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GEM QUALITY GAHNITE FROM NIGERIA

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PREAMBLE

Natural blue spinels are reasonably common, gahnospinels comparatively rare and gahnite (zinc spinels) of gem quality even rarer. It was not surprising, therefore, that, when the Royal Scottish Museum was presented with several, blue to blue-green, gem-quality octahedral crystals of gahnite, of cuttable size (maximum size approximately 1 cm in diameter), enquiries were made to find out if cut stones were available. Regrettably all the cut stones to date (July 1981) had already been sold to a German company and no more would become available until later in the year. All the work therefore was done on the available rough material, with or without polished faces.

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OCCURRENCE

The gem quality blue octahedral crystals of gahnite occur in a complex pegmatite 3.2 km NNW. of Jemaa (locally known as Gidan Wiya), Nigeria. The pegmatite, which is 1·8 metres wide, strikes north-south and cuts dark hornblende-biotite streaky gneiss. The extent of the pegmatite, which forms a distinct very heavily forested ridge, is difficult to determine but is in excess of 91 metres. Mineralogically the pegmatite consists of quartz, muscovite and albite with accessory tantalite and schorl tourmaline. Other pegmatites in the Jemaa area have produced dark green opaque gahnite.(1)

Previously reported occurrences of gahnite include Sweden at Falun,(2) Western Australia,(2) New Zealand,(2) Scotland,(2) Portugal,(2) Bavaria at Bodenmais,(3) Brazil,(3) Canada,(4) Spain,(4) Italy,(4) Finland,(4) India,(4) Madagascar(4) and at various localities in the U.S.A.(3) The majority of these localities do not produce gahnite of suitable gem quality. The only references to gem-quality gahnite are transparent material of very good green colour (similar to tourmaline) from Brazil(3) and nearly pure gahnite, green in colour and transparent recently found and cut as a gemstone,(5) from Madagascar.(6)

At Jemaa the gahnite is moderately abundant and of gem quality, but it is not known if there is sufficient suitable material available to take this gemstone out of the collectors item category.

PROPERTIES

Gahnite is a member of the spinel series and there is an isomorphous series from spinel ($MgAl_2O_4$) to gahnite ($ZnAl_2O_4$) as indicated by the gahnospinels [$(ZnMg)Al_2O_4$]. Similarly an isomorphous series exists from spinel to hercynite ($FeAl_2O_4$) as indicated by the black opaque pleonaste or ceylonite [$(MgFe)Al_2O_4$] which is sometimes cut for use in mourning jewellery.

The blue gahnite was analysed, using atomic absorption techniques, by Mr Richard A. Batchelor, of the Department of Geology, St Andrews University, and corrected for an Al_2O_3 component identified by x-ray diffraction, which from the d spacings and chemistry is a good fit for αAl_2O_3, i.e. corundum. The analysis is reproduced below in Table 1.

In addition to the isomorphous replacement of magnesium by zinc the Nigerian gahnite also has 4% ferrous iron, for magnesium,

TABLE 1

		corrected for calculated Al_2O_3 inclusion
SiO_2	0.72	0.77
Al_2O_3	59.10	56.00
FeO	3.58	3.85
MnO	0.08	0.09
MgO	0.12	0.13
CaO	0.10	<0.10
ZnO	36.68	39.44
SnO_2	<0.04	<0.04
Total	100.42	100.42

TABLE 2

Gahnite(5) (green stone)
585 nm weak
553 nm moderately strong
509 nm moderately strong
460 nm strong
433 nm moderately strong

Gahnite (Nigeria) (blue stone)
700–677.5 nm strong
677.5–660 nm weak
645–617.5 nm moderately strong
605–585 nm moderately strong
580–560 nm weak
556 nm moderately strong
554–553 nm weak
480–465 nm weak
465–457.5 nm moderately strong
433–400 nm weak becoming moderately strong

Spinel(6) (blue stone)
632 nm weak to moderately strong
592 nm weak to moderately strong
555 nm weak to moderately strong
480 nm weak to moderately strong
459 nm weak to moderately strong

Gahnospinel(7) (blue stone)
632 nm moderate
592 nm weak
577 nm weak
557 nm moderately weak
552 nm moderately weak
508 nm very weak
480 nm moderately strong
459 nm strong
443 nm very weak
433 nm very weak

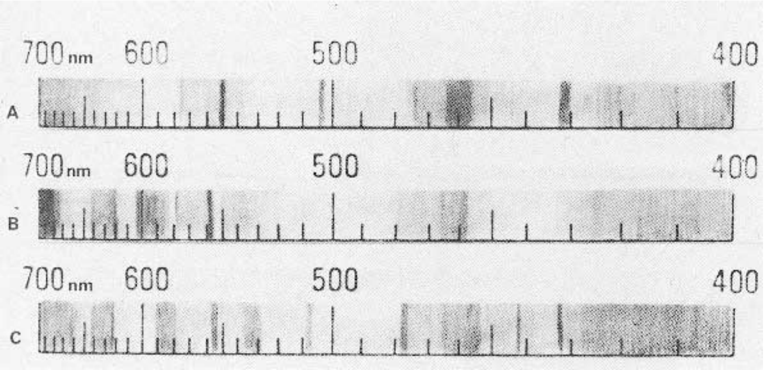

FIG. 1. A. Gahnite.(8)—B. Gahnite from Jemaa, Nigeria (blue).—C. Spinel (blue).(6)
(Crown Copyright Reserved)

isomorphous replacement. It is this iron which is responsible for the blue colour of the stones and a typical, rich looking, ferrous iron spectrum was obtained on an Eickhorst cold-light spectroscope unit. This absorption was very similar to that of blue spinel(6) and gahnospinel(7) rather than that of gahnite(8) described by Liddicoat (Figure 1 and Table 2).

The Nigerian gahnite appears to lack any moderate to strong absorption centred around 433 nm. It also has two sharp well defined fine lines of non-absorption between areas of mixed absorption intensities. These are at 580 nm and 555 nm and could possibly be mistaken for weak emission lines. Further the Nigerian gahnite has absorption bands in the red-orange-yellow range (700 nm–570 nm) similar to that of spinel and gahnospinel but not previously described for gahnite.

The refractive index, determined on a Rayner Dialdex refractometer, using sodium light, was between 1.793 and 1.794.

The specific gravity, measured on a Berman density torsion balance using as pure and homogeneous mineral fragments as possible, and within the 10–25 mg range for greatest accuracy, was found to lie within the range 4.400 to 4.589. The specimens with the greener hue tending to be at the lower end of the range (Figure 2).

There was no fluorescence under long-wave and short-wave ultraviolet light, and no change under the Chelsea colour filter when the stones were illuminated with a quartz incandescent lamp.

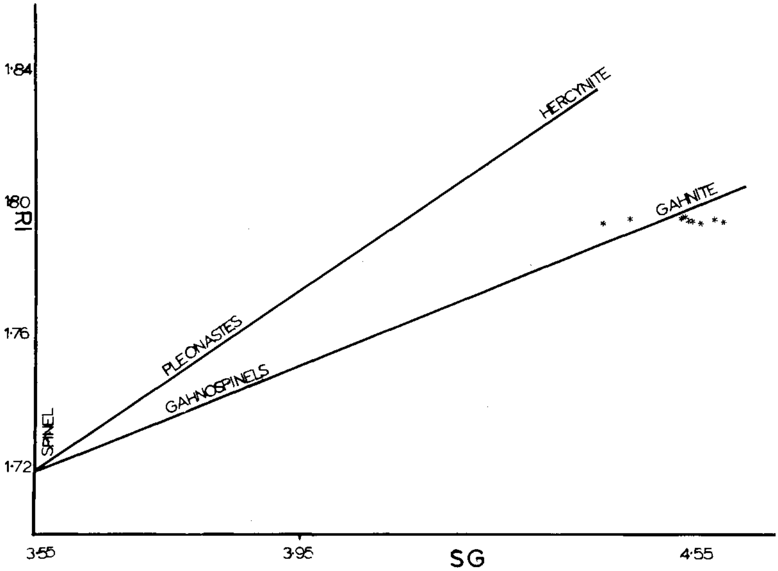

FIG. 2. RI/SG plots of gahnite grains on a spinel-gahnite-hercynite framework. *(Crown Copyright Reserved)*

When illuminated with a tungsten incandescent lamp, the stones showed a marked red coloration.

On exposure to x-rays for 1 hour 20 minutes there was no permanent or temporary colour change. However when the gahnite was heated, in an oxidizing environment, there was a distinct and permanent colour change. The exact point of colour change was not seen as stones retained their colour up to the point of their glowing red hot, at which point and thereafter the incandescence masked any natural body colour. Stones kept at 1000 °C for 1 hour showed, on cooling, a colour change from blue to blue-green, while stones heated to 1400 °C turned a dark olive green. No rupturing of the crystals occurred during heating, even though they were moderately included and flawed. It is postulated that the colour change is due to some of the ferrous iron being oxidized to ferric iron, which normally gives a yellow colour. This in conjunction with the ferrous (blue colour) iron gives an over-all green effect.

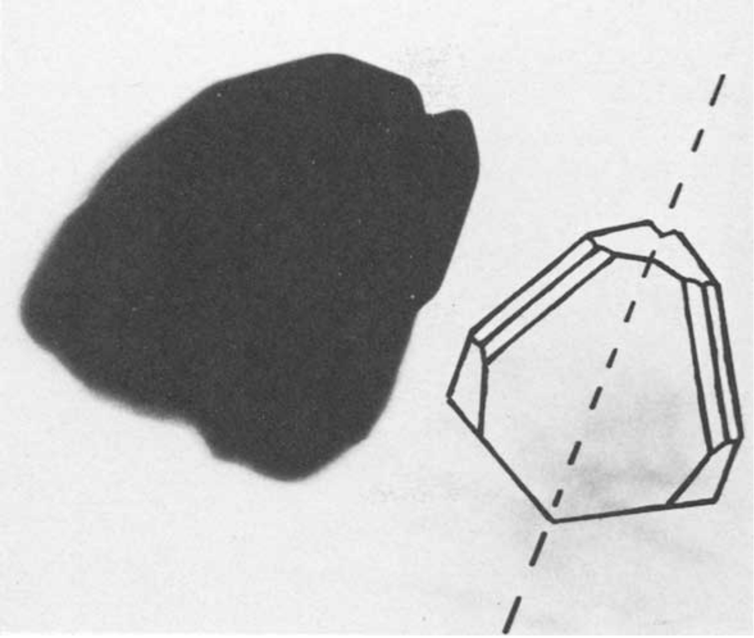

FIG. 3. Heart-shaped twin crystal of columbite with the ideal form sketched alongside. × 600.

INCLUSIONS

The majority of the gahnite crystals are rich in inclusions. These were studied using a Leitz Dialux polarizing microscope and a Vickers M41 microscope with camera attachment and automatic exposure unit. Crystals were immersed in methylene iodide (RI 1.742) to facilitate the study. Most crystals had flaws and cracks and these were in some cases filled with reddish-brown or yellow-brown films of secondary iron oxides. Other inclusions are described hereunder.

1. *Black opaque plates and tabular prismatic crystals.*

A large grain of this mineral which was near the surface of a gahnite crystal was removed and proved on microprobe analysis to be columbite, not previously described as an inclusion in gahnite.(9) The common heart-shaped twins of columbite were also identified (Figure 3).

Reddish anhedral grains, with a refractive index greater than that of the gahnite (Becke line test), showing pleochroism and extinction under crossed nicols, are thought to be thin sections of columbite.

2. *Very dark red to reddish-brown sub-translucent anhedral to sub-euhedral grains with hexagonal markings.*

These grains have a higher refractive index than the host gahnite (Becke line test) but show no pleochroism and remain dark between crossed nicols (Figure 4). On this basis they are thought to be haematite.

3. *Transparent hexagonal, prismatic, doubly terminated, crystals.*

These crystals show a random orientation and distribution throughout the gahnite. They show parallel extinction and interference colours ranging from middle 1st order to high 2nd order. Their refractive index is less than that of the host gahnite (Becke line test) (Figure 5). On this basis they are thought to be either apatite, quartz or beryl. A gahnite crystal was broken to reveal a colourless inclusion of the type described. This small fragment was identified by x-ray diffraction as beryl. This does not mean that the other alternatives proposed are not present in the gahnite.

4. *Small prismatic transparent colourless to pale yellow, sometime greenish or with pale green halo, crystals, most of which are doubly terminated.*

The refractive index of these crystals is greater than that of the gahnite (Becke line test). Most crystals show tension cracks radiating from them, but these are difficult to see in many cases except under crossed nicols. Extinction is parallel to the prismatic faces and crystals show vivid interference colours (Figure 6). On this basis they are thought to be zircons.

5. *Transparent thin hexagonal platy crystals with cleavage traces parallel to the planar surface.*

These crystals have a refractive index less than that of the host gahnite (Becke line test) and show interference colours from 1st to high second order. Sections parallel to the cleavage gave 1st order colours. Extinction is parallel to the cleavage trace. Where one

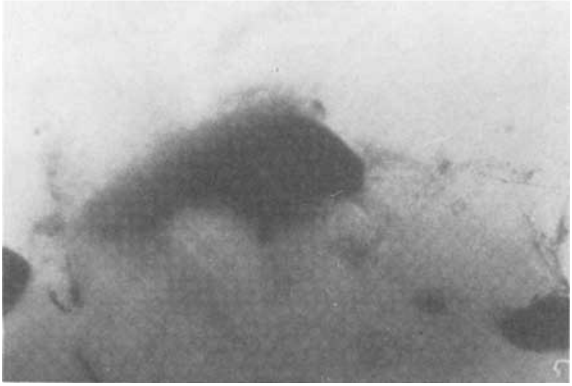

FIG. 4. Haematite inclusion. *(Crown Copyright Reserved)*

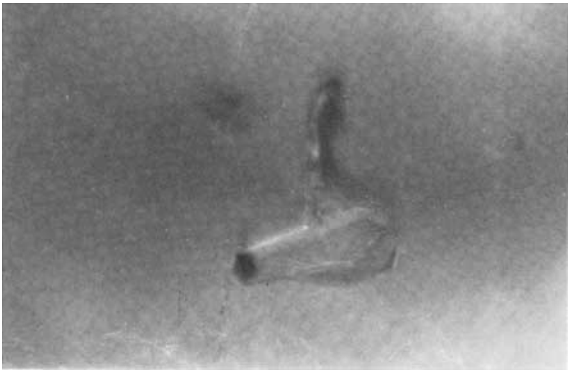

FIG. 5. Colourless hexagonal crystal. × 500. *(Crown Copyright Reserved)*

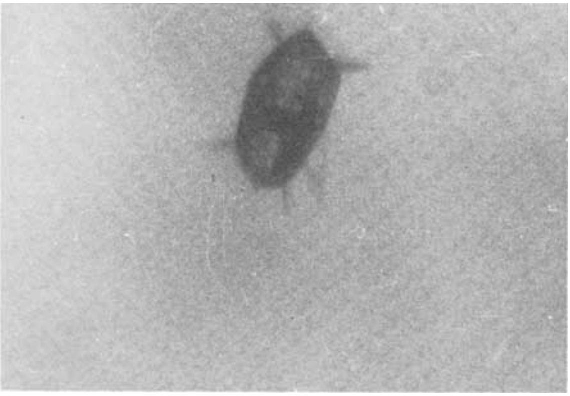

FIG. 6. Prismatic, doubly terminated, crystal with tension haloes. × 900. *(Crown Copyright Reserved)*

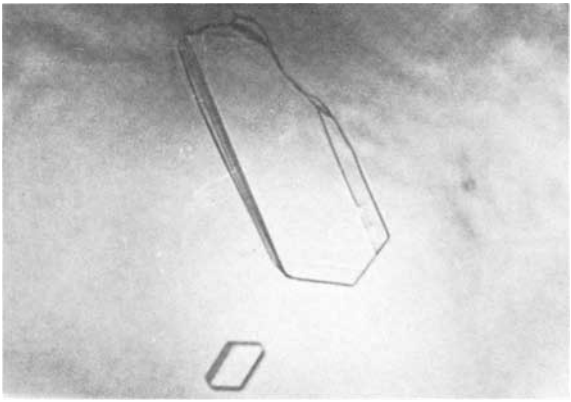

FIG. 7. Mica crystals. × 800. *(Crown Copyright Reserved)*

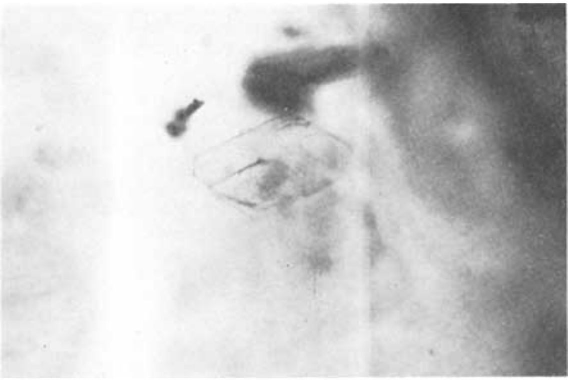

FIG. 8. Mica crystals. × 200. *(Crown Copyright Reserved)*

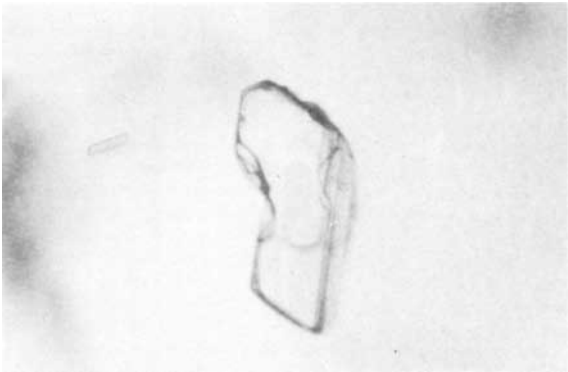

FIG. 9. Mica crystals. × 500. *(Crown Copyright Reserved)*

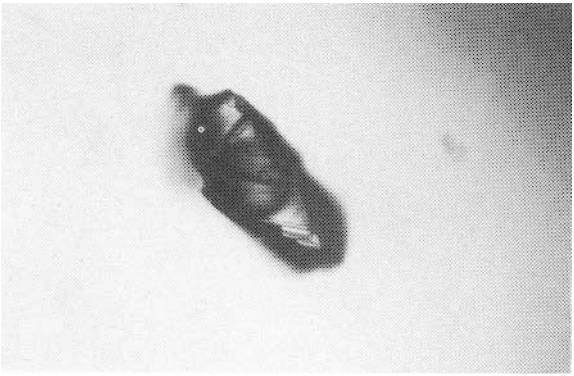

FIG. 10. Two-phase inclusion. × 500. *(Crown Copyright Reserved)*

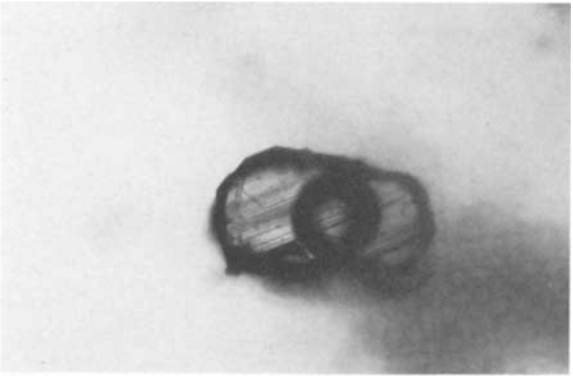

FIG. 11. Two-phase inclusion. × 500. *(Crown Copyright Reserved)*

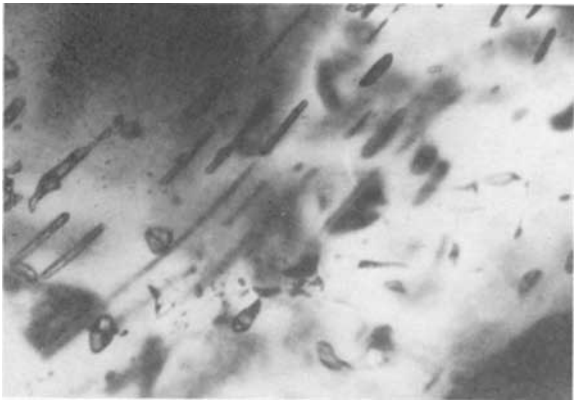

FIG. 12. Elongated two-phase inclusions. × 450. *(Crown Copyright Reserved)*

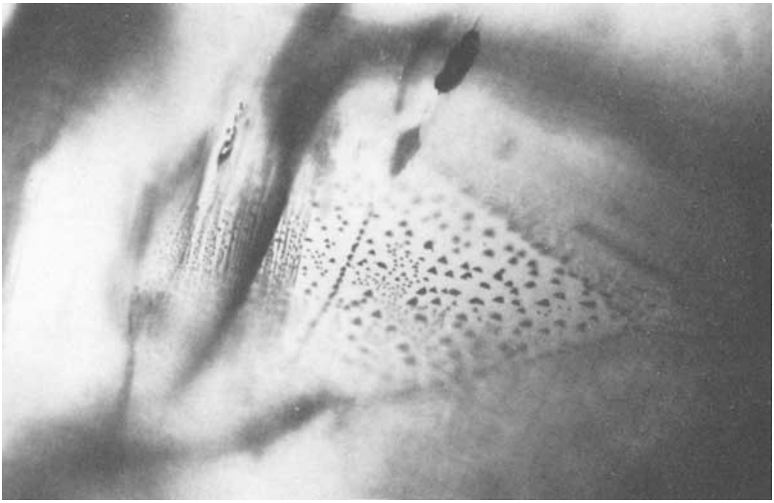

FIG. 13. Gahnite-gahnite interface markings. × 600. *(Crown Copyright Reserved)*

grain reached the surface of a polished face a negative biaxial interference figure was obtained. On this basis they are thought to be mica (Figures 7, 8, 9).

6. *Negative euhedral crystals with two-phase inclusions, liquid and gas.*

These two-phase inclusions are very common in most crystals. The forms of the negative crystals are distorted octahedra; and in most cases the distortion is quite extreme (Figures 10 & 11). In cases of exceptional distortion they give the impression of liquid feathers with two-phase inclusions (Figure 12).

Other negative inclusions, not showing two phases, are also abundant. These either occur as large octahedra, or arguably dodecahedra, randomly distributed within the gahnite crystals or else as small groups or swarms, sometimes with preferential alignment to the crystallographic structure of the gahnite. Many of these octahedra are quite dark and may in fact not be negative crystals but octahedra of hercynite.

Gahnite crystals are also found as inclusions within the gahnite and these sometimes showed black triangular markings at the interface with the host (Figure 13). These may represent a separate mineral phase.

7. As stated earlier corundum was identified as a phase in powdered gahnite during x-ray diffraction. It was not possible, however, even tentatively to identify corundum in the specimens examined. No hexagonal inclusions, either tabular or prismatic, showed a relief only slightly less than that of the gahnite, nor was there any parting or twinning visible.

CONCLUSION

Dependant upon the availability of suitable gem quality material these Nigerian gahnites could represent a significant addition to the gem market. Although they could well match sapphire in appearance, their physical properties, spectra and inclusions are so distinctive that there should be no possibility of mistaken identity if tests are carried out.

ACKNOWLEDGEMENTS

I am most grateful to Mrs Judith Kinnaird, of the Geology Department, University of St Andrews, for providing the specimens on which the work was done and for the description of the gahnite occurrence.

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SILLIMANITE CAT'S-EYES FROM KANGAYAM, MADRAS, INDIA

By Prof. Dr P. C. ZWAAN, F.G.A.

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INTRODUCTION

Some months ago four cabochon-cut greyish green stones with a fair cat's-eye effect were sent in for identification to the Netherlands Gem Laboratory (NEL), which is housed in the National Museum of Geology and Mineralogy in Leiden. They were said to originate from Kangayam, Madras, India, and were sold as 'apatite cat's-eyes'.

