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Saint Dunstan's House, Carey Lane, London EC2V 8AB
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Cover Picture

Ornamental button in 22 ct gold set with Burmese red spinel crystals. The crystals are approximately 8-9mm from point to point; the base is 22mm in diameter. Button provided by Mr S. Moussaieff of the London Hilton Jewellers Ltd.
Photograph by E. Alan Jobbins.

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Heat treatment of Geuda stones – spectral investigation

R.N. Ediriweera, B.Sc. (Cey.), M.Sc. (Lond.), DIC, Ph.D. (Lond.), and S.I. Perera, B.Sc. (Sri Lanka), M.Phil. (Hong Kong)

Ceylon Institute of Scientific and Industrial Research, P.O. Box 787, Colombo, Sri Lanka.

Abstract

It is well known that Sri Lankan corundum with the milky white opaline character called 'geuda', when subjected to heat treatment can be converted to clear blue sapphires. In order to understand the processes taking place during heat treatment a large number of such stones were heated at different temperatures in the range 1200-1900°C for varying periods of time. The stones were spectroscopically examined after each heat treatment. The spectra so obtained confirms that the $(Fe\text{-}Ti)^{6+}$ bi-particle is responsible for the blue colour in the transformed stones. They also show that iron and titanium exist as Fe^{3+} and Ti^{3+} before heat treatment. The heat treatment process reduces the Ti^{3+} content significantly but not the Fe^{3+} content.

Introduction

'Geuda' is defined as the milky-white opaline character seen in some corundum based stones (Gunaratne, 1981). Sri Lanka has large reserves of corundum stones showing this feature. It is well known that certain varieties of these geuda stones when subjected to heat treatment can be converted to blue sapphires. In this investigation a large number of such stones were examined spectroscopically at different stages of heat treatment in order to gain an understanding into the transformations taking place.

Experimental Details

Around 50 stones showing 'geuda' characteristics were heated for varying periods of time at different temperatures in the range 1200-1900°C. The colour of these stones before heat treatment ranged from white to yellowish brown to light blue. None of them were of a transparent nature originally. The stones were cut and polished to present flat parallel surfaces and placed in alumina crucibles inside a furnace chamber fabricated from alumina refractories. The crucible was heated using an oxy-acetylene flame adjusted to give a neutral to slightly reducing flame. The stones were examined spectroscopically after heating for specified periods of time. The specimen was illuminated with white light and the transmitted light fed to a monochromator (EG & G 555). The output of the monochromator was analyzed using the EG & G 550 Radiometer/Photometer to obtain the intensity of each wavelength in the range 420-720 nm.

Results

On heating beyond 1500°C around 90% of the samples turned into blue sapphires having varying colour intensities. Heating at higher temperatures resulted in sapphires of a darker blue. The clarity also improved. The spectra of all these stones clearly showed the development of a broad absorption band beyond 560 nm as the blue colour developed. There were two other notable features which were shown by a majority of the stones. These are (a) a weak absorption at 540 nm which was present initially but gradually disappeared as the blue colour developed, and (b) a weak absorption at 450 nm which persisted throughout the heat treatment process.

The room temperature absorption spectrum of a representative sample which showed all the three features mentioned above are given in Figures 1 to 3.

This was a silky bluish-grey stone which showed a brownish colour under transmitted light (Figure 1). Heating at 1700°C turned it into a blue stone (Figure 2). Further heating in the temperature range 1800-1850°C turned it into a dark blue sapphire (Figure 3).

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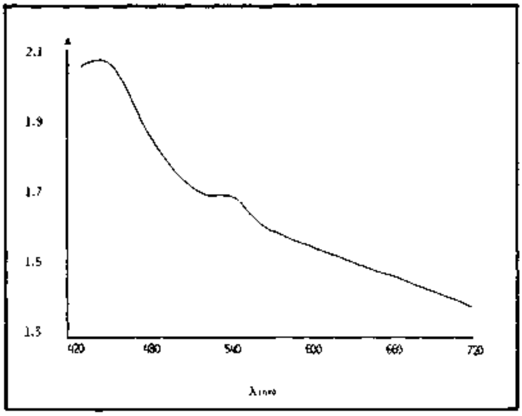

Fig. 1. Absorption spectrum before heat treatment.

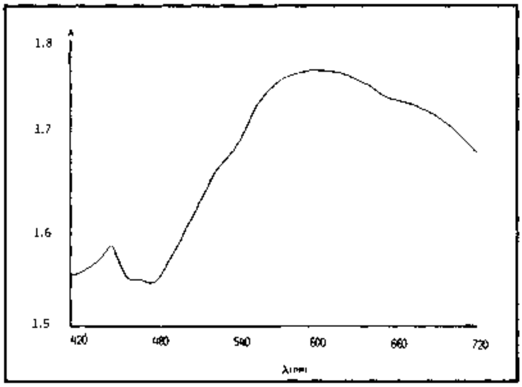

Fig. 2. Absorption spectrum after heat treatment at 1700°C.

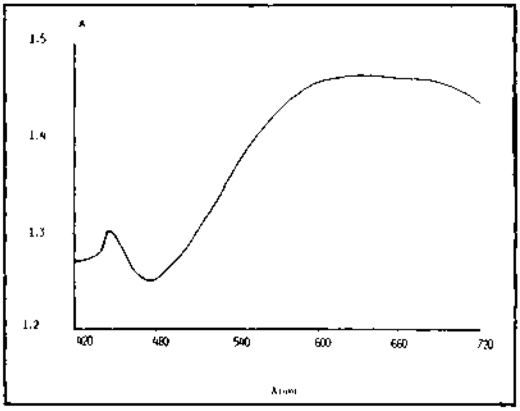

Fig. 3. Absorption spectrum after heat treatment at 1800-1850°C.

Discussion

The results presented above show three characteristic developments during heat treatment:

(1) development of a broad absorption band beyond 560 nm;

(2) reduction or disappearance of the weak absorption at 540 nm; and

(3) persistence of the weak absorption at 450 nm.

The broad absorption band beyond 560 nm in corundum have been associated with a $(Fe\text{-}Ti)^{6+}$ bi-particle (Eigenmann & Gunthard, 1972). The absorptions at 540 nm and 450 nm have been associated with Ti^{3+} and Fe^{3+} respectively (Schneider and Bank, 1980). Hence our results lead to the following conclusions:

(1) the blue colour in heat treated 'geuda' stones is due to the $(Fe\text{-}Ti)^{6+}$ bi-particle. This confirms the hypothesis of Harder and Schneider (1986) presented to explain their electron microprobe analysis;

(2) the Ti^{3+} concentration reduces appreciably during heat treatment;

(3) the Fe^{3+} concentration is not affected appreciably during heat treatment.

Based on these conclusions the following model is presented to explain the transformations taking place during the heat treatment of geuda stones:

(a) both Ti^{3+} and Fe^{3+} are present in 'geuda' stones with Fe^{3+} in excess;

(b) under heat treatment the $(Fe\text{-}Ti)^{6+}$ bi-particle forms using up the Ti^{3+} and Fe^{3+};

(c) Ti used up for the formation of this bi-particle reduces the Ti^{3+} content significantly;

(d) Fe^{3+} being in excess, the total Fe^{3+} content is not significantly affected by the bi-particle formation.

Acknowledgements

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The Muslim Lapidary

Some aspects of the gem folkways in Sri Lanka

M.M.M. Mahroof

Colombo, Sri Lanka

It is well known in gemmology that Sri Lanka* was and is famous for its wealth of gems. The ancient chronicle, the *Mahavamsa*[1], reputedly one thousand five hundred years old, speaking of the consecration of an early king *Devanampiya Tissa*, says:

> 'Pearls of the eight kinds, namely horse-pearl, elephant-pearl, waggon-pearl, myrobalan-pearl, bracelet-pearl, ring-pearl, kakuda fruit-pearl and common (pearls) came forth out of the ocean and lay upon the above in heaps. All this was the effect of Devanampiya Tissa's merit. Sapphire, beryl, ruby, these gems and many jewels and those pearls and those bamboo stems they brought, all in the same week, to the king.'

While Sri Lanka has had a good press for its gems throughout the centuries, concern for the human element and the mechanics of the gem trade has not been as pervasive[2]. Pliny; the fifth century Buddhist Chinese pilgrim Fa Hian; Cosmas Indicopleustis; Marco Polo; Odoric; Jordanus; Ibn Batuta; Ribeiro; and in more recent times, Max Bauer; Count de Bournon; C.G. Gmelin; M.H. Klaproth; were among those who had written, often admiringly, of Sri Lankan gems. Modern text writers, like Herbert Smith (and his subsequent editors) and Anderson deal with Sri Lankan gems more as a class and less as a country[3]. Webster gives more space but not so much as he devotes to Burma[4].

The present article attempts to deal with the activities of a community, members of which have been active in the sphere of gem trade throughout a millenium and more. While it would be hyperbolic to say that 'the trade is today almost entirely in the hands of Moslems as in the past'[5], it would be true to say that their task is that of the earthworm bringing the undersoil to the surface and thus helping to keep the soil and the economy sweet and fresh and alive.

*Until 1978 Sri Lanka was known as Ceylon. Both terms are used in the article, depending on context.

Gem cutting by the traditional method, Ratnapura. *Photo by E.A. Jobbins.*

The Muslims of Sri Lanka

Today the Muslims form seven per cent of the total population of Sri Lanka and number just over a million individuals. They are believed to be the descendants of the Arab sea-farers, who controlled the Indian Ocean trade up to the sixteenth century[6]. The standard history of Ceylon (Sri Lanka) noted that 'Arab historians have recorded that in the first decade of the eighth century the King of Ceylon sent to the Viceroy of the eastern Caliphate the orphan daughters of Muslim merchants who had died in his dominions' and that 'at the end of the Anuradhapura period [tenth century] there were communities of Muslims at seaports like Mahatitta and Colombo'[7].

