1	63.2
TiO_2	0.04	–	0.03	0.02	–	–	–	–	–	0.12	<0.02	<0.07	0.13	<0.05	0.01	0.02
Al_2O_3	13.28	–	15.26	14.20	–	–	14.8	13.7	–	14.5	14.8	14.5	14.7	12.7	14.1	14.0
Cr_2O_3	0.10	0.27	0.85	0.76	0.83	0.66	0.8	1.4	0.2	–	0.03	0.03	–	0.45	0.17	0.04
Fe_2O_3	2.52	2.25	2.47	2.18	2.10	0.9	0.4	1.4	0.7	–	1.6	1.4	–	1.2	0.94	1.40
BeO	12.95	–	12.08	13.07	–	–	–	–	–	–	–	11.41	–	10.96	–	–
MnO	0.08	0.10	0.10	0.10	0.10	–	0.0	0.1	0.002	–	–	–	–	–	0.02	0.00
MgO	1.26	2.18	2.15	2.34	1.91	2.6	2.7	2.4	0.6	2.0	2.4	2.2	2.5	4.8	2.77	2.14
CaO	0.69	–	0.41	0.34	–	–	–	–	–	0.3	<0.04	0.53	<0.3	0.13	0.02	–
Na_2O	2.29	1.87	1.91	1.82	2.14	2.1	2.1	1.9	2.0	2.30	2.49	–	2.22	–	2.19	1.75
K_2O	0.18	0.27	0.16	0.13	0.08	–	–	–	–	–	–	<0.5	–	<0.04	0.02	0.03
CuO	0.18	0.41	0.21	0.19	0.11	–	–	–	–	–	–	–	–	–	–	–
NiO	0.04	0.04	0.05	0.06	0.02	–	–	–	<0.02	0.00	–	–	–	–	–	–
V	0.04	–	0.06	0.04	–	–	0.1	–	>0.05	–	1.33	0.53	0.02	0.04	0.02	0.66
									Sc=0.14						(as V_2O_3)	(as V_2O_3)
H_2O^+	1.70	–	1.50	1.67	–	–	–	–	–							
H_2O^-	0.14	–	0.11	0.08	–	–	–	–	–							

1. Light pale green beryl from Kot, Malakand Agency
2. Light green beryl from Bucha, Mohmand Agency. *Analyst M. Tahir Shah* (Rafiq and Jan 1985)

3 & 4. Bluish-green emerald from Amankot area, Bajaur Agency

5. Deep bluish-green emerald from Bucha, Mohmand Agency. *Analyst M. Tahir Shah* (Rafiq and Jan, 1985)
6. Emerald from Mingora, Swat. *Analyst M. Weibel* (Gübelin, 1982)

7 & 8. Microprobe analyses of two emeralds from (Swat?) Pakistan, (Hänni, 1982)

9. Neutron activation analysis of emerald from (Swat?) Pakistan. Average oxide values calculated from element percentages of two samples by Rafiq and Jan (1985) from Schrader (1983)

10 & 13. Neutron activation analyses of emeralds from Barang (Snee *et al.*, 1989)

11. Neutron activation analysis of green vanadium beryl from Gandao (Snee *et al.*, 1989)

12. & 14. Induced coupled Argon Plasma-Atomic Emission Spectrometry analyses of green vanadium beryl from Gandao and of emerald from Barang respectively (Snee *et al.*, 1989)

15 & 16. Microprobe analyses of emerald from Barang and of green vanadium beryl from Gandao respectively (Hammerstrom, 1989)

Gujar Kili, Makad and Charbagh areas of Swat (Hussain, 1982).

Gübelin (1982) suggested a dolomitic host for emerald mineralization in Mingora, Swat. However, detailed petrological and geochemical studies of talc carbonates and associated ultramafics from Indus suture melanges in Swat area clearly show that the talc carbonate rocks are strongly carbonatized serpentinites and serpentinized peridotites. Chaudhry *et al.* (1980) and Jan *et al.* (1968, 1980, 1981) also considered talc carbonate rocks as derivatives from an igneous (ultramafic) parentage.

Prior to this presentation no direct evidence was available to relate emerald mineralization to its source. Jan *et al.* (1981) ruled out the possibility that a granite source may have been responsible for emerald mineralization. They suggested the trench related fluids as a possible source of Be responsible for emerald mineralization in talc carbonates and related ultrabasic blocks of the Mingora melange. They ruled out a granite source of Be on the grounds that while the emerald host of Shangla-Mingora (talc carbonates and related rocks) are Mesozoic, the associated granites are Palaeozoic.

In the Barang-Turghao area the granites and granite gneisses are predominantly S-type, garnet and (at places) tourmaline bearing granite gneisses and amphibole bearing (I-type) granite gneisses. In addition there are minor post tectonic granite bodies of S-type as well as I-type. Kot granite gneiss and Agra-Turghao granite gneiss are S-type. Both have younger Tertiary minor acid bodies including some beryl-bearing pegmatites. The Kot granite gneiss is an extension of Malakand granite gneiss studied by Chaudhry *et al.* (1974, 1976) and Hamidullah *et al.* (1986).

The younger magmatic phases show blue beryl mineralization and some tourmalinization. The Selai Patti amphibole bearing granite gneiss and associated minor acid bodies are as yet not known to contain beryl mineralization or tourmaline of their own. It is, therefore, not possible to relate emerald mineralization with amphibole bearing granite/granodiorite or equivalent gneisses (arc related).

The emerald mineralization in the talc carbonates of the melange zone is characterized by its association with post obduction pneumatolytic and hydrothermal activity. This activity is manifested by silicification and development of emerald and tourmaline. Blue tinges and bluish-green colour of emerald are common. But green and grass green colours also occur.

It is important to note that blue or bluish-green beryl is also mineralized in acid minor bodies associated with Kot granite gneiss and Agra-Turghao granite gneiss. The emerald mineralization can, therefore, be related to post obduction Tertiary pneumatolytic phases related to acid magmatism. This Tertiary acid minor magmatism is associated with the S-type granite gneisses and is a product of anatexis related to the thrust stacking and crustal thickening at the leading edge of the Indo-Pak shield just south of the melange zone containing talc carbonates, some of which are mineralized by emerald. Ghazanfar *et al.* (1986) and Chaudhry *et al.* (1987, 1990) have discussed the Tertiary anatexis at the leading edge of the Indo-Pak plate (just south of the Indus suture melange).

It is in these zones that younger Be-B bearing minor acid bodies (mainly pegmatites) are present. Here melange ultrabasics (bearing Cr) and Tertiary anatectites (Be-B) interact to give rise to emerald mineralization.

Emerald mineralization is therefore, regarded mainly as a product of the interaction of Be-B-Si-Al pneumatolytic activity associated with the emplacement of nearly post obduction younger granites (Tertiary) described earlier. This mineralization is structurally controlled, post obduction and most probably late to post tectonic. Chromium has been imparted by the host talc carbonates which are themselves altered ultrabasics.

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Observations of red beryl crystals from the Wah Wah mountains, Utah

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Abstract

Physical, optical and other properties of red beryl crystals from the Wah Wah mountains, Utah, were studied using spectroscopy, electron spin resonance (ESR) and usual instruments of identification.

1. Introduction

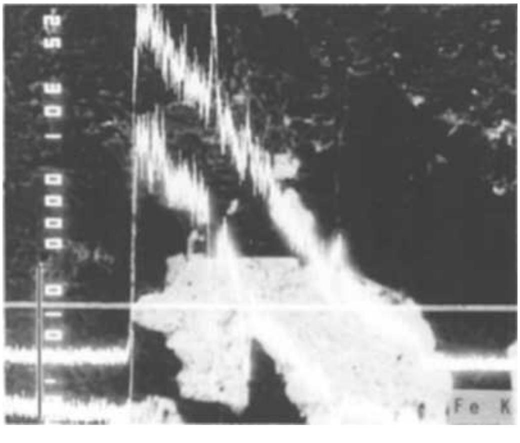
The colour-causing element and mineralogical data of red beryl from Wah Wah mountains, Utah, has already been reported (Nassau *et al.*, 1968; Shigley *et al.*, 1984). Both the Mn^{+2} ion (Nassau *et al.*, 1968) and the Mn^{+3} ion (Shigley *et al.*, 1984) have been suggested as the origin of the colour. In this report, the near infra-red spectrum due to vibrations of the H_2O in Type I and Type II sites (Wood *et al.*, 1967) in a beryl crystal with spectra in the visible region and ESR spectrum for observing the valence state of manganese have been measured with the other gemmological characteristics.

2. Results and discussion

The specimens tested were transparent, one having a modified brilliant-cut style, and were large enough to measure the ESR spectrum without crushing, the weight being 0.200-0.300 ct. The other properties were as follows:

SG	2.63-2.72 using specific-gravity bottle
RI	ε = 1.561-1.565, ω = 1.567-1.571
Birefringence	0.004
Pleochroism	Orange red-purplish red
UV fluorescence	Inert to LW and SW
Chelsea colour filter	Inert
Content of Mn and Fe	0.23 wt% and 1.3 wt% respectively by atomic absorption analysis

Fig. 1. A component image and X-ray line profiles of Fe Kα and Mn Kα for the solid inclusion that appeared on the surface of a rough red beryl. Black bar on the left side represents 100 μm.



Inclusions

Liquid inclusions, minute fractures and black solid inclusions were observed under the microscope. Figure 1 shows X-ray line profiles of Fe Kα and Mn Kα for the solid inclusion which appeared on the surface of a beryl by EPMA. This analysis found the inclusion to be black bixbyite [$(Mn, Fe)_2O_3$].

Spectroscopy

Figures 2A, 2B, shows the absorption spectra of Utah faceted red beryl, natural Colombian emerald and Russian hydrothermally-grown synthetic emerald. The absorption peaks of natural Colombian emerald assigned to one, two and three vibration modes of H_2O molecular in the Type-I site or the Type-II site are observed Figure 2A, spectrum b, at 953, 1145, 1398, 1460, 1833, 1897, 1958 and above 2000 cm^{-1}. Of the absorptions shown in Figure 2A, spectrum b, the strong peak of 1897 cm^{-1} is associated with H_2O in the Type-II site, and the other to H_2O in the Type-I site or free H_2O molecular (Wood *et al.*, 1967). According to Wood and Nassau, H_2O of the Type-I site has two-fold symmetrical axes perpendicular to the *c*-axis of emerald crystals and has no alkali ions nearby. On the other hand, H_2O in the Type-II site has two-fold symmetrical axes parallel to the *c*-axis and has alkali

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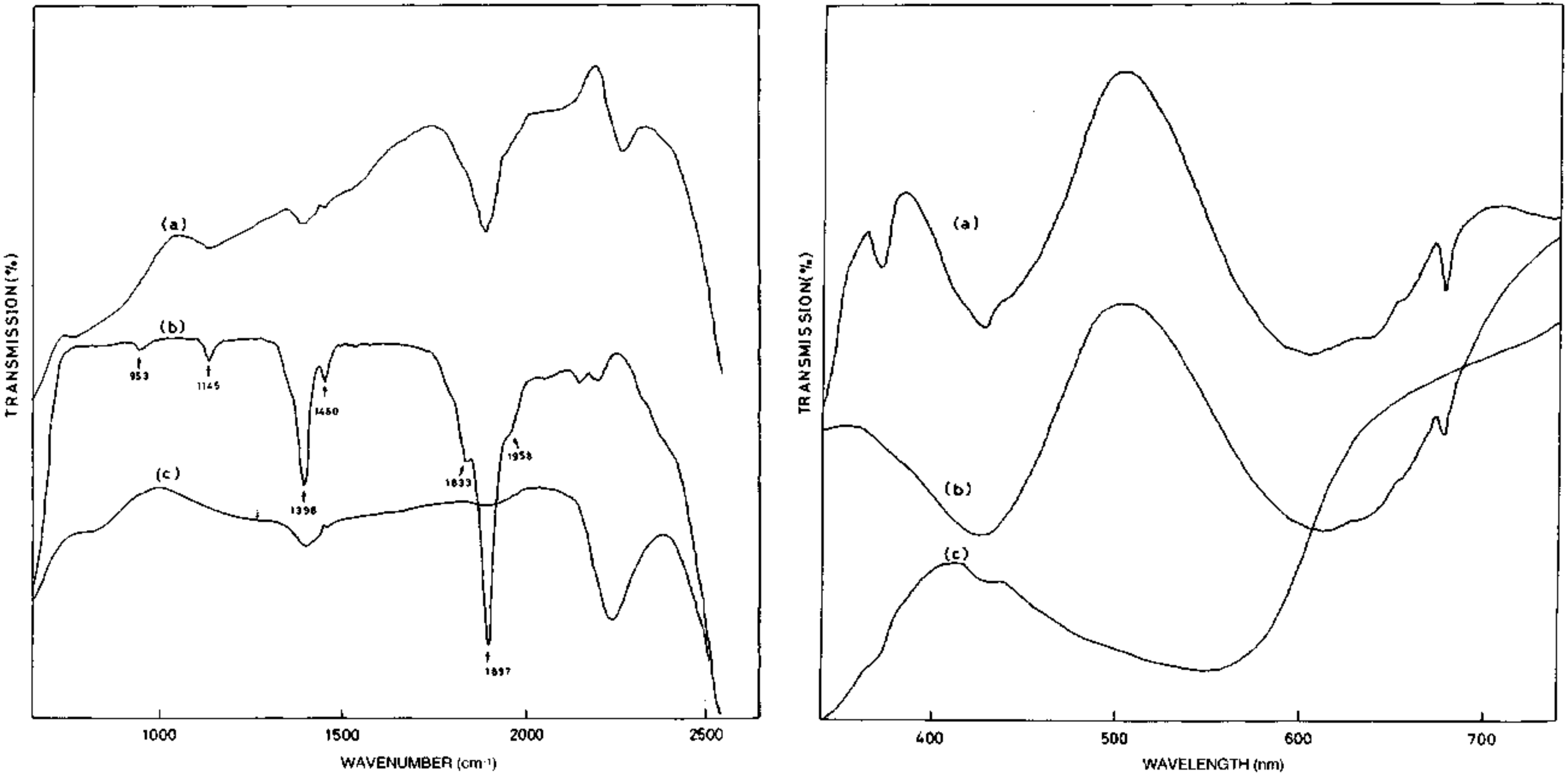

Fig. 2A

Fig. 2B

Fig. 2A, 2B. Absorption spectra of Russian hydrothermally-grown synthetic emerald(a), natural Colombian emerald(b), and Utah faceted red beryl(c).