Although it would have been of interest to report on these stones, as they were found to be sillimanite cat's-eyes, it was not possible to do so as they could not be kept for careful examination. The same applied to two other stones with the same appearance and properties, which were much better cut and sent in by another gem dealer in the same period.

However, another seven stones became available for investigation through the co-operation of Mr H. J. Korevaar, F.G.A., the gemmologist who provided us in the past with

FIG. 1. The seven sillimanite cat's-eyes. 2×

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kornerupine cat's-eyes and cordierite cat's-eyes (Korevaar & Zwaan 1977; Zwaan & Korevaar 1977). He bought the parcel also as 'apatite cat's-eyes' in Madras and was told that the stones were found in Kangayam, 'some 200 miles from Madras in south-westerly direction'.

TABLE 1

Properties of seven cabochon-cut sillimanite cat's-eyes

Number	*Weight in ct*	*Size in mm*	*D (measured)*
1	11.42	14.8 × 10.0 × 9.1	3.210
2	10.77	19.0 × 10.4 × 6.7	3.219
3	9.43	13.0 × 9.7 × 8.7	3.224
4	3.92	10.6 × 7.3 × 5.3	3.226
5	2.95	9.8 × 7.0 × 5.5	3.226
6	2.66	9.7 × 5.3 × 5.8	3.221
7	2.04	7.8 × 6.7 × 5.2	3.196

PROPERTIES

The properties of the stones are given in Table 1. Stone No. 2 is stored in the collection of the above mentioned museum and is officially registered with a number prefixed by 'RGM'. The specimens No. 5, 6 and 7 belong to the collection of the Netherlands Gem Laboratory (NEL); the remaining stones were kindly loaned for examination only.

All specimens have a greyish green colour and a whitish cat's-eye, which is not very sharp (see Figure 1). As these stones are almost opaque, neither their pleochroism nor their optical character could be observed. Some vague absorption bands occur in the blue and violet parts of the spectrum, but they are not of any diagnostic value.

Being cat's-eyes, the stones are cabochon cut. Their refractive indices were therefore measured by using the 'distant vision' method. All stones gave readings near 1.66, which is the mean value for sillimanite.

The density of the specimens was measured by using a hydrostatic balance and ethylene dibromide as an immersion liquid. This property varied from 3.196 to 3.226, with an average of 3.217, which is extremely low for sillimanite.

To obtain a definite identification, x-ray powder photographs of five stones were made by using Fe-radiation and a Debye-Scherrer camera of 114.6 mm. All photographs gave a pattern of diffraction lines, characteristic for sillimanite. The x-ray data of photograph RGM 202 430, taken from cat's-eye RGM 151 867, are given in Table 2.

TABLE 2

X-ray powder diffraction data for sillimanite cat's-eye No. 2 (RGM 151 867).

hkl	*d(obs.)*	*I*	*hkl*	*d(obs)*	*I*
110	5.34	6	332	1.517	7
101	4.56	½	004	1.440	5
200	3.73	5	250	1.419	½
120	3.41	9	520	1.393	½
210	3.35	10	124	1.328	3
002	2.88	6	350	1.307	1
220	2.67	7	252	1.273	5
112	2.53	8	610	1.228	4
130	2.42	5	260	1.213	1
202	2.28	4	532	1.178	1
122	2.20	9	404	1.141	1
230	2.11	5	244	1.102	1
400	1.865	4	542	1.094	2
312	1.832	3	172	1.016	3
330	1.786	½	254	1.012	3
240	1.705	3	370	1.004	4
420	1.679	4	462	0.992	3
042	1.595	6	730	0.986	3
402	1.567	3	444	0.982	3

INCLUSIONS

The cat's-eye effect is most probably due to a fibrous structure. It is not likely that oriented needle-shaped inclusions cause this chatoyancy. Experiments to analyse these inclusions by x-rays only indicated the sillimanite itself. Perhaps the low density of the stones can be ascribed to this fibrous structure.

FIG. 2. Magnetite and haematite included in sillimanite cat's-eye No. 2 (RGM 151 867). 45 ×

FIG. 3. Magnetite and haematite in sillimanite cat's-eye No. 1. 45 ×

Distinct inclusions occur in all the stones and can be seen with the naked eye. They consist of black grains and elongated shapes with a high metallic lustre. The grains resemble the black spots which are characteristic for nephrite from the Lake Baikal district of eastern Siberia. These grains were found to be magnetite by means of x-ray powder photograph RGM 202 500, taken from inclusions in specimen No. 2 (RGM 151 867). The elongated flakes are mainly built up by haematite, according to x-ray powder photograph RGM 202 501, taken from inclusions in sillimanite cat's-eye No. 5. Both iron minerals are intergrown; Figures 2 and 3 illustrate them in specimens No. 2 and 1 respectively.

CONCLUDING REMARKS

Cat's-eyes of sillimanite are often described in the literature. Most gemmological handbooks mention this type of cat's-eye, but it is always considered to belong to the category of unusual stones. Bank *et al.* (1978) describe two specimens from a parcel of cabochon cut stones from Sri Lanka.

The author bought a sillimanite cat's-eye of 1.11 carats from a gem dealer in Mount Lavinia, Sri Lanka, in December 1958. So, this type of cat's-eye is occasionally seen on the market.

As a relatively large number of stones were identified in Leiden only a few months ago, it may be expected that in the near future sillimanite cat's-eyes will come on the market in large quantities.

The stones so far examined, with the exception of the two mentioned above, are badly cut. If cutting can be improved, a type of cat's-eye can be introduced which can be considered as a real enrichment of gemmology.

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THE FRUITS OF THIRTY YEARS OF JAPANESE GEMMOLOGY—A REPORT ON THE AKIRA CHIKAYAMA GEM LABORATORY IN TOKYO

By S. H. GILL, B.A., F.G.A.

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The XVIIIth International Gemmological Conference was held in November 1981 in Japan.* In view of this, and since one of its hosts, Professor Akira Chikayama, F.G.A., C.G., was then currently celebrating his thirtieth year in gemmology, perhaps it is an appropriate time to give a brief account of both Professor Chikayama's career, inextricably interwoven as it is with the development of gemmological science in Japan, and of the fine gemstone collection at the Akira Chikayama Gem Laboratory (A.C.G.L.) here in Tokyo.

Professor Chikayama began studying gemmology in 1951 and during the 1960s taught the science at the Yamanashi Prefectural Lapidary Research Institute at Yamanashi National University in Kofu, Japan's stone cutting centre. He obtained the G.A.'s Diploma in Gemmology and was elected a Fellow in 1966. The following year he began lecturing in Tokyo at the All Japan Jewellers Association, which in 1969 was incorporated into the new Gemmological Association of All Japan. As Director-General of the G.A.A.J., Professor Chikayama supervised its education and research programs as well as designing all of its gemmological instrumentation himself. He is the sole recipient of a government-authorized engineering consultant's licence in gem technology.

The A.C.G.L. began operations in 1979 and was founded to promote a broader and higher education amongst gemmologists. The symbol chosen as its mark was a Japanese twinned quartz crystal for which Kofu, Professor Chikayama's birthplace, is famous. The A.C.G.L.'s sister organization, the Gemmologists' Society of Japan now has a membership of about six hundred.

Professor Chikayama has travelled to almost all of the world's major gem localities, and to many of them more than once. Obversely, when he is in Tokyo he receives many visits from

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*See *J. Gemm.*, 1982, XVIII(2), 176-8.—Ed.

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foreign gemmologists and gem dealers. His books on gems, gem identification and gem cutting number over twenty and are the staple fare of the Japanese gemmologist.

When I arrived here from England in 1980, I was introduced to Professor Chikayama by my good friend, Mr Takayasu Imai, F.G.A., President of the Japan Diamond Exchange, and have subsequently several times been privileged to view his personal collection, the bulk of which constitutes the study collection at the A.C.G.L. It is, by all accounts, the most extensive gemstone collection in Japan, outdoing even the museums. There are approximately 10 000 stones in all—4000 cut gems and 6000 rough specimens. The cut stones are arranged by species as well as by locality and the rough in general by locality alone. The majority of stones have been acquired abroad, often at source, and brought or sent back to Japan. Really large stones are accordingly few, but the variety of localities within each species is truly remarkable.

To mention but a few, there are good collections of cut corundum (including padparadscha), beryl (including Australian emerald), spinel (including gahnospinels), jadeite (in all colours—several visits to Burma), tourmaline (many localities besides Brazil), cat's-eye stones (as a separate collection) and synthetics (Russian, American, Japanese, Gilson in the main—including fancy-coloured cubic zirconia, rutile and YAG). Amongst the extensive rare stone collection I found some interesting 'moldavite' cabochons from both Indonesia and Japan. There are cut stone collections (by locality) from Brazil, Sri Lanka, Burma, Taiwan, Korea and Japan. Needless to say, both in quantity and quality the cut and rough Japanese gemstone collections are unique and include fine jadeite, large topaz, obsidian and both rhodonite and rhodochrosite. By virtue of the nature of the gem minerals occurring in Japan most of the cut material, however, is in cabochon form.

In addition to Japan there are collections of rough (only specimens of known locality) from the U.S.A., Mexico, Colombia (including trapiche emeralds), Brazil, Peru (including palygorskite), Tanzania, Kenya, Malagasy, the rest of Africa (including some splendid Nigerian sunstone), Europe, the U.S.S.R., India, Sri Lanka, Burma, Thailand, Taiwan, South Korea (including large sceptre-shaped amethyst) and Australia.

As one might expect, all shapes and all shades of colour are represented in both the pearl and coral collections. Both are built around Japanese specimens but also include material from various other localities. There is an unusual collection of both cut and uncut glass which includes superb Japanese 'tombodama' beads.

An extensive collection of euhedral crystals of all types must be of tremendous practical value in the teaching of crystallography and an equally complete store of cut stones containing typical inclusions is kept for microscope work. A large series of inclusion photos (taken by the Professor himself) aids in this sphere of study and research.

In his time as a gemmologist Professor Chikayama has designed and developed a gemmological microscope (Olympus J.M.) as well as a brand-new halogen-illuminated one; the Topcon refractometer and a new internally-illuminated one (light-emitting diode type); a spectroscope; the Multispec ultraviolet light source; the Topcon portable diamond proportionscope; the Marumo hydrostatic balance; a diamond conductometer; a portable light source (primarily for diamond grading); a hot-point tester (for use with the microscope); and, of late, a diamond price computer program. Much of this technical development has taken place at the A.C.G.L. recently.

To round off this guided tour of the Gem Laboratory I should make mention of the comprehensive gemstone book library (over 1000 volumes in many languages), the journal collection, a vast gem localities slide library and (rather unusual) a sizeable collection of gemstone and mineral stamps from all over the world.

The over-all impression I wish to convey is one of scope—the scope of the collection in particular, but also the scope of gemmological facilities in general. As always in Japan, everything is impeccably organized, and the visitor is welcomed with the utmost courtesy. It may have taken thirty years to create such a well-equipped institution but it may well be (if it is not already) in the vanguard of world gemmology before another thirty years have passed.

[*Manuscript received 22nd May 1981; revised June 1982.*]

ENERGY DISPERSIVE X-RAY SPECTROMETRY: A NON-DESTRUCTIVE TOOL IN GEMMOLOGY

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SUMMARY

Energy dispersive x-ray spectrometry is a fast and reliable, in a true sense of the word non-destructive, analysing technique for all elements from sodium to uranium. A qualitative chemical determination of gemstones is easily obtainable; in specific cases the discrimination of natural and synthetic material is possible.

Up to ten years ago, x-ray fluorescence analysis was a wavelength dispersive technique. Its use in gemmology remained limited for basically two reasons: purchase and maintainance costs of x-ray equipment are relatively high, and its application may be somewhat restricted since the strength of the exciting primary x-ray source may damage gem materials (Bank, 1980). Colours of gemstones eventually change reversibly, or nearly irreversibly during short exposure times.

Since the discovery of x-rays by Wilhelm Röntgen in 1895, many applications of this short-wavelength-radiation have been developed—not only medical ones, but methods for crystal lattice determination (x-ray diffractometry *sensu lato*), and of spectroscopy (x-ray fluorescence analysis, XFA or XRF) as well.

X-rays are described in terms of wavelength (λ, Å), or of energy (E, eV), both related by $\lambda = 12400/E$. Thus, two principally different spectroscopic applications have to be distinguished, i.e. wavelength dispersive (WDS)—and energy dispersive (EDS)—XRF. Moseley proved as early as 1913 that atomic number Z of a chemical element, and the wavelength (or energy) of its x-ray spectrum is linked in a systematic manner, since, e.g., for the K-family of spectral lines $c_1/\lambda = c_2 \cdot (Z-1)^2$. Similar equations hold for L and M spectra (the symbols K, L, etc. refer to electron transitions between atomic shells, induced by the excitation).

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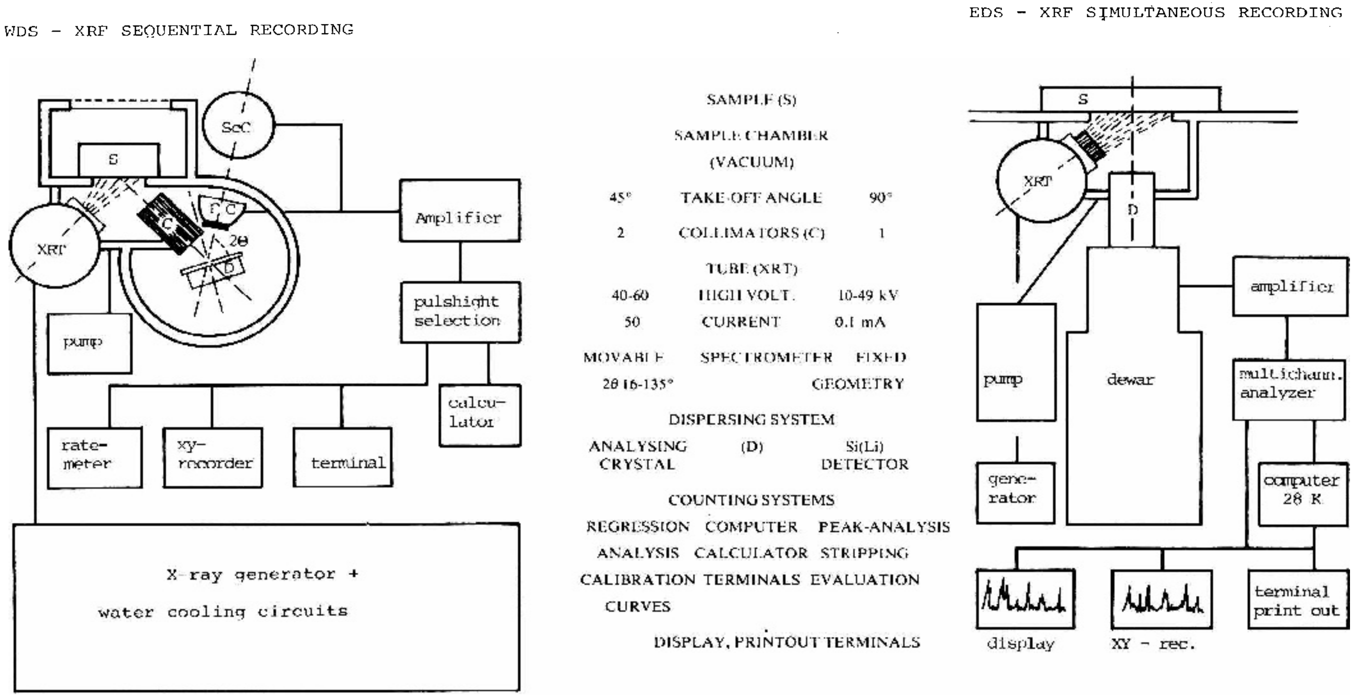

FIG. 1. Schematic set up of a conventional wavelength dispersive (left) and of an energy dispersive (right) x-ray fluorescence device.

As in all other spectroscopic techniques, a sample has first to be excited. This is done in the case of XRF either by electron/ion bombardment (electron/ion microprobe) or by primary x-rays/γ-rays (XFA). The excited, secondary* x-rays consist of different wavelengths/energies corresponding to the chemical elements present in the excited sample. These x-rays have to be split by an appropriate dispersing medium. In WDS analysis this dispersing medium is a crystal with known d-value separating the incoming complex radiation according to Bragg's law $\lambda = 2d \cdot \sin \theta$, where θ is the angle of reflection, d is the lattice constant of the dispersing crystal, and λ finally is the wavelength of an analytically interesting radiation. This implies that WDS spectrometers are operated generally with movable goniometers: the analytical information (to be recorded by appropriate counting systems like gas flow or scintillation counters) comes in sequentially since θ varies for each element (Figure 1).

In EDS—XRF the dispersing medium is a solid state Li-drifted silicon detector with a dispersing power of approx. 150 eV. The incoming complex radiation is split up into distinct energy distributions and displayed by a multichannel analyser. EDS spectrometers have a fixed geometry; the analytical information comes in simultaneously (Figure 1). Since the dispersing power of a solid state detector is much weaker for light elements than that of an analysing crystal (WDS—XRF), overlapping of energy distributions belonging to neighbouring elements ($K\alpha/K\beta$) is widespread. Special peak stripping and deconvolution programs are needed to overcome this principal disadvantage of EDS—XRF. In fact, EDS spectra can only be handled in an easy way, if computer/calculator facilities and suitable software programs are available. This is one of the reasons why EDS—XRF only recently became more popular—the advantages of versatile, cheap and small computers are obvious.

Like other physical analysing techniques, x-ray spectrometry is a *relative* method: for quantitative analysis, measurements on unknown samples have to be compared with those obtained on standard/reference materials. If the chemical composition and physical behaviour of unknown and standard samples are similar, a direct comparison may lead to quantitative results. If, however,

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*'secondary' only in case of conventional XRF where a x-ray tube is used for sample excitation.

strong chemical differences exist, mathematical treatment (absorption correction) of the raw data may become necessary (Bertin, 1978). In cases where sample shape or surface conditions differ greatly, quantitative evaluation of raw data may be difficult, if not impossible. To overcome these problems, either specific methods of sample preparation (like dilution or glass fluxes) or eventually a restriction of the excited sample area to small spots ($\leqslant 0.1$ cm^2) by using appropriate collimating systems become necessary. The latter solution is often used in EDS—XRF, and is of considerable interest in gem analysis, where unknown samples usually tend to be small.

These special difficulties of quantitative analysis, however, are of minor importance when *qualitative* information is being sought: a non-destructive, qualitative analysis of an unknown sample is carried out in a few minutes or even seconds. The energy spectrum, obtained under routine conditions, gives quick information on the elemental composition as far as main constituents are concerned; all elements from sodium ($Z = 11$) to uranium ($Z = 92$) are detectable, i.e. approx. 90% of all natural elements. An experienced operator may even obtain a rough estimation of elemental concentrations.

As mentioned earlier, in EDS—XRF the entire spectrum is treated simultaneously; too much x-ray quanta per time unit would lead to a saturation of the detection system. Thus, the excitation power has to be reduced—either by reducing the tube current, or by inserting a primary filter—until saturation phenomena disappear. Generally, in EDS—XRF the excitation is some thousand times weaker than in WDS—XRF; as a consequence, problems of radiation damage normally do not occur.

An interesting feature of EDS—XRF analysis is the fact that diffraction phenomena may occur. If the primary x-radiation is polychromatic, i.e. if no primary filters are used, diffraction on specific lattice plains of crystalline sample may happen according to Bragg's law (Giessen 1967). Though this technique is not yet widely used, information of diagnostic value can certainly be obtained. In some cases, however, diffraction phenomena are confusing, and the use of primary filters is advisable.

To summarize, quite a few features of energy dispersive x-ray fluorescence (EDS—XRF) are different from conventional wavelength dispersive x-ray fluorescence (WDS—XRF):

EDS—XRF	WDS—XRF
simultaneous recording	sequential or multichannel recording
low excitation power	high excitation power
10 to 50 kV, 0.1 mA = 1 to 5 W	30 to 60 kV, 40 to 50 mA = 2000 to 3000 W
no radiation damage in gemstones	colour of gemstones may change
sample size mm to dm	sample size mm to inch
detectable elements: all chemical elements from sodium to uranium, Z = 11 to 92	
detection limits: 20 to 500 ppm acording to energy of analyte line, and of analysing conditions	
data storage electronically on floppy discs	data stored as numerical values
on-line-computer necessary	on-line computer optional
costs of completely equipped device XX	costs of completely equipped device XXX

In mineralogical—and gemmological—characterization of materials several physical methods of examination are traditionally used. From this tradition a somewhat misleading opinion results as if crystalline matter were defined *only* by its physical properties. In fact, however, chemical data are as important, but—again by tradition—were not looked at closely enough in the past. This traditional attitude obviously has reasons: chemical investigations used to be time *and* sample consuming. In gemmology especially the latter was contra-indicative.

Since nowadays fast and non-destructive means of chemical analysis exist, quite a few problems can be solved, such as chemical similarities/differences of gemstones of different origin (natural or industrial). Some possible applications are mentioned below; not much thorough work has yet been done but knowledge will develop with increasing experience. Valuable and reliable information can be expected in cases of

—certification in rare gem diagnosis
—separation in jade group
—separation of turquoise from its imitations
—detection of diamond substitutes in diamond lots
—cabochon and mounted stone identification
—natural and synthetic glass determination
—characterization of garnets
—discrimination of natural and synthetic gemstones in some special cases

Various gem materials were analysed by EDS—XRF from which the following examples were selected. The content of information varies from qualitative determinations to more refined conclusions, depending on how precise the question that was previously asked. If already much is known on a specific gemstone group, more detailed knowledge on a sample-in-question is obtainable.

Ruby

The energy spectra of a Siam ruby and a synthetic Chatham ruby are shown in Figure 2. Siam ruby, according to the chemical formula of corundum, displays a strong Al line. The continuum (background) and Ag line series are due to the primary x-ray source (Ag tube). Minor elements visible are Cr and Fe. Diffraction peaks are also present. Chatham synthetic ruby has approximately the same energy spectrum. But flux grown synthetic material eventually contains droplets of residual flux as inclusions (Webster, 1975). The Chatham rubies investigated have generally high chromium to iron ratios, similar to Burmese rubies. The molybdenum peak observed in case of the synthetic ruby (Figure 3) is due to the Li-Mo-flux used. It has to be emphasized that the print out has a much poorer resolution than the original spectrum, since 8 channels of the multichannel analyser are contracted to one bar (original resolution being 20 eV/channel).

Emerald

In Figure 4, a Gravelotte emerald and a synthetic Gilson emerald are compared. The characteristic content of traces and minor elements in Gravelotte emerald is obvious. Unfortunately inclusions contribute to the element-rich spectrum as well. The Mg-content is a diagnostic dimension for separation of natural and synthetic emerald (Hänni, 1982). In general, natural gemstones are less pure than their synthetic counterparts.

Alexandrite

Russian and synthetic alexandrite are compared (Figure 5). Again, the synthetic stone is remarkably pure, containing only main elements of the formula, and elements needed for the colour effect. On the other hand, natural alexandrite contains different impurities which were available during the individual formation process of Tokowaya alexandrite. In synthetic alexandrite (Creative crystals) no platinum (crucible material) but molybdenum (flux) was found.

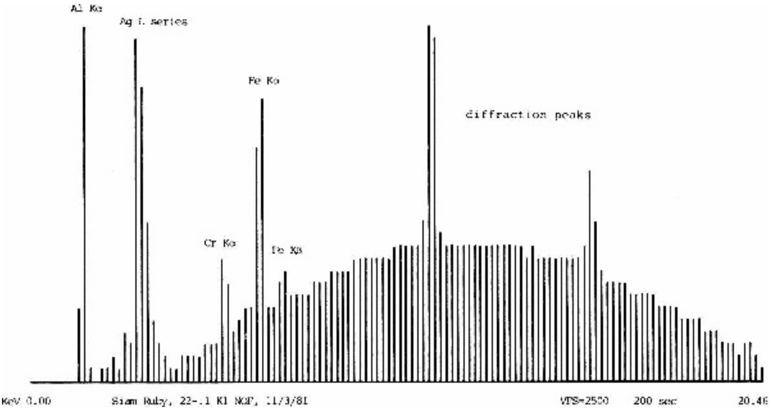

FIG. 2a. Energy spectrum of Siam ruby. The line series of silver L is due to the primary radiation of the exciting Ag-tube.