The Muslim lapidaries of the period roughly up to the sixteenth century lived and worked in what came to be called 'fondachi'[8]. These were trading stations grouped as streets set aside for particular trades and managed by senior and influential traders. Lapidaries formed an important segment of this set up for, like some other trades where the possession of capital was sufficient to ensure domination in the trade, gem-buying and gem-selling, however low or however high, was dependent on physical handling and evaluation of the stones which was the work of the lapidary. A Chief Justice of Ceylon in early nineteenth century and a close observer of Muslim affairs wrote:

> 'During that period [twelfth and thirteenth centuries] the great Mohammedan merchants of Mannar and Mantota [in the north-west of Sri Lanka] received into the immense warehouses which they had established at this emporium, the most valuable produce of the island [Sri Lanka] from their subordinate agents, who resided at the different seaports which were situated in the neighbourhood of those provinces where the various articles of commerce were produced ... from those at Colombo cinnamon and precious stones.'[9]

These stones cut by the Muslim lapidaries were mainly for export, taken up by the Arab ships which regularly called at the seaports of Colombo and Galle (on the southern seaboard). Other stones took their place in the eight-item regalia of the indigenous princes, which included the crownlet, the girdle, the ceremonial thread, the necklace and armlets. Possibly some of them were taken to other countries for other purposes. It was reported that among the articles offered to the Chinese Emperors during fifth to eighth centuries, were pearls, filigreed gold, gems, ivory valances and some very fine shaggy stuff of white colour [10].

At any rate the Chinese of the mediaeval period were appreciative of the expertise of the Muslims for they called the gems of Sri Lanka, 'Mohammedan stones'[11]. Some of the Chinese mariners were Muslims. The Chinese Admiral Zheng He, who commanded the fleet under the Ming Emperor (Ming Yong Le) and who visited thirty countries of Asia between 1405 and 1431, was a Muslim [12].

The structure of the Muslim lapidary and gem-merchants (they were, really, the one shading into the other) was established by the European occupation of Sri Lanka. The Portuguese ruled the Maritime Provinces of Sri Lanka from 1505 to 1658, the Dutch from 1658 to 1796 and the British from 1796 (and the entire island from 1915) to 1948 when Sri Lanka became independent. The Portuguese imposed a series of naval sanctions, including a system of primitive navicerts, upon Muslim vessels. While the redoubtable family of Kunjaly Marikars, who traditionally commanded the fleet of the Zamorin (the Kerala Princes who were inveterate enemies of the Portuguese), were able to run the blockade, the Muslim gem trade, to a great extent, fell into a decline[13]. But the worst was to follow. Acting on the directions of the Viceroy at Goa, the Portuguese officials in Sri Lanka expelled the Muslims, with some exceptions, from Colombo in 1626. About four thousand of them were welcomed by the King of Kandy, the indigenous prince, who ruled the central massif of Sri Lanka and who settled them in the eastern portion of the country[14].

The impact of these diaspora was to fragment the gem trade and gem cutting. Towns on the west seaboard, which were also landing stages, attracted the lapidaries rather like Amsterdam attracting diamond-cutters. Beruwela (called Barberyn by the Dutch) some miles south of Colombo and Gintota, a hamlet of Galle (then a prestigious sea port), became noted for lapidary work. While they were far from official interference, they were not immune from the bourgeoisie who favoured gems. The Muslim lapidaries who had sought refuge in the Kandyan provinces had a different sort of experience. For one thing, they had a definite niche in society. The Kandyan caste structure placed the 'acaries', among whom the goldsmiths and associated craftsmen were reckoned, as fourth in ranking[15]. The Muslim lapidaries were exotic enough to be reckoned among the dominant castes but rigid sumptuary rules confined gem-wearing to a fixed clientele which included the king and the nobility.

When the Dutch took over Ceylon, it entered into the control of the Dutch East Indies Company – the VOC. The VOC was a massive and profitable trading and ruling corporation. In 1669 it paid forty per cent dividend on its capital of 6,500,000 florins. The VOC had 150 trading ships, 40 ships of war and 10,000 soldiers, and maintained the governments of Ternate, Java, Ambon, Macassar, Banda (all in present day Indonesia), Malacca, Ceylon and Good Hope[16]. More importantly, it had in its owners and staff a burgeoning bourgeoisie which gloried in the paintings of Rubens, Hals, Rembrandt, de Hooch and the brothers van der Velde. Gems formed an important part of its lifestyle. The life of the Muslims, lapidaries included, under the Dutch in Ceylon, was neither pleasant nor memorable. They were subject to capitation taxes, confinement to ghettoes, restrained from trade and to registration of residences[17].

Yet there was a constant demand for gem-cutting and gems from the meijneheeren and meijnevrouwen of Dutch Ceylon, the gems forming portable wealth. The seventeenth and the middle eighteenth centuries (by which time the British were flourishing in the Carnatice), saw the rise of the larger zamindar, the 'poligars' in the south of India, who sometimes fought the British or the French or themselves, depending on their territorial needs. For the 'poligars', gems formed an easy way of drumming up support, retaining allies or, at the worst, portable wealth in flight. Lapidaries and gem-traders, nearly all of them Muslims, who had settled down in the coastal towns of south India, became important and their towns became important too. Two of these towns, Kilakarai and Kayalpattinam (in present day Tamil Nadu), were specially famous and were, and are, established centres of the gem trade, though they have failed to obtain high-profile among the itineraries and topographical guide books during the high-noon of British Imperialism[18] or among the popular yearbooks of today[19]. The Muslim lapidaries of Sri Lanka developed a close trading connection with these towns.

The British presence

The occupation of Ceylon by the British was to have important consequences on the gem trade and on the Muslim lapidary in particular. The British abolished trade monopolies as part of the implementation process of the Colbrooke Commission Report[20] and free and open trade sprang up between Ceylon and the British Empire, especially India[21]. Indisputably, these efforts depressed the gem trade. The normal paradigm in the gem trade is composed of the lapidary, the broker and the merchant, major and minor. The constraints of the Dutch had created a great number of brokers and middle-men, mainly Muslims, for the scarcity value of gems made possible the toleration of massive overheads. The open-door policy of the British made gem exports normal; it also enabled the British Establishment in Ceylon, which included the military officers, the officials and the higher mercantiles, to buy their precious stones from the major gem merchants themselves. Higher capitalization helped the major gem merchants to lay in larger stock. Hence, the displaced brokers came on the streets in a manner familiar to most tourists. William Maxwell Wood, the US naval surgeon, who visited Ceylon in 1856, described the scene vividly:

> 'Moormen [ie Muslims], in Arab particoloured caps, with shaven heads and voluminous shawls wrapped around their waists, are everywhere at our heels, on the shores, in the streets, in the hotels and the halls of private houses; even on the roadside to the distance of some miles in the country, they appear importuningly. These Moormen are the traders in jewelry and precious stones. Jewel boxes are taken from the folds of their shawls, and sapphires, rubies, amethysts, carbuncles, emeralds, cat's eyes and moonstones, displayed in gorgeous abundance or else good English and French imitation for these valuables.'[22]

An earlier US writer, William Samuel Wuthman Ruschenburger, also a naval surgeon, visiting Ceylon in 1835 had said the same things[23].

After the 1850s the situation improved somewhat. The opening of the interior of Ceylon for the cultivation of coffee – there were 40,000 acres under coffee in 1840 – and its subsequent decline, for by 1881 coffee had nearly gone out of production, had brought gem-mining into the scene again[24]. The roads that had come up as infrastructure for coffeee, the unemployed men now available, the jobless in the associated trades, were incentive enough.

The gem trade had and has a logic of its own. The gem-miners, who actually dig and prospect for gems, should have the attitude of a beachcomber, for his job is not a neat study of cost-benefit analysis. The lapidary is assured of a regular income but he is dependent on his supplier-employers. The gem merchant, both minor and major, have to be backed by sufficient financial reserves as antidotes to their sometimes inspired guesses at evaluation, the average Ceylonese gem merchant being without benefit of scientific analysis. This is particularly true of the Muslim lapidary and gem-dealer.

Another persistent problem which had affected the Muslim lapidary (by making his services unnecessary) and the Muslim gem-dealer (by evaporating his profits) is the presence of non-natural stones or at any rate, stones which the normal gem dealer is not willing to realize or concede as totally natural. The present day geuda controversy is thus a part of a continuous debate. The US visitors whose views were described earlier in this article, are only a few of the tourists who noted the presence in Ceylon of British and French versions of Ceylon gems. It was officially commented upon, as well. In 1907 Parsons, who headed the Mineralogical Survey of Ceylon, wrote:

> 'Reconstructed rubies are sold in Ceylon sometimes fraudulently as natural stones and sometimes in ignorance of their real character. I was recently offered some stones of this description at Matara [ie a town in southern Sri Lanka]. The only reliable test is to examine the suspected gem under a

microscope. Natural stones commonly show minute cavities which are hexagonal or at all events angular in outline, whereas the cavities in the reconstructed stones are spherical like bubbles in glass. In poor examples, these spherical cavities can be observed even with a good hand lens. The beauty and durability of a reconstructed ruby is equal to a good natural ruby. Reconstructed sapphires do not so closely resemble natural sapphires and the colour and lustre are not satisfactory.'[25]

The world was less sophisticated then but the average Muslim gem-dealer of those days disdained the use of even a hand lens.