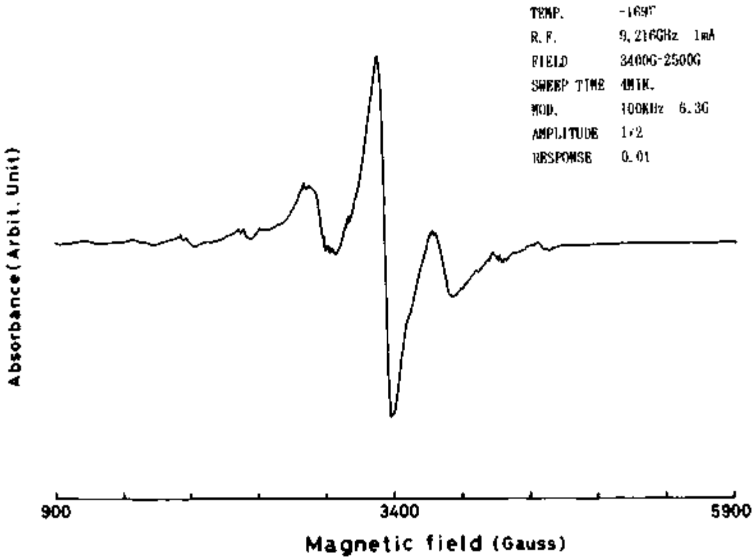

Fig. 3. ESR spectrum perpendicular to hexagonal axis.

ions adjacent to H_2O. The form of the whole absorption spectrum of red beryl (Figure 2A, spectrum c) was similar to that of the natural Colombian emerald, in which both types of H_2O are included, although the absorption of red beryl having its centre at about 1900 cm^{-1} is very weak and broad in comparison with that of natural Colombian emerald. Consequently, the red beryl has both types of H_2O. In the Russian hydrothermally-grown emerald, Figure 2A, spectrum a, the quantity of Type-II water might be more than the Type-I water, as in the case of natural Colombian emerald. The variety and amount of alkali ion adjacent to Type-II H_2O could be strongly influenced by the surrounding environment in which the respective crystals have been grown. It has been reported that a considerable amount of iron is contained in Utah red beryl (Wood *et al.*, 1967; Shigley *et al.*, 1984). The content of iron ion in this red beryl was 1.3 wt% as already shown above. The iron ion has the absorptions in the visible region. In the spectrum of Utah red beryl shown in Figure 2B, spectrum c, the two broad bands of 370 and 426 nm correspond to the absorptions due to the iron ion. These are assigned to Fe^{+3} ion in octahedral sites in beryl crystals (Wood *et al.*, 1968). The same absorption bands were observed in the visible region of Russian hydrothermally-grown emerald spectrum (Figure 2B, spectrum a). The red is caused by a broad absorption band of 540-560 nm and a fairly broad absorption band in the vicinity of 480 nm.

ESR spectrum

Figure 3 shows the ESR spectrum (at $-169°C$) of the red beryl from the Wah Wah mountains, Utah, for the field perpendicular to the hexagonal axis. A sharp spectrum line (Fe^{3+}) and wave-like spectra were obtained, but 'hyperfine splitting' due to the Mn^{+2} ion ($S=5/2$) was not observed. However, the Mn^{+2} ion could be expected to exist in the red beryl, because on the basis of the ESR data, in which 'hyperfine splitting' due to Mn^{+2} ion was observed in synthesized pink beryl crystals (Flamini *et al.*, 1986), it is considered that Mn^{2+} ion ought to give pink-red colours to natural red beryl crystals. Thus the apparent absence of distinct 'hyperfine splitting' in our natural red beryl, which includes 0.23 wt% manganese ion, may be attributed to the interference of the Fe^{3+} ESR spectrum with the ESR spectrum of Mn^{2+}. The ESR spectrum of Mn^{2+} is probably concealed by the wave-like spectra on both sides of the Fe^{3+} line (3325G region, $g=1.980$).

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An examination of garnets from the Sinai Peninsula, Egypt

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Abstract

Dark brownish–red garnets reported to be from the Sinai Peninsula, Egypt, were identified as almandine-spessartine, based upon their gemmological properties, chemistry and current criteria for distinguishing between the different gem garnets.

Introduction

Although garnets occur in a great range of colours, those of a predominantly red hue are no doubt the best known. Such garnets may be essentially pyrope or almandine, or they may be pyrope-almandine or almandine-spessartine mixtures (Stockton and Manson, 1985). Among the sources for one or more of these gems are Austria, Australia, Brazil, Canada, Czechoslovakia, India, Madagascar, Russia, Sri Lanka, United Kingdom (Scotland), USA, Zambia and Zimbabwe (Webster, 1983); Argentina, Japan, Norway, Sweden and Uruguay (Arem, 1987); Afghanistan (Bowersox, 1985); China (Keller and Wang, 1986); Tanzania (Jobbins, 1978); Mexico, Myanmar (Burma), Pakistan, Thailand and Greenland (Rouse, 1986). A review of the mineralogy of garnets can be found in Deer *et al.* (1982).

Egypt has also been a source of red garnets. Pliny mentions 'carbuncles'–a gem name now thought to have referred to garnets coming from an area near Thebes, although Rouse (1986) states this may be a reference to a trading station rather than a mining area. It is known that garnets have been recovered near Aswan in Upper Egypt, at the same locality from which the ancient Egyptians obtained much of their amethyst. Other Egyptian sources are in the Eastern Desert inland from Quseir and northeast of Qena (Andrews, 1991). More relevant to this report, larger stones– more appropriate for fashioning as gems– came from Western Sinai (Aldred, 1978). These reports, however, do not classify the garnets using current gemmological criteria.

It is also known that garnets were used by the ancient Egyptians for personal adornment. Garnets were fashioned for jewellery use as early as the Predynastic Period; a diadem that includes garnets was found in place on the head of a woman buried at Abydos and dating to the time of the Naqada II culture (*c.* 3200 BC). This gem material was most popular during the Middle Kingdom (*c.* 2133-1786 BC) (Andrews, 1991), possibly due to intensive exploitation of Sinai mineral deposits during this period. In the Cairo Museum is a gold collar inlaid with several species of gemstone, one of which is garnet. It is part of a parure of the Princess Khnumet who was buried in the vicinity of the pyramid of Ammenemes II (early XIIth Dynasty) (Aldred, 1978).

Background to study

Fig. 1. These garnets, reportedly from the Sinai Peninsula of Egypt, are part of a 36-bead necklace. *Photo by Maha Smith-DeMaggio.*

While on a trip to Egypt in late 1991, one of the authors (RCK) visited a gem dealer in Luxor who displayed a necklace of dark brownish-red beads represented as garnets (Figure 1). These were said to have been recovered from the south-central area of the Sinai Peninsula, 'two mountains over from Gebel Musa' (Mt. Sinai). According to the merchant, his father obtained the garnets at the mine site several years before, but the exact location was no longer known (unsuccessful efforts had been made to relocate the source). The necklace was subsequently acquired for gemmological examination.

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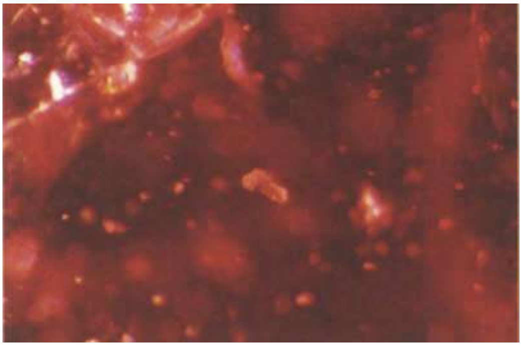


Fig. 2. What appear to be apatite crystals were noted in many of the garnets in this investigation. *Photomicrograph by John I. Koivula. 50X.*

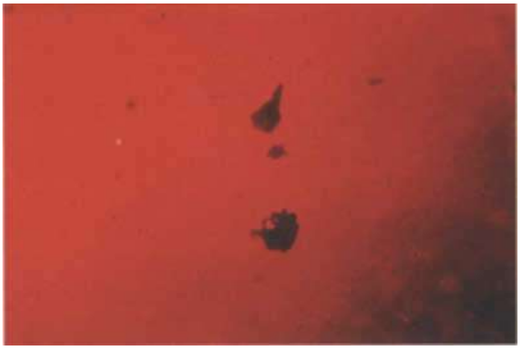
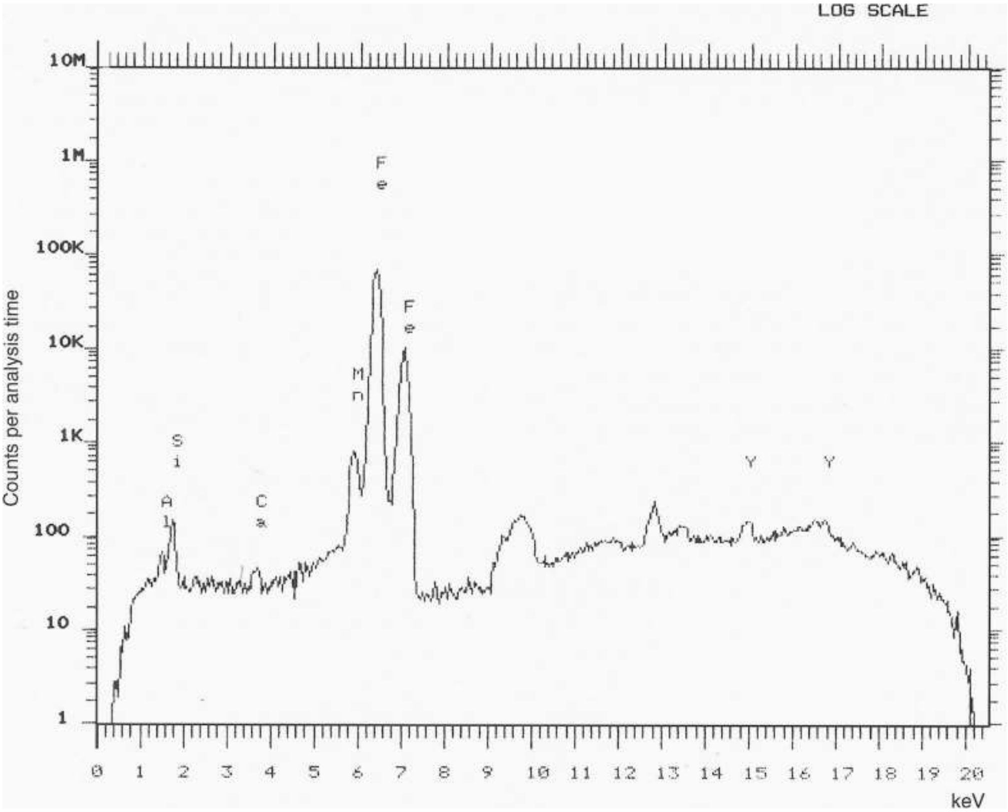


Fig. 3. Black opaque inclusions with the appearance of ilmenite were also detected in many of the garnets described herein. *Photomicrograph by John I. Koivula. 50X.*

Fig. 4. EDXRF analysis detected the presence of both iron and manganese in the garnets in this study. Analysis performed by Sam Muhlmeister using a Spectrace 5000 X-ray unit (tube voltage 20 KV, tube current 0.15mA, atmosphere–vacuum, aluminium filter, livetime 100 seconds.



Gemmological examination

Description:

A necklace consisting of 36 off-round drilled beads ranging in diameter from approximately 12.3 to 13.0 mm.

Colour/appearance:

In reflected light, the beads were very dark brown (almost black) and nearly opaque due to their very dark colouration. In strong transmitted light, however, they were brownish-red and transparent.

Microscopic features:

Magnification revealed numerous partially healed fractures located throughout all of the beads. Crystalline inclusions were also noted and visually identified as apatite (Figure 2) and ilmenite (Figure 3) which are known to occur in garnets of this type (Gübelin and Koivula, 1986).

Refractive index:

Spot refractive index readings were taken using a Duplex II refractometer and white light source. This produced readings from approximately 1.81 to over-the-limits of the instrument.

Chelsea Filter reaction:

The beads appeared yellowish-green.

Ultraviolet luminescence:

All of the beads were inert to both long- and short-wave ultraviolet radiation when examined with 4-watt UV light sources.

Absorption spectrum:

Examination was carried out using both a Beck prism spectroscope mounted on a GIA GEM Instruments spectroscope illuminator base and a GIA GEM DISCAN diffraction-grating spectroscope unit. This revealed absorption bands at approximately 410, 430, 460, 500, 525, and 575 nm.

Chemistry

Energy-dispersive X-ray fluorescence (EDXRF) analysis was carried out by the GIA Research Department using a Spectrace 5000 X-ray unit. This revealed aluminium and silicon as major components, a high iron content with lesser amounts of manganese, and traces of calcium and yttrium (Figure 4). This chemistry is consistent with that of garnets in the almandine-spessartine solid solution series (see Deer *et al.*, 1982).

Conclusion

Based on the gemmological properties and using the criteria established by Stockton and Manson (1985), the garnets in the necklace were identified as almandine-spessartine. The chemical analysis, showing a significant iron component as well as lesser amounts of manganese, further substantiates this identification.

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Gemstone enhancement - detection of polymer-treated jadeite

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During a discussion in 1992 with Emmanuel Fritsch and Ken Scarratt, I was privileged to learn of a forthcoming paper on the treatment and detection of jadeite which had been enhanced using a polymer impregnation process (Fritsch *et al.*, 1992).

The paper divides jadeite into three categories used in Hong Kong:

(A) jadeite which has not been treated other than by traditional surface waxing;

(B) jadeite, the sub-surface of which has been filled by polymer impregnation. The process is preceded by bleaching by immersion in acid;

(C) jadeite which has been impregnated by a staining process.

The paper examines the detection of the 'B' treatment via various visual clues, and concludes that identification is positively achieved by infrared spectroscopic confirmation of the polymer used.

I was delighted to be able to lend to Dr Fritsch three transparencies which showed how the basically equipped gemmologist could tackle and identify such bleached jadeite using an acid testing technique. The test procedure is described in my forthcoming book, but sufficient interest was aroused during lectures in Hong Kong, Canada and Tucson, to relate the procedure in slightly more detail.

Figure 1 shows a trio of:

(a) an untreated slice of green and white jadeite (note the brownish outer skin due to natural iron staining),

(b) a slice which has been acid bleached and polymer filled (note the absence of iron discoloration); and

(c) a cabochon fashioned from the (b) material.

To carry out the test technique, position the specimen so that it presents a flat (or near to flat) portion uppermost – Blu-tak always makes a good anchorage. Use the head of a new domestic pin (held by tongs or a similar tool) to dip and retrieve a droplet of concentrated hydrochloric acid. Touch the acid down as a standing droplet on the jadeite surface, previously wiped clean. It is advisable to add a second or even a third droplet to sustain the acid supply.

Figure 2 shows a 20mm jadeite drilled bead specimen known to have been fashioned at least thirty years ago.

The applied acid droplet can just be seen across the edge of the window reflection. Down the centre of the specimen, it can be seen that the acid has reappeared at the surface of an internal fracture and away from the original applied droplet.

Figure 3 shows a close-up of the acid weeping from below to accentuate two internal fractures which form a diagonal cross. The evidence took some two to three minutes to surface. It is evident that in untreated jadeite ('A' type) the acid is drawn under the surface by the capillary action of the jadeite's cryptocrystalline grain boundaries and/or open fractures. Where there are no evident fractures, a 'perspiration' aureole of acid is seen surrounding the droplet several minutes after the acid application.

When the acid is placed on a specimen of bleached 'B' type jadeite, the acid sits on the surface until it evaporates and cannot reappear elsewherel since the polymer has in fact sealed the micro-porous structure.

My photographs appeared to be at odds with the findings of the GIA Lab which had observed no such diagnostic response. I discussed the discrepancy with Fritsch by telephone and he kindly forwarded one of the GIA specimens which had not responded to their own acid tests.

At first the GIA specimen resisted the hydrochloric acid, but I determined this was due in part to the fine grain texture of the translucent white jadeite specimen. I could see the first glistening response of the acid on the pyroxene but not sufficient to capture by camera. I added a second and third drop of acid at one minute intervals on the same spot and slowly the acid

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Fig. 1. From left to right: (a) untreated green and white jadeite with a brown iron-stained skin; (b) jadeite which has been bleached and polymer-resin treated; (c) a cabochon fashioned from the polymer-impregnated material.

Fig. 2. A 30 year old untreated jadeite bead showing an applied acid droplet across the edge of the window reflection and near the centre of the specimen, also droplets which have re-appeared at the surface of an internal fracture.