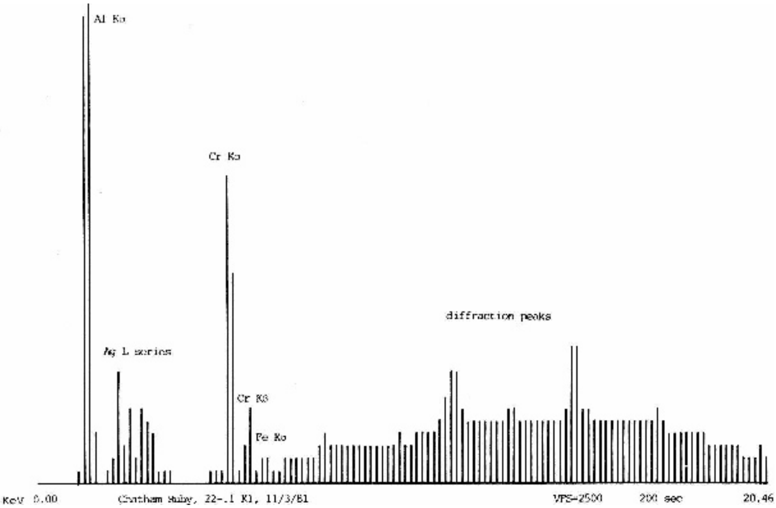

FIG. 2b. Energy spectrum of synthetic Chatham ruby.

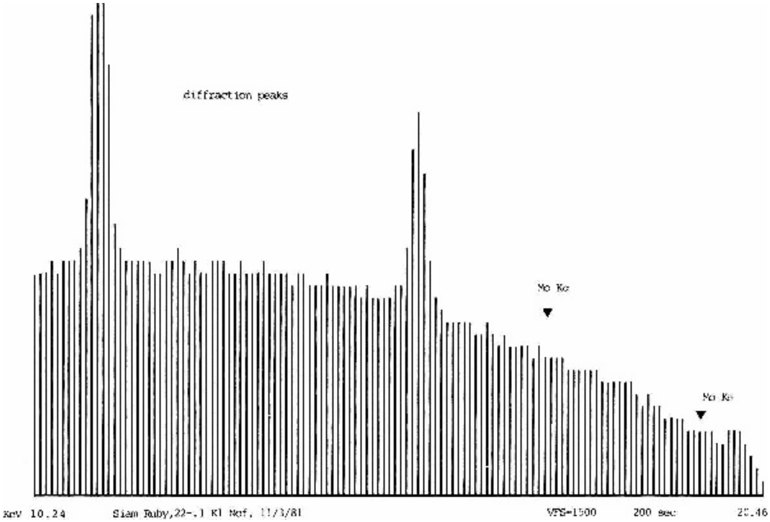

FIG. 3a. Upper half of energy spectrum: Siam ruby, no molybdenum lines.

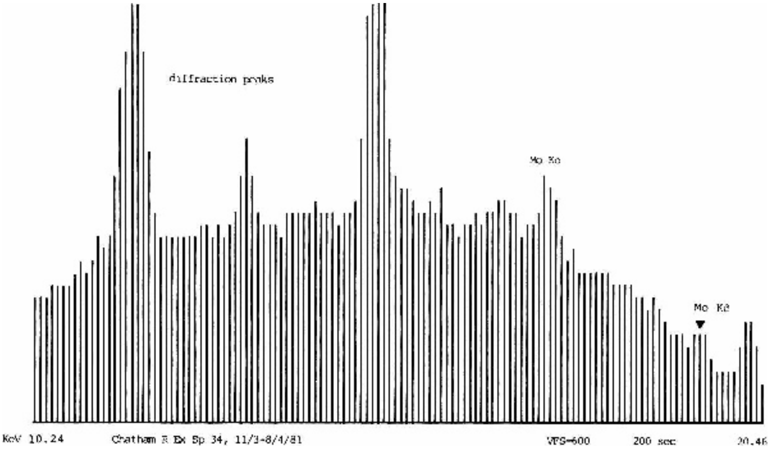

FIG. 3b. Upper half of energy spectrum: synthetic Chatham ruby containing droplets of flux (Mo Kα and Mo Kβ).

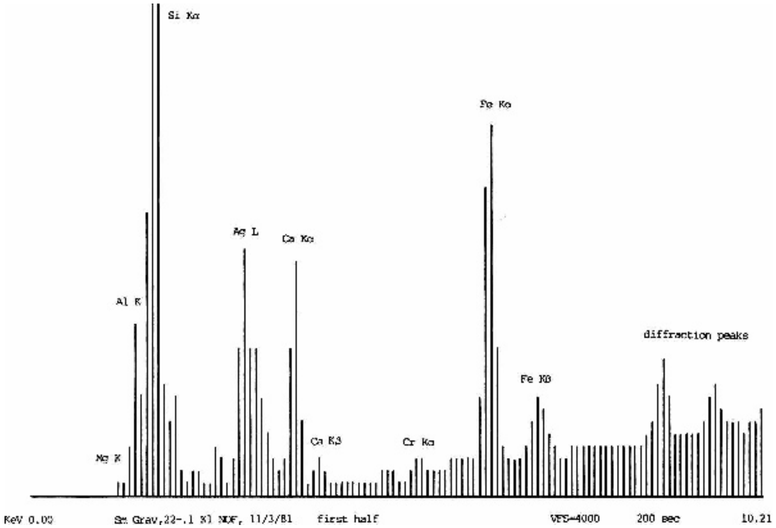

FIG. 4a. Energy spectrum of natural Gravelotte emerald, lower half of spectrum.

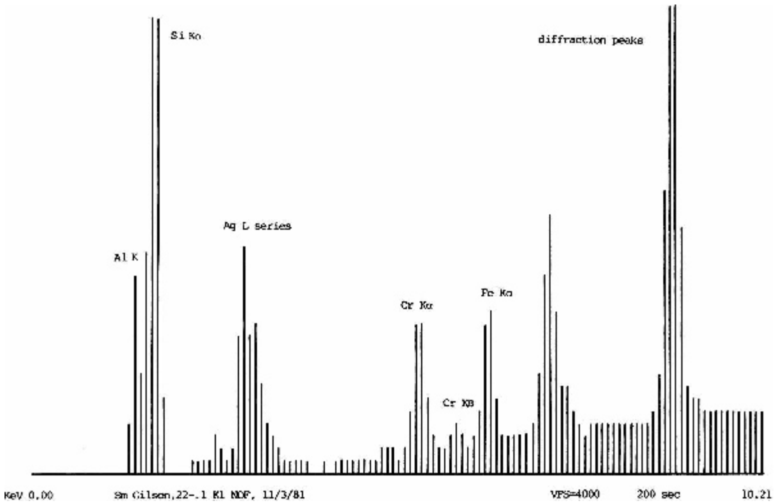

FIG. 4b. Energy spectrum of synthetic Gilson emerald, lower half of spectrum.

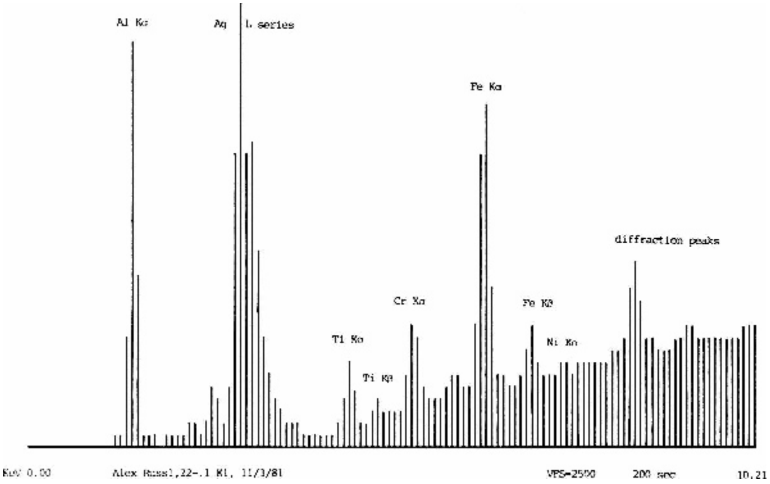

FIG. 5a. Energy spectrum of Russian alexandrite, lower half of spectrum.

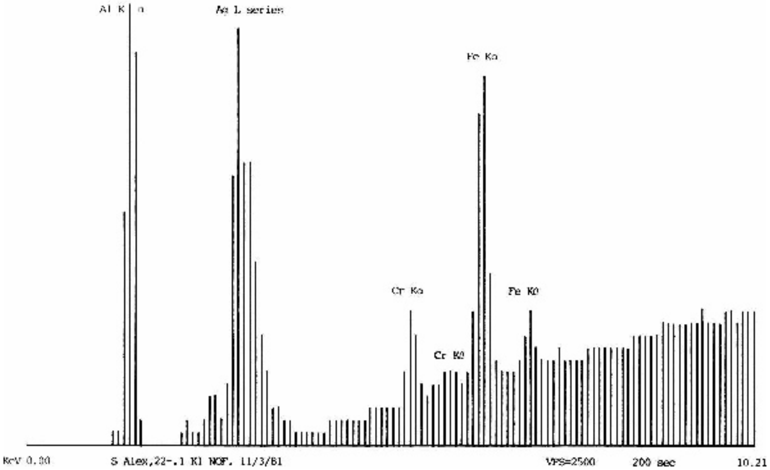

FIG. 5b. Energy spectrum of synthetic alexandrite, lower half of spectrum.

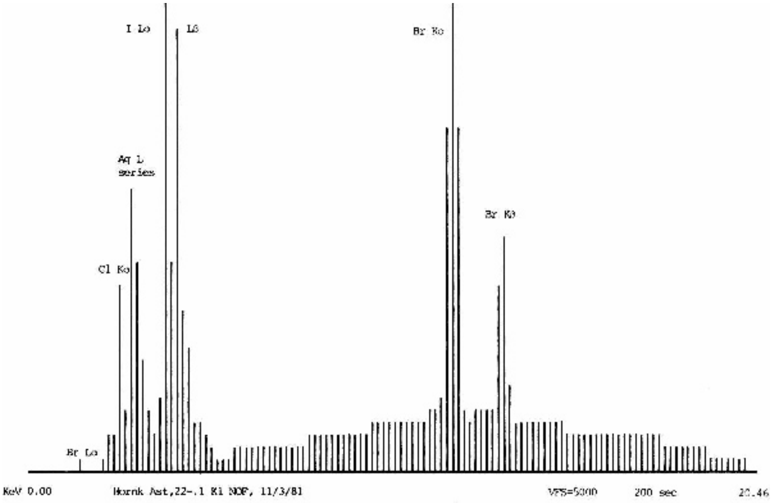

FIG. 6a. Energy spectrum of horn coral.

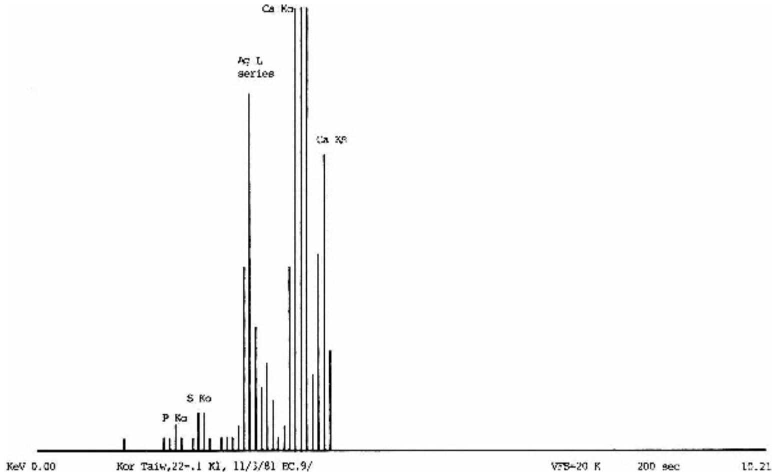

FIG. 6b. Energy spectrum of red coral, Taiwan.

Corals

An investigation of red and black coral (Figure 6) gave typical information on both materials. The red coral consists of calcium-carbonate, as expected. The Ca signals are very strong. Additional minor elements such as S, P, Mg and Sr were observed. In a naturally red coral the colour is due to iron oxide, which is present in sea-water. Dyed red corals generally do not contain iron but are treated with aniline dyes which are free of iron. The black coral of horn substance was surprising, since the main constituents were found to be Cl, I, S, Br and some Fe.

The list of applications of EDS—XRF will be extended when more attempts are made to use compositional characteristics for gem identification. In this sense, this study is just a hint for further development of this rapid and reliable method.

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MINERAL INCLUSIONS CONTRIBUTE TOWARDS ELUCIDATING THE GENESIS OF THE DIAMOND

By Professor Dr E. GÜBELIN, C.G., F.G.A.

(being a revised version of the lecture given to the Gemmological Association of Great Britain in the Great Hall of Kensington Town Hall on 6th October, 1981)

The genesis of the diamond has been the subject of intensive scientific investigation for many years, and its mineral inclusions have decidedly contributed towards shedding brighter light on the many enigmas and secrets it has been guarding for so long. Indeed, the mineral inclusions qualify as exhibits in a unique showcase, demonstrating the course of events which promoted the formation of their host crystal in regions below the Earth's Crust, far beyond our reach.

Nowadays an increasing mineralogical curiosity is awakening about the significance of the chemical relationships of coexisting minerals as a means of explaining the P-T conditions prevailing during the formation of crystals. On the whole, both experimental and naturally-occurring systems yield evidence of the initial crystallization and subsolidus changes in silicate minerals. Thus, frequent entrapment of olivine, pyroxene and garnet inclusions in diamond, as well as the characteristic and interrelating epi- and syn-taxial growths of these four principal mineral components of the diamond-bearing xenoliths in the kimberlite, undoubtedly corroborate that these four minerals are *in sensu stricto* paragenetic. This means that they crystallized simultaneously, from one and the same mother melt. Growth features, morphologies and sizes, further reveal that they formed while floating in a melt, and that diamond in particular has crystallized as a stable phase. By means of the well-known stability field of these paragenetic minerals, it has become possible to elicit the equilibrium conditions of the accompanying diamond which so often plays the part of their host. Although it has thus become possible to gain a definite idea of the P-T conditions under which diamond crystallized, its more intimate secrets—the stimulating event and subsequent stages of diamond growth—are not yet precisely understood.

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Systematic analyses of the main chemical elements of mineral inclusions in diamond have also resulted in the now established knowledge that these guest minerals belong to two different mineral suites: chrome-bearing olivine, chrome-pyrope-garnet, the orthopyroxene enstatite and chrome diopside, comprise the *ultramafic suite,* while ordinary forsteritic olivine, pyrope-almandine-garnet and omphacitic clinopyroxene containing appreciable amounts of Na and Al, are ascribed to the *eclogitic suite.* It is quite plausible that these two suites were subjected either to different physical or chemical conditions of formation, or to both, because mineral inclusions belonging to both groups have not yet been observed in a single diamond, whereas various mineral inclusions from the same suite may coexist within the same diamond.

The accompanying illustrations depicting mineral inclusions in diamond are arranged in two groups according to these two mineral suites—that is to say they are separated into ultramafic and eclogitic inclusions. Yet, ere the reader's interest is allowed to turn to the portraits of these guest minerals in the diamond as manifested by the illustrations, the author wishes to premise a few preliminary remarks concerning some of the characteristic features which are common to many of them: the guest minerals in diamond have been effectively protected against further chemical reactions with other silicates and oxides as well as sulphide-phases due to their sealed enclosure within the inert diamond host.

A distinctive feature of many of the syngenetic inclusions is their morphology: the guest crystals usually exhibit well shaped forms, but they are xenomorphous, i.e. they are not their inherent habits, but rather those of the host diamond, which means that the diamond has imprinted its own habit onto the entrapped crystals.

The specific types of minerals that occur as inclusions in diamond have similar chemistry, despite their origin in geographic localities remote from one another.

The concurring presence of the same mineral species in the external as well as the internal mineral assemblage of the diamond, permits the conclusion that the diamond crystallized from a melt during rock-forming processes.

Furthermore, the different chemistry of the guest minerals in diamond and the same mineral components of the kimberlite, reveals that the diamond was not formed in the kimberlite—at least not during its later stages, i.e. not during its ascent and volcanic eruption through the Earth's Crust.

Surely, the presence of mineral inclusions in diamond can only be understood with reference to diamond growth.

The outstanding theory acknowledged today concerning the formation of diamond is based upon the knowledge that genetically ideal conditions varying from 40 to 60 kbar and amounting to approximately 1250 °C prevailed at relatively great depths in the Earth and that such conditions must be expected in regions of the Upper Mantle. The evidence of crystal perfection and of external crystal morphology of diamonds suggests that diamonds grew in equilibrium and crystallized during the solidification of an ultramafic silicate melt, saturated with carbon. In agreement with this interpretation, thorough investigation of mineral inclusions in diamond discloses that they crystallized from a picritic (=olivine-rich) magma, rich in water and carbon-dioxide, in the presence of immiscible iron-, nickel- and copper-sulphides. In the course of this highly reactive phase, and while the rocks themselves must have undergone several changes, the diamond and its guest minerals were born.

Yet, before we may deal with these details, it may be advantageous to examine the Earth's internal structure and to locate the actual birthplace of the diamond. In the course of geological research, some definite ideas have developed about the structure of our Earth, and we believe these to be quite trustworthy. We may assume that the innermost core consists of iron and nickel—with a composition somewhat concurring with the iron meteorites which drop to our Earth as samples from other cosmic bodies.

The core is surrounded by a sphere of Al-Ca-Fe-silicates which we call the Lower Mantle, including a transition zone.

The Lower Mantle is embraced by an exterior silicate-shell consisting of minerals and rocks partly in molten, partly in solid condition.

It is only the outermost skin of this Upper Mantle which is accessible to our direct observation. Everything that lies below these depths must always be left to conjecture. Our deepest drill-holes have only reached a depth of 10 000 m, and the deepest shafts sink down to merely 5200 m—just a few miles. In comparison with the thickness of the individual strata, these human drill-holes are

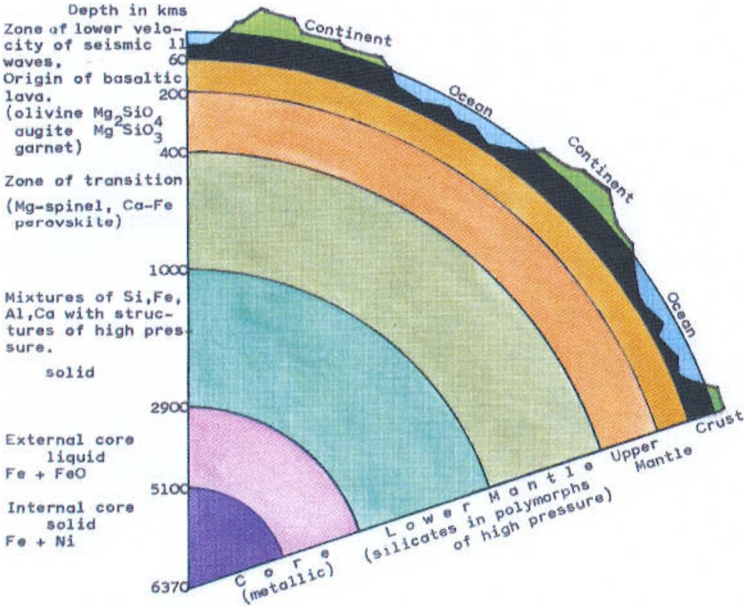

FIG. 1. Section of the Earth showing its internal structure (after Schick & Schneider, 1973).

but pin-pricks! It is comprehensible that geologists have tried to obtain better ideas about greater depths of the Earth's interior, because all processes in the external border-zone—the so-called Crust—where the majority of our raw material is deposited, are closely connected with the interior of our planet. Thus geologists have established a triple division of the silicate zone—which is named the Upper Mantle—according to which the uppermost layer—the Crust—consists of rocks known to us. The Crust is estimated to measure between 11 and 60 km (with an average of 33 km) in thickness.

Below the Crust, the Mohorovicic-discontinuity forms the boundary towards the middle zone of the Upper Mantle, where in places the material is in that molten state which we call *magma*.

Magma, or liquid rock, probably only occurs locally in small

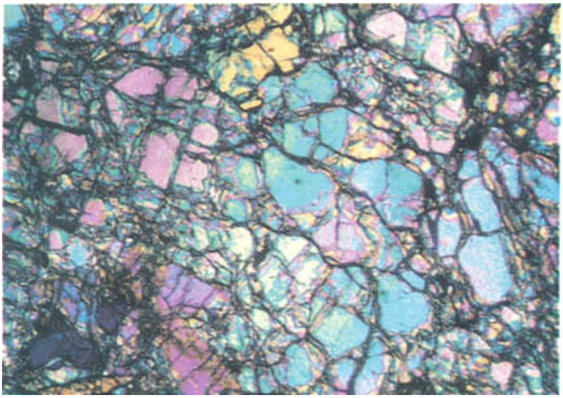

FIG. 2. Thin section of peridotite, a monomineralic rock consisting entirely of olivine grains. + polars.

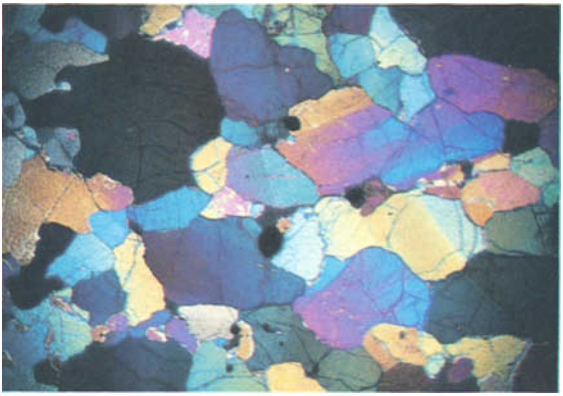

FIG. 3. Thin section of dunite, a peridotite in which the mafic mineral is almost entirely olivine, with accessory chromite (black grains). + polars.

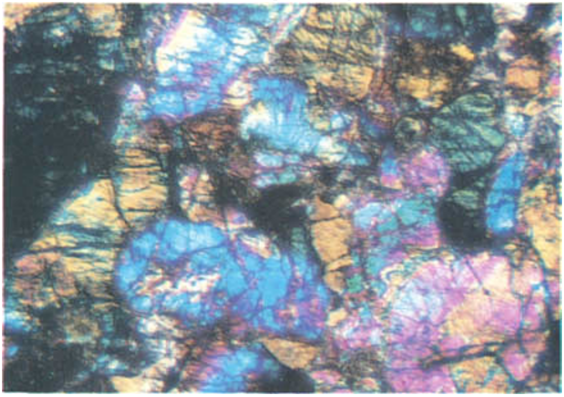

FIG. 4. Thin section of garnet-lherzolite, a peridotite mainly composed of olivine (which is normally predominant) and bimineralic pyroxene. The cataclastic condition of the grains is quite conspicuous. (The angular black grain at the lower edge is garnet). + polars.

areas where melting has taken place. This shell reaching down from about 33 to about 200 km—and according to our ideas, playing host to ultramafic rocks—is of eminent importance to the formation of diamond, because it is this shell which supplies the molten basic material—so to say the matter of the womb—from which diamond crystallized. We must assume that this zone of magma in the Upper Mantle has approximately the same homogeneous composition throughout its entire extension, though some areas must be quite heterogeneous and differ chemically at different horizons and localities. This must especially be the case below those areas of the Crust where diamond is found.