The 1914-18 World War depressed the prices but the consequent inflation arising as an aftermath of the War made the acquisition of gems a more attractive proposition. Thanks to the risk-taking propensities of the average Muslim gem-dealer, the Muslims did not face a bleak future in the gem field. The *Handbook for Ceylon* for 1922, could state rather confidently: 'The stones are bought up by Moorish [ie Muslim] dealers to be cut and polished. Many of the best stones are exported to Europe and America but the inferior varieties are largely sold locally or in India.'[26] The work of avant-garde (then and now) jewellers like Fabergé and art movements like art deco had their spin-offs in Ceylon, when a demand was created for matching gems and fancy stones. By the 1930s the oldest Muslim gem firms had been sixty to seventy years on the scene. British, European and American collectors had come to include Ceylon gems in their portfolios. The debacle of World War Two was followed by the 'economic miracle' in Germany and later in Japan and yet again by the boom of the sixties when gem sales were keeping pace with works of fashionable animal painters in sales value. Constraints, and the geuda controversy were to replace them later[27].

The Muslim lapidary; the craft

The lapidary is the archetypal figure in the Muslim gem world in Sri Lanka. Characteristically, and with reason, successful gem dealers arise from lapidaries and sometimes, uncharacteristically, gem dealers lapse into lapidaries again. This is because a feel for the stones and a careful cultivation of the eye is essential to the gem dealer, for at every evaluation he pits his experience against the seller and buyer and has no benefit of science.

The typical Muslim lapidary is a man in his late twenties or thirties. Probably his father or near kinsman was a lapidary before him and so *ad infinitum*. It is not a job for the hobbyist or for the do-it-yourself enthusiast. It is essentially a painstaking and boring job. A hereditary concern for minute detail is needed. For it was mainly a Muslim occupation. For instance, a century ago of the 199 lapidaries working in Ceylon, 170 were Muslims.[28] Owing to the coming of machinery, the picture has changed somewhat.

The Muslim lapidary works on a changeless apparatus. One hundred and fifty years ago, Ruschenburger wrote as follows:

> 'They sit under a veranda or shed, in front of the house, squatted on their heels behind a rude lathe, raised a few inches from the ground. On the end of the axle there is a round plate of iron or steel, about eight inches in diameter, placed vertically, which is made to revolve backwards and forwards by a drill-bow about four feet long, made of bamboo and worked by the right hand, while the left applies the stone to be cut, held tightly between the finger and thumb against the wheel. A sort of emery or finely powdered sapphire of coarse quality, moistened with water, is the only intermediary substance used in cutting the stone.'[29]

That was in December 1835. Louis Siedle writing in 1933 stated that from 1912, carborundum manufactured in USA had replaced powdered corundum because carborundum is harder[30].

Polishing of stones has not undergone changes either. For corundum, the copper lap is normal; softer stones like moonstones need a wooden lap. The stones are cemented to wooden holders and held against the polishing surface. This is, of course, for cabochon cuts. Faceting requires an elaborate procedure, within this appropriate technology. The copper lap is horizontal and, by primitive driving gear, runs quite fast. By means of an elementary goniometer fixed on a sliding rod, facets of the stone are polished. The polishing material is paddy husks burnt to a soft consistency.

Of late, Linde A and other materials are coming into use and laps and arbours are of the modern do-it-yourself varieties. But the precision of modern laps and belt transport systems are not very familiar to the average lapidary who can stop and start with hand-power which he is used to.

The weaknesses of the cutting system of the Muslim lapidary are part of the mythology of the subject. It is remarked that the Muslim lapidary sacrifices shape at the altar of weight. But there are two reasons for this situation. The dealer who tells the lapidary to cut desires to have the maximum possible caratage, for stones are sold on the carat and not on the precision cutting. The second reason has been presaged even ninety years ago. The American visitor, Mary Thorn Carpenter, who visited Ceylon in 1890 wrote that:

'Here [in Colombo] also are the jewellers' shops, where we were shown glittering heaps of precious stones but found scarcely a good ruby or sapphire among them. Streeter of London and the great New York firms purchase all the valuable gems, leaving flawed and imperfect stones for tourists'.[31]

Given that good stones would be re-cut abroad if exported, there is little incentive in bravura gem-cutting.

The traditional Muslim lapidary has one over-riding advantage. Decades of experience gives him the perfect feel for the stone and its qualities. For instance, an experienced lapidary can say that a particular good blue sapphire is from the Rakwana (south central of Sri Lanka) area and that particular placing had been worked out by 1900. Being bereft of even elementary knowledge of crystal systems, axes, Miller's indices, the (now exploded) theory of the Beilby layer not to speak of sophisticated procedures like energy dispersive analysis or X-ray diffraction, the lapidary has a confidence sometimes rudely shaken, of his own experience. This is a case of ignorance being truly bliss.

In Sri Lanka, as is well known, the local jewellery trade does not contribute in large measure to the gem trade. Current wedding jewellery, with some outstanding exceptions, is gold-based and 22 carat at that. Less affluent women used to wear, on a gold base, a 'pavé' of 'Rangoon diamonds' (popularly called 'Rangoon kamalam') but that fashion is phasing out. Traditional Muslim jewellery of Sri Lanka is often chunky and a few are similar to those worn in Egypt during the first part of the nineteenth century[32]. Thirty years ago some Muslim women wore wedding necklaces with alternating chunks of gold and coral, rather like some Omani jewellery[33]. Muslim males wear, if at all, only silver rings with stones cut en cabochon.

Hence, most gems in Sri Lanka are exported; at any rate, all stocks of stones are exportable. The following propositions may be hazarded:

(a) sales may be divided into (i) one-off sales, e.g. lucky finds, which do not affect the market; (ii) sales by brokers, which increase the overheads; (iii) sales between minor and major merchants, which are always in favour of the major merchants; (iv) sales between minor merchants and those between major merchants, which is a reflection of replenishment of portfolios;

(b) the price paid is a guess of what the foreign buyer is willing to pay; hence, a buyer needing a special or fancy gem generally drives up the prices of all gems;

(c) in boom times, the heavy circulation of stones brought about by these passing through very many middle-men, raises prices unduly and a single refusal to buy, through negative multiplier effects, drives down prices unduly. Hence, booms have an inbuilt depressing factor;

(d) gem booms are related to booms in luxury articles, e.g. carpets.

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Black diamonds of Type IIb

S. Scandella, FGA

Gübelin Gemmological Laboratory, Denkmalstrasse 2, CH-6006 Lucerne, Switzerland.

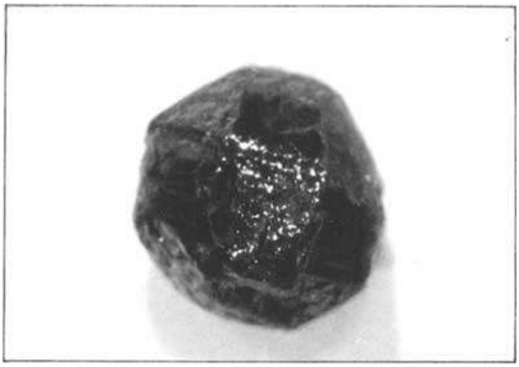

Fig. 1. Black diamonds, rough, 1.82 ct, electrical conductor. Maximal length 8 mm.

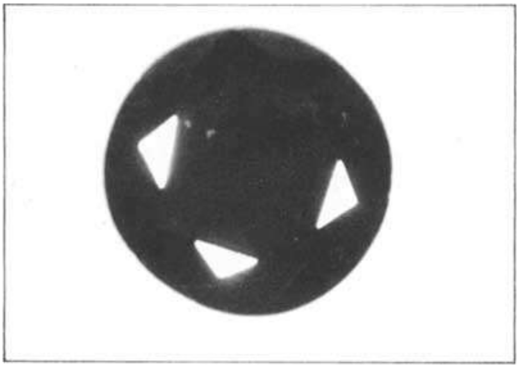

Fig. 2. Black diamond, brilliant cut, 0.44 ct, electrical conductor. Maximal diameter 5 mm.

Recently the Gübelin Gemmological Laboratory investigated five black diamonds for research purposes whose weight was between 0.37 ct. and 1.82 ct. There were two rough and three cut stones. It was stated that their origin was a source in Africa.

Several tests were carried out. The microscopic examination revealed masses of dark inclusions, which are responsible for the black colour and for the low transparency throughout the stones [1].

Colour was of natural origin. Heavily irradiated diamonds would show some spots of dark green colour in transmitted or reflected light[1 and 2]. However, the most astonishing thing that we discovered, for the first time in our records, was that two of the crystals showed electrical conductivity under 220 volts. This means that the two specimens belong to the Type IIb category (Figures 1 and 2).

With this note, our purpose is to prompt similar investigations. We would be interested in communicating with anybody having noticed similar properties in black diamonds.

Acknowledgements

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Further evidence for the controls on the growth of vanadium grossular garnets in Kenya

R.M. Key, FGA, and P.G. Hill***

*British Geological Survey, Murchison House, Edinburgh EH9 3LA
**Department of Geology, University of Edinburgh EH9 3JW

Abstract

The physical and chemical controls on the growth of green vanadium grossular garnet in SE Kenya ascertained by Pohl and Neidermayr (1978) are confirmed on a regional basis. An intimate association of marbles with the host graphitic gneisses was mandatory for garnet growth during a regional metamorphism which reached granulite facies conditions. Kelyphitic rims around garnet pods in SE Kenya are not retrogressive products but also formed in the granulite facies due to an increase in the CO_2 content of the fluid phase. The graphitic gneisses represent altered bituminous black shales and testify to widespread late Proterozoic seafloor organic activity in the Mozambique Orogenic Belt throughout East Africa.