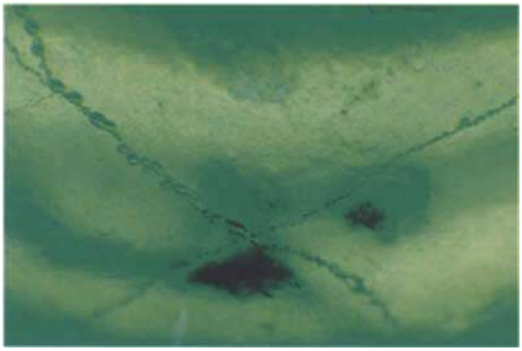

Fig. 3. Close-up of the acid droplets which have migrated up along two internal fractures in untreated jadeite.

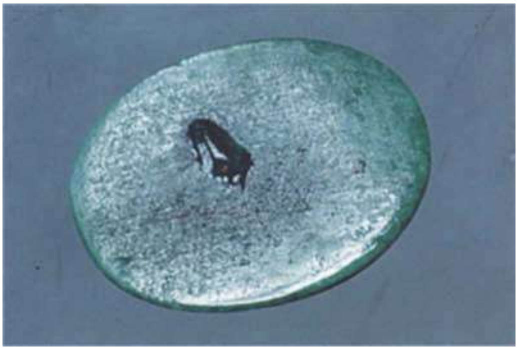

Fig. 4. Cabochon of stained jadeite ('C' type) made from more porous material. The centrally applied acid drop has sweated profusely over a surrounding aureole which covers the whole surface of the cabochon.

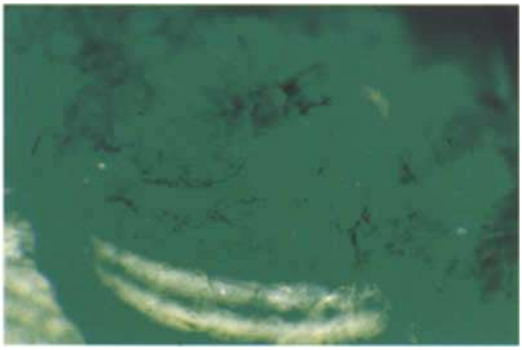

Fig. 5. Stained jadeite with an acid drop on the surface; the drop acts as a lens and reveals the staining pattern more clearly.

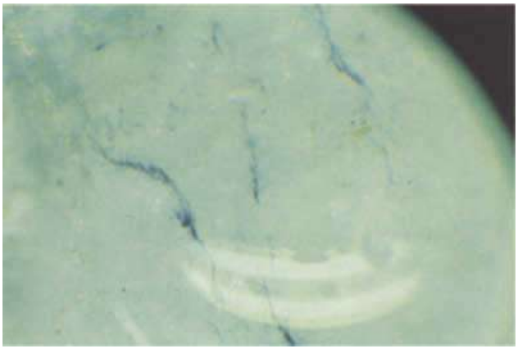

Fig. 6. Traces of the initial mauve stain agent in a green stained jadeite.

reappeared elsewhere, but the effect was somewhat thwarted by the decorative grooving which patterned the carved leaf design of the surface as shown by Fritsch *et al.* (1992).

A further telephone conversation pointed to opposing results until I happened to ask the temperature in Los Angeles. The 100°F+ temperature with air conditioning contrasted with the temperate Scottish climate in which I was domiciled and the discrepancy was explained by the rapid evaporation at higher temperatures with air conditioning. I also found mixed results in Hong Kong with their ubiquitous air conditioning.

Dr W. Hanneman of California was quick to point out an inexpensive solution (doesn't he always!). Place a glass cell or dish over the specimen subsequent to the acid drop application, and include under the glass a small receptacle or water to maintain normal conditions.

A further confirmation of an untreated surface also came to light. After the concentrated hydrochloric acid had sat on the untreated surface (type 'A' jadeite) for several minutes, the action of wiping away the acid droplet with a white tissue revealed a brown iron stain, though this was not apparent to the eye in the droplet itself. Such staining would be removed as part of the deep cleansing acid action prior to polymer treatment of type 'B' jadeite.

Figure 4 shows a green stained jadeite. The 'C' type relies on a more porous type of jadeite to gain access by the stain agency. As a result, the drop of hydrochloric acid quickly reveals the nature of such a porous material as it sweats profusely in a surrounding aureole, in this case covering the whole underside of the cabochon.

Polymer treatment of stained jadeite would no doubt seal and prevent such a result, but it is relatively easy to spot the staining of jadeite. The waxing of jadeite is a long standing practice to present the best polished surface (lustre). It was found that even freshly waxed jadeite did not interfere with the above acid tests.

In the course of acid testing the stained jadeite type 'C', the applied droplet of acid acted as a lens which resolved the stain agencies more distinctly (see Figure 5). A water droplet does the same of course, as also does a 10X lens.

The green staining of jadeite is actually a two-part process, the earlier part often involving a purple staining agent. Sometimes the purple stain is still in evidence after the final staining process (see Figure 6).

I trust this will be found to be a helpful adjunct to the main paper researched and reported in such detail by Dr Emmanuel Fritsch and his colleagues.

Reference

Fritsch, E., *et al.*, 1992. Identification of bleached and polymer impregnated jadeite. *Gems Gemol.*, 28, 3, 176-87.

[*Manuscript received 19 March 1993*]

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Microscopic estimation of refractive index using a dial test indicator and a personal equation

T. Farrimond

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Abstract

Fitting a dial test indicator to a microscope and its use combined with a personal equation, enables reasonably accurate measures of RI to be made in mounted and unmounted stones: some examples are given.

A modification is shown of engineers' digital calipers which facilitate the measurement of depth in mounted stones.

It is often useful to know the approximate value for the refractive index of a gemstone before using the refractometer, particularly for stones with RIs in the region of 1.8 and above. The measurement of real and apparent depth provides a quick way of achieving this, particularly if the microscope is adapted to use a dial test indicator (DTI). With care it is possible to obtain a reasonably good evaluation of the RI of a gemstone using the microscope in place of the refractometer.

Fig. 1. Dial test indicator 0.50mm, X0.01mm.

For this, the relatively inexpensive biological microscope is ideal. It is preferable to have a mechanical stage so that the stone may be moved laterally with its table still remaining parallel to the microscope stage. However, if the microscope does not have a mechanical stage, adjustment of position can still be accomplished manually if care is taken not to touch the stone but only the slide on which it is mounted. The DTI method is both more convenient and more accurate than using a vernier scale mounted to the microscope. The gauge used in this report has a range from 0 to 50mm with scale divisions of 0.01mm. This allows estimations of a fifth part of a scale division (i.e. to an accuracy of about 0.002mm). The gauge is easy to read; a dial size should be selected which enables it to fit comfortably on the microscope (in this case the dial shown in Figure 1 measures 70mm in diameter).

A simple brass mounting bracket with two locating screws may be constructed as shown in Figure 2. It is bored to take the stem of the gauge which is located by means of a 3mm grub screw. The vertical position of the gauge is adjusted by sliding it up or down in the bracket so that when its probe is touching the stage, the dial shows a mid-scale reading with the microscope in focus. This ensures that as the stage is raised or lowered, continuous readings are obtained on the gauge. Once set in position the gauge becomes an integral part of the microscope and may be used for making a variety of measurements. When focusing on a gemstone mounted with its table uppermost, it is safer to focus on the culet first; subsequent focusing may then be accomplished without the risk of damage to the objective. When focusing on the dome of a cabochon (via its base) care is needed to check that the 'surface details' focused on are not dust specks on the substage condenser.

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Moving the condenser downwards slightly removes the problem.

A useful accessory shown in Figures 3 and 4, is a small plate about the size of a microscope slide (75 x 25mm) made of 1.6 or 2mm thick aluminium sheet. This has a series of holes of different sizes drilled in it to accommodate stones of different diameters. A slit is cut to take a gemstone mounted in a ring. This slit is also ideal for mounting trap-cut stones and cabochons. The stones should be checked to ensure that their tables lie parallel to the microscope stage.

The following results were obtained using a 0.52 ct round faceted pyrope garnet. Measurements were repeated 10 times and RIs calculated as follows:

$$\frac{\text{Depth of stone}}{\text{Apparent depth of stone}} = \text{RI}$$

Mean RI (x) = 1.772 Standard deviation of the sample (δ^{n-1}) =0.009

The maximum and minimum values of the ten readings were 1.787 and 1. 756 respectively. The value of RI for the garnet, obtained by a refractometer, was 1.756.

As it stands, the method gives a reasonably good approximation of the stone' s RI but its accuracy may be improved. The values obtained vary with the technique used in focusing on the table and culet so that some practice is needed to ensure consistency. Individuals will have their own method, resulting in possible over-estimation or under-estimation and, just as astronomers used a personal equation for measuring the transit of a star, so an equation may be calculated for the microscope. In this case, the personal equation is found as follows:

Obtained value of RI 1. 772 (10 readings)
True value of RI 1. 756
error = 0.016 over-estimation

As a percentage of the true value, this is

$$\frac{0.016}{1.756} \text{ x } 100 = 0.9\%,$$

over-estimation which should be corrected in all measurements.

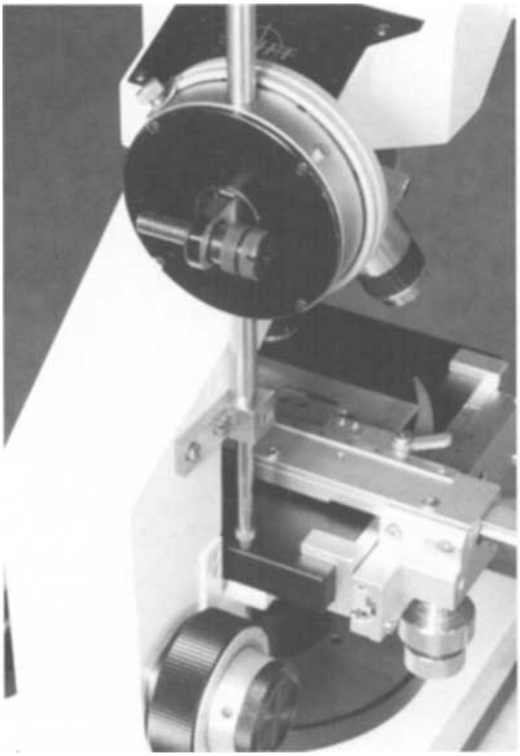


Fig. 2. Probe of mounted dial test indicator (DTI) in contact with stage.

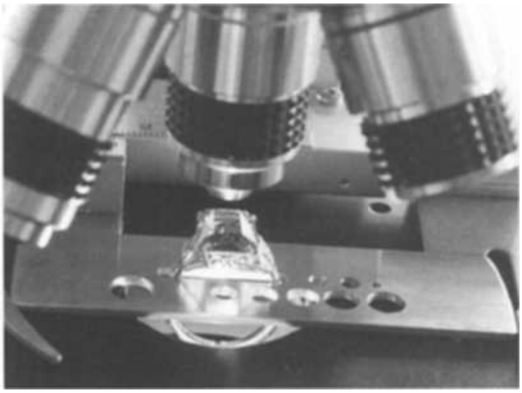
Fig. 3. Mounted stone held in slot of slide.


Fig. 4. Unmounted stone, culet down, in slot.

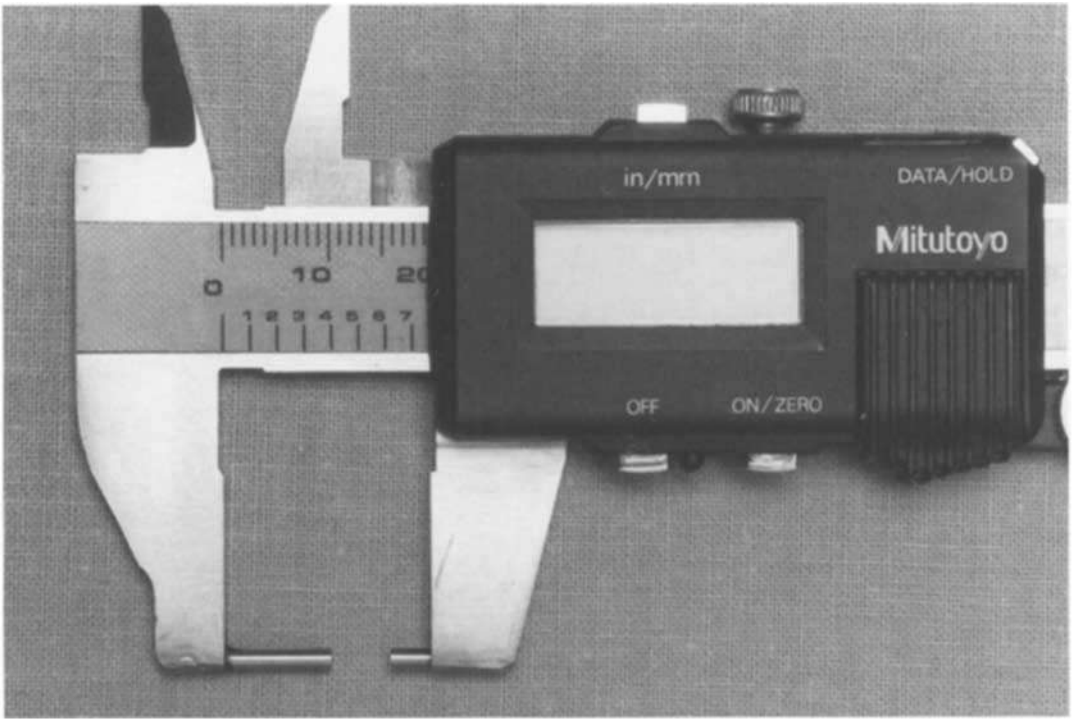



Fig. 5. Electronic calipers with attached, odd-leg 2mm diameter pins.

Applying this correction factor to the measurement of the RI of a trap-cut 2.6ct synthetic yellow sapphire gave the following values:

Microscope value of RI	1.780 (average of 3 readings)
Take off 0. 9% (Personal Error)	0.016
This gives the RI as	1.764

This is within the published range

$$\frac{o+e}{2} = 1.761 - 1.774$$

Other uses of the gauge included the measurement of the depth of an inclusion inside a stone, also the determination of the size of the inclusion (applying, of course, the appropriate correction for the optical effect of 'shallowness' caused by the RI of the stone). When testing ring-mounted stones, it is usually possible to use the transmitted light from the sub-stage condenser, but for some rings side lighting may be needed. In most cases it is easier to measure the true depth of the mounted stones using a Leveridge type gauge.

It is possible to modify (or have modified) engineers' electronic calipers as shown in Figure 5, by grinding down the tips of the calipers and mounting two 2mm diameter pins, one 4mm long, the other 10mm. The electronic calipers give readings to an accuracy of 0.01mm with values displayed digitally and the calipers may still be used after modification for normal measurements since they are self-zeroing.

Second-hand electronic calipers may sometimes be found which have a problem (due to wear) with accurate self-zeroing in the closed position. When pins are attached so that closure occurs at a point 14mm greater than before, the problem disappears as the worn area is not now being used. The second-hand Mitutoyo calipers which were modified cost the equivalent of just under £17. To measure the depth of an unmounted stone optically may be most easily accomplished by placing the stone with its table down over a small hole in the aluminium slide. Sufficient illumination is usually available from the substage condenser so that after focusing on the culet and taking a reading, the slide may be moved laterally to bring an adjacent hole into view and a second reading obtained by focusing on the machining marks around the hole.

Some examples of RIs obtained on different stones are as follows:

(a) This sample was a ring with an 8.8ct yellowish-green synthetic sapphire. Physical depth determined by using calipers was 5.98mm. Three apparent depth readings showed a variability of 3.368, 3.360 and 3.360 (At 100X magnification). Taking the average as 3.3626 gives an RI of 1.778. Subtracting the personal equation factor of 0.9% gives an RI of 1.762.

(b) In the case of a 9.7ct mounted red tourmaline, 8.38 mm deep, internal detail was less clear, therefore a magnification of only 40X was used. Based on three readings and after applying the correction factor of 0.9% the RI value was 1.628.