The general composition of the Upper Mantle is peridotitic (Figure 2), i.e. it is characterized by a combination of silica (SiO_2) and magnesia (MgO), and therefore used to be called SIMA (unfortunately this descriptive acronym has more recently been abolished). Besides these oxides of silicon and magnesium, alumina (Al_2O_3), iron, calcium and alkalis are also present.

The Upper Mantle is the main source of ultrabasic and ultramafic rocks, and among the latter we find some of the diamond's mother-rocks. The difference between 'ultrabasic' and 'ultramafic' rocks lies in their chemical and mineralogical compositions respectively, so that a rock is called 'ultrabasic' if it contains less than 45% SiO_2, while the term 'ultramafic' refers to the mineral composition of a rock: ultramafic rocks are often monomineralic, consisting mainly of mafic material such as augite, hypersthene, olivine etc. "Thus a rock can be both ultrabasic and ultramafic, but it can also be ultrabasic yet not ultramafic (e.g. carbonatite) and vice versa (e.g. websterite). The ultramafic rocks of the Upper Mantle are of igneous origin, yet when *some* of them are examined with regard to texture, it is obvious that they have undergone cataclasis and/or recrystallization, and they would best be considered as recrystallized igneous rocks, as there has probably been little—if any—chemical mobilization between minerals (in this instance the discussion is entirely confined to the xenoliths in kimberlite)".*

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*This and subsequent passages printed between "double quotation marks (inverted commas)" are personal communications by Professor Dr H. O. A. Meyer, Purdue University, West Lafayette, Ind., U.S.A.

The far-reaching distribution of diamond occurrences—from Australia to Borneo, Malacca, India, South Africa and Brazil; from Tanzania via Zaire to Ghana, Sierra Leone, Liberia and Guyana, as well as in Yakutia in Siberia and in the Ural Mountains—offers evidence that diamond must have originated from a widely spread and similarly composed, though in places heterogeneous, magma in the Upper Mantle.

The abundance and variety of inclusions—both monomineralic and multimineralic even in a single diamond—suggest that a complex history must have preceded the genesis of the host diamond itself. The history would appear to have forerun the formation and emplacement of kimberlite. The coexistence of specific mineral-inclusions with the diamond, i.e. their forming the internal paragenesis of the diamond, offers the following interesting interpretation of the diamond's evolution:

"The ultramafic xenoliths in kimberlite include lherzolite ± garnet; harzburgite ± garnet; websterite ± garnet, and dunites. The xenoliths in which diamonds have been found are mainly dunites (Figure 3) and harzburgites, but two lherzolites (Figure 4) have also been known: garnet is present in these rocks. The story of these xenoliths in kimberlite is further complicated by the fact that there are what are called 'fertile' and 'sterile' ultramafic xenoliths. These terms are closely associated with the attributes 'sheared' and 'granular', which were used by Boyd, F. R. & Nixon, P. H. (1975 & 1978) to describe xenoliths with specific textures. In general, a fertile xenolith is one that could upon partial melting produce 'basaltic' material plus a residuum. A sterile xenolith cannot produce 'basaltic' material through partial melting, and may perhaps itself be the residuum of a previous partial melting episode. Thus, in summary, there is some *deus ex machina* that introduces fertile ultramafic rocks into the Upper Mantle. Partial melt episodes applied to these fertile rocks result in 'basaltic' liquid plus sterile residuum rock. Principally, there has only to be enough carbon present, in order to obtain diamond, and hence diamond may occur in several types of ultramafic xenolith—and this concurs with actual observations. The role of CO_2 and of H_2O has been neglected in the above discussion, but it is plausible that these volatiles take an active part in the partial melt episodes by lowering melting temperatures, etc."

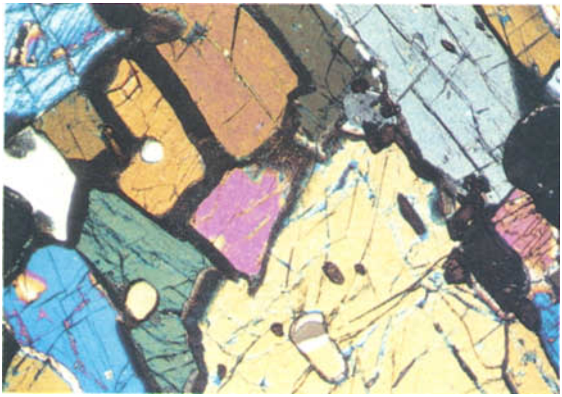

FIG. 5. Thin section of eclogite, an igneous derivate from ultramafic, fertile peridotite consisting of clinopyroxene, garnet (two black grains at the short edges), olivine, and rutile (brown grains). + polars.

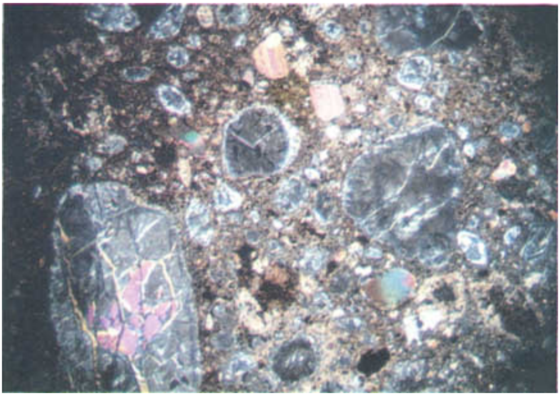

FIG. 6. Thin section of kimberlite, a basic igneous porphyritic rock containing abundant phenocrysts and xenoliths, some of the latter being mother-rocks of diamond. + polars.

The diamond-bearing ultramafic xenoliths consist, in varying compositions and mixtures, chiefly of olivine, pyrope garnet, orthopyroxene (enstatite), diopsidic clinopyroxene (chrome-diopside) with some accessory minerals such as chalcopyrite, pentlandite, graphite and—DIAMOND (Figures 2, 3, and 4).

The other main suite of xenoliths in which diamond occurs are the eclogites (originally called 'griquaites') (Figure 5). These are igneous rocks, for no evidence of classic metamorphism may be perceived, and they consist of an assemblage of bimineralic clinopyroxenes and garnet with a proportion of jadeite molecule in the clinopyroxene. It has been suggested, "that some of the eclogite xenoliths are in fact the crystallization products of the 'basaltic' liquid that was expelled from fertile ultramafic rocks during episodes of partial melting. The idea appears highly plausible since it explains the apparent intermixing of ultramafic and eclogitic rocks in the Upper Mantle."

The principal mineral components of eclogite are pyrope-almandine garnet and omphacitic clinopyroxene. The rarity of clinopyroxene inclusions in diamond is surprising in view of the abundance of this mineral in kimberlite and associated xenoliths. Rutile and to a certain extent also olivine, are common accompanying minerals, and the following even rarer subordinate minerals may occur: coesite, corundum, cyanite, ilmenite, jadeite, pyrrhotite, quartz, high sanidine, spinel, graphite and—DIAMOND (Figure 5).

The relationship of the ultramafic and the eclogitic mother-rocks of diamond to each other seems clear: eclogite is the solidified low-melting fraction of fertile ultramafic rocks, precipitated after partial melting, whereas the ultramafic xenoliths are most likely the result of an early high cataclasis and/or re-crystallization.

There is a strong implication, if not a certainty, from natural deposits, that diamond crystallized by slow precipitation from a molten or partly molten peridotite (Figure 4), on condition that this occurs in the stability field of diamond. For a 'dry' peridotite this means theoretically a temperature above 1800 °C and a pressure of at least 68 kbar (depth 200 km), but for a phlogopite-bearing peridotite, these equilibrium conditions would be reduced to some 1100 °C and 45 kbar (depth approx. 135 km) (Figure 7). Either of these events may have taken place during a period or periods of partial melting, which resulted in cataclastic ultramafic rocks and truly igneous eclogites—the recognized mother-rocks of diamond. Consequently, these diamond-bearing xenoliths may be considered as igneous high pressure derivates of cataclastic and melting processes, whereas diamond is to be understood as a side-product of these extrordinary incidents. This formidable evolution of the diamond occurred in various periodic successions (Figure 21).

With regard to diamond growth, there are some rules which must be observed; for instance, no diamond forms unless the pressure is high enough for diamond to be stable at the particular prevailing temperature. The habit of the diamond depends principally upon the pressure and temperature at the instant of formation. The temperature probably also influences the colour.

Large diamonds were formed by processes of pressure increase and/or temperature decrease close to the transition line diamond/graphite (Figure 7): the slower these processes, the larger and more perfect diamond crystals could have formed. When these processes happened rapidly, and/or at pressures considerably higher than those necessary for equilibrium, the rate of nucleation and growth of the crystals was greater, resulting in smaller and less perfect crystals (carbonado, ballas and other polycrystalline forms).

It is well known that diamonds from different regions or mines can, statistically, be distinguished on the basis of their dominant crystal form, structure, average dimensions, colour grade, and to some extent also by their inclusions, although mineral inclusions more decidedly differentiate between the ultramafic and eclogitic origin of the diamond. From the above discussion, such differences may be interpreted in terms of different growth conditions.

A number of outstanding problems still exist, such as the source of carbon necessary for diamond to crystallize as well as nitrogen, which is a common impurity and is responsible for yellow, brown and green colours. In the case of carbon, its source is still a matter of conjecture, "though one may assume that carbon was concentrated beyond its saturation level in the magma. Consequently the most important carbonate mineral, calcite, occurs in some xenoliths of kimberlite and in kimberlite itself. Yet strangely enough calcite is uncommon in the eclogite and ultramafic xenoliths, although some of these contain diamond and occasionally graphite. Apparently carbonate minerals could not

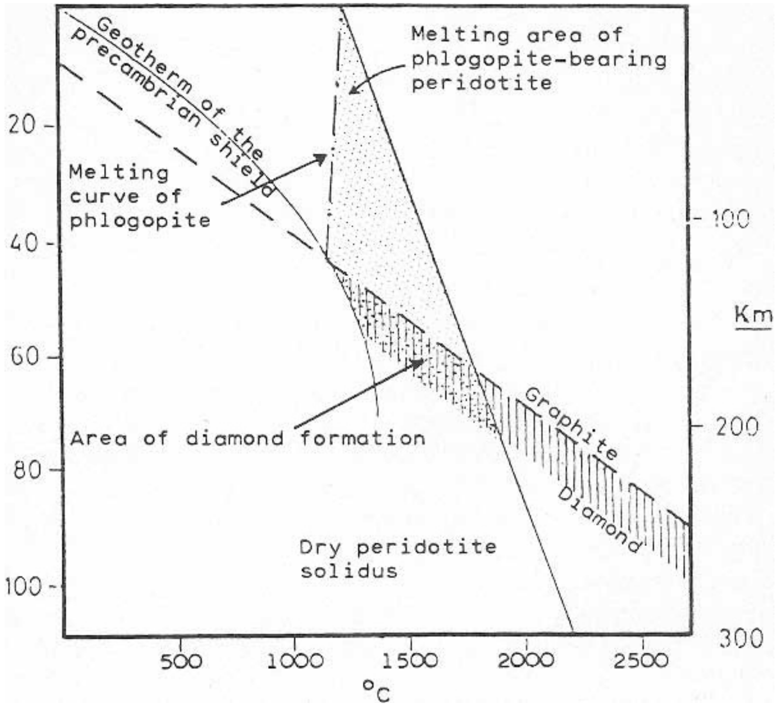

FIG. 7. Diagram demonstrating the influence of mica upon Mantle melting and the genesis of diamond.

readily form in the diamond-bearing xenoliths, and thus carbon was caused to crystallize as diamond". It may be recalled at this instance, that for diamond to form, all that is required is the presence in sufficient quantities of carbon! "Whether or not the magma was eclogitic or ultramafic is immaterial, as it is the physico-chemical rules governing crystallization that are important, and the presence or absence of carbon."

Quite possibly, a carbon or diamond phase originated from the reduction of carbon dioxide. The reduction could be centred around a specific reducing agent—where its absence in abyssal magma could mean absence of diamond as well. Pyrrhotite could fill this role as a reducing agent. It is a common primary inclusion in many diamonds from various sources.

A possible moderate-temperature/high-pressure reaction between iron-rich pyrrhotite and carbon dioxide is:

$$2FeS_{(solid)} + CO_{2\,(gas)} = 2FeO_{(solution)} + S_{2\,(gas)} + C_{(cryst.)}\,\text{(Diamond)}$$

(Langford *et al.*, 1974)

This open-system reaction would be diffusion controlled by the carbon dioxide. The diamond phase could form directly, bypassing a graphite- or carbide-phase. The FeO (ideal) would either combine with excess silica or dissolve in the host-rock's silicates.

Another possibility consists in the following reaction:

$$2FeO + CO_2 = Fe_2O_3 + CO$$
$$2FeO + CO = Fe_2O_3 + C \quad \text{(Diamond)}$$

The results of more recent investigations of the composition of gases such as H_2, CH_4, H_2O, C_2H_4, N_2, CO_2, CO, and Ar, trapped within diamonds, are not inconsistent with the genesis of diamond by a gas-phase—solid-phase reaction under a variable environment. Water has been observed as a major component of the included gases and this may suggest that water was present in the Upper Mantle during diamond crystallization. As a matter of fact, it is accepted today that the H_2O-CO_2-rich fluids and Fe-Ni-Cu-Co-sulphides play an important part in the genesis of natural diamond. They are present in the silicate melt from which diamond crystallized—probably as miscible volatiles and immiscible sulphides.

Preliminary calculations indicate that the following secondary reactions are combined with similar primary reactions and explain the observed data qualitatively:

$$H_2 + CO_2 \rightleftharpoons H_2O + CO \qquad 4H_2 + CO_2 \rightleftharpoons CH_4 + 2H_2O$$
$$CH_4 + CO \rightleftharpoons H_2O + H_2 + C\,\text{(Diamond)}$$

These reactions adequately explain the composition of the gases released from the natural diamonds, except for N_2 and Ar. The latter gases are believed to be inert in the diamond growth process (Giardini *et al.*, 1975).

Since the diamond converts into graphite when heated to more than 1200 °C in a vacuum, it would have altered into graphite during cooling if it had not refrigerated very rapidly, which, so to say, caused the diamond structure to undergo 'deep freezing'!

The basis of this knowledge was also offered by ore in diamond, when a black mineral inclusion was analysed which was basically pyrrhotite (FeS) in composition, and was found to contain a high proportion—almost 8%—of nickel. Apparently little or no exsolution of nickel had taken place during the cooling of the original mixed mineral, which suggests that the diamond host cooled very quickly, granting no opportunity to the nickel minority to exsolve. Pyrrhotite can only accommodate about 1-2% of Ni in solid solution (Figure 20). (Gübelin, 1977.)

From those focal places in higher regions of the Upper Mantle where diamond was formed, the diamond was shot into higher spheres of the Crust and even above the Earth's surface by sporadically occurring eruptions, during which the rocks resulted in a breccial kind of rock—known to us as kimberlite (Figure 6). In the course of this event many diamonds became embedded in the kimberlite rocks of the volcanoes and their conduits. Diamond is not an inherent but an accessory mineral of these kimberlite rocks, which fill the chimneys of the volcanoes or spread as lava over the adjacent terrestrial surfaces. The speed of ascent must have been sufficiently great to preclude sedimentation of the high-density peridotite- and eclogite-xenoliths, and also to prevent resorption or inversion of the diamond into graphite.

Unfortunately, the foregone hypotheses, while explaining many features of the genesis of diamond and its deposits, offer no elucidation as to the peculiar phenomenon of time and space of diamond deposits. A startling majority of kimberlite pipes—perhaps as much as 90%—were all emplaced in the Late Cretaceous era, i.e. about 140 to 200 million years ago, through volcanic eruptions which brought the diamond to the surface of the Earth. One may well wonder about the tremendous forces on the Crust-Mantle of the Earth during part of this geological era which promoted these volcanic eruptions. We certainly have to be grateful that diamonds were preserved for us and, further, that they have become accessible above the surface of the Earth and thus come into the hands of men.

PHOTOMICROGRAPHS OF MINERAL INCLUSIONS IN DIAMOND

Olivine is the most frequent and most important mineral inclusion in diamond (Figure 8). It furnishes a typical example of epitaxial growth within the diamond: the crystals are stretched pinacoids after the body-diagonal, whose pinacoidal face (010) grows on octahedral faces (111) of the diamond in such a way that the longitudinal axis extended along the diagonal [110] runs in

FIG. 8.

parallel alignment with the edges of the octahedron. The identity period of the structure of olivine in the direction [110] is $\sqrt{a_0^2 + b_0^2} = 7.75$ Å and in the diamond along the same direction $a_0 . \sqrt{2} = 5.04$ Å (Strunz, 1968). The difference of 2.71 Å does not

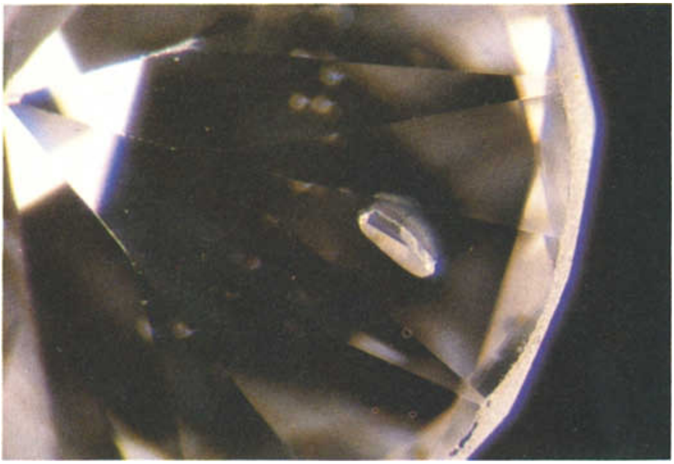

FIG. 9.

seem to be an obstacle in the way of epitaxial growth. Olivine in ultramafic diamond contains bivalent chromium, the content of which varies from 0.01% to 0.1% or more. Pre-cambrian olivine contains more CrO than mesozoic olivine. (Meyer & Boyd, 1972).

Frequently, the olivine crystals in ultramafic diamond distinguish themselves by containing a tiny dark brown grain of chromite (Figure 9).

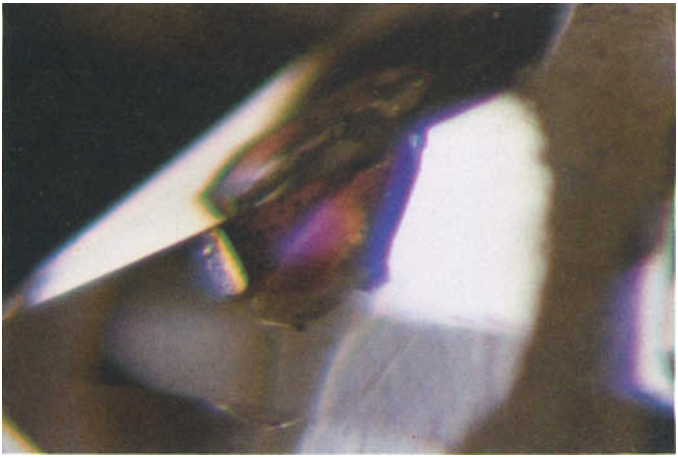

FIG. 10.

Pink to dark red chromium-rich pyrope garnet is a characteristic hallmark of ultramafic diamond (Figure 10). The proportion of trivalent chromium in pyrope garnet also varies remarkably, as may be assumed by the difference in the shades of a hue that might be called claret or burgundy red. The content of Cr_2O_3 may sometimes reach as high an amount as to place the pyrope garnet into the neighbourhood of knorringite-garnet.

FIG. 11.

Reddish-brown to brown garnets are pyrope-almandine garnet (Figure 11) and belong to the eclogitic suite of mineral inclusions in diamond; they are more iron- than chromium-rich. Guest garnets in diamond do not seem to be aligned to any crystallographic or preferred direction of the host crystal. Both varieties of garnet excel with a slightly increased proportion of Na_2O which indicates high formation pressure.

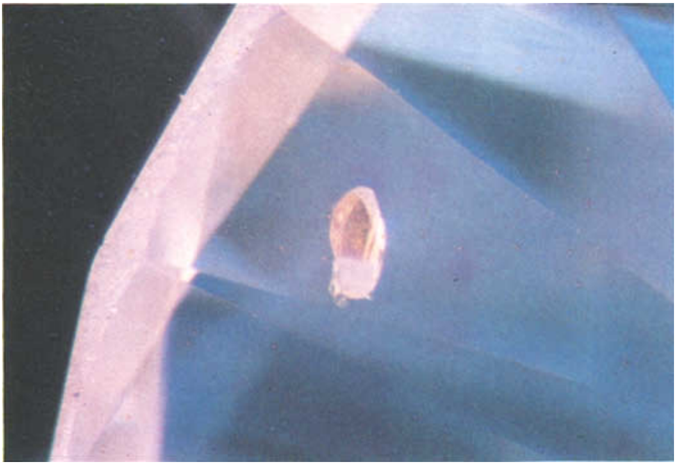

FIG. 12.

The *orthopyroxene enstatite* (Figure 12) characteristically occurs as a significant inclusion in diamond originating from an ultramafic mother-rock. It is noteworthy for its limited tolerance of chemistry in that it is constituted of 92% En in most cases, the remaining molecules being bronzite and/or hypersthene. Consequently it appears most often colourless (and is then difficult to discern from olivine) or pale brown. Enstatite was first mentioned by the author (1952).

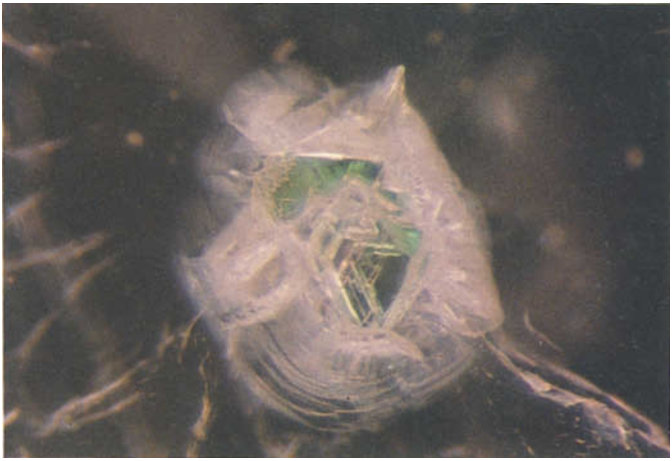

FIG. 13.

Of the *clinopyroxene* inclusions the *diopsidic* variety is also assigned to ultramafic diamonds (Figure 13). It is easy to recognize by its conspicuous emerald-green colour, which it owes to an admixture of chromium oxide, which may reach contents as high as 15 wt%. The author was the first to identify chrome-diopside in diamond (1969). The guest mineral in diamond strongly resembles its counterpart in ultramafic xenoliths, and usually seeks the association of chrome-bearing olivine, pyrope-garnet and chromite.

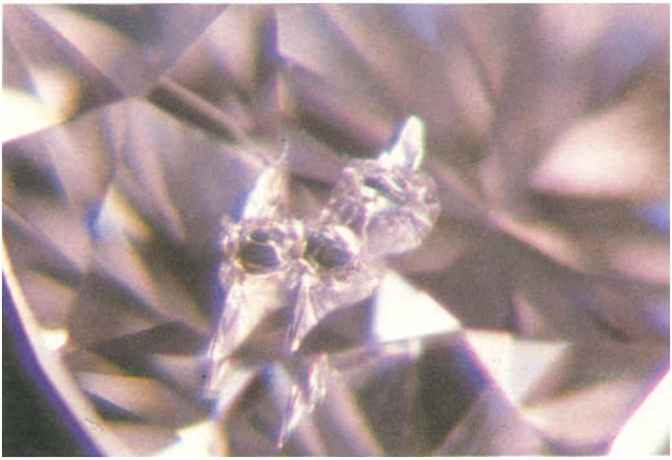

FIG. 14.