Introduction

From their work in SE Kenya, Pohl and Neidermayr (1978) concluded that there are four controls on the distribution of the green gemstone, vanadium grossular garnet ('tsavorite'), as follows:

1. *Regional Lithostratigraphy:* the garnets form within a single lithostratigraphic unit.
2. *Lithology:* the garnets are confined to graphitic gneisses which are either rich in calcium (due to the presence of thin marble seams or calcareous pods), or which are immediately adjacent to marble beds. This control was first noted by Bridges (1974).
3. *Availability of Chromophore:* a supply of V (cited as the main colouring agent by Gübelin and Weibel, 1975) Mn, Ti, Fe and Cr from the host gneisses.
4. *High Grade Metamorphism:* the vanadium grossulars formed during a regional progressive metamorphism under either upper amphibolite or granulite facies conditions.

These four controls reflect the standard conditions necessary for metamorphic mineral growth: favourable PT conditions and a suitable chemical environment. The purpose of the present study was to see if the same four controls have a regional application as valid exploration guides for new vanadium grossular garnet deposits. New data on the chemistry of the host graphitic gneisses and on metamorphic conditions in SE Kenya are presented.

The graphitic gneisses are part of a metasedimentary sequence in the Mozambique Orogenic Belt; a complex Upper Proterozoic to Lower Phanerozoic province which extends from Mozambique northwards through Eastern Africa as far as Ethiopia (*see* Holmes, 1951; Cahen *et al.*, 1984; Key *et al.*, in press). The vanadium grossulars were first discovered in Tanzania, with gem quality stones mined in the south-east of the country at Lelatema Hills. (Gübelin and Weibel, 1975). Subsequently, better quality garnets were also found on either side of the Tanzania/Kenya border. Mineral exploration in north-central Kenya, within the Mozambique Orogenic Belt, by a joint UK (British Geological Survey) – Kenya (Mines Department) team in the early 1980s located similar garnetiferous graphitic gneisses north-east of Baragoi (Figure 1, Key, 1987). However, in central Kenya at least, other major graphitic gneisses, e.g. at Ol Doinyo Ng'iro (Stewart, 1963), are devoid of vanadium garnets. Comparisons between the garnetiferous and garnet-free graphitic gneisses are used to test the four controls of Pohl and Neidermayr (1978) on vanadium grossular growth.

Regional Lithostratigraphy

In SE Kenya (Taita Taveta area of Figure 1) the vanadium garnets are confined to a single part (Lualenyi Member) of a thick sequence of marbles, graphitic gneisses and various biotite gneisses which Pohl and Neidermayr (1978) refer to as the Kurase Group (after Saggerson, 1962). In central-north Kenya a similar metasedimentary sequence is recognised as a distinctive mappable unit continuous over several hundred kilometres along

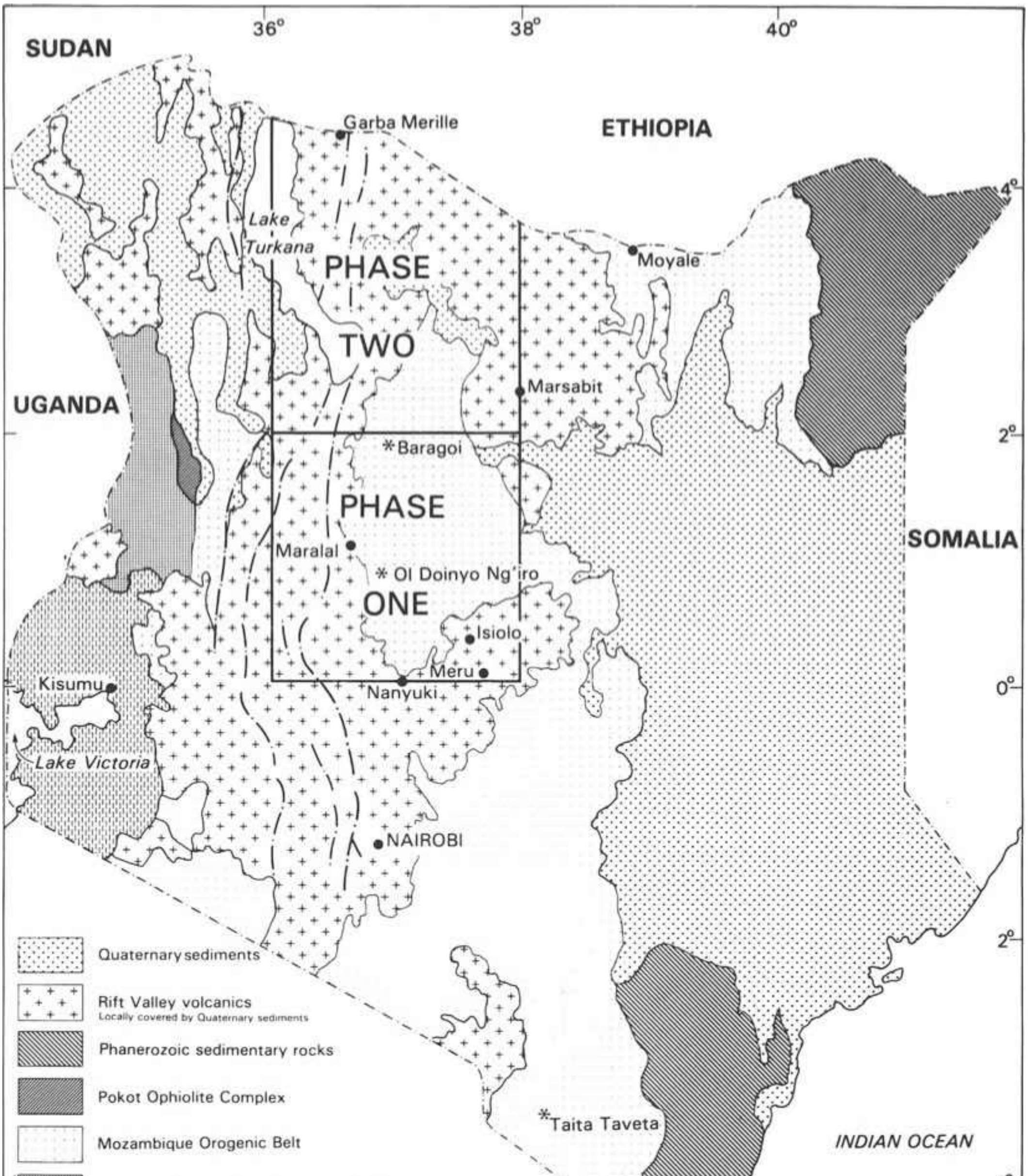

Fig. 1. Geological map of Kenya showing the main graphitic gneiss localities (*) and the area of northern Kenya explored jointly by the British Geological Survey and the Kenya Mines Department.

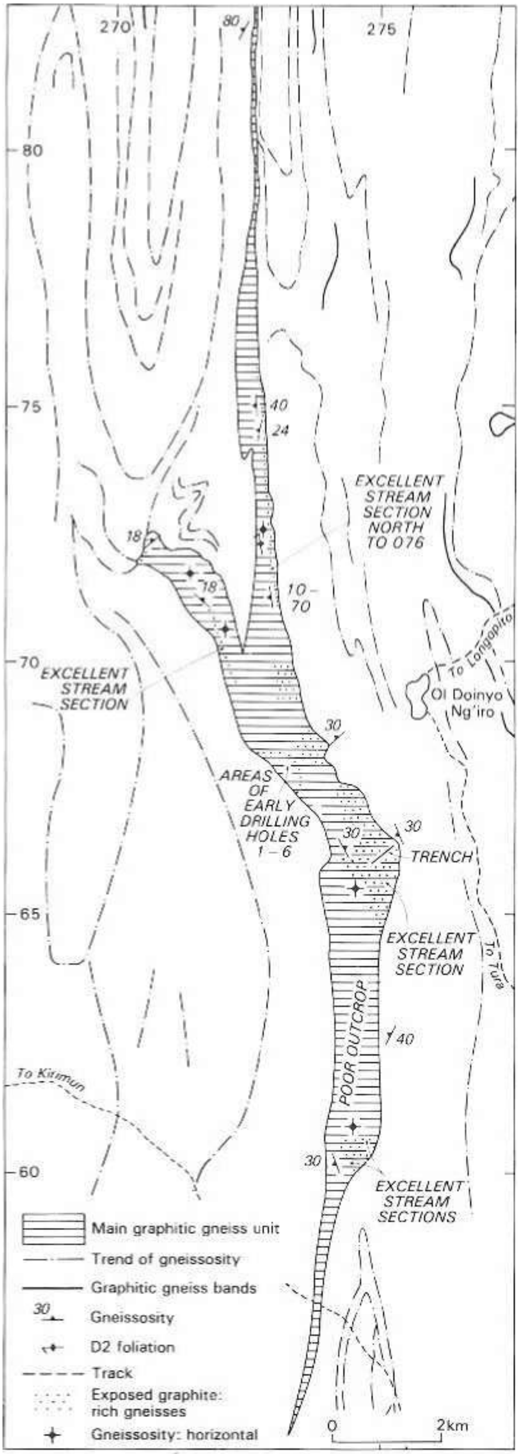

Fig. 2. The Ol Doinyo Ng'iro graphitic gneiss.