(c) A 1.5ct diamond, mounted in a ring, gave three readings with an average apparent depth of 1.740. The physical depth was 4.29mm. The calculated RI value less the 0.9% correction factor gave a value of 2.42.

(d) A synthetic ruby cabochon, depth 6.36 mm, viewed with transmitted light, the dome of the cabochon facing the substage condenser (stone mounted in the slit on the aluminium slide). A few specks of dust on both surfaces aid the observations. Apparent depth values at 40X magnification are 3.575 and 3.577. RI value = 1.778 - 0.016 = 1.762

It is necessary in making all the above observations to focus on the *same* details each time, selecting a point in the centre of the stone and focusing via the table, or base in the case of the cabochon, at the deepest portion of the apex. Readings should be continued until consistent values are obtained. If the microscope is binocular, the appropriate eyepiece should be carefully adjusted to ensure that both left and right views show identical sharpness. If polarizing filters are fitted in the oculars (as in this microscope) they should be rotated, in the case of a birefringent stone, to show only one image (the *same* image in both oculars). Objectives with 4X and 10X magnification combined with a 10X eyepiece usually give sufficient clearance between objective and stone (15 and 7mm respectively) at magnifications of 40 and 100 times. When testing a cabochon which is mounted dome downwards in the slit on the microscope slide, its centre can be ascertained by viewing the dark edges of the slit, which appear as two curved lines. The centre is at the point where the two lines are closest together and also symmetrically positioned in the microscope field. It could be advantageous to construct specific correction factors for different sizes and shapes of stones and also for the various magnifications used. In this way, the microscope becomes a convenient tool for the measurement of refractive indices without any restriction on the magnitude of the RI.

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Towards a mathematical gemmology. Thinking in terms of ratios makes a difference

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Abstract

The author analyses the separation of light rays in doubling and 'fire' in terms of Snell's Law, and shows that the amount of separation varies inversely with the product of the highest and lowest RIs. Doubling strength and a new index that the author calls 'dispersing strength' are therefore recommended as being more accurate than birefringence and dispersion, respectively, whenever gemmologists wish to quantitatively discuss visual effects based on divergent light rays. Finally, fresh insight is given into the problem of colour fringes appearing during readings of a refractometer in white light, with the author suggesting that a comparison of the gem/hemicylinder critical angles in violet and red light is more useful than a comparison of the respective dispersions of gem and hemicylinder.

Introduction

One of the simplest observations that a gemmology student learns to make is the recognition of the doubled images of the back facets of a cut gemstone. This 'doubling' effect is positive proof that a stone is doubly refractive (DR), and therefore it is a useful test for separating diamond from some of its simulants.

Gemmology instructors typically explain that the amount of doubling depends on two factors: the path length of the light inside the gem and the gem's birefringence. Birefringence is the difference between the highest and lowest RIs of a DR material. Subtracting the two RIs is generally assumed to indicate the amount of separation between the two images: a gem which has high birefringence (e.g. zircon or peridot) will show more doubling than a gem which has low birefringence (e.g. topaz or quartz), if all other factors are equal.

However, in the ninth edition of *Gem Testing*, B. W. Anderson added a parenthetical comment to his discussion on the doubling effect of gems that have high birefringence: 'J.-P. Poirot, Director of the Paris gem-testing laboratory, has made the important observation that for a given birefringence the doubling effect is more marked in stones of low RI than in those of high index' (Anderson, 1980).

This article explains Monsieur Poirot's qualitative observation in quantitative terms, thereby revealing a fresh approach to understanding the amount of doubling that we see in gems that have high birefringence. The same analysis is then applied to our observation of dispersion and a new type of index is presented to quantify our understanding of a gem's ability to split white light into the colours of the rainbow.

Background concept

When a ray of light travels from a rarefied medium (such as air) into a denser medium (such as a gemstone), it generally undergoes several changes: it slows down, it bends towards the 'normal' (an imaginary line perpendicular to the interface) and sometimes it splits. The refractive index (RI) of a gem is the ratio of the speed of light in air to the speed of light in the gem. The higher the refractive index, the more the light slows down.

Snell's Law states that there is a fixed relationship between the angle at which a light ray strikes an object's surface and the angle at which the light ray is bent ('refracted') while it travels through the object. Measuring both the incident and refracted angles outward from the normal, Willebrord Snell (1591 - 1626) determined their relationship to be:

$$(1)\ \frac{\sin i}{\sin r} = n \text{ where n is the object's refractive index}$$

Therefore, the higher the refractive index, the more sharply a light ray is bent when it enters the object.

When an incident ray of light splits into two rays inside a gem (double refraction), each ray slows and bends by a different amount. As a result, it becomes necessary to refer to *two* refractive indices. Subtracting the lowest RI reading from the highest RI reading gives us the gem's birefringence.

Isaac Newton discovered that a material's RI

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varies according to the wavelength of the incident light. Each of the component wavelengths of white light slows and bends by a different amount. Because the sides of a prism are not parallel, we are able to see the colours of the spectrum distinctly as they each bend by their characteristic amount.

The variation of RI with wavelength is called dispersion. The numerical value of dispersion is usually given as the difference between the RI of the Fraunhofer B line (686.7 nm) in the red part of the spectrum and the RI of the Fraunhofer G line (430.8 nm) in the violet part of the spectrum.

Do the simple subtractions involved in determining a gem's birefringence and dispersion describe any quantity that is mathematically meaningful? Generally speaking, the answer is 'no'.[1] Only by looking closely at Snell's Law can we accurately relate a gem's birefringence and dispersion to the *separation of light rays* that we observe in doubling and prismatic effects. Snell's Law views RI not as a single piece of data (i.e. speed of light in a gem) but rather as a *relationship* between measurements (i.e. a fixed ratio between two sines at *all possible* angles of refraction).

Separation, as perceived by the eye and as depicted in drawings of light ray paths, depends entirely upon *angular* separation and path length. Angular separation depends on the angle of incidence and the refractive indices, while path length is determined by the size and cut of the gem as well as the facet and angle through which the gem is viewed. Of all these factors, only the refractive indices are related to the nature of the gem material itself - the RIs are what we are referring to when we say 'diamond has a lot of fire' or 'peridot shows strong doubling'.

Another Approach

Although double refraction is the splitting of a *single* incident ray while dispersion is the separation of an *infinite number* of superimposed incident rays (i.e. the various wavelengths of white light), the two phenomena are mathematically equivalent; from one angle of incidence come two (or more) angles of refraction.

In both dispersion and birefringence, the angular separation is the arithmetic difference between the angle of refraction of one ray and the angle of refraction of another ray. Thus, an *exact* answer to 'How much divergence is there between the two rays?' can be achieved by subtracting the two angles of refraction. Subtracting the two RIs gives only a *rough approximation* of the divergence.

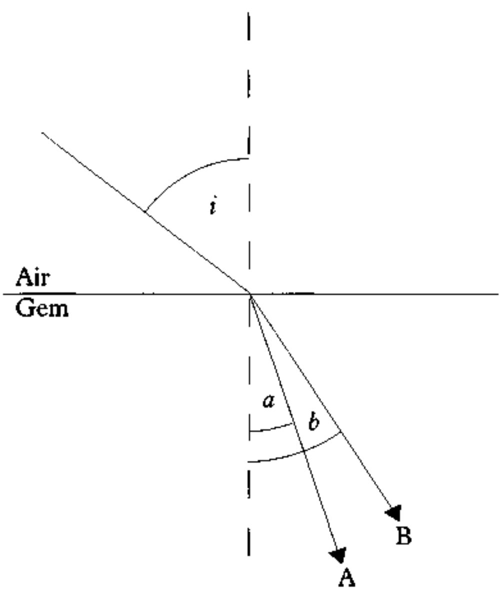

Fig. 1. Splitting of an incident light ray

In Figure 1, the angular separation between refracted rays A and B can be expressed as b - a. We can derive an exact formula for this divergence by using Snell's Law (with the RIs of A and B represented as n_a and n_b, respectively):

$$\text{(2)}\quad n_a = \frac{\sin i}{\sin a} \quad \text{therefore} \quad \sin_a = \frac{\sin i}{n_a}$$

and similarly:

$$n_b = \frac{\sin i}{\sin b} \quad \text{therefore} \quad \sin_b = \frac{\sin i}{n_b}$$

The formula for an exact calculation of divergence is therefore:

$$\text{(3)}\quad b - a = \arcsin \frac{\sin i}{n_b} - \arcsin \frac{\sin i}{n_a}$$

However, a *close approximation* of divergence can be found by simplifying the exact formula, based on the fact that the divergence of rays is nearly always very small. (The dispersion of diamond and the birefringence of high zircon each produce an angular separation that is less than 1°.)

According to Maclaurin's theorem, the relationship between a small angle and its sine is nearly linear (Jenkins and White, 1976). Therefore, we can make a reasonable approximation of a small angular separation by replacing the quantity b - a with the quantity sin*b* - sin*a*. The formula then becomes:

$$(4)\ b - a \approx \sin b - \sin a \approx \frac{\sin i}{n_b} - \frac{\sin i}{n_a} \approx \sin_i \left(\frac{1}{n_b} - \frac{1}{n_a}\right)$$

As can be seen from formulae 3 and 4, the angular separation between two refracted rays varies directly with their angle of incidence. Discussions that compare materials of different optical density in terms of their refracting power generally assume a constant angle of incidence. If we therefore remove the quantity sini from formula 4, we arrive at the following formula which provides us with a highly accurate index of the 'diverging power' of any mineral (relative to other minerals of known RI):

$$(5)\ \text{diverging power} \approx \frac{1}{n_b} - \frac{1}{n_a} \approx \frac{n_a - n_b}{n_a \times n_b}$$

Doubling Strength

The doubling strength of a gem is understood as the degree to which the gem material produces a doubling of the images of its back facets (relative to other gems illuminated at the same angle of incidence and viewed with equal path length).[2]

How does formula 5 compare with birefringence in determining doubling strength? The quantity $n_a - n_b$ can be recognized as the birefringence, which formula 5 states must be divided by the quantity $n_a \times n_b$ (the product of the gem's highest and lowest refractive indices) to give a close approximation of the doubling strength. In other words, the doubling strength produced by a given birefringence varies inversely with the two RIs (i.e. *roughly* in inverse proportion to the square of the mean RI).[3]

Table 1 compares the birefringence of 14 common gem materials with their doubling strength as derived from formula 5. The doubling strengths of two gems *can* be compared linearly: the fact that calcite has about 1.8 times the doubling strength of sphene means that the angular separation between the two rays of the former will be approximately 1.8 times the size of the angular separation between the two rays of the latter for any given angle of incidence (see Tables 2a, 2b and 2c).

Formula 5 explains why calcite shows 85 per cent *more* doubling than synthetic rutile, even though calcite's birefringence is only 60 per cent as large. Similarly, we find that the doubling strength of synthetic rutile is *less* than that of sphene, despite its birefringence being nearly twice as much as sphene's. Compared to zircon, peridot has 61 per cent of the birefringence and 83 per cent of the doubling strength. Dioptase has lower birefringence than zircon but *higher* doubling strength.

Table 1: Birefringence and doubling strength

Gem	Lowest RI	Highest RI	Birefringence	Doubling Strength
Syn Rutile	2.616	2.903	0.287	0.0378
Calcite	1.486	1.658	0.172	0.0698
Sphene	1.900	2.050	0.150	0.0385
High Zircon	1.925	1.984	0.059	0.0155
Dioptase	1.655	1.708	0.053	0.0187
Benitoite	1.757	1.804	0.047	0.0148
Sinhalite	1.668	1.707	0.039	0.0137
Peridot	1.654	1.690	0.036	0.0129
Diopside	1.675	1.701	0.026	0.0091
Tourmaline	1.624	1.644	0.020	0.0075
Spodumene	1.660	1.676	0.016	0.0058
Quartz	1.544	1.553	0.009	0.0038
Topaz	1.619	1.627	0.008	0.0030
Corundum	1.762	1.770	0.008	0.0026

Table 2a: Double refraction in calcite

Incident angle	Refracted angle of o-ray	Refracted angle of e-ray	Angular separation
15°	8.98°	10.03°	1.05°
30°	17.55°	19.66°	2.11°
45°	25.24°	28.41°	3.17°
60°	31.49°	35.65°	4.16°
75°	35.63°	40.54°	4.91°

Table 2b: Double refraction in sphene

Incident angle	Refracted angle for n_α	Refracted angle for n_γ	Angular separation
15°	7.83°	7.25°	0.58°
30°	15.26°	14.12°	1.14°
45°	21.85°	20.18°	1.67°
60°	27.12°	24.99°	2.13°
75°	30.56°	28.11°	2.45°

Table 2c: Comparison of calcite and sphene

Incident angle	Angular separation in calcite	Angular separation in sphene	Ratio of separations (calcite/sphene)
15°	1.05°	0.58°	1.81 : 1
30°	2.11°	1.14°	1.85 : 1
45°	3.17°	1.67°	1.90 : 1
60°	4.16°	2.13°	1.95 : 1
75°	4.91°	2.45°	2.00 : 1

Dispersing strength

Formula 5 can also be used to clarify our understanding of dispersion in a gem. The fire that we see in a diamond is a result of its cut (crown height and crown angle) and carat weight (path length). However, when we compare a diamond with other gems of similar size and ideal cut, their differences in fire depend entirely on their ability to produce angular separation between the various wavelengths undergoing refractions.

As explained above, formula 5 gives a close approximation for angular separation-better than simple subtraction of RIs. Making a distinction analogous to the contrast between doubling strength and birefringence, we can use formula 5 to calculate a 'dispersing strength' which is more accurate than simple dispersion.

Table 3 compares the dispersion of five SR gems with their dispersing strength as derived from formula 5. Estimates had to be made for the red and violet RIs, because all of the numerous reference sources available to me list net dispersion without indicating the actual B and G RIs (except for diamond).

The dispersing strength of strontium titanate is about 4 times that of diamond, a fact stated in numerous gemmological texts. In comparing these two gems, dispersing strength gives nearly the same answer as dispersion, because the RIs are so close.

However, as the RI decreases, a given dispersion acquires more dispersing strength. Thus, compared to diamond, cubic zirconia's dispersion is 36 per cent higher but its dispersing strength is 69 per cent higher. GGG's dispersion is only 2 per cent higher than diamond's, but its dispersing strength is 54 per cent higher. The fire of GGG is thus closer to that of CZ than to that of diamond.

Furthermore, the dispersing strength of YAG is *greater* than that of diamond (approximately 0.0083 vs 0.0075). I suggest that the reason a piece of YAG does not show as much fire as a diamond is because the ideal proportions for diamond simulants have not been calculated with as much precision as Tolkowsky and others devoted to the cutting of the diamond. If cut to its own specific ideal proportions, YAG could show as much fire as diamond.[4]

Table 3: Dispersion and dispersing strength

Gem	Red (B) RI	Violet (G) RI	Dispersion	Dispersing strength
Strontium Titanate	2.36 (est.)	2.55 (est.)	0.190	0.0316
Cubic Zirconia	2.14 (est.)	2.20 (est.)	0.060	0.0127
GGG	1.950 (est.)	1.995 (est.)	0.045	0.0116
Diamond	2.407	2.451	0.044	0.0075
YAG	1.820 (est.)	1.848 (est.)	0.028	0.0083

I hope that a reader who has access to the exact B and G RIs for the various diamond simulants (including natural zircon) will be avid enough to calculate their dispersing strength from formula 5.

Dispersion on a hemicylinder

The problem of colour fringes at the shadow edge when reading a refractometer in white light is due to a 'difference' in dispersion between the gem and the refractometer's hemicylinder. What is the difference? Again, it is not a simple subtraction.