Omphacitic clinopyroxene (iron-bearing diopside) (Figure 14), typically marks the internal paragenesis of eclogitic descendancy and is more abundant in Premier diamonds than elsewhere. In many instances these pyroxenes are very pale greyish-green, and their colour may be masked by the high refractive index of the host diamond (as, by the way, is often the case with mineral inclusions

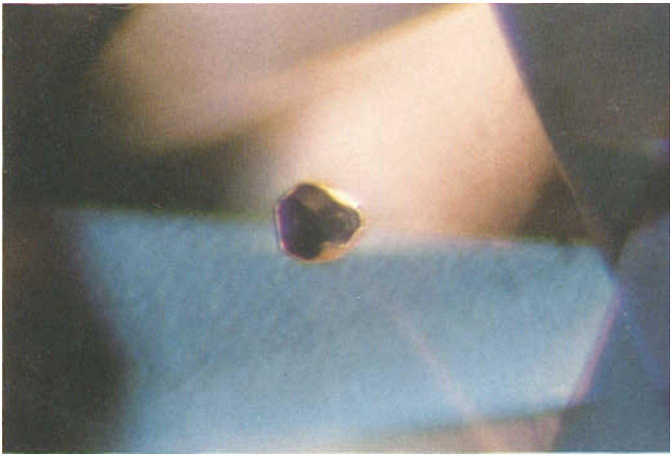

FIG. 15.

in diamond). Some of these omphacitic diopsides belong to the space-group C2/c instead of P2/n, the latter being normal for the same mineral in eclogite.

In concurrence with most chromium-bearing mineral inclusions, *chromite* (Figure 15) also belongs to the mineral association in ultramafic diamonds. It forms dark brown to black grains or well-shaped octahedra with a strong metallic lustre. Chromite inclusions in diamond are the most magnesian and chromian of terrestrial chromites (Meyer, 1975).

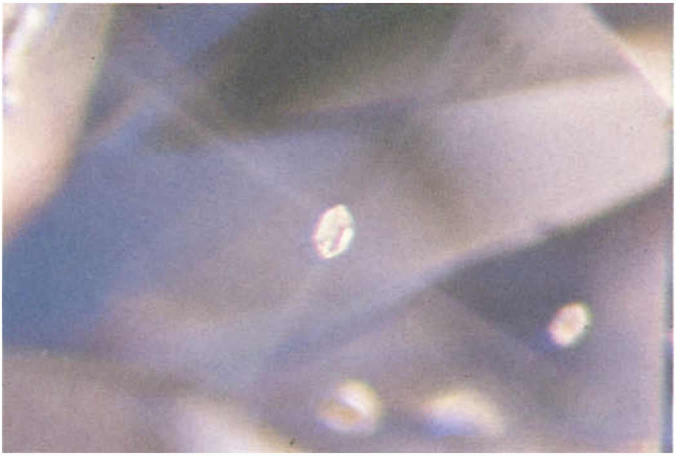

FIG. 16.

Minor mineral inclusions designating their host diamond's eclogitic origin are coesite, ruby and rutile, and, in extremely rare cases, also cyanite and ilmenite. Coesite, the high pressure polymorph of quartz (Figure 16), was first discovered as a guest mineral in diamond, before it had been found in a free state in nature. Whenever SiO_2 is incorporated in crystalline form in diamond, it should be coesite and not quartz, for the boundary curve of the stability field of coesite runs from 30 kbar and 500 °C to 45 kbar and 1500 °C, and therefore crystallizes under equal growth conditions to those of diamond. Only a very few diamonds have heretofore become known with coesite inclusions, and most unfortunately their original source is still uncertain.

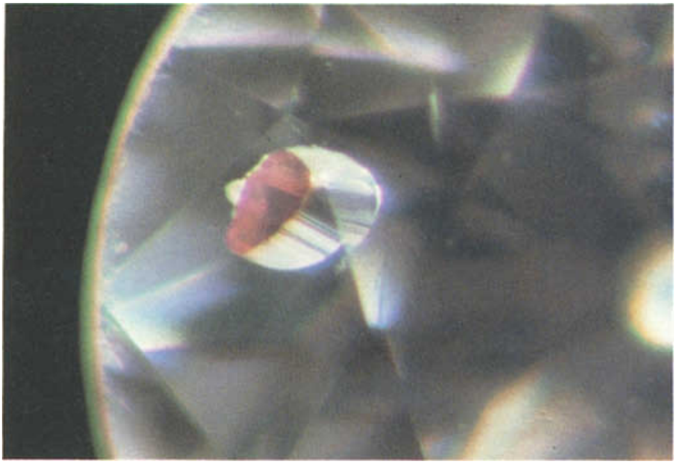

FIG. 17.

The possibility that corundum could take shelter in diamond was doubted for a long time, and it was indeed only two years ago that a ruby (Figure 17) was identified as a guest mineral in diamond for the first time (Meyer *et al.,* 1981). While weak reddish fluorescence and an extremely fine emission line at about 693 nm seemed to indicate ruby, a quantitative analysis by the electron microprobe confirmed its nature. Compared to a Burmese ruby, it disclosed similar though slightly different amounts of trace elements, e.g. SiO_2 0.18% (0.29%); TiO_2 0.00% (0.09%); Cr_2O_3 0.96% (1.30%); and FeO 0.00% (0.22%). (The figures in brackets refer to natural Burmese ruby). It is interesting to notice that it shared a small percentage of SiO_2 with ordinary natural ruby, while it was devoid of FeO. Interestingly, the ruby inclusion was not in epitaxial relationship with its host crystal, contrary to what one might expect in view of the high P-T conditions under which the ruby-diamond couple crystallized.

Rutile, (Figure 18) being one of the more abundant accessory minerals in eclogite, may be expected to occur as a guest mineral in diamond of eclogitic origin. Strangely enough it does not seem to be frequently found inside diamonds. Those few samples which

FIG. 18.

have been observed were reddish-brown in colour, moderately transparent, and prismatic, and two chemical analyses showed them to be conspicuously pure, with less than 0.4 wt% of other oxides (Meyer *et al.,* 1976).

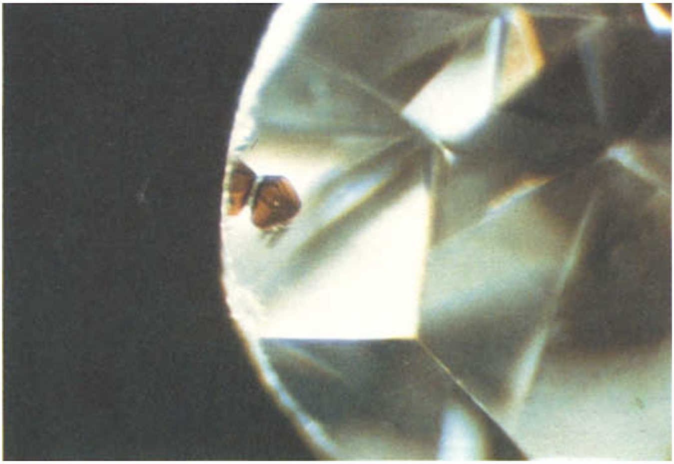

FIG. 19.

The existence of iron-rich biotite as an inclusion in diamond (Figure 19) is highly suggestive, because biotite decomposes to olivine plus other solid phases below 40 kbar, and to garnet plus other solid phases above 40 kbar. It is of value to remember at this instance that olivine in particular, but also garnet, are common primary inclusions in diamond. So far, however, mica has appeared only rarely as a guest mineral in diamond. The circumstances may indicate that biotite was only marginally stable under minimal conditions for diamond formation (Figure 7) (Giardini *et al.*, 1974).

FIG. 20.

Sulphide inclusions either with clearly pronounced crystal shapes or as irregular fragments are quite often encountered within diamond. The morphology is hardly ever theirs, but usually adopts the crystal faces and edges of the diamond habit. The inclusion portrayed in Figure 20 consists of a multimineralic assemblage pyrrhotite (FeS—major component), pentlandite (NiS—minor component in solid solution inside the iron sulphide), chalcopyrite (Cu-Fe-S—forms a kind of crust wrapping the other components) and SiO_2, whose structure could not be determined, but which can only be coesite. The tension cracks darting out from this multi-mineralic inclusion into the diamond matter are very characteristic of many similar inclusions. Their blackness is not due to total reflection of light but to finely disseminated sulphide material, or graphite lining the walls of the fractures. The mechanism of deposition of these ultra-fine black films within fractures completely enclosed by the diamond host is not yet understood (Gübelin, 1977).

FIG. 21.

Diamond crystals within diamond (Figure 21) substantiate the conviction that diamond did not crystallize in one continuous process, but in periodical successions. The fact that in numerous host diamonds the guest diamond is not in congruent crystallographic orientation, elucidates that the latter did not act as a seed, but was rather overgrown at random. Sometimes two or even more generations may be found inside the youngest host diamond, and often the entrapped diamond is of darker colour (yellow to brown) than the enclosing crystal.

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AMBER FROM THE DOMINICAN REPUBLIC

By HELEN R. FRAQUET, F.G.A.

There has been some confusion in the gem world following the appearance of large quantities of amber from the Dominican Republic. Initial reaction has been guarded—that it is not amber at all, or that there is something, unspecified, wrong with it. In fact this amber was first noted by Christopher Columbus in the fifteenth century during his second voyage to the West Indies, and by the early twentieth century its appearance was being widely reported in quite obscure journals. The following is taken from the *Transactions of the Dumfriesshire and Galloway Natural History and Antiquarian Society* (Labour, 1914-15).

> 'A few years ago an interesting discovery of amber was made in the island of San Domingo. It appears to exist in considerable amount, and often in pieces of good size suitable for making carved objects of much beauty. It possesses a fluorescence similar to that seen in some of the amber from Catania, Sicily.'

The lack of identity for Dominican amber is explained by commerce, for until 1979 Germany purchased nearly all the amber direct from the island, and back in Europe it was mingled with Baltic amber, its source unacknowledged. Today any piece of amber has to be polished by the Dominicans before exportation, and it is against the law to export rough resin.

Research into amber has taken great steps forward since the mid 1960s. Tradition dictated that amber came from a pine-like tree, but most Baltic ambers give different infrared spectral patterns from modern pine resins, the pattern being nearer to that of the araucarian *Agathis Australis.* Also modern pine resins lack succinic acid—the second traditional attribute for amber (Langenheim, 1969).

The presence of succinic acid in ambers is now thought by some to be a by-product of ageing. 'Succinic acid occurs as a normal oxidation product of amber and is thus by no means indicative of its origin' (Rottlander, 1970).

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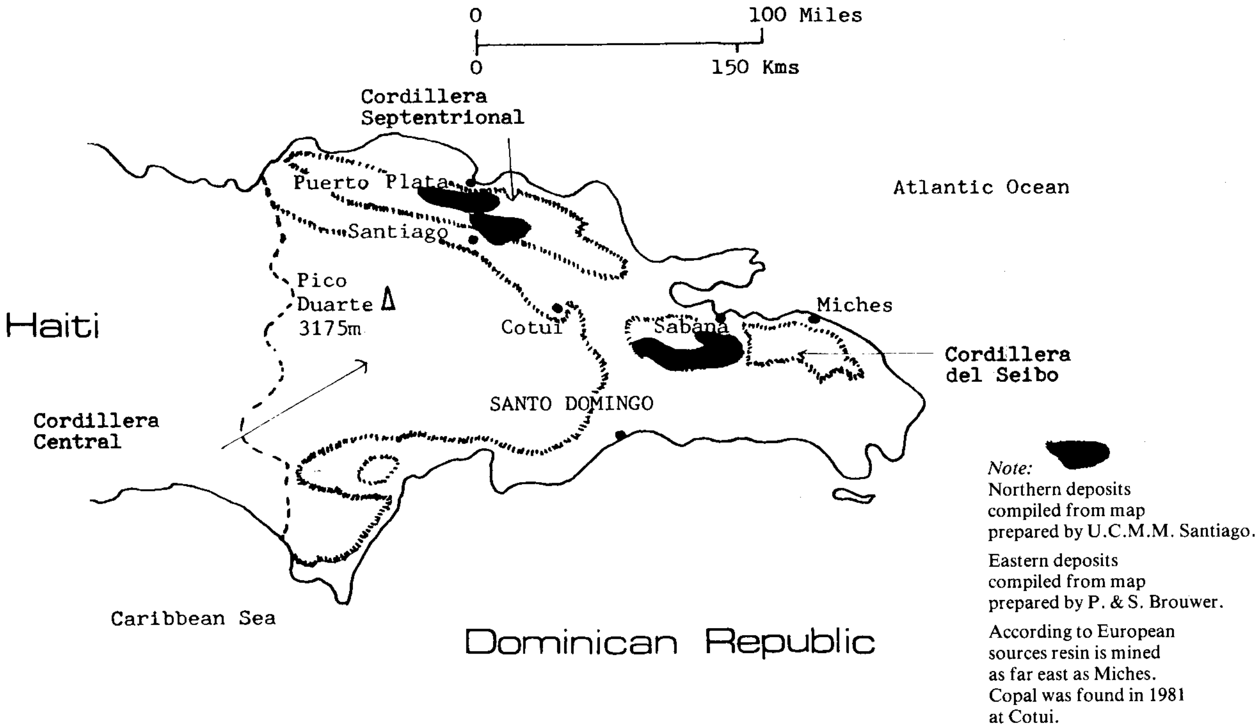
Whilst many papers are available on Baltic amber and ambers from North America, very little has been published about Dominican amber. With this in mind I made a field trip to the island in 1981, and the following is a report of my findings. I am greatly indebted to the staff and students of the Universidad Catolica Madre y Maestra (U.C.M.M.), at Santiago de los Caballeros, to Dr Pompelio Brouwer, retired Minister of Mines and Petroleum Products, and to his son Salvador Brouwer, Geologist with Falconbridge Nickel Ltd, for permission to refer to key, unpublished papers. In Europe I have received assistance from Dr Dieter Schlee, of the Staatlichen Museum fur Naturkunde, Stuttgart, Georg Dommel, of Ambar del Caribe, Dusseldorf, and Alan Jobbins, of the Institute of Geological Sciences, London.

The Dominican Republic comprises the eastern two-thirds of the island of Hispaniola (see map on page 323). It covers an area of 48 442 km^2 and is traversed by two mountain ranges—the northern Cordillera Septentrional, and the Cordillera Central, which boasts the highest peak in the Caribbean (Pico Duarte). The climate is subtropical (30 to 35 °C), and the Spanish-speaking population of five million is concentrated in three or four large towns, leaving much of the hinterland unpopulated and unmapped.

The amber found on the island is of several varieties, thought to be of differing geological ages. In the main it ranges from 25 to 35 million years old, but resin found in 1981 at Cotui is much more recent and should be classed with copal. The finding of a variety of ambers in one place is a common phenomenon; the amber from the Baltic region varies in age from Jurassic (Bornholm), through early Eocene (Danish Mo-Clay deposit—which does not contain succinic acid), to late Eocene (Samland Peninsula). Due to a deterioration in the climate the formation of amber in the Baltic seems to have stopped early in the Oligocene, somewhat later in Romania, while it was still functioning in the Miocene in Sicily (Larsson, 1975 & 1978).

Jean Langenheim, of the University of California, (1969) gives a list of geological occurrences and botanical affinities between some fifty ambers, using infrared spectroscopy to match absorption peaks in fossil and modern resins. The following examples have been extracted as being of interest to gemmologists:



Note:
Northern deposits
compiled from map
prepared by U.C.M.M. Santiago.

Eastern deposits
compiled from map
prepared by P. & S. Brouwer.

According to European
sources resin is mined
as far east as Miches.
Copal was found in 1981
at Cotui.

Map showing amber occurrences in the Dominican Republic.

Occurrence	*Geological Age*	*Possible Plant Type*
SE. Coast, England (London Clay formation)*	Paleocene-Eocene	*Burseraceae*
Hukawang Valley, Burma	Eocene	—
Baltic Coast	Eo-Oligocene/Miocene	*Pinaceae*
Dominican Republic	Oligocene	—
Chiapas, Mexico	Oligo-Miocene	*Leguminosae (Hymenaea courbaril)*
Romania	Miocene	—
Northern Sicily	Tertiary	—

Comparisons of infrared absorption spectra featuring Dominican amber appear in papers by Saunders *et al.* (1974) and Langenheim & Beck (1968). Six spectra of Dominican amber were shown in the latter paper. Four came from the Santiago area and gave a similar trace, but two from Palo Quemado gave more generalized spectra—possibly due to increased oxidation. The varieties were classified as Types I and II (although they came from the same region) and their spectra were found to be different from other North and South American ambers. As no extant group gave a similar pattern, the botanical source could not be ascertained at that time. Following my visit to the island in 1981 the Natural History Museum in London made a series of infrared spectra tests on my samples; their findings are given in the Appendix (page 332).

For the purpose of this report I am calling the two major amber deposits by the geological formations in which they occur. This is to prevent the oft-repeated errors which occur due to duplication of place names on the island.

AMBER FROM THE ALTAMIRA FORMATION

Amber is found scattered in a 60 km^2 area to the north and east of Santiago de los Caballeros in the Cibao valley. Within this area lie the deposits of Los Cacaos, Palo Quemado and Loma el Peñón, which produce high quality amber. The amber-bearing strata are exposed along three faults within the Cordillera Septentrional in the northern part of the island included in the Bahamas Arc. This fact is important, as it has long been speculated that there might be rich amber deposits in Haiti, which occupies the western third of the island, but the arc does not extend into Haiti.

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*Highgate Copalite, included here since Judith Frondel, Harvard Univ., linked Highgate Copalite with the Baltic amber glessite. Using x-ray diffraction techniques to identify α-amyrin, these two fossil resins were linked to the *Burseraceae* family of angiosperm trees (Frondel, 1967).

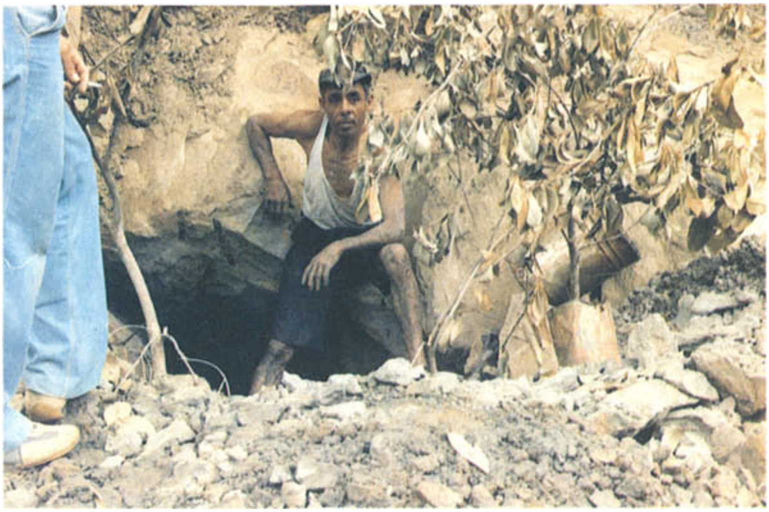

FIG. 1. Excavations for amber in grey mudstone near La Cumbre, Dominican Republic.
(Photo Helen Fraquet)

The amber occurs in a sequence of limestone, sandstone, mudstone and conglomerate, exposed by tectonic movements. It is restricted to the grey carbonaceous mudstone beds and is often associated with lignite. The mines of La Toca are associated with the upper NW.-SE. fault, those of Los Higos, Pulido and Rio Arriba with the central fault, and those of Palo Quemado and Los Cacaos with the lower SW.-NE. fault. The strata around the mines are extensively faulted, and altitudes vary from 300 to 1000 metres within short distances.

The following concise description of deposits is from a local university project undertaken in 1979 (Díaz *et al.*)

Location	*Altitude*	*Observations*
Palo Quemado	420m	Along a fault line, on the eastern side of Palo Quemado stream
west of Pulido	720m	Near a fault line, in unconsolidated mudstones
near La Cumbre road	700m	In layers of carbonaceous mudstones
Rio Amina	460m	On the west bank of the Arriba river, in a well-cemented sandstone
Los Cacaos	620m	Unconsolidated clay
Loma de Carlos Diaz, Rio Licey Blanco	500m	In massive material (limolita arenosa)
La Toca	700/800m	In layers of carbonaceous mudstones

The steeply-sided hills are covered with rough pasture or tropical hardwood forest, and access between settlement and mine is usually by footpath only. This difficult terrain hinders large-scale modern extraction of the amber, and most of the mines are simply holes, dug to a depth of 3 to 6 metres with the aid of pickaxes and shovels. There are many accidents due to landslips and seepage of water into the workings.

I visited two mines in the area. The first was about a kilometre off the La Cumbre road, down one side of a steep hill, across the boulder-strewn river in the valley, and about 100 metres up the other side. A vein of grey mudstone was being extracted from the sandstone hill, the miners working at some distance from each other to prevent landslips. The holes were dug with pickaxes, the harder sandstone being retained as a roof support. The mudstone was then collected in large tin cans or sacks and passed to workers outside the mine who washed the loosely consolidated mudstone with water and removed the amber. The extraction of the amber was unsystematic, and it was not clear why the mudstone was not taken to the near-by river to be washed in running water. One of the mines had caved in three weeks before my visit, and the owner was laboriously clearing away the overburden with the help of a wheelbarrow.

The second mine was about 10 km distant, and we were able to take the university Land Rover (a gift as part of an aid-project from the U.K.) to the site. Here a group of twenty miners were stripping the top-soil with the aid of a bulldozer. The machine had been hired by a merchant in Santo Domingo, the capital, and he was to take a percentage of all amber found. The expense would be justified, in the miners' view, as the amber they hoped to locate was of the blue fluorescent variety which commands the highest prices for export. At both mines I was told that the blue amber outcropped at the top of the hills, near the surface.

AMBER FROM THE YANIGUA FORMATION

There is a certain lack of agreement between Dominicans and Europeans about the characteristics of amber from the east of the island. I myself found it to be a much brighter yellow, and brittle under the diamond saw unlike its northern neighbour, which can be sliced very finely indeed and is most satisfactory to work with.

The following information about amber from the Yanigua area is taken from a treatise prepared by S. and P. Brouwer (1980). It represents the Dominican viewpoint.

The amber from the east of the island is softer, and is thought to be younger than that of the north. However, its large size and the predominance of blue and green fluorescing varieties has encouraged the extraction of amber from this remote and inhospitable site since the 1950s.

The Yanigua sedimentary formation is of Miocene age, and its amber has much in common with amber found in Chiapas, Mexico. Amber-bearing strata occur in a series of small valleys, bounded to the north and west by the Los Haites karst platform, and to the south and east by igneous rocks, in part belonging to the Cordillera del Seibo. The sediments are similar to those of the Altamira—limestone, clay and carbonaceous mudstone (lutite). The amount of lignite associated with amber declines westward. The sediments are horizontal with little tectonic movement except at La Cumbre (El Valle zone) where the formation has tilted.

About fifteen small mines are concentrated around Sierra de Agua, Colonia San Rafael and Yanigua, the outcrops at Sierra de Agua being at the top of the formation and Yanigua the base. Extraction is by pickaxe, the mudstone is often softer than in the northern formation, and up to 80 lbs of amber may be found in a pocket. Problems associated with a difficult terrain (altitude varies from 100 to 400 m) and a high rainfall (2000 mm) limit mechanization, although transverse trenches are dug at Sierra de Agua and intermediate platforms for collecting waste are frequently constructed.

The amber is usually very clear and clean, and the fact that it is of larger size than that of the Altamira is possibly due to the area having experienced less tectonic disturbance. Inclusions in the amber from this location have been analysed at the Smithsonian Institution in Washington and were found to have associations with *Hymenaea courbaril.* This is the tree thought to have produced the amber from Chiapas, Mexico, and is of especial interest as it is an extant species, now growing near mangrove swamps in the tropics.