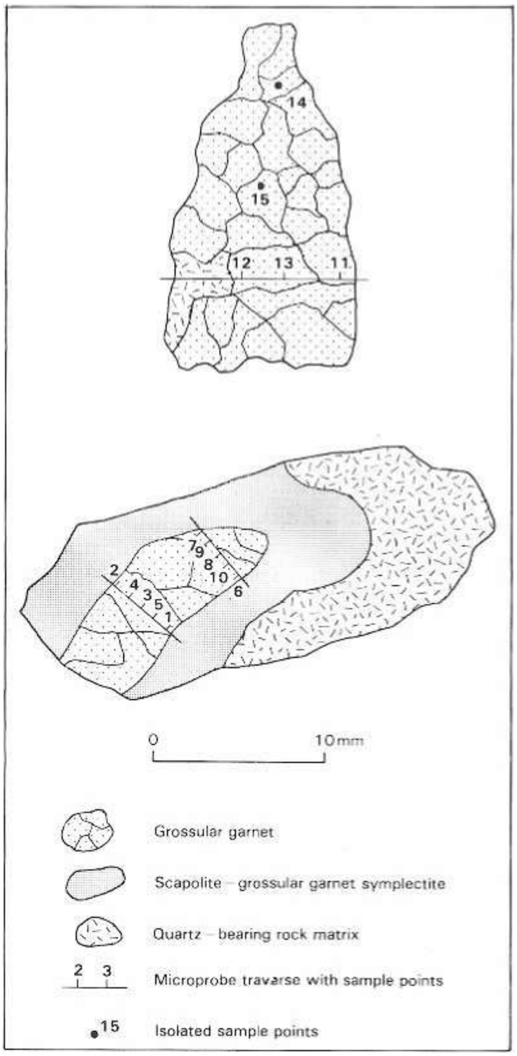

Fig. 3. Details of the analysed serial sections of vanadium grossular garnet from Lualenyi (Taita Taveta locality of Figure 1).

strike (Shackleton, 1946). It is referred to as the Ol Doinyo Ng'iro Gneisses (Hackman *et al.*, in press). The geological histories of the Kurase Group and Ol Doinyo Ng'iro gneisses are indistinguishable; both comprise altered marine continental shelf deposits laid down at about 840 million years ago (geochronological evidence reviewed in Cahen *et al.*, 1984; Key *et al.*, in press). They record the same late Precambrian history of early recumbent folding and thrusting accompanied by high grade metamorphism, subsequent upright folding, and finally retrogression with uplift and cooling at about 500 million years ago.

Table 1 – Mineral assemblage of three major graphitic gneisses within Kenya

Lualenyi

1. Graphite + quartz + plagioclase ± orthoclase, microcline, muscovite

2. Graphite + quartz + sillimanite + muscovite + accessory rutile, apatite, tourmaline, sulphides

3. Graphite + quartz + clinopyroxene + clinoamphibole + scapolite + epidote + grossular

4. Graphite + quartz + clinopyroxene + scapolite + sphene + secondary carbonate, iron oxide, serpentine

Baragoi

5. Graphite + quartz + plagioclase + boitite ± vanadium grossular garnet, muscovite, microcline, sillimanite or kyanite

6. Graphite + quartz + muscovite + opaline quartz

Ol Doinyo Ng'iro

7. Graphite + quartz + plagioclase ± biotite, sillimanite, iron oxides

1,2,3 Pohl & Neidermayr (1978)

4,5,7 This study

6 Baker (1963)

The south-east and central-north Kenya inliers of the Mozambique Orogenic Belt are separated by a volcanic carapace related to the Cenozoic East Africa Rift System (Figure 1). In a complex tectonothermal province such as the Mozambique Orogenic Belt, it is impossible to correlate disconnected lithological sequences in exact (member status) detail. However, the Kurase Group and Ol Doinyo Ng'iro gneisses are correlatable as a unique succession of thick marbles and major graphitic gneisses.

Lithology

Throughout Kenya the host graphitic gneisses form conformable beds up to 1000m thick, which, like all lithologies in the metamorphic belt, lens out along strike (Figure 2 is a typical example). Marble intercalations, calcareous pods and adjacent marble are ubiquitous in SE Kenya (Pohl and Neidermayr, 1978). At Ol Doinyo Ng'iro in central Kenya there are no intimate marble associations with the main garnet-free graphitic gneiss unit. In northern Kenya, around Baragoi, the graphitic gneisses lack internal calcareous pods but there are immediately adjacent marble seams (Baker, 1963).

The mineralogy of the graphitic gneisses is summarized in Table 1. At Lualenyi (near Taita Taveta) the green vanadium garnets either occur in randomly distributed (calcareous) pods or as disseminated idioblastic crystals. There are only disseminated garnets in the Baragoi graphitic gneisses. No vanadium garnets occur at Ol Doinyo Ng'iro where old graphite workings (Stewart, 1963) provide excellent exposures.

Gübelin and Weibel (1975) as well as Pohl and Neidermayr (1978) suggested that the graphitic gneisses represent altered bituminous black shales. A diagnostic characteristic of unmetamorphosed Phanerozoic sapropels is their relatively high vanadium contents. Wedepohl (1964) records values of up to 5000 ppm V in bituminous shales and limestones. This compares to a mean value of only 56 ppm V in surficial deposits of the USA (Shacklette *et al.*, 1971) and a mean value of 59 ppm for the Canadian Shield (Eade and Fahrig, 1973). As vanadium is also relatively immobile during high grade metamorphism (Eade and Fahrig, 1973) it remains in its original host rock to enter the new metamorphic mineral assemblages. Table 2 shows new analyses for V, Cr and TiO_2 of Kenyan graphitic gneisses as well as other contemporaneous East African graphitic gneisses. Their high vanadium contents and other data indicate that they are altered bituminous black shales. The wide

Table 2 – V, Cr and TiO_2 contents of graphitic gneisses from the Mozambique Orogenic Belt of East Africa

Locality	*V*	*Cr*	*TiO_2*
Kenya	(ppm)	(ppm)	(wt %)
Lualenyi	1259	732	0.78
Ol Doinyo Ng'iro – low grade	748	284	1.41
Ol Doinyo Ng'iro – high grade	1697	331	2.02
Taita Hills	1052	985	0.82
Tanzania			
Morogoro	249	91	2.19
Merelani	446	72	1.31
Madini Pit	934	79	1.31
Daluni	680	219	1.10
Malawi			
Katengeza	630	718	2.12
Lumbadzi River	588	1015	1.09
Lobi Pit	1902	701	3.37
Zimbabwe			
Lynx Mine	239	152	0.29

X R F analysis by David Bland as part of the BGS study of graphite resources of East Africa. Each analysis is of a single rock sample: 4 gms of powdered rock are mixed with 1 gm of elvacite binder and pressed into a disc. Note also that Sarbas *et al.*, (1984) record 1157 ppm V and 329 ppm Cr from graphitic schists from Lualenyi.

areal extent of contemporaneous graphitic gneisses within the Mozambique Orogenic Belt indicates a major phase of organic seabed activity during the Late Proterozoic.

Availability of Chromophores

As well as having anomalously high V contents (the green grossular garnet's main chromophore) all the graphitic gneisses, irrespective of whether they contain grossular garnet, contain significant amounts of Cr and TiO_2 (Table 2). Microprobe analysis across two serial sections of a typical vanadium garnet pod (Figure 3) from Lualenyi are very similar to the garnet composition (see Table 3) quoted by Gübelin and Wiebel (1975). Analyses presented in Table 3 were carried out on a Cameca Camebax electron probe microanalyser operating at an accelerating potential of 20KV with a probe current, as measured in a Faraday Cup, of 20 nanoamps. Standards used in calibration were as follows:– wollastonite for silicon and calcium, jadeite for sodium, corundum for aluminium, periclase for magnesium and rutile for titanium; other elements (vandium, chromium, manganese and iron) were calibrated against pure metals. Matrix corrections were carried out using a ZAF process similar to that described by Sweatman and Long (1969).

The high resolving capabilities of the fully focusing spectrometers fitted to the microprobe almost enables the overlap of Ti Kβ and the V Kα peak to be ignored. In the mineral under discussion, where vanadium far exceeds titanium, and in which the titanium content is low, the residual overlap effect is so small as to be negligible. Of

TABLE 3: Results (in wt.%) of microprobe analyses using a Cameca Camebax Microbeam. Sample from Taita Taveta (Lualenyi area) with analytical points shown in Fig.3. The scapolite and symplectite garnet analyses are from the kelyphitic rim shown in the same figure.