Recall that the shadow edge is determined by the critical angle between the hemicylinder and the gem. The critical angle is directly related to the *ratio* between the RI of the hemicylinder (n_{hemi}) and the RI of the gem (n_{gem}):

$$(6)\quad \text{critical angle} = \arcsin \frac{n_{gem}}{n_{hemi}}$$

The appearance of colour fringes at the shadow edge means that the critical angle between hemicylinder and gem varies slightly for different wavelengths of light. Therefore, the influence of dispersion on the sharpness of a refractometer reading should be calculated by comparing the critical angle in red light to the critical angle in violet light. If the two critical angles are nearly equal, the effect of dispersion will be almost nil (i.e. colour fringes will be difficult or impossible to see).

To minimize the colour fringes, we need to produce a situation that can be expressed as follows:

$$(7)\quad \arcsin \frac{n_{gemR}}{n_{hemiR}} \approx \arcsin \frac{n_{gemV}}{n_{hemiV}}$$

Formula 7 is approximately equivalent to:

$$(8)\quad \frac{n_{gemR}}{n_{hemiR}} \approx \frac{n_{gemV}}{n_{hemiV}}$$

Therefore, the important consideration in determining the effect of dispersion on colour fringes is *division*, not subtraction. That is, we should not be comparing the dispersion of the gem (n_{gemV} - n_{gemR}) and the dispersion of the hemicylinder (n_{hemiV} - n_{hemiR}), but rather the *ratio* between the two RIs in red light and the *ratio* between the two RIs in violet light.

For example, an ideal ('colour-fringe free') shadow edge would be present on a hemicylinder that has $n_v = 1.92$ and $n_R = 1.88$ (dispersion = 0.040) if the gem being tested has $n_v = 1.550$ and $n_R = 1.518$ (dispersion = 0.032)

In this case,

$$\frac{n_{gemR}}{n_{hemiR}} = 0.8074 \text{ and } \frac{n_{gemV}}{n_{hemiV}} = 0.8073.$$

The 'match' is therefore nearly perfect (assuming that the ratio remains the same for all of the wavelengths between red and violet), despite the 'difference' between the dispersion of the hemicylinder (0.040) and the dispersion of the gem (0.032).

Conclusion

The formulae presented in this article are not 'news' to those who are acquainted with the field of optics. Old mineralogy textbooks such as Dana's *A Textbook of Mineralogy* contain numerous formulae that are far more complex than those of this article. Indeed, many mathematical analyses of optical phenomena dating back to the nineteenth century remain valid (e.g. the optical indicatrix was presented by L. Fletcher in 1892).

Therefore, this article is not about the discovery of a new formula. Rather, it is about the application of old formulas to a new field of science called 'gemmology'. I am writing to encourage gemmologists to get in step with the mathematical concepts that optical mineralogists have been using for the past hundred years.

The simple subtraction involved in determining birefringence and dispersion is, to put it bluntly, a simplistic approach. As a rule of thumb, we can say that when the birefringence or dispersion equals at least 2 per cent of a gem's RI, a gemmologist's interpretation of visual observations (i.e. angular separations) will become distorted unless he or she has been trained to think in terms of ratios (doubling strength and dispersing strength) rather than differences.

Notes

1. The subtraction of RIs *is* meaningful when a mineralogist estimates birefringence from the observation of interference colours in a specimen of known thickness. Here it is useful to view the difference between high and low RIs as the different speeds of the two rays. When the thickness is constant, the difference in speed causes a 'retardation' (i.e lag) between the two rays. The exact distance of any retardation corresponds to one of 'Newton's colours', which are shown in sequence on a Michel-Levy chart (Hurlbut and Klein, 1977). A mineral's birefringence can be estimated from the chart, according to the following formula (Phillips, 1971):
   retardation = thickness x birefringence.
2. Recalling the formula that is the basis for the Duc de Chaulnes method (Webster, 1983), it should be noted that the doubled images do not lie in the same plane. Because the two rays have different RIs, the two facet images produced by them have different apparent depths.
3. The term 'mean RI' is commonly encountered in mineralogy texts. It should be recognized as an abstract concept that does not have a specific relationship with crystal structure. For example, averaging the highest and lowest RIs of a biaxial stone generally does *not* give the beta RI.
   Using 'mean RI' in the formula for doubling strength increases the number of steps involved in the calculation and gives results that are slightly too low in cases of very high birefringence: synthetic rutile = .0377 and calcite = .0696 (compare these figures with the corresponding figures in Table 1).
4. The amount of fire that one sees in a well-cut diamond depends on both the crown angle and the crown height. An ideal crown angle maximizes the 'fanning out' of the various wavelengths when they exit the gem (i.e. the spectral colours are easier to see because their rays are spread more). A large crown height increases the size of the crown facets relative to the table (i.e. it increases the *proportion* of internally reflected light that has its component wavelengths spread enough to be easily seen) (Pagel-Theisen, 1989).

References

Anderson, B.W. *Gem testing*, 9th edn, p.51 (1980) and 10th edn (1990) p.43 on Poirot.

Hurlbut, C.S. and Klein, C., 1977. *Manual of mineralogy* 19th edn, p.206 on Michel-Levy.

Jenkins, F.A. and White, E., 1976. *Fundamentals of optics*, 4th edn, pp. 150-1 on Maclaurin's theorem.

Pagel-Theisen, V., 1989. *Diamond grading ABC*, 9th edn, pp.145-6 on dispersion.

Phillips, F.C., 1971. *Mineral optics: principles and techniques*, pp. 91-2 on retardation, chart of interference colours folds out after p.100.

Webster, R.,1983. *Gems*, 4th edn, p.714 on refractometer colour fringes, p.724 on de Chaulnes formula.

Gemmological Abstracts

BANK, H., 1992. Demonstrationsobjekt 'Gemmologische Brosche' als pädagogisches Anschauungsmaterial. ('Gemmological brooch' as educational material.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft* **41**, 2/3, 101-5, 1 photograph, bibl.

The brooch contains twenty-one gemstones, all somewhat deviating from 'normal' colour. Dr Bank had this brooch made up to demonstrate to students the difficulties of determining the gem materials in set pieces. E.S.

BENNETT, D., KEELING, J.L., 1992. Imitation lapis lazuli, charoite and azurite malachite. *Australian Gemmologist*, **18**, 3, 83-5, 6 figs.

Rough specimens obtained at Loxton Gemboree, South Australia, are described. Cabochons were cut from these. In general one needs imagination to associate these materials with the natural stones they are supposed to imitate [natural charoite is violet or lilac in colour, not Royal blue as the imitation, and not orange-brown as in the natural stone, illustrated]. Described as not very attractive, intended for cheap jewellery only. SEM showed them to be made of powdered barite and gibbsite plus colouring in an organic cement containing perspex. R.K.M.

BROWN, G., 1992. The elephant and its ivory. *Wahroongai News*, **26**, 10, 19-16, 18 figs.

An interesting listing of elephant species (proboscidae) from the Eocene era to the present day, illustrated by photocopies of line drawings including mammoths, mastodons and earlier fossil species, some of which might well be represented in 'fossil' ivories extant today. R.K.M.

BROWN, G., BEATTIE, R., 1992. Vietnamese ruby fakes: a problem requiring urgent solution. *Australian Gemmologist*, **18**, 4, 108-14, 36 figs.

Arrival of good quality rubies from Luc Yen and other Vietnam localities in 1990 occasioned much excitement, but many parcels, whether rough or cut, were and still are, heavily adulterated with stones from other sources, or with fragmented Verneuil type synthetics which had been tumbled to a water-worn appearance. More elaborate fakes were also found; synthetic material shaped to crystal habit with quench-cracking and lateral striation to increase deception, often heat-treated to reduce curved striae, oiled or waxed, impregnated with blue-dye, or infilled with fragments of real stones. Many natural stones painted with red nail varnish. Composites of either ruby or sapphire could contain both natural and synthetic material.

When cut, most of these are easily identified by conventional gemmological testing, but the rough parcels are much more difficult and it is advisable to polish a 'window' before arriving at a final decision.

Adulterated sapphire rough could be tested for the absence of a 450nm band in the synthetic material spectrum.

Natural rubies share inclusion types with those from Burma, with additional features of blue zoning, pyrrhotite rods (brassy or black), or colourless rods of calcite, orange rutile, fine bluish clouds of rutile needles and flux-like masses of orange norstrandite.

Writers say that to survive, the Vietnam ruby and sapphire industry must eliminate these practices at once. [Otherwise parcels from these sources may be rejected as untrustworthy.] Some fakes were crude but surprisingly ingenuous.

A valuable paper! R.K.M.

CAVENEY, R.J., 1992. De Beers Diamond Research Laboratory Report 1992. *Indiaqua Annual 1992/3*, 275-7, 9 photos in colour.

The main gem interest in this report is a brief account of the cutting of the shield-shaped 273 Centenary diamond. The diamond was cut, under conditions of high-level security, in the DRL premises, scientists and engineers of the laboratory developing the necessary specialized equipment. This included the scaife and special dops fed with a liquid coolant. A thermocouple attached to the stone monitored its temperature during cutting and, with the aid of a sophisticated control system, ensured that the gem was not subjected to any abnormal or sudden forces or to thermal variations.

In the Mineral Processing Division, work progressed during the year on the development of a fully integrated sorthouse for diamond recovery. New designs of X-ray machine, optics and ejector technologies were introduced to improve the efficiency of sorting. P.G.R.

COENRAADS, R.R., 1992. Sapphire and rubies associated with volcanic provinces: inclusions and surface features throw light on their origin. *Australian Gemmologist,* **18**, 3, 70-8, 11 figs, 1 map.

Like many other sources worldwide, the alluvial sapphires of New England, NSW, are of volcanic origin, in this case from the Central Province region. The paper describes these and other fields, crystal habit, inclusions, mining methods and many other matters in considerable detail. R.K.M.

COLDHAM, T.C., 1992. The Australian sapphire industry. *Australian Gemmologist,* **18**, 4, 104-7.

A history of sapphire mining and processing in Queensland and New South Wales, with problems and possible future. R.K.M.

COOPER, M.P., 1993. Letter from Europe. *Mineralogical Record,* **24**, 3, 231-7, 8 photos (5 in colour).

European mineral shows during 1993 have featured transparent gem-quality green zoisite from Pakistan (one crystal at least displaying pronounced dichroism); very large spessartine crystals from the Shagar valley, Pakistan; gem-quality emerald crystals from Nigeria; fine deep-coloured aquamarine crystals from Jos, Nigeria (the reporter feels that the deep colour is natural). M.O'D.

DISSANAYAKE, C.B., RUPASINGHE, M.S., DHARMARATNE T., 1992. Fluorine hydrochemistry in a topaz-rich area in Sri Lanka. *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **41**, 2/3, 111-16, 2 maps, 1 table, bibl.

Halogens are often used in geochemical exploration for mineral deposits. Fluorine, the most reactive of the halogens, is useful for the exploration of F-bearing gem minerals such as topaz, fluorspar and tourmaline. A study of the Elahera gem deposits in Sri Lanka shows that the geochemistry of F in ground-water could be used to locate areas of F-bearing gem materials. E.S.

DOMENECH, M.V., 1992. Les gemmes singulars del Tresor Imperial de Viena. *Gemologia,* **34**, 89, 4-8, 3 photos in colour.

Brief description of a fine emerald, a garnet and an agate plate, with other gems, forming part of the Imperial Treasures of the Hapsburgs, held in the Hofburg, Vienna. M.O'D.

DUCHAMP, M., 1992. Deux sommets de la gravure sur cristal de roche: les portraits de l'amiral de Ruyter et de l'empereur Leopold 1er. *Revue de gemmologie,* **113**, 5-7, 3 photos (1 in colour).

Two celebrated engraved rock crystal portraits are described. M.O'D.

FM-TGMS-MSA Symposium on garnet, 1993. [Short papers from the Symposium]. *Mineralogical record,* **24**, 61-8, 4 photos in colour, 13 figs.

The short papers cover: nomenclature and classification of garnets; the causes of colour in garnets; crystal structures, chemistry and properties of garnets; inclusions in garnets; geological occurrence of minerals in the garnet group; chemical and physical properties of vanadium-, chromium-, and iron-bearing garnets; garnets in architectural paints; garnets in the gem-bearing pegmatite dikes of San Diego County, California; garnets of Magnet cove, Arkansas; a new garnet locality in Connecticut; the McBride property [Hull County, Quebec]. M.O'D.

FRITSCH, E., MUHLMEISTER, S., BIRKNER, A., 1992. A preliminary spectroscopic study of the Biron synthetic pink titanium beryl. *Australian Gemmologist,* **18**, 3, 81-2, 3 figs.

UV visible and infrared were used, giving similar results to those for other Biron synthetic beryls. G. Brown has said that this material is easily identified by normal gemmological tests. R.K.M.

GODOVIKOV, A.A., BULGAK, L.V., 1993. Die Malchansker Elbait-Lagerstätte im russischen Transbaikalien. *Lapis,* **18**, 1, 13-15, 5 photos in colour, 1 map.

Gem-quality pink and green elbaite is found in the Malchansk pegmatites in Russian Transbaikalia. An interesting feature of some of the tourmaline is the high content of Bi_2O_3; the Malchansk pegmatites contain several bismuth compounds. M.O'D.

HANNAFORD, R., 1992. The carat: the unit of weight. *Australian Gemmologist,* **18**, 4, 117-18, 1 fig. used as cover design.

An antique scale bought by Mr Hannaford for gold weighing had an incomplete set of weights in old English fractional carats which

means the scale is for gems and must predate 1914, when the British ratified the new weight. He quotes Herbert Smith's *Gemstones* in which the varying gram values worldwide are given. Such fractions were recorded separately and not added together. [Abstracter has a Moe diamond gauge booklet which quotes weights similarly.] The English carat was 0.2053 grams until 1914 when the standard carat of 0.200 grams was adopted. [The maker of the scale is quoted as De Crave, but I suspect that this is in fact De Grave, a well known maker in Victorian times.]
R.K.M.

HÄNNI, H.A., 1992. Considérations terminologiques au sujet des émeraudes du Nigéria de couleur bleu-vert. *Revue de gemmologie,* **113**, 2-4, 1 photo and 3 figs in colour.

Bluish-green emeralds from Nigeria offer a problem in nomenclature. However, a Cr absorption line can be seen at 683nm and the stones thus fulfil the Cr-content criteria for emerald despite their strong blue component.
M.O'D.

HARDER, H., 1992. Rauchmondsteine, eine neue Mondstein-Varietät. (Smoky moonstones, a new moonstone variety.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **41**, 2/3, 69-84, 8 photographs, 3 tables, 1 maps, 1 schematic drawing, bibl.

Underneath the colourless and white moonstones near Implube, east of Ratnapura in Sri Lanka, 'smoky moonstones' have recently been found. They exhibit a flash of blue or white from a dark body. The blue, semi-blue and white moonstones have different alkali contents. The white quality is richer in potassium, the blue in sodium. In the top blue more than half of the alkali position in the lattice of the feldspar is occupied by sodium, so it is more of an albite than an orthoclase. A higher Fe^{2+} content is the chemical reason for the smoky moonstone quality which makes the blue shine better visible.
E.S.

HENN, U., 1992. Uber die diagnostischen Merkmale von synthetischen Alexandriten aus der Gemeinschaft Unabhängiger Staaten (GUS). (About the diagnostic characteristics of synthetic alexandrites from the former Soviet Independent States.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **41**, 2/3, 85-93, 10 photomicrographs, 2 graphs, 1 table, bibl.

The identification of the synthetic alexandrites produced by flux-pulling or hydrothermal method are the absorption spectra and some microscopic features. These do not appear in all examples, as the products are very clean and only sometimes leave traces of their production processes.
E.S.