The largest piece of amber found on the island to date comes from the Yanigua, although it is invariably credited to the Altamira in translated literature available overseas. It weighs 18 lbs and was found in March 1979 in Sabana de la Mar county. The piece is now displayed in Santo Domingo in the Plaza Criolla. Another fine piece weighing 10.56 lbs was displayed in the summer of 1982 at an exhibition of amber in Schaffhausen, Switzerland. The provenance of this piece is not known apart from the rough designation of 'northern cordillera'. It was found quite recently by a child planting a coffee bush. Both these pieces are oval and flat, of a dense rich brown colour similar to burmite.

COLOUR

The majority of amber from the Dominican Republic is of a transparent golden yellow colour. This is often not realized, for much of the amber appears to be rich mottled brown, but this colour is due to detritus included within the clear yellow amber. Very little of this 'brown' amber reaches Europe, most of it being exported to the U.S.A., where it commands high prices for curiosity value. The yellow grades from almost colourless (which I found for sale only at Puerta Plata on the northern coast) to a deep red. This latter is often due to a portion of the rough exterior being retained to lend depth of hue, a point confirmed by the frequency of crazing, associated only with newly-polished amber of this colour. Dominican amber will redden due to oxidation in common with other ambers. I examined several sacks of rough amber at source in the mountains, and extracted three or four pieces of ruby-red, deeply crazed amber which had a 'rusty' coating similar to Etruscan amber carvings found in museums. I had previously been shown lignite by the miners and told that this was 'over-ripe amber'; they were not convinced of the truth when I showed them the friable deep-red amber.

The blue fluorescent amber is an interesting phenomenon as the brilliant oily sheen only appears by reflected light as a surface effect. The blue can in some cases be replaced by a green or even purple hue, and these pieces are much sought after.

The finding of fluorescent amber (rather than amber placed under UV light in a laboratory) is very exciting, as it was previously thought that this type of amber only came from Sicily (simetite). The Sicilian source is now worked out, and, as the colour appears to fade once taken from the ground, I had despaired of ever handling any. The colour fades quite rapidly. Pompelio Brouwer had some blue amber photographed for an American magazine in

FIG. 2. Dominican amber showing colour variations in rough and worked material. *(Photo E. A. Jobbins)*

1977[*] and when it is examined today, only a few years later, the marked deadening of the colour is very apparent.

The most famous amber fluorescing necklace was made of simetite for W. A. Buffum[†] in the nineteenth century. I located the gems in 1974, in an attic where they had lain undisturbed for 20 years. The once-brilliant red, pink, blue and green drops, which feature in so many jewellery books, are now a uniform cherry red.

Dr Dieter Schlee has undertaken a detailed study of this natural fluorescence and considers it to be due to the spread of organic particles emanating from wood, induced during a heating and melting of the amber lump (possibly due to volcanic action). Certainly the blue is evidenced widely in deep brown multi-inclusioned pieces. Amber which is quite clear and yet still shows a blue or green tinge is rare; it is very possible, however, that these pieces were altered by their close proximity to the more common wood-included amber.

Cloudy amber is rare. I only have one piece in my possession—a deep orange with cream swirling clouds. This is quite unlike anything else and bears a close visual affinity to amber found in Arkansas, U.S.A.

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[*] Zahl, P. A., Nat. *Geo.Mag.*, September, 1977, 423-35.
[†] Author of *The Tears of the Heliades, or Amber as a Gem,* London, 1896.—Ed.

During my visit I also purchased three cloudy pieces of green amber—one blue/green and two olive green. Green amber is very rare indeed, I only saw one other piece, placed in a jeweller's window in Santo Domingo. It measured 2 inches by 1 inch and had been carved into a frog.

INCLUSIONS

The Dominican amber is very rich in inclusions, over 100 animal species have been identified already, and, because there is no mechanization, most of the insect, plant or mineral 'fossils' are seen by the labourers before they are lost in the production of amber jewellery.

Cataloguing of inclusions is now being carried out in Germany, Switzerland and the U.S.A., with the number of relatively large inclusions giving much excitement. It must however be remembered that, although bees, parts of geckos and even a complete frog have been recovered, these specimens are much smaller than their modern equivalents. When one speaks of a bee or a wasp in amber, the actual inclusion is probably only 5 mm in size. If one is presented with a modern look-alike which measures 25 mm, the piece is a fake. The fossil inclusions have not shrunk; it is simply that the larger specimens had the power to climb out of the sticky resin and free themselves.

Occasionally the inclusion will have retained its colour. There is a very famous example of a beetle with brilliant green iridescent wings, and flies with red or yellow eyes. The inclusions which I find most interesting are those which depict movement, ants carrying young grubs, or fighting termites. Dr Paul Whalley, of the Natural History Museum at South Kensington, was kind enough to examine a series of inclusions I brought back to this country, and his initial comments are as follows:

Specimens 1 & 2 contain small parasitic wasps *(Hymenoptera)*
Specimen 3—a large peltid beetle, a scolytid beetle and a fly
Specimen 4—a caterpillar—probably an early instar of a noctuid moth
Specimen 5—fragments of plants, a beetle and a delicate gall-midge
Specimen 6—a spider and termites—the latter are the family *Termitidae* and are one of the workers of the group

Specimen 7—plant debris
Specimen 8—plant debris
Specimen 9—Crane-fly *(Diptera, Tipulidae)*
Specimen 10—Parasitic wasps *(Hymenoptera)*
Specimen 11—Mordellid beetle *(Coleoptera)*
Specimen 12—*Lepidoptera,* gelechoid moth

One of the termites and the caterpillar skin are being investigated more fully, and the plants are to be dealt with at a later date.

Little work has been carried out to date on the mineral inclusions, and unfortunately the paper by Flamini *et al.* (1975) did not cover Dominican amber. However, I have observed two-phase (gas-bubble in liquid) inclusions, and metallic dendritic forms. I found no 'sun spangle' stress inclusions in Dominican amber, confirming the findings of Crowningshield (1977-8). This surprised me as they are a common occurrence in nature, even in amber from our own East Coast, as evidenced by the Perowne Collection in the Sedgwick Museum, Cambridge.

MANUFACTURE

Most of the amber is transported from the hills by mule, and polished in the larger towns behind the merchants' shops. Even the smallest pieces are used, the outer crust being removed on an emery or wooden wheel and the finish applied with tripoli powder and a cloth wheel. The poorer pieces are sold by street vendors and, although cheap, are usually chipped and ill-matched when examined in detail. The only evidence I found of processed amber was the production of tiny chips into cast resin picture-frames. From the gemmologist's point of view the most dangerous development has been the coating of recent copal-like resin, which comes from the Cotui area, with an epoxy compound to render it more stable and less likely to craze. This venture to my mind has put in doubt the whole production capacity of several hundredweights of genuine fossil resin a year, and, unless it is stopped or the government press for it to be sold under a separate name, I foresee major problems.

Amber has been finished into jewellery on the island since the 1950s, when a Cooperative of Industrial Artists was set up by the Government. Many similar schemes have followed, the last being set up in Santiago in March 1981, but the Dominicans seem happier to produce at their own pace, without western-imposed regimes of order-dates and completion schedules.

The quality of the jewellery is poor with few exceptions. This is very sad, as the quality of the amber is excellent. What seems to be missing is a sense of pride or self-discipline, which would ensure that the beads of a necklace were at least drilled through the centre or that pendants were finished without cavities due to slipshod workmanship. I found only one merchant on the island who stocked really first-class items, but unfortunately he was not on the government list of official exporters, and I have had monumental difficulty in obtaining shipments from this man.

The design of the jewellery is pleasing; the clear, limpid character of the resin lends itself to the production of free-form pendants and pastille-drop necklaces. Bands of soft wire are bound round the amber lumps to make them secure and attached to each other by s-linked chains. This style of jewellery is very distinctive and unique to Dominican amber.

Much of the carving is geared to the American market. Americans have long visited the island in cruise ships, and larger lumps tend to be carved with North American Indian braves. Smaller lumps depict Central American folkart or even Buddhas. I asked about this strange subject matter and was told that the market tended to divide into the ethnic and the antique, so the Dominicans covered both spheres. Less common were carvings of elephants, domestic animals, or odd mis-shapes glued together to represent mushrooms, a man walking his dog, a couple sitting on a bench, etc. However, the pieces I consider a real success are the heart, leaf or natural drop-shaped pendants; these are quite beautiful and merit a place in any jewel box.

The only care Dominican amber needs is the usual prevention of oxidation. To keep the surface from crazing or becoming dull, an application of natural wax should be used. The amber should be kept away from strong light and heat and preferably stored in a box to prevent it being smashed by harder objects in the gemmologist's collection.

APPENDIX

The infrared spectra of five specimens were obtained using a Perkin Elmer model 683 spectrophotometer. A few milligrammes of each resin were ground with dried potassium bromide and pressed into discs before recording their spectra over the wavenumber range 4000 to 400 cm^{-1}.

1. Miches specimen. This clear yellow, very friable material gave a typical copal or recent resin spectrum with sharp intense peaks. The spectrum very closely matches those of some African copals in the collection of the British Museum (Natural History), particularly those from Sierra Leone, Congo and Zanzibar.

2. 'Best Santiago Amber'. A pale yellow-brown cohesive resin, difficult to grind.

3. La Cumbre (Santiago deposit). A deep red resin.

4 and 5. 'True Green Amber'. Two pale green, cloudy carved specimens bought in Santiago or Santo Domingo.

These last four specimens gave similar spectra, typical of retinite type fossil resins. The differences in the spectra are almost entirely in the intensities of the two peaks at 1640 and 885 cm^{-1} and hence are probably related to age or degree of oxidation.

The Miches specimen has the highest volatile content and shows the strongest 1640 and 885 cm^{-1} peaks, while the others show a progressive decrease in the intensity of these peaks together with a general broadening of the spectral pattern from specimen 2 to 5. These other spectra also show a gradation between the two Dominican types given by Langenheim and Beck (1968) and have a close resemblance to their type 1 spectral pattern for amber from Chiapas, Mexico.

G. C. Jones, Department of Mineralogy, British Museum (Natural History).

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[*Manuscript received 25th July 1981, revised 2nd February 1982.*]

THE STRUCTURE OF CAMEO SHELL

By R. KEITH MITCHELL, F.G.A.

Comments on this subject at the end of A. E. Farn's interesting contribution to the October 1980 issue of this *Journal** prompted me to take a closer look at some of the cameos in my possession. Mr Farn and I are both somewhat fanatical in our belief in making full use of the 10× lens, and I feel slightly surprised that neither of us has commented on this structural feature before.

In most, if not all, cameos examined, I found that the brown, orange-brown or pink layer (the inside of the shell which is normally used as the background surrounding the raised white shell of the cameo) has its very fine grain running in more or less parallel lines in one direction, while that of the white raised cameo runs approximately at 90° to it. Simple and easily seen grain is illustrated in Figure 1, but it will be noticed that here it apparently does not extend over the whole cameo. Careful lighting and focusing might find it in other parts, but grain is rarely obvious in the white part of the shell. In fact it is present over almost all of this small broken fragment, and on the hip of the figure and the rump of the horse its direction is at right angles to the grain I have illustrated.

It is almost impossible to get macrophotographs showing all the grain in the several layers involved, owing partly to the fact that white grain on white shell needs very careful lighting and exposure and, more particularly, to the further fact that each layer is at a different focal distance and the depth of field is not sufficient to bring them all into focus at one time even when working at the smallest apertures. For this reason the fine cameo head in Figure 2 has had the directions of the grain inked in. The dark brown background is grained vertically; the edges and other lower parts of the outlined head are grained roughly at 90° to the brown layer grain, while the major part of the head is high (thick) enough to break into yet another layer in which the graining is again parallel with that of the brown base layer. The graining of the lower layers continues, of course, under all higher layers. The inked lines indicate only the directions of this graining. The actual spacing of grain lines is variable, but is usually very fine and close together.

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FIG. 1. White 'grain' seen quite clearly in part of an antique shell cameo. ×6

The appearance is not unlike that of the flecking that is seen on conch pearls. There are about thirty grain lines in the length of the nose of this cameo, while there are more than 100 lines in about a 6 mm length of the coat collar. In each case the effect is seen most clearly when light is shining along the grain rather than across it, and often only then. In some areas it is quite difficult to see and requires much manipulation of lighting, cameo and lens to bring the grain into prominence.

Microscopic examination of a fairly thick broken edge of another cameo showed that the grain lines appear to be composed of criss-crossing straps of rather fibrous-looking crystals, approximately at the angles expected of aragonite rhombohedra. In the sea, any spaces present would be water-filled. In dry shell they contain air. The visible grain marks the lines of weakness in each single layer and any cracking tends to follow the grain direction. This is a serious matter affecting the survival of the univalve animal, and nature has seen to it that strength is obtained by allowing successive layers to cross, rather in the way that wood

FIG. 2. A fine shell cameo in which grain directions have been lined in to show how successive layers have the 'grain' in directions roughly at 90° to each other. × 4

grain is crossed in a plywood sheet. Some parts of each shell may contain areas which are too dense to exhibit graining, and it may be that successive layers are separated by very thin ungrained layers. The coat of the head illustrated has exceptionally close grain and is probably approaching an area which would show no graining.

Mr Farn's interest was awakened by a question about shell cameo doublets and he rightly pointed out that these are unlikely to have been made owing to the difficulty in finding two pieces of concave shell which would exactly fit each other.

But, in searching through my own shell cameos, I found an antique one (Figure 3) in a simple gold mount which is made from almost flat shell, the carved front showing nicely developed grain and a backing which appears to be the normal orange-brown layer, but which is badly cracked (Figure 4) without any sign of the cracking being visible from the front. A powerful fibre optic light source allowed me to see into the cameo and obtain the photomicrograph shown in Figure 5. This shows a layer of what is

FIG. 3. An antique cameo which on closer examination proved to be a doublet. × 5

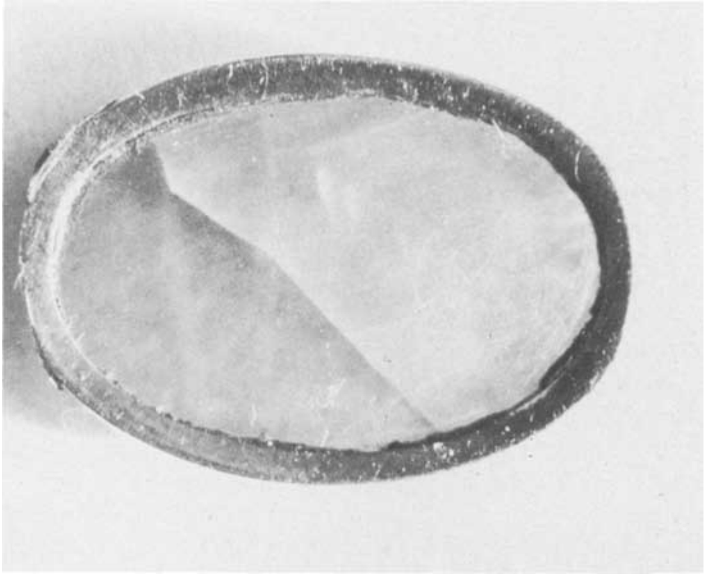

FIG. 4. Back of Figure 3, showing that this is badly cracked while the front is undamaged, suggesting that the two layers are not contiguous.

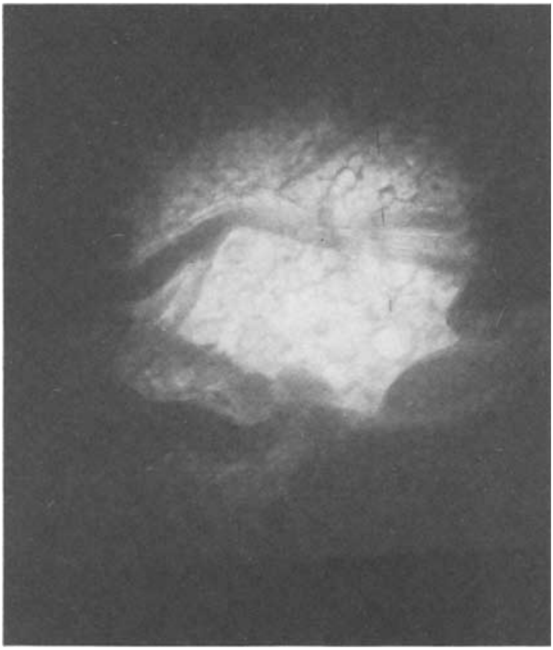

FIG. 5. A powerful light shone through the cameo doublet reveals a layer of what can only be a dried organic adhesive. The orange-brown of the back was almost certainly in this layer and when fresh probably affected the low-carved areas of the cameo front. × 10

undoubtedly dried out adhesive, almost certainly an organic glue, which is also probably responsible for most of the colour seen in the backing layer. Mr Farn is probably right in his surmise that such a cameo would be difficult to make, but this is proof that it is not impossible. *Why* it was made is not known.

A further reward resulted from this search. Another white cameo, earlier dismissed as a thin and rather uninteresting shell carving, showed no signs of any of the expected graining and had a very glassy looking base layer. It was cold to the tongue (shell cameos are also colder than paste in this test), was birefringent in all positions between crossed polars and eventually proved to be a very nice antique chalcedony hard-stone carving on a classical satyr-and-nymph theme.

Cameos have been moulded in a porcellanous pink and white paste, but these never show any graining.

[*Manuscript received 7th May, 1981.*]

OILED OPALS

By R. KEITH MITCHELL, F.G.A.

Way back in pre-war days I remember a very reputable jewellery manufacturer buying a badly cracked ruby and commenting that I would not recognize the stone once he had finished oiling it.

It is fairly common knowledge that cutters have made a practice of oiling some emeralds to reduce the visibility of cracks. Here it is said that heated tallow is used, but there is no definite information on the process, which is probably regarded as a lapidary's secret.

In the past year or so I have seen a number of very nice opals offered with a note that they have been oiled. The prices asked have been quite low for the apparent quality of the stones.

Opal is known to consist of close-packed spheres of amorphous silica which, when these are in regular layers and of one size, give rise to the well-known play of colour due to diffraction at a lattice of voids. These voids are the spaces between the submicroscopic spheres which, although in contact with their neighbours, cannot fill all the space available.

It is known that all opal contains from 6% to 10% of water. Most of this is held in the voids or interstices between the spheres, but some may be trapped in the spheres themselves.

In opals from some localities there are sufficiently spaced gaps in the structure to allow a very slow evaporation of this water content, and eventually fine hair-line cracks develop due to shrinkage, and, being air-filled, these are all too obvious and spoil the opal.

Figure 1 illustrates such an opal ruined by drying cracks. In this stone the play of colour is confined to the front of the cabochon. The back is a putty-coloured potch which was evidently less porous and did not shrink by the same amount. Another large opal had a similar structure, but both the gemmy section and the potch had developed drying cracks. In this case the cracks in the two layers were roughly at 90° to each other.

Cracks in opals are more easily seen if the stones are examined with light passing from one side across the cracks. If it passes down

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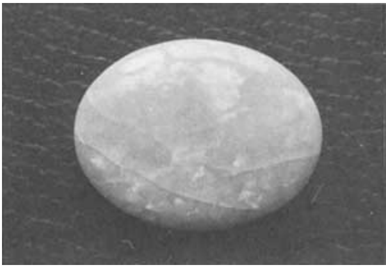

FIG. 1. Untreated opal ruined by drying cracks.

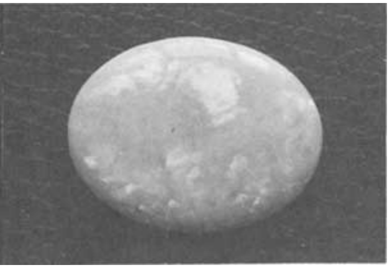

FIG. 2. The same opal after immersion in a fine oil. Cracks are completely concealed but are *not* cured.

their length the cracks are less easily seen. Vertical illumination also tends to make them less visible.

By no means all potch-backed stones will develop cracks. Equally it cannot be said that a homogeneous stone will not crack. Usually stones from certain localities seemed to be more prone to the trouble than are stones from another area. Drying cracks usually come right to the surface of the stone but rarely go right through it.

Figure 2 shows the same opal after immersion in a fine oil at room temperature for several hours. The oil has a RI of 1.413, a little lower than that of the opal. Ideally they should be of the same RI, but it is not easy to find a stable oil, which will not discolour, with the exact RI. This one is close enough, and it has entered the cracks and removed the air in all but one place on the left-hand edge of the stone. They are no longer visible. The failure to fill this one crack is probably due to its width at this point. One might expect air to be trapped by the oil, but it seems to penetrate fully and to push out the air.

The cracks may become visible again fairly quickly as the oil itself evaporates, but it will be some time before they become as obvious as they were before treatment. Oil might oxidize, but, cut off from air by the closeness of the cracks, this would take time. It is more likely to become dirty by contamination.

If such opals are offered as untreated stones their detection may be a little difficult. Newly treated stones might have a faint scent of the oil about them; their surface may be slightly oily and difficult to wipe clean. Immersion in a solvent, such as spirit, may remove some of the oil and bring the cracks into prominence again. Soaking in warm water for some hours in a black container may reveal 'oil-slick' traces.

A very careful examination of the surface of the stone will often reveal the edges of otherwise invisible oiled cracks as very fine hair-lines. To see these it is necessary to allow light to reflect from the surface and to examine this closely with a 10× lens. Concentrate on the reflected light and ignore play of colour or any subsurface light. In the stone illustrated only two of the several cracks were detectable in this way. If the crack edges are easily seen then the stone can be one which was unusually badly affected by the drying cracks. Easy-to-see cracks after treatment usually mean that the cracks were wider than usual, or that the stone has been repolished. Felt-pen ink rubbed into the surface of the opal may concentrate in the edges of cracks and make them more easy to see. This is destructive testing, but such ink can usually be removed by wiping it immediately with a swab of cotton wool moistened with spirits. The ink may collect in surface scratches, so some care in interpretation is needed.

The ethics of oiling are not clear. If an opal is sold with the information that it is an oiled stone then no one can complain. If the seller knowingly omits to mention the fact of oiling and obtains a higher price for a damaged stone, then clearly that is improper. But difficult problems may arise when a seller is quite unaware that the stone he is selling has been oiled. Whether it is actionable as contrary to law is a question for lawyers, depending as it does both on the precise facts and on whether they can be proved.

[*Manuscript received 25th May 1982.*]

SOME OBSERVATIONS AND MISCONCEPTIONS REGARDING OPAL

By G. A. COOK, F.G.A.

> Now the melancholy god protect thee, and
> the tailor make thy doublet of changeable
> taffeta, for thy mind is a very opal!
> Shakespeare, *Twelfth Night*

Opal—that wonder of the mineral world whose mysterious fire has lighted men's imaginations since early times—has had a curious and chequered history as a gemstone of worth comparable to the change in its own scintillating patterns.

Until recent times, opal must have been a rare gemstone. Pliny states that India was the sole origin of the stone. This location is disputed by many authorities, who state that Hungary must have been where the mines were situated since it was closer. Hungary in those days was possibly incorporated in the frontier province of Dacia, the Hungarian plain being the western portion of this area. The situation of the mines is only a 'stone's throw' from the plain at Červenica, and other locations nearby, which are in present day Czechoslovakia. Records suggest that mining started in the thirteenth or fourteenth centuries, and evidence is required of mining prior to this.

The Romans, Pliny in particular, are generally accurate in describing locations of gems. For instance, India is held to be the source of diamonds, rubies, sapphires, star sapphires, aquamarine, moonstones and emeralds. India produces these stones to this day, emerald having comparatively recently been rediscovered there. There is thus little reason to dispute Pliny stating that India is the only location in his time, although he describes another stone called 'Paederos' which seems to be similar to opal and has a white 'background': the finest quality of this came from India, but he mentions other sources for lower grades. Common opal is found near Bombay. Could not the mines be long lost and await rediscovery? Or were they perhaps worked out? Or was Pliny referring to other stones which display iridescence, like labradorite, opalized agate, or the recent discovery in Canada called Ammolite?* The name of opal itself is of Sanskrit origin and means

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*See W. Wright, 'Korite'—Fossil Ammonite Shell from Alberta, *J. Gemm.*, 1981, XVII, 6, 406-15; the name for this material now approved by C.I.B.J.O. is 'ammolite'.—Ed.