	MAIN GARNET																Scapolite	Symplectite Scapolite	Symplectite Garnet		
	(a)	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15					
SiO2	38.70	39.07	39.05	39.24	39.17	39.27	39.26	39.29	39.24	39.18	39.09	39.78	39.00	39.22	39.56	39.53	43.78	43.85	37.60	37.73	40.81
TiO2	0.25	0.46	0.42	0.44	0.40	0.45	0.45	0.47	0.43	0.45	0.40	0.47	0.45	0.43	0.29	0.43	0.02	0.01	1.05	1.14	0.95
Al2O3	20.90	20.99	20.80	20.68	20.68	20.84	20.88	20.78	20.80	20.87	20.85	22.20	22.01	21.91	22.44	22.44	29.79	29.20	12.23	12.34	13.90
V2O3	3.30	2.19	2.05	2.32	2.12	2.18	2.12	2.26	2.41	2.22	2.40	0.84	0.55	0.98	0.47	0.49	0.00	0.04	11.45	11.38	10.71
Fe2O3	0.05*	0.11	0.12	0.10	0.10	0.11	0.09	0.20	0.08	0.09	0.09	0.09	0.08	0.09	0.07	0.08	0.02	0.01	0.55	0.52	0.30
CaO	35.10	35.30	36.23	35.95	36.07	36.19	35.99	35.81	36.17	36.07	36.16	36.13	36.38	36.13	36.55	36.59	19.69	19.09	33.57	33.95	31.11
MgO	0.50	0.49	0.47	0.51	0.52	0.50	0.49	0.56	0.46	0.48	0.50	0.52	0.49	0.50	0.43	0.51	0.03	0.03	0.55	0.51	0.70
Na2O	0.10	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.03	0.01	0.01	0.02	0.03	0.01	0.02	0.01	2.27	2.29	0.02	0.01	0.17
MnO	0.75	0.69	0.75	0.77	0.76	0.71	0.73	0.83	0.68	0.71	0.70	0.82	0.79	0.79	0.64	0.74	0.03	0.04	1.41	1.17	1.24
Cr2O3+	0.19																				
Total	99.84	99.30	99.90	100.01	100.00	100.26	100.00	100.21	100.29	100.07	100.19	100.87	99.76	100.05	100.47	100.81	95.61	94.58	98.42	98.75	100.00
UV		0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00			0.03	0.03	0.03
AD		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01			0.04	0.04	0.03
GR		0.95	0.95	0.95	0.95	0.95	0.95	0.94	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.96			0.88	0.89	0.88
PY		0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02			0.02	0.02	0.01
SP		0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01			0.03	0.03	0.03
AL		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00	0.00

(a) - Analysis of Gubelin & Wiebel (1975)

* - As FeO

+ - Cr2O3 in GT1-GT10 < 0.05 ; in GT11-GT15 < 0.03 ; in symplectite garnet < 0.10

greater importance is the effect of V Kβ on Cr Kα. In this situation a significant overlap occurs, to the extent where the Cr value determined is substantially overestimated. Chromium levels are therefore reported in terms only of a maximum concentration. Nevertheless the Cr_2O_3 values are significant in terms of its effect as a chromophore.

Neither section shows significant chemical zoning although there are differences in V_2O_3 and Al_2O_3 between the two sections. The V_2O_3 values increase in direct proportion to the decrease of Al_2O_3 confirming that the chromophore replace aluminium in the general grossular formula, $Ca_3Al_2(SiO_4)_3$.

High Grade Metamorphism

Upper amphibolite or granulite facies metamorphic conditions prevailed throughout Kenya during the period of vanadium grossular garnet formation (Cahen *et al.*, 1984). Around Baragoi in north Kenya granulite facies conditions were attained; two-pyroxene charnockites are sandwiched in the metasedimentary sequence which includes the graphitic gneisses (Dodson, 1963; Key, 1987). However, further south around Ol Doinyo Ng'iro the metamorphism remained in the upper amphibolite facies.

Pohl and Neidermayr (1978) suggested that in the Taita Taveta (Lualenyi) area, granulite facies assemblages are confined to a basal charnockitic igneous complex. This possibly represents an older basement to the metasediments affected by a subsequent lower grade (upper amphibolite facies) metamorphism when the vanadium grossular garnets were formed. Alternatively, Bagnall (1964) from his work in NE Tanzania, concluded that a single metamorphism affected the metasediments and associated igneous complexes and produced granulite facies assemblages in both. At Lualenyi the vanadium grossular garnet pods are enclosed by kelyphitic rims of epidote, scapolite, quartz, clinopyroxene and spinel. Pohl and Neidermayr (1978) concluded that the rims are late retrogressive products of the garnet cores. However, Sarbas *et al.*, (1984) showed that the scapolite-bearing rims formed during progressive metamorphism at higher grade (T>650°C, 3Kbars) than the enclosed garnet.

Fig. 4. Vanadium grossular garnet pod together with a cut stone in foregound. *(Photograph by E.A. Jobbins)*

Thin section examination of a typical garnet pod and its kelyphitic rim from Lualenyi identified a fine symplectite within the rimming scapolite (Figures 6 and 7). Subsequent microprobe analysis of the symplectite identified highly vanadiferous (10%-12% V_2O_3) grossular garnet in meionitic (only 2.29% Na_2O) scapolite (Table 3). The new microprobe data suggests that the reaction, V-grossular + quartz + CO_2 + Na^+ → Meionitic scapolite + V-enriched grossular, took place to produce the kelyphitic rim. The symplectite texture implies a stable co-existence (during synchronous growth) between the meionite and V-enriched grossular (Perchuk *et al.*, 1985).

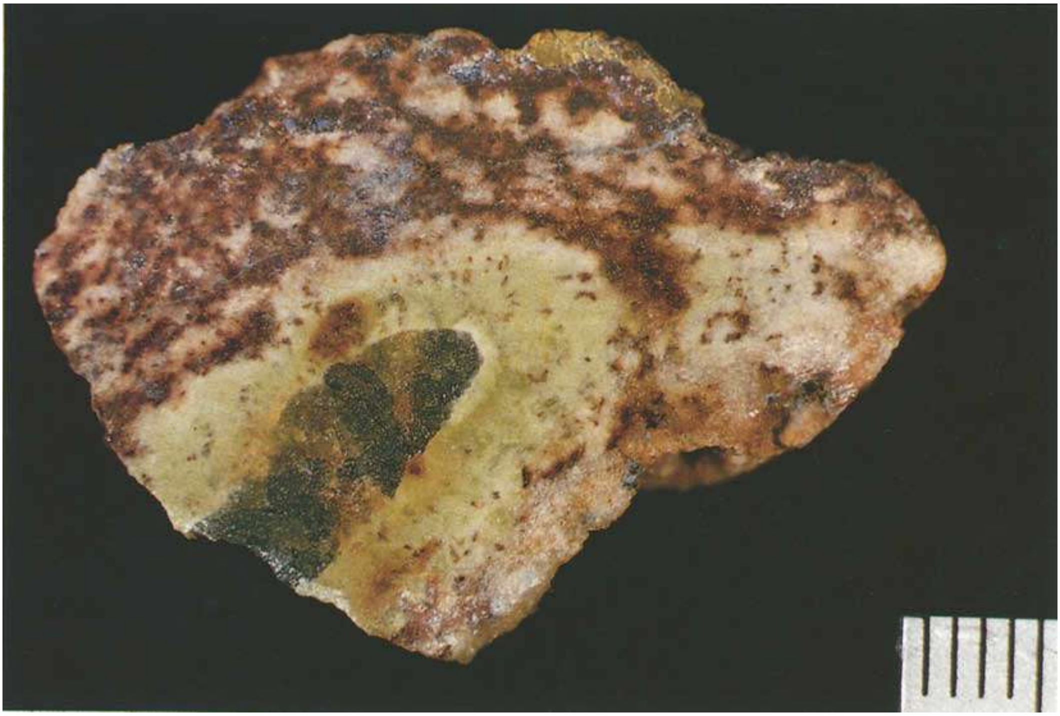

Fig. 5. The analysed garnet pod and its kelyphitic rim.

The assemblage grossular + quartz has been experimentally found to be stable under granulite facies conditions at over 750°C at 5 Kbars (Warren *et al.*, 1987) or 832°C at 7 Kbars (Perchuk *et al.*, 1985). Skmulovich (1979) as well as Gordon and Greenwood (1971) note that under these extreme conditions the assemblage is only stable at XCO_2 < 0.20 (XCO_2 is the mol. fraction of carbon dioxide in the fluid phase). Similarly, meionite is known (Oterdoom and Gunter, 1983; Goldsmith and Newton, 1977) to be the scapolite end member stable under granulite facies conditions; Baker *et al.*, (1987) suggest that its co-existence with grossular garnet indicates temperatures over 750°C at over 5 Kbars pressure. Therefore the kelyphitic rims appear to have formed under granulite facies conditions due to an increase in XCO_2 with sodium metasomatism. The ubiquitous marbles and calcareous lenses associated with the garnetiferous graphitic gneisses are an obvious source of both these components. Ferry (1983) showed that during high grade regional metamorphism of carbonates the progressive mineral reactions involved hydrolysis. This caused release of sodium (as NaCl) and CO_2 from the carbonates during reactions such as:

Calcic amphibole + calcite + quartz + H Cl → Diopside + sphene + NaCl + H_2O + CO_2 + Ca Al_2 Si_2O_8.

Schreurs (1984) also concluded that CO_2 fluids become common under granulite facies conditions and Walsh (1960) suggested regional alkali metasomatism in SE Kenya at or after the thermal peak. An upper temperature limit to the granulite facies