HENN, U., BANK, H., 1992. Aquamarine aus Moçambique. (Aquamarine from Mozambique). *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **41**, 2/3, 107-10, 1 photograph, 1 graph, bibl.

Aquamarines of fine colour (Santa Maria) were found in the sixties in primary deposits at Mocuba in Mozambique. RI 1.572-1.580, to 1.582-1.589, DR 0.009. SG 2.70-2.73. The colour is caused by Fe. Microscopic studies show tiny fluid inclusions and hollow tubes. Analysis shows the iron content to be between 2.06-2.55 weight % FeO.
E.S.

HENN, U., BANK, H., 1992. Gemmologische Kurzinformationen. (Short gemmological notes.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **41**, 2/3, 63-7, 6 photographs.

A De Beers synthetic diamond of 0.43ct is discussed. It is a yellow, of Type Ib, fluorescent under long- but inert under short-wave UV. Under the microscope one could see definite colour zoning, hollow tubes which were the remnants of the catalyst and some very fine clouding.

In November 1991 some cut black diamonds were offered in the trade which turned out to be radio-active; high radiation made these stones unsafe. This also applied to some radio-active blue topazes. According to German law, stones which have been treated and exceed certain limits of radio-activity cannot be traded.

The article then deals with some synthetic zinc oxide from Poland, colourless beryl crystals covered with synthetic emerald film, green glass from Zambia traded as emerald crystal and a faceted cut tourmaline from Brazil with the zoning at right angles to the *c*-axis; the pink colour was caused by Mn^{3+} and the yellow by Mn^{2+}.

A green material with brown specks was found in New South Wales; it is a mixture of plagioclase and jadeite and can be used as an ornamental stone called 'nunderite'.
E.S.

HLAING, U.T., 1992. Myanmar jade: an update. *Australian Gemmologist,* **18**, 3, 79-80, 4 figs.

Deals with legend of jade discovery in the thirteenth century, although regular trade did not start until late in the eighteenth century. Natural resources and gems are State owned, but exploited jointly with private companies. Finest gems are sold abroad by Myanmar Gems Enterprise to bring foreign currency, but smuggling has led to a jade centre in Bangkok, Thailand. Sales have improved since jadeite was sawn to disclose its quality. R.K.M.

HOLZHEY, G., 1992. Praktische Gemmologie am Beispiel historischer Pretiosen. (Practical gemmology as applied to historical sculpture.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 95-100, 3 photographs, bibl.

The sculpture discussed is a silver-gilt elephant produced by the goldsmith and jeweller J.M. Dinglinger in Dresden in the first quarter of the 18th century. The dimensions are 17.5 x 12 cm, height 13.5 cm; it is listed in the inventory of 1725 of the 'Gruenen Gewoelbe'. The saddle of the elephant is studded with precious stones, 21 emerald cabochons, but only 22 of the 41 rose-cut stones are diamonds, the remainder are rock crystal or colourless topaz. The quality of the emeralds is variable. E.S.

HUTTON, D.R., TROUP, G.J., 1992. Magnetic resonance spectrum of Torrington emerald. *Australian Gemmologist*, **18**, 3, 89-90, 2 figs.

An investigation of electron-spin resonance of emerald from another Australian locality, identifying a greatly reduced content of vanadium in comparison with stones from Poona or with Colombian emerald. Comparison with Biron synthetic emerald also made. R.K.M.

JACKOWSKA-POLEWCZAK, A., 1991. Kamienie szlachetne i ozdobne Madagaskaru. *Mineralogia polonica*, **22**, 3, 79-87, 1 map.

Gem minerals are described and brief geological and mining details are given for Madagascar. M.O'D.

JANOSZCZYK, B., 1992. Problem otrzymywania syntetycznych opali szlachetnych. *Mineralogia polonica*, **23**, 1, 89-93.

Some considerations of the Gilson synthetic opal are offered with theories on the possible methods of manufacture. M.O'D.

KEELING, J.L., FLINT, R.B., 1992. Almandine garnet crystals from the Prydz Bay area, Antarctica. *Australian Gemmologist*, **18**, 3, 85-8, 8 figs, 2 maps.

Red to brownish-red almandine crystal fragments found on Vikoy Island, near Davis, were examined and found to be of expected habits with trapezohedron predominant, usually heavily striated. R.K.M.

KOIVULA, J.I., 1992. The gemmological properties of extraterrestrial peridots. *South African Gemmologist*, **6**, 10-16, 5 photos in colour.

Transparent to translucent nodules of peridot have been found in pallasites, meteorites with a metallic network of nickel and iron. Properties are within the range for gem peridot but stones show acicular inclusions caused possibly by stress- and heat-caused exsolution. M.O'D.

LASNIER, B., POIROT, J-P., SMITH, D.C., 1992. Intercroissances de jadéite de différentes compositions dans les jades révelées par cathodoluminescence. *Revue de gemmologie*, **113**, 8-11, 5 photos in colour, 4 figs.

Zoned cathodoluminescence can be seen in crystals of jadeite and provides a means of distinguishing compositional variations. M.O'D.

LIEBER, W., 1993. Farbzonen in Kristallen: Beobachtungen im Mineralreich. *Lapis*, **18**, 1, 29-48, 15 photos in colour.

Among the examples of zoned minerals discussed are rock crystal, amethyst and tourmaline; the paper includes a discussion of chemical reasons for the phenomenon. M.O'D.

LINTON, T., BROWN, G., 1992. Hofer gemstone colorcard. *Australian Gemmologist*, **18**, 4, 122-4, 1 fig.

Despite its name this is intended to determine the colour temperature of light available in which to judge stones. It does not define the colour of stones. R.K.M.

MENZIES, M.A., BOGGS, R.C., 1993. Minerals of the Sawtooth batholith, Idaho. *Mineralogical Record*, **24**, 3, 185-202, 20 photos (6 in colour), 1 map.

Among the minerals found in miarolitic cavities and pegmatite dikes in the granite of the Sawtooth batholith in south-central Idaho are gem-quality aquamarine and colourless topaz. Smaller crystals of spessartine are also reported. Some aquamarine crystals reach over 10cm in length. M.O'D.

PASTERNAK, A., 1993. Rock star. *ES*, the *Evening Standard* magazine, June 1993, 2 photos in colour.

Reporter's interview with London merchant Laurence Graff. M.O'D.

PETERSEN, O.V., SECHER, K., 1993. The minerals of Greenland. *Mineralogical Record*, **24**, 2, 4-67. 76 photos (colour and black-and-white), 6 maps, 22 figs.

Among the minerals of Greenland with ornamental application are tugtupite, sphene, garnet, ruby and sapphirine though few can be counted gem quality apart from the first two named. The paper is a welcome and exhaustive up-to-date descriptive summary of one of the world's major mineralized areas. M.O'D.

PLASZYNSKA, M., 1992. Some remarks on the applications of Baltic amber today and in ancient and medieval times. *Mineralogia polonica*, **23**, 2, 75-6.

A brief account of the use of amber through the ages. M.O'D.

POIROT, J-P., 1992. Ambre naturel, ambre pressé, ambre synthetique. *Revue de gemmologie*, **113**, 25-6, 1 photo in colour, 1 fig.

A brief resumé of the various types of amber and amber simulants with details of some manufacturing processes where appropriate.
M.O'D.

READ, P.G., 1993. Diamonds in the desert. *Canadian Jeweller*, April 1993, 27-8, 1 photo in colour.

Covers the history of the discovery of diamonds along the Namibian coastal desert in what was then German South West Africa, to the development of the CDM mining operation after World War I and its incorporation into the De Beers group. (Author's abstract) P.G.R.

ROBERT, D., 1992. La coloration artificielle du béryl. *Revue de gemmologie*, **113**, 23-4, 4 photos in colour, 1 fig.

Various ways of colouring beryl are briefly described. M.O'D.

ROBERTSON, A.D.C., SUTHERLAND, F.L., 1992. Possible origins and ages for sapphire and diamond from the central Queensland gem fields. *Records of the Australian Museum, Suppl.*, **15**, 45-54, 1 map, 1 photo.

Mining of sapphire has been carried out for over 100 years in this area, the classic grains of sapphire reputedly derived from the local basalt. New work has shown, however, that the sapphires originate in pyroclastic rocks and are associated with zircons. The zircons are of two types: older low-uranium zircon and younger high-uranium zircon. The occurrence of low-uranium zircon suggests that conditions may have been appropriate for the emplacement of diamondiferous material during this period.
R.A.H.

SAADI, J.A., GRASSO, J.C., 1992. Rhodochrosite from Argentina. *Australian Gemmologist*, **18**, 4, 125-32, 26 figs.

Describes the Capillitas mines, which yield this beautiful pink to red ornamental mineral, in considerable detail. In a region producing much superlative material, it seems that the Ortiz mine is top in quality, some of which would appear to be facetable. The major output is slabbed for decorative use, carved or used for cabochons.
R.K.M.

SCHUBNEL, H-J., 1992. Les gemmes et l'histoire de la minéralogie de Louis XIII à Charles X. *Revue de gemmologie*, **113**, 14-18, 14 photos (7 in colour).

Mineral and gem collections at the Muséum National d'Histoire Naturelle, Paris, reflect the collecting activities of several French kings. The three main collections are the Jardin du Roy (1626-1730) with an emphasis on the medicinal use of minerals; the Cabinet Royal d'Histoire Naturelle, (1739-1793), displayed in 99 showcases and Le Muséum National d'Histoire Naturelle (1793 to the present). Approximately 243,000 specimens are now in the collections.
M.O'D.

THOMAS, A.E., THOMAS, C.A., 1992. Garnets of the alluvial diamond diggings, pt 2. *South African gemmologist*, **6**, 3, 5-9, 3 photos in colour.

Garnets from two areas are examined and described with details given of their weight, colour, RI, SG, fluorescence, absorption spectrum and inclusions. The two areas are: diggings in the Vaal River catchment from Boskuil through Bloemhof and Christiana to Warrenton in the western Transvaal; and an area in the northern Cape between Schmidtsdrift, Douglas, Higg's Hope and Prieska, including the confluence of the Orange and Vaal Rivers. Attempts are made to place the stones on a garnet colour scale. M.O'D.

VOYNICK, S., 1993. Synthetic gemstones: high fashion, higher tech. *Compressed air*, **98**, 4, 8-15, 9 photos in colour.

A brief resumé of the use of man-made crystals as gemstones with notes on the problems of identification. M.O'D.

WILLIAMSON, L., 1992. A new theory of archaic jades. *Bulletin of the Friends of Jade*, 7, 42-7.

Drawing on the development of ideographs some idea of the use of Chinese jade artefacts can be obtained. Diagrams are taken from Karlgren, Grammata Serica Recensa, Stockholm, 1957. M.O'D.

ZHANG, P., 1992. Gem-quality scapolite from Sinjiang region, West China. *Australian Gemmologist*, 18, 4, 115-17, 2 figs.

Prospects appear to be good for purplish pink scapolite found in association with sphene in this region, both as facetable and as cat's-eye material. R.K.M.

What's new in minerals? 1993. [various authors]. *Mineralogical Record*, 24, 3, 219-30, 1993. 32 photos (31 in colour).

Shows at Tucson and Pasadena are reviewed. Among the gem-quality species observed were yellow beryl from Skardu, Pakistan; rhodochrosite from the Sweet Home mine, Colorado; green zoisite from Skardu; very fine etched heliodor from Ukrainia and etched sherry-coloured topaz from the same country; diamond crystals from north- western Hunan province, China; also from China were light blue aquamarine crystals; orange clinohumite from Kukh-i-Lal, Pamir mountains of Tajikistan; brazilianite from Baixo, Guandu, Minas Gerais, Brazil; large pale bluish-green datolite, also danburite and axinite from Dal'negorsk; emerald and alexandrite from the Malysheva mine, Takavaya, Urals; topaz from Mursinka, Russia; sillimanite from Rakwana-Deniyara, Sabaragamuwa province, Sri Lanka (one crystal seen measured 1.8cm); chrysoberyl twins from Teixeira da Freitas, Bahia, Brazil and from Medeiros Neto in the same state; near gem-quality sapphirine from Androy, Malagasy Republic. M.O'D.

ANON, 1992. Opal theft. *Australian Gemmologist*, **18**, 4, 115, 1 fig.

A short note on a split pair of red pin-flash boulder opals (4.5 x 3.5cm each) stolen from the Museum of Victoria. Finder to inform Dr Bill Birch of that Museum (010 61 03 669 9878). R.K.M.

Zeitschrift der Deutschen Gemmologischen Gesellschaft, 1992. **41**, 4, 121-97.

This issue of the *Zeitschrift* is dedicated to the 60th anniversary of the German Gemmological Association. It starts with a short history and aims of the Association illustrated with photographs of past and present presidents. The anniversary was celebrated with a two-day symposium on 27 and 28 September 1992 and the inaugural speech by Professor Dr Bank is reprinted. There were 27 contributions which are reprinted in condensed versions, both in German and English. The subject matter of the lectures was varied, from new observations on the origin of tiger's-eye dealing mainly with the crocidolite from Griqualand West, to various production methods of producing synthetics in Japan. Antique Roman gemstones including mosaics were discussed. Two extremely interesting lectures on diamonds dealt with diamond and diamond-like thin film coatings and a review of the Argyle mines. Other subjects were: heat-treated pink spinel from Sri Lanka; trace elements and conditions for heat-treatment as factors of the gem quality of corundums; colour and causes of colour in green beryls and their nomenclatural delimitation; polymers as gemstone-relevant materials; identification of fissure treatment in gemstones; new occurrences of precious stones in Bohemia (opal- hyalite, aragonite and natrolite, smoky quartz, cassiterite and fluorite); gemstones in Nepal; a new device for obtaining a reflected IR spectrum; spectrometry and X-ray fluorescence of sapphires; cathodoluminescence of precious stones and minerals; fresnoite, a new synthetic ornamental stone (fresnoite was found in metamorphic sanborite-quartzite zone near Fresco, California); first catalogue of Raman spectra of gemstones; the present condition for ruby (in Japan and including rubies from Vietnam which, according to the author, might come from other localities); contributions to the crystal growth analysis of natural and synthetic rubies; identification of a dominant negative rhombohedral 'd' plane $(01\bar{1}2)$ in natural ruby; morphological aspects of diamonds, natural and synthetic, stable and metastable growth; new gemmological materials analyzed by CISGEM (pearl, mother-of-pearl, doublets and imitations); beauty grades of gemstones (ruby, tourmaline and tanzanite); analysis of Burmese and Thai rubies by PIXE; gemstones of the Swiss Alps; Embilipitiya, an interesting gem deposit in Sri Lanka (almandine garnet, spinel, cordierite and kornerupine). The contributions are illustrated by 20 photographs, 2 maps, numerous graphs and tables. E.S.

Book Reviews

CLARK, A.M. 1993. *Hey's Mineral Index.* Chapman & Hall, London. pp. xi, [852]. £50.00. ISBN 0 412 39950 4.

First a bibliographical note on the history of this major work. It began life in 1950 as the first edition of *An index of mineral species and varieties arranged chemically* [spine title and familiarly known as *Chemical index to minerals*]. The second edition with the same title appeared in 1955; thereafter the work was continued in two appendices published in 1963 and 1974, the latter with P.G. Embrey as co-author. The main work was also reprinted with minor corrections.

The work was compiled by, and is a memorial to Max Hey whose name is fittingly commemorated in the present title. This is one of the three or four mineralogy texts forming the foundation of all serious study.