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'precious stone', having reached us through Latin.

Opal has had a reputation in recent times for bad luck. This is probably due in part to its softness, its sensitivity to sharp knocks and pressure. Amorphous material lacks the durability of crystal.

Bad luck? Possibly as an investment. However, if opal is taken care of, it should stand the test of time. There is a specimen in the Museum of London which is a fine water opal—part of a jeweller's hoard from the seventeenth century. The stone is as fresh as the day it was cut. It would be intriguing to discover the origin of this stone.

Opal should avoid modern detergents. If the stone has crazing, the solution of water can seep into these fissures through the lowering of surface tension and undermine the stability of the gem. Tales of woe have been heard of opal disintegrating during the domestic chore of washing dishes, not to mention the deleterious effect of the abrasion of this process. Gemstones deserve better treatment.

Sir Walter Scott is regarded as the instigator of the legend of the 'Curse of the Opal', possibly drawing, we hear, on earlier Germanic legends. The relevant passages occur in *Anne of Geierstein* published in 1829. This late production of Scott was written at a time when he was endeavouring to wipe out a large debt and prolifically produced several uninspiring works. The novel takes place in medieval Germany and Switzerland during the time of Charles the Bold and concerns the fortunes of one Arthur Philipson, who is in reality the son of the Earl of Oxford, working for the Lancastrians who are anxious to secure the Duke of Burgundy's favours.

A minor character, Lady Hermione, who has little bearing on the main plot, wears an opal talisman clasp in her hair. This lady is said to be of Persian origin and she appears as if out of nowhere. She marries the Baron Arnheim and becomes his spiritual tutor. Hermione fancies that the opal reflects her many moods. A malevolent character called Madame de Steinfeldt tries to cause rumours about the family indulging in sorcery. To 'confute the calumnies' of this lady, Baron Arnheim makes a display of dropping holy water on his wife's forehead, a drop of which accidentally touches the stone with which Hermione always avoided having contact. At this moment the stone gives out a sparkle and goes lifeless. After which time the girl goes into a swoon and is carried off to her room. When the room is opened after a period of time, nothing is found except a pile of ashes on her bed. Later in the novel it is mentioned that the Baroness de Steinfeldt was thought to have administered poison. The opal was supposed to warn its wearer of the approach of poison. This indicates that, although the lady suffered an unfortunate fate, it was not in fact due to the opal. But, although the gem changed, its wearer could not avoid the subtle poison of hate. Scott states that the holy water dulled the stone. This property does not occur with normal water. Opal brightens in water; this fact is often used when rough material is sold. Hydrophane opal too becomes iridescent when immersed in water.

In the book it mentions the malignant baroness also possibly laid claim to the stone as the Persian lady's family won it in battle from the Soldan (Sultan) of Trebizond. This is interesting as Trebizond is in present day Turkey, which is a minor source of opal; in the region of Gediz in Anatolia fire opal occurs in rhyolite. Later in the book, however, another girl, Annette Veilchen, states: 'Oh! a single daisy twisted with content into one's hair is worth all the opals in India, if they bind us to torment ourselves and other people, or hinder us from speaking our mind, when our heart is upon our tongue'. This indicates that country as being thought to be a major source of the gem in Scott's day; the rest of the sentence is open to interpretation.

As far as being a Talisman to warn the bearer of the approach of poison—the present writer can attest that once, while camping on a beach in Mexico, he awakened in the nick of time as a scorpion was about to sting his neck. He had in his possession a box of opals recently negotiated. Bad luck? Certainly not. A Talisman? Well, he would certainly like to think it was at least due to this in part.

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Pliny, *The Natural History,* translated by John Bostock and H. T. Riley, book XXXVII, chap. 21, pp.415-17: chap. 46, pp.436-7, London, Henry G. Bohn, 1857.

Scott, Walter. (The Waverley Novels, Vol. XXIII, 1829.) *Anne of Geierstein,* chap. XI, pp.131-8: chap. XXII, pp.284, 295. (1899 edn.)

Kunz, George Frederick. *The Curious Lore of Precious Stones.* chap. V, pp.143-75. J. B. Lippincott Co., 1913. (Dover edn, 1971.)

Webster, Robert. *Gems. Their Sources, Descriptions and Identification.* 2nd edn, chap. 10, pp.187-96. London: Butterworths, 1972.

[*Manuscript received 14th April, 1982.*]

GEMMOLOGICAL ABSTRACTS

BAKER (E.). *The 'big hole' has been drained.* Lapidary J., **36**, 1, 36-58, 20 figs (19 in colour), 1982.

Gives an account of a visit to some of the South African diamond mining operations. M.O'D.

BALL (R. A.). *Further studies on iridescence of marine shells.* Aust.Gemmol., **14**, 10, 266-71, 2 diagrams, 8 figs, 1982.

An account of earlier work on this subject with photomicrographs which emphasize the structural dependence of the phenomenon. R.K.M.

BANERJEE (A.), PENSE (J), SCHNEIDER (W.). *Der schwarze Diamant.* (Black diamond.) Uhren, Juwelen, Schmuck, 6, 47-9, 5 figs, 1979.

The possibilities of black diamond as an ornamental stone are discussed. M.O'D.

BOLICK (K.). *We mined for emeralds.* Lapidary J., **36**, 2, 410-12, 1982.

An account is given of amateur mining in the Hiddenite area of North Carolina. M.O'D.

BOSCH FIGUEROA (J. M.), DE LA FUENTE CULLELL (C.), ARBUNIÉS ANDREU (M.). *Estudio mineralogico y gemologico de los olivinos de Yaiza (Lanzarote).* (Mineralogical and gemmological study of olivine from Yaiza (Lanzarote).) Gemologia, **14**, 49/50, 5-18, 9 figs (1 in colour), 1981.

Olivine from the basaltic lava of Lanzarote has some gemmological interest. Physical and optical properties are established; material is found as rounded pebbles, some containing chromite crystals. SG is 3.341-3.364, RI 1.650-1.659, 1.688-1.694 with a DR of 0.035-0.038. Three absorption bands were detected at 497, 474 and 455 nm. M.O'D.

BROWN (G.). *The geological time scale.* Wahroongai News, 9-10, December, 1981.

Lists geological ages, eras, periods and epochs, but not all in the same direction. R.K.M.

BROWN (G.). *A system for identifying turquoise.* Wahroongai News, 21-3, December, 1981.

A logical sequence for identification of turquoise and detection of imitants, simulants, synthetics, dyed and waxed stones. R.K.M.

BROWN (G.). *Identifying Gilson synthetics.* Wahroongai News, 5-6, January, 1982.

Very brief identifying features for Gilson synthetic emerald, turquoise, opal, lapis lazuli and coral. R.K.M.

Brown (G.). *A visit to Australia's first commercial emerald mine.* Wahroongai News, 13-17, 2 figs, April, 1982.

An interesting account of an historic mine near Emmaville in the mountains of NE. New South Wales which was discovered in 1890. It produced green beryl which shows no apparent sign of chromium content and so is referred to by the writer as '? emerald'. The yield was poor in quality, and, once the exploratory vertical shaft had been driven to 300 feet without finding more and better deposits, it was more or less abandoned until 1965, when it was surveyed again. In 1981 it was 'dewatered and demucked' with the idea of working the shallow lode again. [Abstracter has a small parcel of 'Australian emerald rough' which almost certainly dates from the 1890s. The crystals correspond closely with Mr Brown's description of the beryl from this mine. They show no sign of chromium but are recognizably an emerald colour.]

R.K.M.

Brown (G.). *An interesting amber imitation.* Aust.Gemmol., **14,** 10, 272-3, 3 figs, 1982.

A bead necklace of amber enclosed in polyester resin. R.K.M.

Brown (G.) *Lechleitner coated beryl inclusions.* Aust.Gemmol., **14,** 10, 274-5, 6 figs, 1982.

Well illustrated account of these inclusions. R.K.M.

Brown (G.). *Metamict gemstones.* Wahroongai News, 19-21, May, 1982.

A general explanation of the metamict condition. Raises question why U and Th atoms cause metamictization in some minerals and not in others. [Age of mineral deposits has something to do with it. Gem deposits of Sri Lanka, source of the only two metamict gems, low zircon and ekanite, have derived from extremely old rocks. The process is a very long slow one.] R.K.M.

Brown (G.). *Korite = a unique organic gem.* Wahroongai News, 17-18, May, 1982.

A description of this ammonite gem material* which retains its spectacular iridescence despite 70 million years as a fossil. History of its discovery and marketing is given. Author suggests that it can be identified by its RI (1.52-1.67) and its SG (about 2.80). [But most material is made up into doublets with quartz cabochon tops which would make such tests difficult. Iridescence is probably enhanced by the dark matrix.] R.K.M.

Brown (G.), Bracewell (H.). *Chudleigh Park peridot.* Aust.Gemmol., **14,** 10, 253-6, 8 figs, 1982.

Interesting account of a little-known source of gem peridot at Mount Batchelor in North Queensland. Cut stones up to 20 ct possible in yellow-green to deep green. Brown shades are not found, suggesting that the material is low in iron. Reticulated cracks and other inclusions are thought to be peculiar to this source. R.K.M.

Brown (G.), Snow (J.). *The Portalab.* Aust.Gemmol., **14,** 10, 258-63, 11 figs, 1982.

A report of the G.A.A. Instrument Evaluation Committee on a portable testing kit of zoom microscope with fibre optic quartz halogen light source, polariscope,

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*The name for this material approved by C.I.B.J.O. is 'ammolite'.—Ed.

spectroscope, UV lamps, refractometer, heavy liquids, dichroscope, hot-point tester, polishing cloth and electric circuitry, which packs into a 45 × 33 × 15 cm carrying case and weighs 13.5 kg. Total cost £1500 plus. Stability of microscope mount is criticized. R.K.M.

BROWN (G.), KELLY (S. M. B.), MAIN (A.). *Examination of a cat's-eye iolite.* Aust.Gemmol., **14,** 10, 264-5, 6 figs, 1982.

A rare form of this gem. R.K.M.

BUTLER (J.). *Suggested fluctuations in trade popularity of some gem materials during 1980.* Wahroongai Nes, 7-8, January, 1982.

Attempt to assess popularity by amount of trade advertising. [This confuses cause with effect.] R.K.M.

COOKE (C.). *Collecting gemstones in Wyoming.* Lapidary J., **36,** 1, 228-34, 9 figs, 1982.

Though jade is the most important gem material found in the State of Wyoming, other materials of ornamental interest are also found. They include agatized wood, dinosaur bone, chalcedony with black dendrites, small diamonds and obsidian. M.O'D.

CROWNINGSHIELD (R.). *Cultured ¾ blister pearls.* Gems & Gemology, **XVIII,** 1, 36-8, 8 figs in colour, 1982.

A new type of three-quarter blister cultured pearl from the Philippines, in which the nacre covers a large bead very closely. Compares favourably in durability with the much more fragile mabe blister pearl which suffers from structural weakness and is easily damaged. The new type is often attractively coloured and marked with slight convergent grooves. R.K.M.

DAHLBERG (J. C.). *Take another look at Minnesota rocks.* Lapidary J., **36,** 1, 66-72, 17 figs in colour, 1982.

Among ornamental stones found in the State of Minnesota are quartz (rock crystal), jasper, massive goethite, pyrite, marcasite, yellow binghamite and haematite in the form of kidney ore. M.O'D.

DAVIES (G.). *The origin of the 'N2' absorption band in natural yellow diamonds.* Portugaliae Physica, **12,** 3/4, 241-61, 6 figs, 1981.

The N2 band, one of the causes of the yellow colour in some natural diamond, is shown to correlate in strength with the N3 band (which absorbs mainly in the ultraviolet portion of the spectrum). The N2 band absorbs in the visible. The yellow colour is caused by the operation of both bands. The N2 band is discussed. M.O'D.

DILLON (S.), ed. *Gems news.* Gems & Gemology, **XVIII,** 1, 58-61, 3 figs (2 in colour), 1982.

Ashton Mining (Australia) predict annual production circa 20 million carats of diamond by 1986. Cut diamonds mêlée from Russia is causing anxiety among cutters in Belgium. Ghana's remaining diamond mine may close. Australia is backing diamond production in Guinea. Indian cutters seeking new sources of rough diamond. Israel diamond processing is increasing. South Africa opens diamond bourse. Sunsvall, Sweden, is location of first diamonds found in Europe. South African company has started diamond cutting in Taiwan for Far East market. General Electric, U.S.A., are imprinting diamonds with electro-static identification which attracts a dust to form numbers which can then be wiped away.

Aquamarine specimen from Dassu, Pakistan, is illustrated. Synthetic amethyst is being marketed as natural and is largely undetectable. Russia is producing synthetic opal. Israel is now the largest emerald polishing centre. A 4.02 carat taaffeite is reported. Pala tourmaline mine has tunnelled 715 feet into new pegmatite areas and found four pockets of crystals, mostly uncuttable.

Tucson Gem and Mineral Show: aquamarine from Brazil and Afghanistan, fine emeralds from Afghanistan and Pakistan, Umba River corundums, orange garnets and tsavolites, cultured Biwa pearls from Japan and China, peridots, spinel, spodumene, sugilite, topaz and tourmaline were on display. Tanzanite was scarce.

R.K.M.

DONNAY (G.), DONNAY (J. D. H.). *Symmetry and twinning in diamond.* Soviet Physics-Crystallography, **26**, 6, 729-32, 1981.

Though tetrahedral habit is known in natural diamond it has never been reported from synthetic material. It is believed that natural tetrahedra grow in the presence of graphite and methane (i.e. 3- and 4-coordinated carbon). Diamond is assigned by structural crystallographers to point group $m\bar{3}m$, which assumes eight equivalent carbon atoms in the cell. Morphologists assign observed forms to $\bar{4}3m$, which postulates two types of carbon atom. M.O'D.

FERGUSON (R. W.). *Graveyard Point 'Pilgrimage'.* Lapidary J., **36**, 2, 384-401, 23 figs (15 in colour), 1982.

Graveyard Point lies just inside the Oregon border with Idaho. The material sought is plume agate with a clear to white background with plume-like formations which can be orange to brown or even black due to marcasite inclusions. M.O'D.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVIII**, 1, 44-9, 21 figs (18 in colour), 1982.

Diamond with roiled table facet, an emerald ring from a three hundred year old wreck, and a fake emerald crystal made by hollowing out a low grade beryl crystal and filling it with green cement, are described and illustrated. A possible synthetic green beryl reported from Australia. Other unusual synthetic emeralds are described and illustrated, some transmitting red flashes in strong lighting. A light pink carved head proved to be pink common opal. Mr Crowningshield reports that Lake Biwa pearl cultivators have some control over the colour and shape of the pearls produced. He saw Australian blister pearls which used coloured plastic inserts which were highly transparent to x-rays. Also he reports that most Australian yellow sapphire rough is heated to remove the green element and to lighten colour. Some Bangkok light yellow sapphire from heated colourless rough is colour fugitive. Darker stones said to be permanent in colour. Sugilite used in bead, cabochon and carved forms is splendidly illustrated. A 10.13 taaffeite identified at Santa Monica lab. is thought to be the largest one so far recorded. R.K.M.

GOLDMAN (S.). *GE develops process to brand codes in diamonds.* National Jeweler, pp.41-2, 2 figs, May 1, 1982.

A report on the work of Dr R. C. DeVries and R. E. Tuft, of General Electric, Schenectady, N.Y., which describes the formation of an identification code or symbol beneath the table facet of a polished diamond by means of ion implantation techniques. The ion implanter emits a beam of charged ions which penetrates the diamond's surface, creating through a code-bearing mask a pattern which has an electrical conductivity different from the surrounding area. This implanted pattern can be revealed for identification purposes by giving the diamond an electrostatic charge and then dusting it with a special powder. Application of the method may be inhibited by the high cost of the equipment and by the fact that the implanted pattern can be altered or removed by repolishing. P.G.R.

GOOD (A.). *Chemically-induced colour in sapphire.* Gems, **13**, 5, 32, 1 fig, 1981.
[The Abstracter has asked for the abstract of this paper already published in J.Gemm., 1982, XVIII (2), 165 to be replaced by the fuller abstract which follows.—Ed.]

Geuda stones from Sri Lanka can be clarified by causing titanium dioxide in the stone to migrate into the lattice as a result of heating. Stones without latent rutile are now being treated chemically to produce a similar improvement in colour and clarity. One treatment consists of coating the sapphire in a powder containing the necessary transition element and then applying heat. One stone examined had an even colour and characteristic Geuda colour (steel blue). A surface skin of colour was seen on immersion in methylene iodide, together with surface pitting and diminution of colour towards the edges of the main pavilion facets. These were shown to have been repolished. The stone was inert under UV and only a faint trace of absorption at 450 nm could be seen. M.O'D

HOBBS (J. M.). *The jade enigma.* Gems & Gemology, **XVIII**, 1, 3-4, 6-19, 16 figs (13 in colour), 1982.

A careful summary of jades and jade imitants, including natural minerals, dyed minerals and glasses, and of methods of identifying them. [It is not clear whether the inserted, unattributed article on page 5, with one unnumbered fig. in colour, entitled *The Question of Jade Nomenclature,* is, or is not, part of Ms Hobbs's paper. This attempts to clarify the nomenclature of the two true jades, never easy when there are substantial variations in composition between specimens.] R.K.M.

HODGKINSON (A.). *Methods for identifying new diamond doublet.* Retail Jeweller, **21**, 522, 21, 4 figs, 1982.

In the absence of reflectivity and thermal conductivity meters a doublet with diamond crown and CZ pavilion will show reflection of an outside object or of light in both table and junction planes. Differences in girdle texture serve to identify unmounted specimens M.O'D.

JENSEN (D. E.). *Travels with two rolling stones.* Lapidary J., **36**, 2, 390-4, 13 figs (12 in colour), 1982.

Reminiscences by the retired Vice-President of Ward's Natural Science Establishment of Rochester, New York, in which travels to Idar-Oberstein, Castleton (Derbyshire, England) and a variety of locations in the eastern United States are described. M.O'D.

KOIVULA (J. I.). *Some observations on the treatment of lavender jadeite.* Gems & Gemology, **XVIII**, 1, 32-5, 5 figs in colour, 1982.

42 specimens of lavender jadeite were sawn in two, and one half of each was heated. Organic dye should be bleached by this treatment, and 28 specimens were so bleached. These all showed strong orange fluorescence under long-wave ultraviolet light before heating. Assumption that these were stained stones was confirmed by visual identification of dye in crevices in stones. Remaining 14 stones showed weak brownish-red fluorescence under long and short ultraviolet; no dye was seen in cracks. The two groups differed in their fluorescence under x-rays. It is still uncertain whether the second group contained jadeite treated with inorganic dyes.
R.K.M.

LIVINGSTONE (A.). *Laser saw cuts diamonds without breakage fear.* National Jeweler, p.69, 1 fig., May 1, 1982.

Contains a description of the equipment developed by J. Ehrenwald, President of Laser Sawing Services, New York. The cutting loss of 3 to 4% using the laser saw (this is 2% higher than with conventional sawing methods) is compensated by the ability to saw difficult stones and to produce ornate shapes such as butterflies, horse heads and hearts. Laser sawing is two to three times faster than conventional sawing or cleaving methods, but is five times more expensive to operate. P.G.R.

McMACKIN (C. E.). *Hunting Arizona's banded agate nodules.* Lapidary J., **36**, 1, 166-70, 10 figs, 1982.

A personal account of the discovery of nodules of banded agate, some with an attractive orange tint, in the eastern Arizona. M.O'D.

NOGUES CARULLA (J. M.). *Tecnicas de crecimiento cristalino.* (Techniques of crystal growth.) Gemologia, **15**, 51/52, 5-24, 11 figs, 1981.

A useful summary of the various techniques by which gem quality crystals may be grown. M.O'D.

PARADISE (T. R.). *The natural formation and occurrence of green quartz.* Gems & Gemology, **XVIII**, 1, 39-42, 2 figs in colour, 1982.

In a region of the Nevada-California border, amethyst, green quartz and citrine are found in the one locality. All three colours are due to iron in one form or another. Distribution suggests that green was produced by heat from an ancient rhyolite extrusion. R.K.M

PENSE (J.), BANERJEE (A.). *Identifizierung von Perlen nach einer neuen Methode.* (A new method of pearl identification.) Uhren, Juwelen, Schmuck, 22, 31, 2 figs, 1978.

The possibilities of neutron activation analysis in pearl testing are briefly discussed. M.O'D.

SCHNEIDER (W.). *Der Opal und seine Nachahmungen.* (Opal and its imitation.) Uhren, Juwelen, Schmuck, 22, 23-5, 6 figs, 1978.

Opal, synthetic opal and Slocum stone are reviewed and their constants and composition tabulated. M.O'D.

SCHNEIDER (W.). *Die instrumentelle Neutronenaktivierungsanalyse (INAA) und Möglichkeiten ihrer Anwendung in der Edelsteinkunde.* (Neutron activation analysis and its possibilities for use in gem testing.) Uhren, Juwelen, Schmuck, 21, 63-5, 4 figs in colour, 1981.

Neutron activation analysis may be useful in gem testing since it can identify trace elements in the specimen without destroying it. Ir, Pt and Mo have been usefully identified by this method and its use for the detection of some man-made stones is thus clear. M.O'D.

SCHRADER (H.-W.). *Zur Unterscheidung von natürlichen und synthetischen Smaragden.* (The recognition of natural and synthetic emerald.) Uhren, Juwelen, Schmuck, 19, 105-10, 5 figs, 1981.

Data so far available on natural and synthetic emerald are collated and reviewed. M.O'D.

SCHWARZ (D.). *Kubisch-stabilisierte Zirkonoxide als Diamant-Imitationen.* (Cubic stabilized zirconium oxide as a diamond imitation.) Uhren, Juwelen, Schmuck, 22, 26-8, 6 figs, 1978.

Composition, structure and physical constants for ZrO_2 are given. Eu-doped material shows a characteristic absorption spectrum. M.O'D.

SCHWARZ (D.). *Fluoreszenz von Mineralien, Edelsteinen und Edelstein-Imitationen.* (Fluorescence of minerals, gemstones and gemstone imitations.) Uhren, Juwelen, Schmuck, 7, 210-16, 9 figs, 1980; 9, 87-92, 7 figs, 1980; 15, 41-4, 12 figs, 1981.

A comprehensive review of luminescence as it effects minerals and gemstones. M.O'D.

SCHWARZ (D.). *Chemismus und Fluoreszenzverhalten natürlicher und synthetischer Spinelle.* (Chemistry and fluorescence behaviour of natural and synthetic spinel.) Uhren, Juwelen, Schmuck, 20, 57-60, 3 figs, 1981.

Synthetic spinel was found to be very pure when examined by optical emission spectroscopy; some Si and some Fe were detected in addition to the elements used for coloration. Mn^{2+} and Cr^{3+} are the chief ions involved in fluorescence. Ti^{4+} is responsible for the bluish-white fluorescence in synthetic spinels. Ga, Ni and Zn have been detected in some natural stones. M.O'D.

SMITH (W. D.). *Missouri lace agate.* Lapidary J., **36**, 1, 90-2, 7 figs, 1982.

Most lace agate in the State of Missouri is found in Washington County where it occurs on the surface with barite. M.O'D.

SRIVASTAVA (S. B. L.). *Gemstone deposits in Rajasthan.* Gem World, **9**, 11, 21-30, 1981.

Chief among the gem deposits in Rajasthan are those in which beryl (emerald and aquamarine) are found. Garnet, topaz, fluorite and apatite also occur. Some pink corundum not of gem quality has been discovered, and it is hoped that better qualities may appear in the future. Almandine garnet occurs at 34 different places in the state. M.O'D.