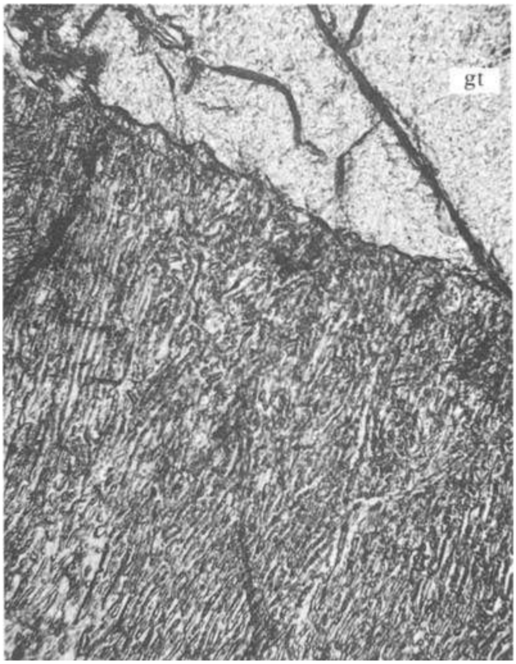

Fig. 6a

0 1 mm

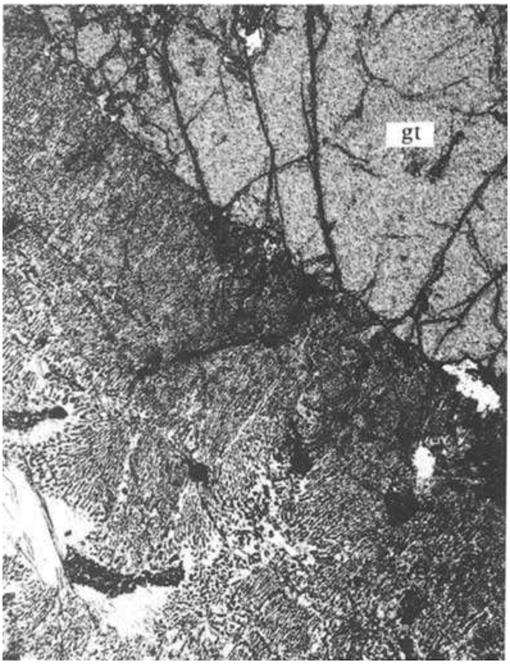

Fig. 6b

0 1 mm

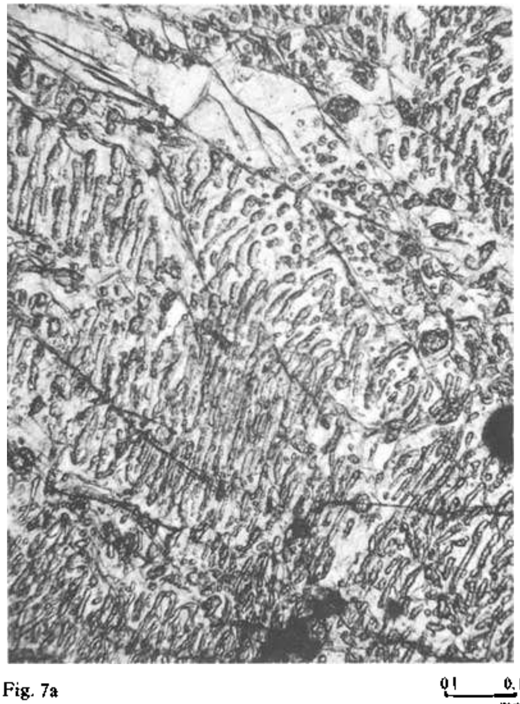

Fig. 7a

0 0.1 mm

Figs. 6 and 7. The symplectite texture in scapolite of the kelyphitic rim.

Fig. 6a. Grossular garnet (top right-hand corner) with kelyphitic rim. Plane Polarized Light (PPL) width of plate = 2mm.

Fig. 6b. Contact of garnet and its kelyphitic rim (PPL). Width of plate = 1mm.

Fig. 7a. Regular trails of V-enriched grossular garnet in rimming scapolite (PPL). Width of plate = 0.5mm.

Fig. 7b. Back-scatter electron microprobe image of scapolite (pale grey) with elongate V-enriched garnet trail (white) and isolated quartz (dark grey). Large scale bar = 10μm.

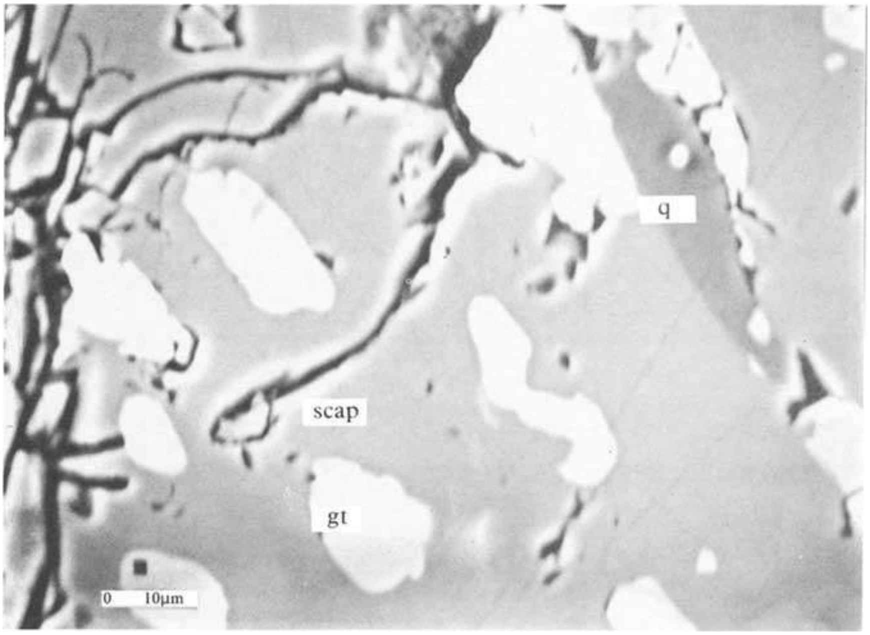

Fig. 7b

metamorphism in SE Kenya is provided by experimental data (Goldsmith and Newton, 1977) which shows meionite breaks down to anorthite and calcite at about 850-875°C over a wide range of pressures. Under similar conditions grossular and quartz break down to wollastonite and anorthite (Huckenholz *et al.*, 1981) although significantly Winkler (1967) notes that this reaction can be hindered by the formation of scapolite rims around grossular.

The new data indicates that the vanadium grossular garnets in SE Kenya formed under granulite facies conditions as did their kelyphitic rims. The marginal symplectites formed because of increased XCO_2 accompanied by a release of NaCl (from adjacent metacarbonates). This conclusion supports the view of Bagnall (1964) that in adjacent NE Tanzania the same period of metamorphism, which attained granulite facies conditions, affected both metasedimentary and igneous basement. The new data also agrees with the findings of Sarbas *et al.*, (1984) that the scapolite-bearing rims formed at higher metamorphic grade than the enclosed garnets.

Therefore, in Kenya at least, the vanadium grossular garnets appear to be restricted to graphitic gneisses affected by a granulite facies metamorphism.

Conclusions

An intimate association of graphitic gneisses and marbles, first recognized by Bridges (1974) is essential for the garnet's growth which may also be confined to granulite facies terranes. The physical and chemical conditions specified by Pohl and Neidermayr (1978) for vanadium grossular garnet growth in SE Kenya are indicated to occur throughout the Mozambique Orogenic Belt in Kenya. The host graphitic gneisses represent altered bituminous black shales and their extensive development indicates widespread Late Proterozoic organic seabed activity. Since granulite facies conditions are not confined to a basal igneous complex in SE Kenya, their occurrence has no significance in terms of basement-cover interpretations.

Acknowledgements

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Medium-dark blue aquamarines from Tongafeno, Madagascar, with high physical and optical properties, and showing three-phase inclusions

J. M. Duroc-Danner, FGA, GG

Geneva, Switzerland

Fig. 1. The seven faceted aquamarines from Tongafeno studied in this article.

Abstract

Aquamarines with high properties are known to occur (A.E. Farn[1], K. Nassau and D. L. Wood[2], J. Sinkankas[3]), and a detailed description of dark blue aquamarines from Zambia was recently published (H. Bank[4]). The aim of this article is to analyse the gemmological properties of aquamarines from Tongafeno, Madagascar, and to compare them with those with similar properties recorded from other localities.

Introduction

Recently, the author has had the opportunity to examine some rough crystals, and seven faceted aquamarines from Tongafeno, Madagascar (Figure 1), the measurements, weights and properties of which are described below.

Location and occurrence

Madagascar (1580 km long and 580 km wide) is one of the largest islands in the world (Figure 2).

Two major groups of rocks cover the island: ancient Precambrian basement rocks and younger sediments. The basement rocks which cover most of the area, consist mainly of gneisses and schists-quartzites. Numerous granite intrusions contributed pegmatite mineralization which is commonly complex and affords a large variety of minerals, including those suitable for gems and mineral specimens.

One of the most remarkaole of all gem pegmatites in Madagascar was mined at Tsaramanga village, 3 km north of Mont Itongafeno, a peak 15 km south west of Antsirabe; this is the locality designated as 'Tongafeno' (Figure 3)[3].