The first two editions listed minerals in chemical order with elements first and rarer compounds last; it also included organic materials and substances inadequately characterized at the time. Mineral classes were assigned a number with species given a running number within the class. These numbers also included doubtful species and varieties; it was and still is difficult to distinguish between these two categories. The present work is arranged alphabetically but still includes the chemical order listing which is given in a concise form at the end of the main text. The names are all published and the sequence also contains some of the commoner mis-spellings, some meteorite and rock names which often resemble names of minerals and some trade names where they resemble mineral names. Each entry contains the chemical composition, group name where applicable [the groupings are much the same as those set out in Fleischer & Mandarino's *Glossary of mineral species.* There is a reference where possible to the description of the original mineral and references are also given for many old names and synonyms. Cyrillic characters are given for Russian language names, so often a cause of contention. It is interesting to find that citations are made in this edition to earlier editions of Dana's *System of mineralogy*; in previous editions of the present work only the sixth edition was used; this is now a rare book and references have been tracked down to their original appearance so that Dana editions 1-5 once more have work to do. Most name variants in Germanic languages are taken from the very rare and very expensive *Handbuch der Mineralogie* series, established by Carl Hintze. Details of crystal system, unit cell dimensions, and formula unit contents [Z] are given; there is also a two- or three-part number related to the previous Hey numbers but not identical to them. PDF (*Powder Diffraction file*) numbers are given for those entries where the unit cell data are held in that file.

An important new feature is the inclusion of type locality for species and well-defined varieties, when this is known. Gemmologists may like to know that the type locality provides the specimen from which the mineral or varietal description is first made. Although some politico-geographical changes have been made since original papers were written, this book still manages to be up-to-date, taking into account the unification of Germany (but not the disintegration of the former USSR and Yugoslavia). The remainder of the entry gives the origin of the name, reference to important chemical redefinitions that have occurred during the history of a species, synonyms and varietal names - these may be based on habit, colour or chemical differences. Data concerning unnamed species is not given in this edition, nor is the pronunciation table, since the author admits that even in a single laboratory (and even more in the field) two people rarely agree on this topic - perhaps there was something to be said for the Oxbridge accent when shouted against the wind!

The book is amazing value for its price and a superb, long-awaited work. M.O'D.

KAZMI, A. H. and O'DONOGHUE, M. 1990. *Gemstones of Pakistan: Geology and Gemmology.* Gemstone Corporation of Pakistan, Peshawar. pp. viii + 146, 24 black and white figs. 72 colour plates, 19 tables, Price £35.

This book might easily be considered as the sister publication of the earlier work *Emeralds of Pakistan*, especially since A. H. Kazmi is a co-author of both texts. Both have a geological bias, but this work has the avowed intention of stimulating budding gem geologists and jewellers to go out and make more gem discoveries. To this end the authors provide a twenty page general introduction to gemstone composition, properties and distribution; this includes the use of testing instruments, cutting and polishing and the procurement of rough. A list showing worldwide distribution of gemstones by countries is also provided.

The physical and geological features of Pakistan are described in the next chapter, which includes useful maps and sections explaining the tectonic setting. The latter is used as a basis for describing gemstones according to their various tectonic associations. Pakistan emeralds are described in some detail under the 'Indus suture associated gemstones' heading and are compared with their synthetic counterparts.

Ruby and spinel (often blue) are among the gems found in an extensive belt of crystalline marble found in the Hunza valley and elsewhere which forms part of the 'Karakoram suture associated gemstones' chapter. Pegmatites are widely distributed in Pakistan and this is reflected in the variety of gemstones in the chapter on 'Pegmatite associated gemstones'. The descriptions of aquamarine, tourmaline, feldspar, quartz, topaz and others are accompanied by good colour photographs and useful diagrams. The chapter on 'Gemstones in hydrothermal veins' deals with zircon, rutile, agate and the notable pink topaz from Katlang which merits a detailed description. The book concludes with a brief section on miscellaneous gems and the gem market in Pakistan. There is a comprehensive bibliography.

A major feature of the book is the excellent colour photography; largely the painstaking work of Dr Edward Gübelin on the inclusions and A. H. Kazmi on the mineral specimens and the good topographical pictures. The contents pages are reasonably informative, but there is no index. It is unfortunate that Photo No. 1 of an engraved emerald is the colour of a blue sapphire. Despite its geological bias, the book is very readable and should be on the shelves of those gemmologists who are curious about the origins of the gemstones they admire, collect, test, sell or incorporate into beautiful artifacts.

E.A.J.

SINKANKAS, J., 1993. *Gemology. An annotated bibliography.* 2 vol. Scarecrow Press, Metuchen NJ. pp. xxxiii, 1179, illus. in black-and-white. ISBN 0 8108 2652 6. £179.50.

At last gemmology has a worthy bibliography, and if one single event helps a subject to come of age this must be it. This is a bibliography in the sense of a catalogue raisonné rather than a list of books, with many old problems now at last laid to rest, freeing the student for other work and perhaps even building upon this one since the output of books and papers shows no sign of lessening.

The book opens with a foreword by Richard T. Liddicoat and continues with a preface in which the parameters of the book are described. It is certain that no previous bibliography exists and when Sinkankas began a literature search for his first book, published in 1955, he found that it was necessary not only to consult a very large number of existing books for their citations but also to acquire many of them and, at the same time, recording their bibliographical details as fully as possible. From these careful beginnings the present work has sprung; the library of books acquired now graces the Gemological Institute of America. It has taken something like forty years to bring this project to fruition.

During the compilation of the bibliography many books were consulted and recorded, perhaps for the last time since some were printed on so poor a paper that they cannot now be repaired. For this reason Sinkankas has provided as much detail as possible, including cloth types, colours, lettering, ornamentation, bevelled edges and endpapers. Such details are also provided for most of the other entries as well so that there will always be a record in the event of disaster.

The scope of the bibliography is based on size and relevance of the subject- matter. Thus many works are included which are peripheral to the main study of gemstones; such books include works on engraved gems, regalia, gem lore and biographies, with other topics. A limit of 15 pages was set for inclusion but shorter pieces of importance are included. Most entries are in English, with European languages covered to a lesser (but still considerable) extent. Books and papers must be in the Roman alphabet but this of course includes the romanization of works in Cyrillic and oriental scripts.

Numbered entries are under author where possible and follow accepted bibliographical practice. The preface explains this is some detail; entries may be abbreviated for short articles and full when a major work is cited. In such cases the entry begins where possible with a brief biographical sketch of the author so that important contributors to the literature of gemmology are highlighted; such treatment is especially useful for historical and classical figures; today's major writers will be tracked down in their turn. Among British figures are Anderson, Webster, Herbert Smith, Blakemore, Bruton and the present reviewer.

Physical details of the book cited are very full and enable the student to distinguish editions, re-issues and variants from one another - this is not always easy since in the earlier part of this century dates of publication were not always given and there was no ISBN. Notes on illustrations are also very valuable since these may vary a great deal within a particular work which is printed more than once. Some very large books were published or re-issued for a particular small, wealthy group of collectors. Even large library catalogues do not always show this type of thing. Those interested can look up such entries as Heber R. Bishop's *The Bishop collection: investigations and studies in jade*, where full details of a celebrated limited circulation work will be found. In my years as a curator at The British Museum I passed this enormous two-volume book in its glass case many hundreds of times - now I know its contents!

However, this is not the only kind of book whose contents are described since Sinkankas provides descriptions of the text of virtually all the monographs cited. He also gives details of major reviews. Much of the small detail pertaining to an entry is abbreviated and a table sets these out over four pages. This section is followed by a list of serial publications and by a list of bibliographies and references consulted. These are listed alphabetically by compiler. It is remarkable and says much for the skill of the author that all this preliminary matter occupies only 33 pages.

At many openings title pages of important books are reproduced; this not only makes an attractive and useful break in the text but helps the student to see quickly which edition he has or wishes to know about. A superb work with quite a reasonable price for the amount of information contained and a credit to our science. M.O'D.

THEMELIS, T., 1992. *The heat treatment of ruby and sapphire.* Gemlab Inc. pp. xviii, 236, illus. in black-and-white and in colour. £65.00. ISBN 0 940 965 10 0.

The book is sub-headed 'An account of the most commonly practised heat treatment methods and apparatuses which alter the appearance of the ruby and sapphire; their occurrences, descriptions, inclusion characteristics, identification and other features'. This aim has been comprehensively achieved and the text must be in the hands of all gemmologists and students, although the price may seem a little high to some. The book is described as a limited edition, so a quick purchase may be advised. After an introduction to corundum in which the main characteristics, including cause of colour, are described, the effects of heat are outlined, to be more exhaustively covered later in the text where specimens from individual locations are discussed. At this point the author is content to list and describe heat and diffusion processes for the various colours of corundum. Fourteen different processes are considered; they include darkening and lightening of colour, development of colour change, production of asterism and removal of excess silk, diffusion treatment and some experimental treatments. Next comes a section on how inclusions may be affected by treatment, followed by general notes on corundum identification.

By chapter five the author embarks on as full an account of heat treatment as can be found anywhere. Particularly welcome are the notes on the types of equipment required and on the ways in which the stones are prepared for treatment. A 70-page chapter then describes corundum by country of origin, giving details where known of whether or not the stones are routinely treated. The amount of detail is very large and much of it is of the greatest use to workers not primarily interested in colour alteration as well as to those working directly in this area. The vexed questions of disclosure of treatment, of country of origin and of value form the final chapter, though there is a bibliography and index. As so much of the material in this excellent book is newly-acquired, the reader will find it a vital adjunct to existing modern books on gemstones: much of the information will filter through papers and bulletins supplemented where necessary by even more up-to-date accounts since this is the most important development area of gemmological investigation. The details seem to be correct; there are some misprints of names and some papers mentioned in the text are not found in the bibliography, but these are not important points when so much of the material is new to the literature. Colour pictures, which are grouped together, show interesting and hitherto unpublished examples and are of good quality. M.O'D.

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

GIFTS TO THE GAGTL

The GAGTL is most grateful to Mr Fawcett of the Cultured Pearl Co. Ltd for the gift of a cultured Mabe pearl.

NEWS OF FELLOWS

Dr Roger Key, who is on secondment from the British Geological Survey, will be in Botswana for the next two years as Principal Geologist in charge of field mapping.

On 25 April 1993 Peter Read gave a talk on gem instruments to students of the Queensland Branch of the Australian Gemmological Association at their headquarters in 20 Rosslyn Street, East Brisbane. He was also invited by the President, Roy Beattie, to be guest speaker at the Branch's Diploma Dinner in Brisbane on 1 May, and gave a talk on 'Diamonds and De Beers'. Before his talk he presented GAA diplomas to that year's successful Queensland candidates.

Peter Read in Brisbane presenting a GAA Certificate to successful Queensland candidate Bradley Kearton. On the left is Roy Beattie, President of the Queensland branch of the Gemmological Association of Australia.

MEMBERS' MEETINGS

London

The following meets were held at the GAGTL's new Gem Tutorial Centre situated on the second floor at 27 Greville Street, London EC1N 8SU:

On 1 April 1993 Dr E. Gübelin gave a lecture entitled 'The significance of natural and artificial inclusions in diamonds'. Those present were treated to a show of many excellent slides that Dr Gübelin used to illustrate his lecture.

Dr E. Gübelin at GAGTL lecture

On 14 April 1993 Dr Jamie Nelson gave an illustrated talk on 'Light scattering effects in gemstones'. Much of the talk dealt with recent developments in Raman scattering spectrometry. This is the ultimate laboratory tool for non-destructively characterizing those gemstone inclusions which lie below the polished surface of a stone.

On 27 April 1993 an illustrated talk was given by Stephen Kennedy entitled 'Rubies in the laboratory'.

On 11 May 1993 Christopher Cavey gave an illustrated talk on 'Engraved gems'.

On 14 June 1993 the Annual General Meeting was held (a full report of which is given below) fol-

GAGTL GEM TUTORIAL CENTRE

27 Greville Street, London EC1N 8SU

Gems for retailers

8-9 September

Two full days of practical experience with mounted stones. Investigate and test the stones you are likely to handle in the retail environment. Discuss suitable selling and talking points with gemmologists who have an extensive knowledge of the retail jewellry trade.

Price £164.50

Two days of diamonds

15-16 September

For an insight into gem diamond origins, grading, simulants and treatments.

Price £223.25

Synthetics and enhancements today

22-23 September

Are you aware of the various treated and synthetic materials that are likely to be masquerading alongside the gemstones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss these two days of investigation?

Price £223.35

Precious stones and crystals

Evening course commencing 28 September

The University of London's Centre for Extra-Mural Studies will run a course of ten evening classes at the GAGTL Gem Tutorial Centre to be held on each Tuesday from 28 September to 30 November, from 6.30 to 8.30 p.m.

Each week Ian Mercer, B.Sc., FGA, the GAGTL's Director of Education and a University Extra-Mural geology lecturer, will introduce a different aspect of these fascinating materials.

The course will appeal to beginners as well as qualified gemmologists.

For an application form and further information contact Alison Sutton at the University of London Centre for Extra-Mural Studies, 26 Russell Square, London WC1B 5DQ, or telephone Alison on 071-631 6654.

Price £50.00

DIY Laboratory

30 September

Spend a day finding out about the basic gem testing instruments. You will be looking at the principles by which these instruments work and the results you should obtain. You will also be constructing some instruments of your own.

Price £111.63 (includes materials)

Preliminary workshop

12-14 October

One-day practical tuition for Preliminary students and anyone who needs a start with instruments, stones and crystals; student discount

Price £44.65; GAGTL students £31.73

Jade

10 November

An unrivalled opportunity to handle jade, under the guidance of Alan Jobbins and Christopher Cavey.

Observe the great variety of jades, their simulants, artificial treatments and 'accidental' alterations.

Where are the limits to identification?

Price £111.63 (including lunch)

Photographing gemstones

23 November

Spend the day in the company of Frank Greenaway, one of the leading photographers of gemstones. A rare opportunity for you to enhance your photography.

Price £111.63 (including materials and lunch)

ALL PRICES INCLUSIVE OF VAT AT 17.5%

lowed by a Reunion of Members and a 'Bring and Buy' sale.

Midlands Branch

On 30 April 1993 at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held, at which David Larcher and Gwyn Green were re-elected Chairman and Secretary respectively.

On 13 June 1993 a trip to Castleton and Treak Cliff Caverns Ollerenshaw Collection, Derbyshire, was arranged for members.

North West Branch

On 19 May 1993 at Church House, Hanover Street, Liverpool 1, Dr J. Franks gave an illustrated talk entitled '"Lalique" jewels, from 1992 Paris Exhibition'.

On 16 June 1993 at Church House a 'Members and Friends' evening was held, which included a 'Bring and Buy' sale.

ANNUAL GENERAL MEETING

On 14 June 1993 the Annual General Meeting of the Gemmological Association and Gem Testing Laboratory of Great Britain was held at 27 Greville Street, London EC1N 8SU.

David Callaghan chaired the meeting and opened by saying how pleased he was that so many had attended. Although the previous AGM had been held on the second floor of 27 Greville Street, David stated that this was the first to be held in the newly completed Gem Tutorial Centre. The whole aspect of gemmology has now become very much more involved with the modern synthetics and gemstone treatments now appearing. The Centre is now able to offer an increasing number of courses to enable those with an interest in gemmology, either as a hobby or within the trade, to identify such gemstones. 'So it is now possible', David continued, 'to buy books and gem testing instruments, then take a course to find our how to use them - all in the same building'.

David Callaghan then announced that he was to retire from the Council of Management and from the position of Chairman at this meeting. He said that he had very much enjoyed his term as Chairman and thanked all those who had given him help and support over the years. It had been agreed that the Office of Chairman should not be filled immediately. Because of the changes in the company as a result of the merger between the Gemmological Association of Great Britain and the Gem Testing Laboratory, it was decided to seek the opinions of members on how they see the roles of Chairman and President of the merged company before any new elections are made.