SUNAGAWA (I.). *Natural and synthetic gem materials, a comparison.* Bulletin de Minèralogie, **104**, 2/3, 128-32, 3 figs, 1981.

A general comparison of growth features of natural and man-made gemstones with particular reference to surface microtopography (emerald), internal morphology (diamond). M.O'D.

SWINDLE (L. J.). *Amethyst quartz with goethite inclusions.* Lapidary J., **36,** 1, 144-57, 21 figs, 1982.

Amethyst with inclusions of goethite are found in the pegmatite areas of Pike's Peak, Colorado. Some unusual specimens are described and illustrated. M.O'D.

TAYLOR (G.). *The new science.* Wahroongai News, 7-8, December 1981.

Expounds the basic law that all systems must fall to their lowest energy state and shows how this affects the growth of crystals. R.K.M.

TUCKER (E.). *Jade forms from ancient China.* Gems & Gemology, **XVIII,** 1, 20-31, 9 figs in colour, 1982.

A superbly illustrated paper on the historic and mythological significance and origins of the forms of jade carvings. R.K.M.

VASHISHTHA (S.). *Diamond and its simulants—1.* Gem World, **9,** 11, 25-36, 1 fig., 1981.

The chemical composition and physical constants of diamond are given with illustrations of some of the commoner forms. Important world sources are also listed. M.O'D.

VILARDELL (A.). *Relación entre las proporciónes de talla perfecta en estilo brillante del diamante.* (Relationship between the proportions of a perfect cut in brilliant style of diamond.) Gemologia, **15,** 51/52, 25-34, 5 figs, 1981.

Various angular relationships are illustrated in an attempt to find the ideal brilliant. M.O'D.

ZEITNER (J. C.). *The quest for green bolts—1.* Lapidary J., **36,** 2, 378-410, 22 figs (13 in colour), 1982.

This paper deals with emerald localities in North Carolina, with particular reference to the Rist mine, Hiddenite, Alexander County, where a large good quality parcel with a total weight of 3507ct was found in 1979. Some of the best emerald was found in a pocket with quartz and feldspar. A few of the stones have been cut. M.O'D.

Barite, the fascinating mineral. Journal of Gem Industry, **19,** 6, 69-74, 1981.

A general review of barytes and its (limited) gem potential. M.O'D.

The structure of matter. Wahroongai News, 11-16, February 1982.

An interesting resumé of the known facts of molecules, atoms and crystals. Basic facts clearly explained. R.K.M.

BOOK REVIEWS

BAUER (J.), BOUSKA (V.), TVRZ (F.). *Der Kosmos Edelsteinführer.* (Kosmos guide to gemstones.) Franckh'sche Verlagshandlung, Stuttgart, 1982. pp.226. Illus. in black-and-white and in colour. DM24.

This is a small-format guide of a kind by now familiar to those readers who find general works convenient to carry about. This one, translated from Czech and written by Czech authorities on minerals, is of more than passing interest to Western readers, since the examples depicted are almost all from East European or Russian localities. The text is unexceptional and the illustrations and production of quite good quality; a quick glance through the pictures shows a doubtful euclase depicted as such though the crystal is clearly tetragonal; too much red from the reproduction process spoils the picture of cordierite and the use of the names olivine, peridot and chrysolite is confusing, but on the whole the book is recommended. M.O'D.

CHU (A.) CHU (G.). *Jade—Stein des Himmels.* (Jade—stone of heaven.) Franckh'sche Verlagshandlung, Stuttgart, 1982. pp.151. Illus. in black-and-white and in colour. DM48.

Providing that the German title is not literally translated should the book as a whole be put into English, there should be no confusion with *Jade—stone of heaven* by Richard Gump, first published in 1962. This new book is well produced and covers the origin, working, pricing and detection of the jade minerals, with some quite elegant illustrations. There are a short bibliography and a list of German museums possessing jade collections. M.O'D.

LITTICH (F.). *Historische Diamanten und ihre Geschichte.* (Historic diamonds and their study.) Rühle-Diebener-Verlag, Stuttgart, 1982. pp.163. Illus. in colour. Price on application.

With unexpectedly and inexplicably large type (for these straitened days) this is an alphabetical list of most, if not all, named and celebrated diamonds. Preceding the text is a section of fairly well produced colour reproductions. Tables of diamonds by weight (both cut and rough) and a short bibliography conclude the book. M.O'D.

PERRY (N.), PERRY (R.). *Practical gemcutting.* David & Charles, Newton Abbot, 1982. pp.95. Illus. in black-and-white. £6.95.

This is a workmanlike addition to the already extensive range of books on faceting. Profusely illustrated in the text, it is intended to enable the reader to cut stones for himself without necessarily attending a formal class. It succeeds very well. The absence of a bibliography matters little in this case since it would only refer in the main to works similar to this one. M.O'D.

STRACK (E.). *Perlenfibel.* (A primer on pearl.) Rühle-Diebener-Verlag, Stuttgart, 1982. pp.168. Illus. in black-and-white and in colour. Price on application.

This bids fair to be the standard textbook on pearls in German, and an English translation would be welcome. Preceding the text is a section of 174 coloured photographs, and there are more pictures, in black-and-white, in the text. Well drawn diagrams illustrate some features of testing and a good deal of space is devoted to the various methods of pearl recovery. M.O'D.

ASSOCIATION NOTICES

OBITUARY

NORMAN ADAMSON HARPER

The untimely death, on 8th July 1982, of Norman Harper, F.G.S., F.R.G.S., F.G.A., Vice-President of the Gemmological Association, brought to an end the career of a remarkable man who had fought valiantly against increasing ill-health for a number of years.

A friendly, generous and kind-hearted man, with a natural ability to organize and to communicate, he had been Vice-Chairman and then an excellent Chairman of the Association for almost twenty-five years.

In the past Norman would introduce me as the chap who had 'done him out of the Tully Medal in 1934', and I would point out that Robert Webster was making a similar claim—they would have to fight for second place between them. These exchanges were made with the best possible good humour and without the slightest hint of animosity. Norman Harper was like that.

Born in Newcastle-upon-Tyne and educated in the North-East, Norman came down to Birmingham to join W. A. Perry & Co. in 1932. He was basically a forthright man, and this and much of his good natured humour and his very real appreciation and enjoyment of life undoubtedly stemmed from his early Geordie background. He was made a director of the firm, when it was formed into a limited company, and became joint Managing-Director when Alderman Perry died.

He obtained his Diploma in 1934, a year which he liked to describe as 'Vintage'. The War years saw service with the Auxiliary Fire Service and in 1946 he was among the first students to sit the Retail Jewellers' Examination and was the first holder of the Greenough Trophy. He became a member of the Gemmological Association Council in 1952 and was elected Vice-Chairman in 1955. In that year he organized, with others and in conjunction with the Birmingham Museum and Art Gallery, a very fine exhibition of gems. His 'Introduction to Gemstones', written at that time, is now the official guide to that section of the Museum.

From 1947 he taught Gemmology at the Birmingham School for Jewellers and was responsible for the gradual build up of instruments and specimens into a first class teaching collection.

He was the instigator of the Gemmological Association's Diamond Course, which had its beginning in his diamond classes in Birmingham in 1962. In 1965 he became our Chairman and served in that capacity with considerable distinction until ill-health forced his retirement in 1978. He then became a Vice-President of the Gemmological Association.

A member of the National Association of Goldsmiths' Council from 1954 to 1978, he was their Vice-Chairman and then their Chairman in the early 60s. He was a Guardian of the Birmingham Assay Office, a Freeman of the Worshipful Company of Goldsmiths and a Freeman of the City of London.

It is perhaps typical of a man with so great a zest for life that he should have taken up flying and become a skilled amateur pilot, taking part in International Air Races and specializing in aerobatics. In his younger days he enjoyed horse riding. He played golf, but described himself, with characteristic honesty, as an 'atrocious player'. Despite his many honours and achievements he was essentially a modest man.

Norman Harper leaves a widow, Brenda, and four sons and a daughter. Our heartfelt sympathy is extended to them in their great loss. He was an expert gemmologist and a very good jeweller, who strove always towards educating others to his own high standards. He worked constantly to promote the provincial centres of training. A fine public speaker and a good friend, whose passing is a grievous blow to all those who knew him, he will be greatly missed. R.K.M.

Mr Taichiro Imai, F.G.A. (D.1965), Tokyo, Japan, Chairman of the Gemmological Association of Japan, died on the 13th June, 1982. He was the first person in Japan to study and obtain our Diploma. He then devoted himself to promoting the study of gemmology in his country and set up the G.A.J. The British rules were used as a basis for the Association. Since then he had done much in Japan to improve the knowledge of gems and the standards of trading.

Professor Dr W. F. Eppler died on 5th June, 1982: a Tribute by B. W. Anderson will be published in the *Journal* in January next.

GIFTS TO THE ASSOCIATION

The Council is indebted to the following for their gifts:

Mr C. R. Cavey, F.G.A., Greenford, for a piece of rhino horn.

Mr R. A. Holt, London, for two fancy-coloured cut sapphires, one red tourmaline, one aquamarine crystal, one opal carving and one tourmaline cat's-eye.

NEWS OF FELLOWS

In May 1982, Mr Michael O'Donoghue, M.A., F.G.S., F.G.A., gave a course of four lectures on 'Gemstones' to the University of Kent Adult Extension Class at Sevenoaks. Mr O'Donoghue also gave a lecture on 'Commercial features of gemstones' to the Amateur Geological Society on 29th June, 1982.

On 12th August, 1982, Dr W. G. Cross, M.B., M.S., B.D.S., F.G.A., was elected Master of the Worshipful Company of Barbers (the 593rd Master since the Worshipful Company was formed in 1308).

MEMBERS' MEETINGS

Midlands Branch

On 4th July, 1982, members visited Wollaton Hall, Nottingham, and viewed the fine mineral collection exhibited there.

North-West Branch

On 3rd June, 1982, a social evening was held at the Northern Cricket Club, Moor Park, Thornton, Liverpool.

South Yorkshire and District Branch

On 8th June, 1982, at the Sheffield City Polytechnic, Mrs E. Holloway gave an illustrated talk entitled 'Myth and legend of the Japanese netsuke'.

ANNUAL GENERAL MEETING

The 51st Annual General Meeting of the Association was held at Saint Dunstan's House on the 12th May, 1982, at 6.00 p.m.

Mr David Callaghan, the Chairman, welcomed members and reported upon the work of the year, referring particularly to the various gifts received by the Association, especially the Chairman's Badge, the Hong Kong fan, and the Norwegian crystal group. He also mentioned the visits by the Secretary to Milan, Hong Kong, Tokyo and the XVIIIth International Gemmological Conference and G.I.A. Symposium in order to put the G.A. of G.B. in the forefront of the world of gemmology. He thanked the organizers of the practical gemmology week-ends to help students and also all those connected with the Jubilee celebrations, in particular Mr Eric Bruton for producing the catalogue and writing up the history and the Secretary for researching and collecting many of the facts.

The Chairman spoke of the changes in the Examination Prizes and the generosity of Prof. Dr Hermann Bank, F.G.A., which enabled us to offer annually two prizes—to be known as the Anderson/Bank prize for the Diploma Examination and the Anderson silver medal—in commemoration of Basil Anderson's 80th birthday.

Mr Alec Farn's retirement and Mr Ken Scarratt's appointment as Director of the L.C.C. Gem Testing Laboratory were mentioned by the Chairman; he also drew attention to the new Fellowship tie, which was produced to commemorate the Golden Jubilee. He expressed his thanks to Rayners for their continued interest in the Association and the production of gem-testing instruments, and finally he gave special thanks to Mr John Chisholm for all his good work with the *Journal* and Mr Lawson Clarke for his willingness to continue in office for another year.

The Treasurer gave his Financial Report and proposed the motion, which was seconded by Mrs S. Hiscox, 'That the audited Accounts and Report of the Council for the year ended 31st December, 1981 be and are hereby adopted', and it was carried unanimously.

Sir Frank Claringbull, Messrs David Callaghan, Noel Deeks and F. E. Lawson Clarke were re-elected as President, Chairman, Vice-Chairman and Treasurer respectively, and Messrs L. F. Cole, P. Daly, A. E. Farn, A. Hodgkinson, C. B. Jones and A. W. Round were re-elected and Mr J. P. Brown elected to the Council.

Mr Douglas King tendered his resignation from the Council, as he felt that the time had now come for him to step down to allow a younger person to be elected. His resignation was accepted with regret.

Messrs Hard Dowdy Watson Collin & Co. were re-appointed as Auditors of the Association.

COUNCIL MEETING

At the meeting of Council held on Wednesday, 12th May, 1982, at Saint Dunstan's House, (1) it was decided that with effect from 1st January, 1983, the membership subscription rates would be as follows:

Ordinary Members: £15 per annum

Fellows: £12 per annum.

(2) the following were elected to membership:

FELLOWSHIP

Coote, James W., Westlake Village, Ca, U.S.A. 1950
Heiskanen, Anu P. K., Helsinki, Finland. 1981
Hettiaratchi, Theja C., Berlin, W. Germany. 1981

ORDINARY MEMBERSHIP

Azaz, Henri N., Witney.
Bae, Sang Kea, Seoul, Korea.
Bagby, Craig, Gaylord, Mich., U.S.A.
Cavallero, Michele, Valenza, Italy.
Cotton, Pamela D., Manchester.
Dawson, Susan H., Grantham.
Devlin, Terry A., Westcliff-on-Sea.
Donkin, Josephine K., Potters Bar.
Down, Brian J., Newent.
Dyson, Glenn, Camberley.
Faridi, Waris J., Karachi, Pakistan.
Ferguson, Brian, Ottawa, Ont., Canada.
Galbiati, Franca E., London.
Golby, Nicholas G., London.
Gould, Lewis, London.
Griffiths, Paul A., Sutton Coldfield.
Howell, Stephen Q., San Francisco, Ca, U.S.A.
Huggett, Bryony C., Woking.
Imai, Seiichi, Fukuoka-Shi, Japan.
Karamallis, Stelios, Athens, Greece.
Khan, Deborah R., Bromley.
Kok-Visser, Astrid S., Nairobi, Kenya.
Larsson, Alf C., Kyrkslatt, Finland.
Li, Chung-Man J., Hong Kong.
MacKenzie-Graham, Sandra, Burlingame, Ca, U.S.A.
Mahaux, Jacques, Overijse, Belgium.
Martijnse, Christiaan-Jan, Groot-Ammers, Netherlands.
Meguro, Sadayuki, Tokyo, Japan.
Mubarik, Ahmad, Hayes.
Parker, Hazel, Macclesfield.
Pong, May-Mei H., Hong Kong.
Pozarnik, Florence, Chatenay Malabay, France.
Raney, Gerard, Redwood City, Ca, U.S.A.
Seaward, Patricia B., Torrance, Ca, U.S.A.
Shah, Chandni R., Nairobi, Kenya.
Shah, Nitin N., Mombasa, Kenya.
Stock, Cindy F., Wells.
Stuart, James T., Eugene, Oreg., U.S.A.
Taishi, Takanori, Los Angeles, Ca, U.S.A.
Thomas, Elizabeth L., Salisbury, Zimbabwe.
Tsui, Yee Wah J., Hong Kong.
Waylett, Colin P., Denia, Spain.
Wessmann, Steen, Hørve, Denmark.
Wong, Che Cheung J., Hong Kong.
Worden, Robert J., Blackpool.
Wurm, Lise A., San Francisco, Ca, U.S.A.
Zuhair, Nazeel, Dharga Town, Sri Lanka.

EXAMINATIONS 1983

Examination dates for 1983 are as follows:
Gem Diamond Examination: Monday, 6th June.
Examinations in Gemmology:
    Preliminary: Tuesday, 28th June
    Diploma:
        Theory, Wednesday, 29th June
        Practical, Thursday, 30th June (also in London Tuesday, 28th June and Friday, 1st July).

THREE-DAY DIAMOND GRADING AND GEM IDENTIFICATION COURSES

The Gem Testing Laboratory of the London Chamber of Commerce started in September a series of three-day courses for Diamond Grading and a separate course for Gem Identification. Both courses will be repeated monthly. Full details available from The Director, L.C.C. & I., Gem Testing Laboratory, 36 Greville Street, London, EC1N 8AU.

GEMS, JEWELS AND GEOLOGY COURSE

The Geological Museum and the Department of Extra-Mural Studies of the University of London are arranging a 12 week lecture course to be held at the Museum. The course, which is entitled 'Gems, Jewels and Geology', begins on the 12th January, 1983, and meetings will start at 18.30 hours. The fee for the whole course is £12 and anyone wishing to have further information should write to the Department of Extra-Mural Studies, University of London, 26 Russell Square, London, WC1 5DQ.

The course is designed to link the formation of gem minerals in their geological environment with various methods used in their mining and recovery and their ultimate use in jewellery both ancient and modern. The lecturers are experts in their respective fields and will be drawn from the national museums and famous gemmological laboratories.

DR JOHN SINKANKAS

Captain John Sinkankas, U.S.N. (retd), well known to all gemmologists as the author of fine books on gemmological subjects, received the degree of Doctor of Humane Letters, *honoris causa,* on 20th May, 1982, from the William Paterson College of New Jersey, where he was a member of the class of 1936.

G.I.A. ALUMNI ASSOCIATION

The formation of the G.I.A. Alumni Association has recently been announced by Mr Richard T. Liddicoat, jr, Hon. F.G.A., President of the Gemological Institute of America. Fellows of the Gemmological Association may become Associate Members (annual subscription $60). Further information may be obtained from Mr Robert A. Earnest, Executive Director, 1660 Stewart Street, Santa Monica, California 90404, U.S.A. [telephone (213) 829 2991, ext. 279].

LETTERS TO THE EDITOR

From Mr R. J. Peace, B.Sc., F.G.A.

Dear Sir,

Many gemmology students apparently find difficulty in visualizing the precise shape of the spinel twin. The usual diagram presented in textbooks is Figure 1.

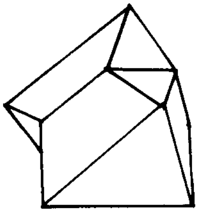

FIG. 1.

The twin is theoretically derived by cutting a regular octahedron with a plane passing through the midpoints of the six sides (the twinning plane) and rotating one of the resulting halves through an angle of 180° in this plane (Figures 2 and 3).

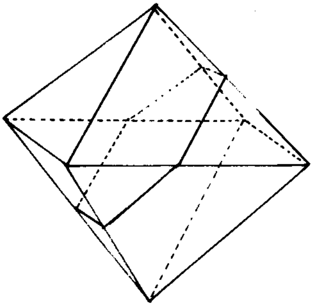

FIG. 2.

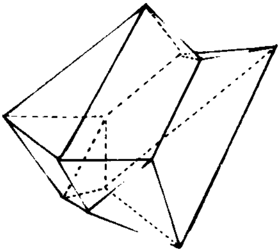

FIG. 3.

The spinel twin diagrams, Figure 1 and Figure 3, do not readily show that

(i) the cross section through the octahedron is a regular hexagon,

(ii) the front and rear faces are parallel equilateral triangles,

(iii) the re-entrant angles formed by the small triangular faces are equal to and in the reverse direction of the angles between the tetragonal faces.

As an alternative approach, I suggest that the spinel twin shape can be *envisaged* as being made from a hollow equilateral triangular prism that has been subjected to pressure at the midpoints of the three vertical sides in directions along the bisectors of the equilateral angles and acting in a horizontal plane (Figure 4).

When this occurs, the mid cross-section becomes a regular hexagon, the vertical height very slightly decreases and re-entrant angles are formed, whilst the remaining alternate faces of the hexagon 'bulge outwards'. The resulting shape can be represented as Figure 5.

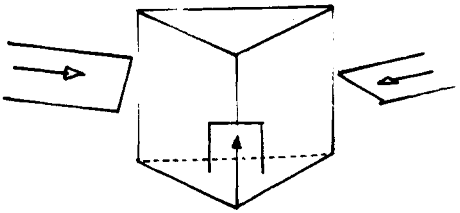

FIG. 4.

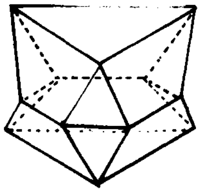

FIG. 5

In thinking of a trigonal prism subjected to pressure in this way it must be clearly understood that there is no suggestion that this basic shape in the trigonal crystal system could ever create a shape belonging to the cubic crystal system. Both the twisting of the sliced octahedron and this present suggestion of compression and expansion of edges are, of course, quite impossible in actual crystal formation. They are only put forward in an effort to explain the shape of the three-dimensional octahedral twin in the two dimensions of a written text.

Yours etc.,
R. J. PEACE.

16th May, 1982.
Withernsea, North Humberside.

From Mr Peter Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A.

Dear Sir,

Since my report on the Ceres Diamond Probe was published in this *Journal*,* at least a dozen different models of this type of instrument have appeared on the market. I have personally tested nine of these instruments, and am also responsible for the electronics design of both the original and the improved version of the Rayner Diamond Tester for Gemmological Instruments Ltd.

All of these instruments have so far been described as thermal conductivity testers, and have been designed to detect the drop in temperature of a heated probe tip when thermal energy is transferred from it, via a material such as diamond, into a heat sink. This heat sink comprises either the gemstone mount, or a metal test plate. It is instructive, however, to read the excellent theoretical analysis of the heat flow mechanisms as presented by Dr D. B. Hoover in his article in the July 1982 issue of the *Journal*,† as this helps to explain the various anomalies in the operation of these instruments.

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*Read, P. G. Thermal Diamond Probes, *J.Gemm.*, 1980, XVII (2), 85-94.
†Hoover, D. B. The Thermal Properties of Gemstones and their application to Thermal Diamond Probes, *J.Gemm.*, 1982, XVIII (3), 229-39.

One design feature in some of the simpler thermal probes is the use of a very hot probe tip (in some instances the manufacturers warn against blistering the fingers!). This results in both an increase in the ability to discriminate between diamond and its simulants, and a decrease in the instrument's dependence on gem temperature and ambient temperature ranges.

The majority of thermal probes use a semiconductor element such as a thermistor or a silicon voltage-reference diode to act as both a source of heat and a temperature sensor. One model, the Singapore-built 'Presidium Gem Tester', is unique in that it uses a copper-constantan thermocouple and a separate heating element (this is the instrument marketed by the G.I.A as their 'Gem Diamond Master' and referred to in Hoover's article).

Hoover's suggestion that thermal probes could be used in a more quantitative manner to distinguish between other gem species has already been exploited by Gemtek in their 'Gemmologist' instrument. This is designed to discriminate not only betweeen diamond and its simulants, but also between stones such as aquamarine and blue topaz whose thermal conductivities (or thermal inertias) are sufficiently separated. As the thermal conductivities of non-diamond gems lie in the range of 10 to 40 Watts/m/°C* (compared with diamond's range of 1000 to 2600) this is no mean technical feat. The necessary increase in sensitivity of the instrument demands careful handling, however, as stone temperature, ambient temperature and probe pressure become critical factors. (I am preparing a test report on this model for a future issue of the *Journal*).

The most searching test for a thermal probe type instrument is to check whether it will discriminate between a small diamond at body temperature (i.e. in a ring worn on the finger) and a large corundum at room temperature. Although colourless sapphire would not normally be mistaken for a diamond, it makes a good test stone in this respect as its thermal properties are closer to those of diamond than any of the other simulants. Cubic zirconia, by way of contrast, has very poor thermal conduction and is easily identified by the simplest of the thermal testers.

Even with the most sophisticated of the thermal diamond probes it is prudent (as with the reflectivity type instruments) to check calibration against a known diamond and corundum before making a test. In keeping with good gemmological practice, results should always be confirmed by the use of at least one alternative test (e.g. reflectivity measurement, facet condition, inspection, etc.).

Yours etc.,
PETER READ

16th August, 1982
Bournemouth, BH1 3UB, Dorset.

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*Quoted in preferred S.I. units.


Rayner

Historical Note

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

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

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

Notes for Contributors

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

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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