The Annual Report and Accounts of GAGTL for 1992 were approved and signed.

Messrs A. E. Farn, D.G. Kent and R.K. Mitchell were re-elected as Vice-Presidents and, in recognition of his work for the Association over many years, Mr E. Bruton elected as Vice-President.

Mr I. Thomson was re-elected to the Council of Management; the election of Mr T.J. Davidson was confirmed and Mr N.W. Deeks was elected.

Messrs H. Levy and E.A. Thomson retired from the Members' Council. Messrs J. Kessler. G. Monnickendam, L. Music, J.B. Nelson and P.G. Read were re-elected and Messrs P. Dwyer-Hickey and R. Shepherd elected to the Members' Council.

Messrs Hazlems Fenton were re-appointed Auditors.

This concluded the business of the meeting.

Retirement of David Callaghan

Mr Ted Thomson then gave the following vote of thanks to David Callaghan on his retirement as Chairman of the GAGTL.

'I stand to say a few words on your behalf on the occasion of David Callaghan's retirement from the Chairmanship of the GAGTL and the Council of Management. If anyone ever deserved a long and happy retirement from public service it is David. It is quite amazing how long and comprehensive his service is and how early he started.

'David joined Hancocks as an apprentice at the age of sixteen and has worked for them all his life so far. He took his FGA in 1958 as part of his apprenticeship under the guidance of Miss Willis, who inspired his love of opals. Miss Willis, incidently, was one of the first ladies to qualify for the FGA and is now living in Leigh-on-Sea at the ripe age of ninety-four.

'During his career at Hancocks David has become an authority on gemstones, silver, high class jewellery and especially Victoria crosses, and has lectured worldwide on these topics. In the '60s he became a Director of Hancocks, a Freeman of the City of London, a Liveryman of the Clockmakers Company, a Freeman of the Wax Chandlers and in 1983 a Liveryman of the Goldsmiths Company. This latter shows an appreciation of his services to the trade.

'He was Chairman of the Precious Stone Diamond and Pearl Section of the London Chamber of Commerce from 1977-80. At that time this committee was the main connection between the trade and Government, and had many responsibilities in addition to running the Laboratory. He was a sucker for punishment as he

FORTHCOMING MEETINGS

London

Throughout 1993 there is a programme of meetings on the second floor at 27 Greville Street. Refreshments will be available from 6.00 p.m. and lectures will start at 6.30 p.m.; these will be followed by discussion and closing about 7.45 p.m. The charge for a member will be £3.50 and, as places are limited to 55, entry will be by ticket only, obtainable from GAGTL.

20 September	'Photographing minerals and gems'	Frank Greenaway
6 October*	'Diamonds in the Laboratory'	Eric C. Emms
18 October	'The distinction of natural from synthetic diamonds.'	Professor I. Sunagawa
8 November	'Thai evening'	Amanda Good and Martin Issacharoff
22 November	'CIBJO matters' - the gem trade in Europe	Harry Levy
7 December*	'Pearls in the Laboratory'	Ana I. Castro and Stephen Kennedy

The GAGTL Annual Conference is to be held on 24 October 1993 at the Great Western Royal Hotel, Paddington. This will be followed on 25 October by a GAGTL Open Day and the Presentation of Awards. Full details of these events are given on p. 386.

Midlands Branch

24 September	'Deep diamonds.'	Dr Jeff Harris
29 October	'Rescued from the scrap box.'	David Wilkins
26 November	A practical demonstration of light behaviour in gemstones.	Dr Jamie Nelson

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

North West Branch

15 September	Jonathan Condrup from Sotheby's, London	
20 October	'Minerals in the Bronze Age'.	Tony Hammond
17 November	Annual General Meeting	

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

* Please note change of date: make a note in your programme card.

was also Chairman of the National Association of Goldsmiths from 1976-78 as well as an Examiner for the Retail Jewellers Diploma.

'I have a feeling, however, that his real love has always been the GA and the Laboratory. When Doug King had to retire from the Chair of the GA in 1980 David stepped in and since then has headed the Association with skill and enthusiasm. He was instrumental in seeing through the merger with the Laboratory in 1990 - which was no mean feat. It was very appropriate that he should lead the merged organization since his support for the Laboratory over so many years has been very significant in establishing continued development of its activities and resources - both through support from the Trade and acquisition of new instruments. In particular he did a lot of the background work to enable the Laboratory to acquire the UV-VIS spectrophotometer - appropriately named the Basil Anderson spectrophotometer - in 1984.

'So on behalf of his old colleagues at the Chamber of Commerce and more especially his many friends and colleagues at the GAGTL, I would like to thank you David for the many things you have done for the Trade in so many facets and would ask you to accept our gift as a small token of appreciation of your contribution and in the hope that you will have many years of enjoyment from it'.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 25 March 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Gold Laboratory Membership

J. & B. Cousins & Sons Ltd., 8,9,9a Sun Street, Canterbury, Kent.
Graff Diamonds Ltd., 16 Greville Street, Hatton Garden, London EC1N 8SQ.
Gruet, 52 Rue La Fayette, 75009-Paris, France.
King's Diamond Trading Company, Rm 701-5 Lane Crawford House, 70 Queen's Road, Central Hong Kong.

Ordinary Laboratory Membership

Gold Arts, 7 Brighton Place, Brighton BN1 1HD.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 21 April 1993 at Hancocks & Co., 1 Burlington Gardens, London W1X 2HP, the business transacted included the election of the following:

Ordinary Membership

Bastians, Indramal Chitranganie, London.
Bray, Betty A., Abilene, Tex, USA.
Brown, Symon, Cockermouth, Cumbria.
Cliff, Graham, Eltham, London.
Everest, Andrew, London.
Kleiser, Alwen, Holyhead, Gwynedd, Llgsidis.
Smith, Ian Hobden, Thatcham.

At a meeting of the Council of Management held on 19 May 1993 at GAGTL, 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Ordinary Membership

Bae, Sang-Kea, Seoul, Korea.
Bonnyarak, Orapin, Johor Bahru, West Malaysia.
De Narvaez, Mauricio, Bogota, Colombia.
Devon, Jill, Felstead.
Howard, Stanley, Mill Hill, London.
Nolens-Verhamme, Paule, Sint Truiden, Belgium.
Wood, Victor, Ilford.

At a meeting of the Council of the Management held on Wednesday 16 June 1993 at GAGTL 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Balter, Jonathan, London. 1992.

Ordinary Membership

Booth, Diane, Cromer.
Branco, Rui Jose Portela Jorge, Viseu, Portugal.
Gangsted, Anne, Bangkok, Thailand.
Keen, Paul, London.
Pellas, Isabelle, London.
Schmid, Huldrych, Bachenbulach, Switzerland.
Tandjung-Teo, Liti M., London.
Targiello, Barbara, Lublin, Poland.
Zanettin-Barbin, Fabrizia, Geneva, Switzerland.

Gold Laboratory Membership

Chatila & Sons Ltd, 22 Old Bond Street, London W1X 3DA.

Ordinary Laboratory Membership

Eugenios Petrides, GG, FGA, London NW3 3AX.

CORRIGENDUM

On p. 353 above, the illustrations for Figures 29 and 30 were transposed

Letters to the Editor

From Kurt Nassau, Hon. FGA

Dear Sir,

I feel somewhat hesitant in submitting comments to no less than three of the articles in the October 1992 issue of *The Journal of Gemmology* (Vol. 23, No. 4). Perhaps I can be excused this momentary excess in view of the many other issues where I have not had any comments at all!

The determination of the ages of emeralds by rubidium-strontium analysis (Vidal, Lasnier and Poirot, p. 198) is certainly an original way of distinguishing natural emeralds. If this test were to come into professional use, however, I believe that it would not be too difficult to subvert. Emerald synthesizers could merely add controlled amounts of rubidium and strontium isotopes to their growth medium and so simulate any age desired in their synthetic material!

In his otherwise excellent article on symmetrical polyhedra for gemstones (pp 207- 14), Lurie uses the correct term 'vertex' interchangeably with the term 'quoin'. I have consulted several dictionaries and believe that 'quoin' is an incorrect usage. The multivolume *Oxford English Dictionary* (1933 on to the most recent 1987 supplement), for example, defines 'quoin' as applying to the 'external *angle* of a wall or building' or to the 'internal *angle* or corner, as of a room' or an '*angle* or an angular object', among other less relevant meanings. When an author employs an inappropriate usage such as 'quoin' for 'vertex' ('an angular *point*, as of a triangle or polygon' in *OED*; plural vertexes or vertices), then he needs to supply justification for such a usage lest he mislead others.

Finally, the author of the interesting article on the electrolytic oxidation treatment of sapphires (Wang Chuanfu, pp. 195-7) does not appear to be familiar with the many variables applicable to sapphire heat treatments, such as temperature, time, and precise oxidation-reduction conditions. The failure of his single attempt at heat treatment does not demonstrate that his material could not be changed to a desirable blue under more appropriate conditions. His explanation for the observed colours in terms of simple Fe^{2+}, Fe^{3+} and Ti^{3+} absorptions also omits consideration of the most important absorption, that of Fe-Ti charge transfer. Finally, he suggests that his electrolysis causes Ti to diffuse into the sapphire, without checking (or at least without reporting) whether this produced a colour concentration layer at the surface. Were this to be the case, his process would no longer be a heat or oxidation treatment but would become a surface diffusion process, with quite different implications for disclosure.

Yours etc.,
Kurt Nassau
21 December 1992
Lebanon, NJ, USA.

From Jos Lurie

Dear Sir,

In regard to Dr Nassau's comments I wish to reply as follows:

Dr Nassau is perfectly correct; having now carefully consulted numerous works I acknowledge that in my paper 'quoin' should read 'vertex' in all cases. I regret the error but trust that my meaning was clear.

Yours etc.,
Jos Lurie
9 March 1993
School of Mines, Technikon Witwatersrand,
PO Box 3293, Johannesburg 2000.

From Wang Chuanfu

Dear Sir,

Many heat-treatment methods of sapphire have been used for Chinese sapphires and many variable factors such as temperature, time, atmosphere conditions, etc., were investigated. Although heat-treatment method is very simple, it is not suitable for Chinese sapphire (containing high content of Fe (1-5wt% Fe_2O_3)). Owing to the high content of Fe the absorption of Fe-Ti biparticle is difficult to form a peak.

Now this method has a great commercial value and it is a pity that my paper only simply reports as above.

Yours etc.,
Wang Chuanfu
Vice Director
General Research Institute for
Non-Ferrous Metals, Beijing 100088, PR China.
15 March 1993

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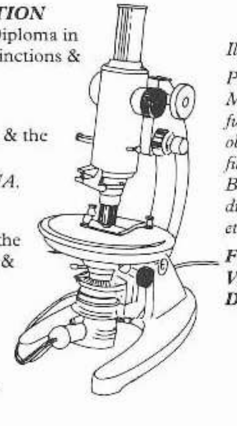

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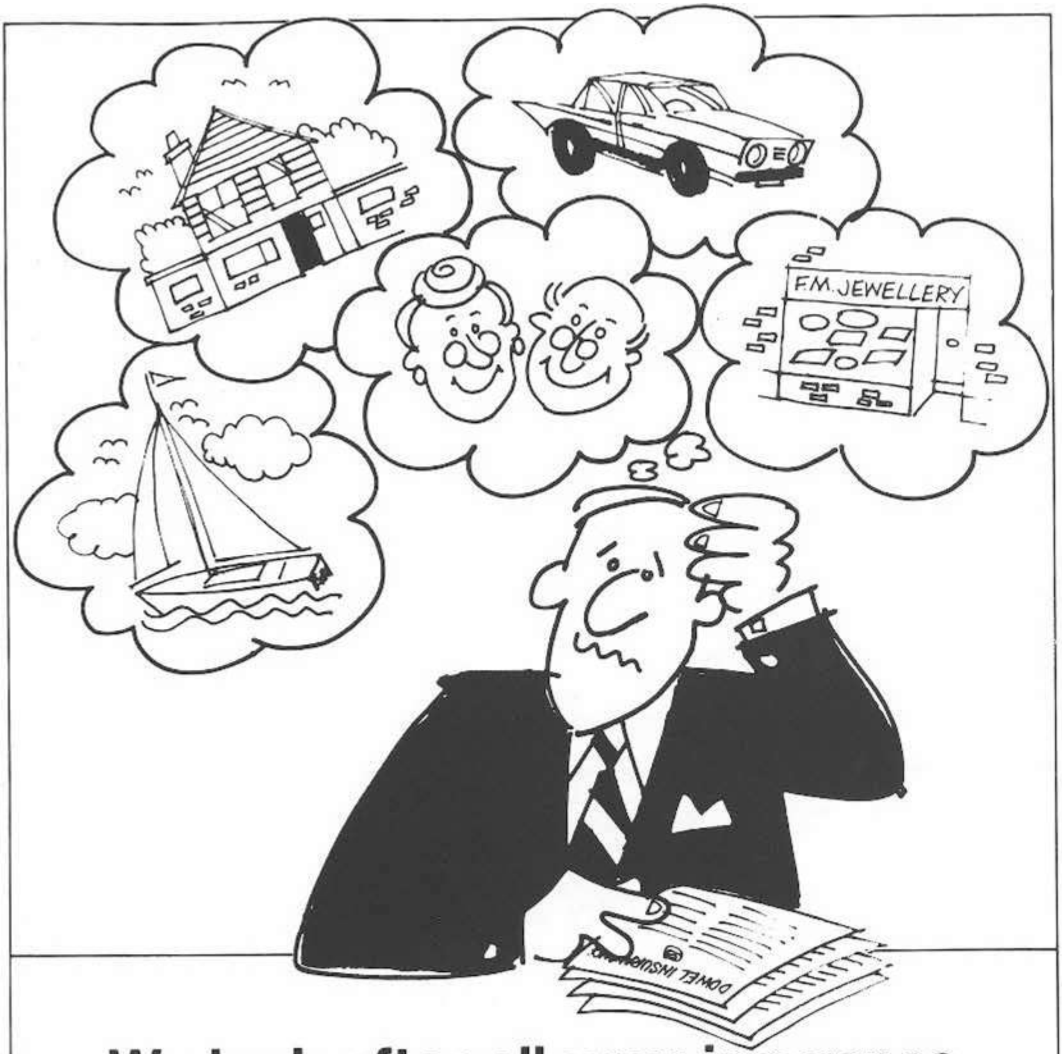

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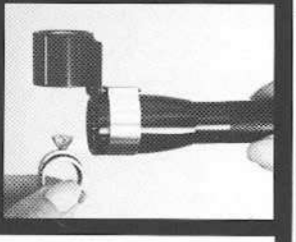

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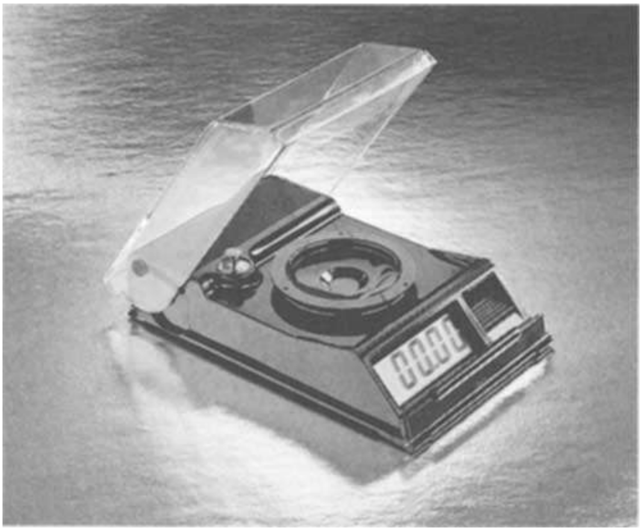

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