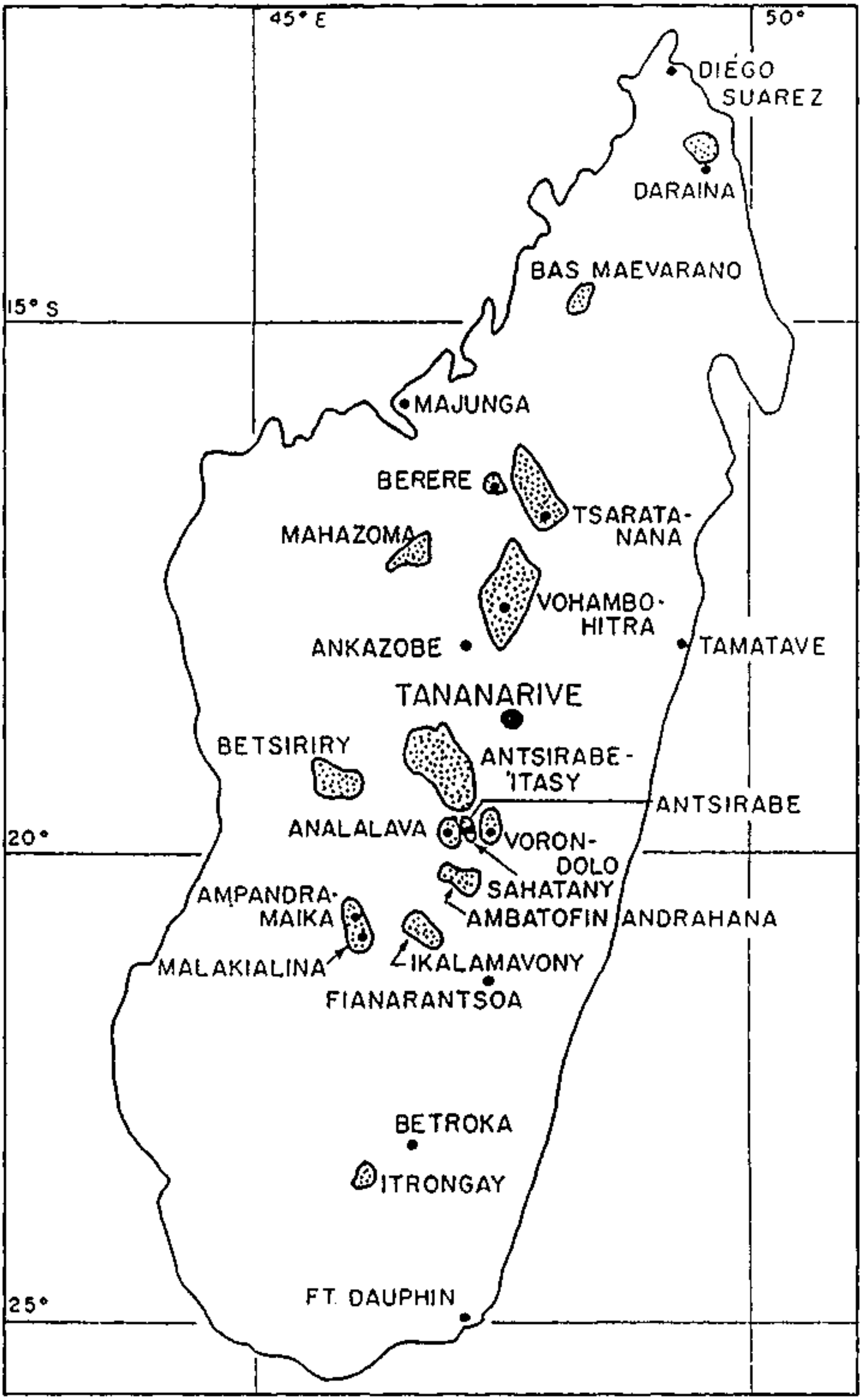

Fig. 2. Island of Madagascar, showing pegmatite deposits and the region of Antsirabe from where the aquamarines studied originate.

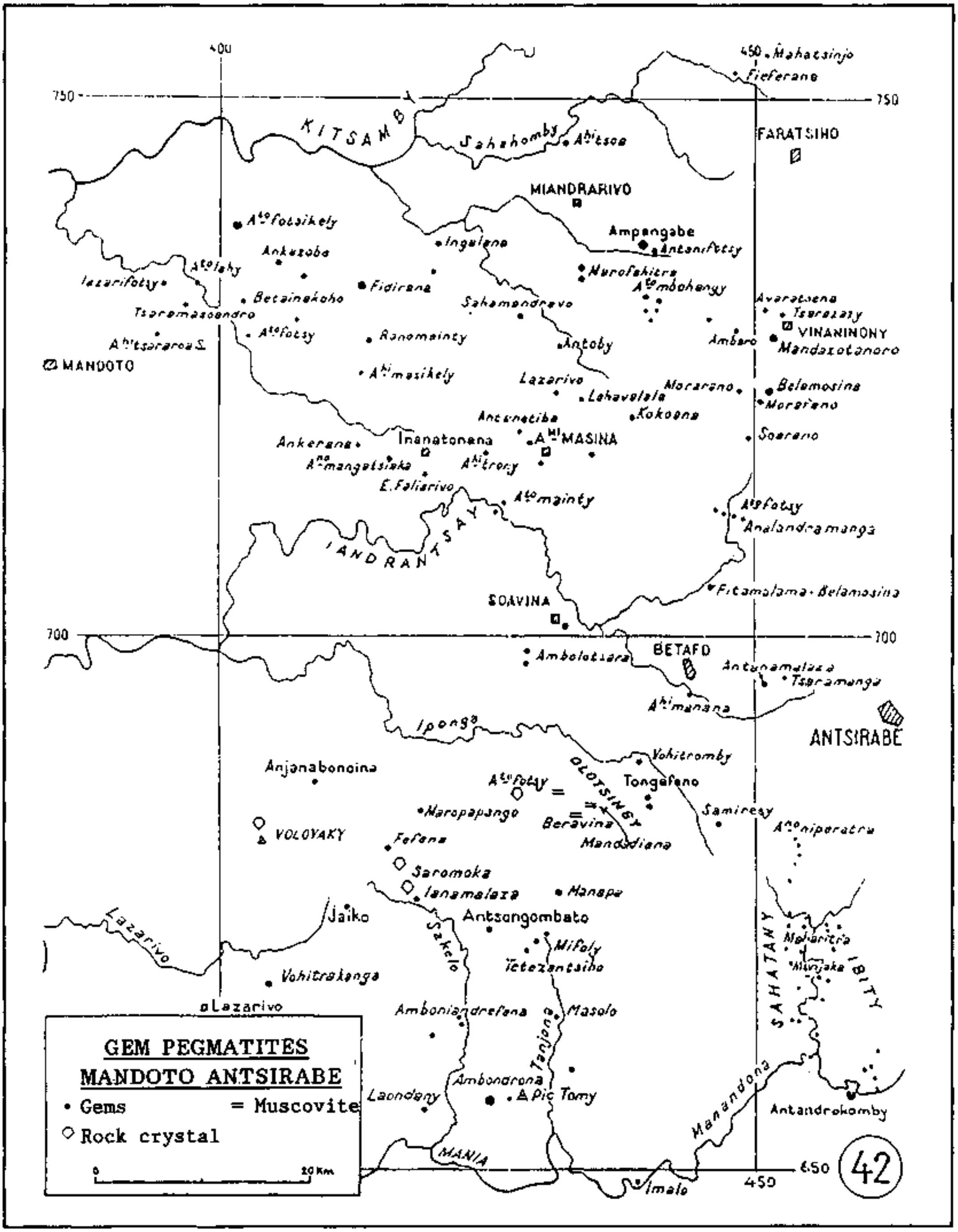

Fig. 3. Geographical location of the aquamarine deposit at Tongafeno.

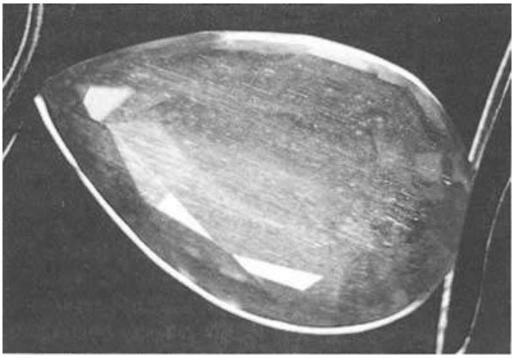

Fig. 4. Long, dense, canal-like needles running along the c-axis.

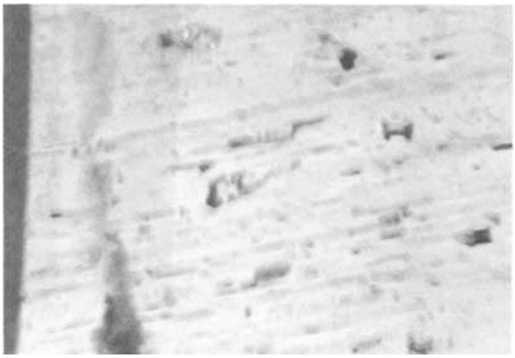

Fig. 5. A three-phase inclusion observed in an aquamarine from Tongafeno.

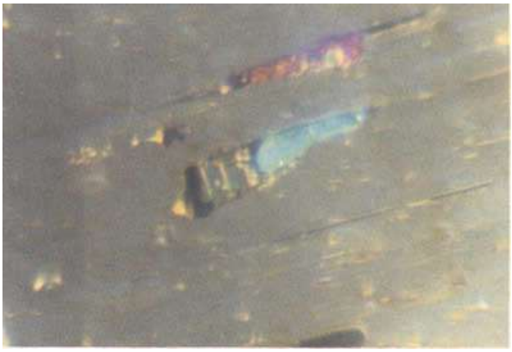

Fig. 6. The same inclusion as Figure 5 observed between crossed polaroids (half closed).

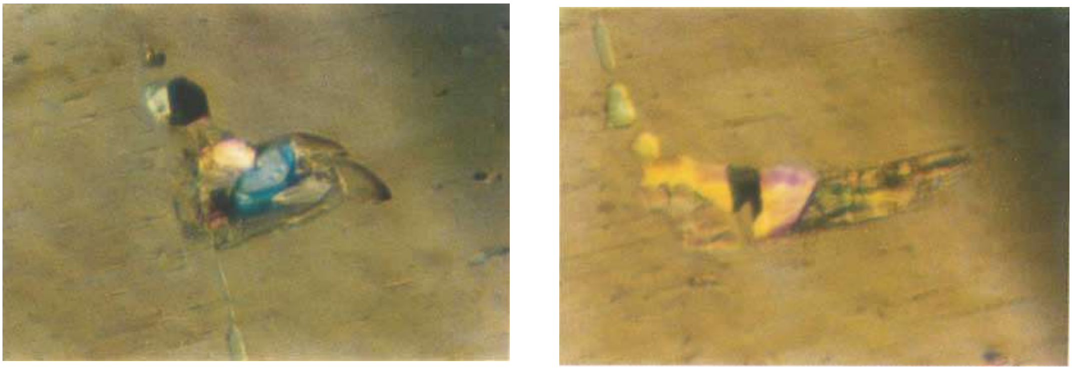

Fig. 7. Multi-phase inclusions observed in an aquamarine from Tongafeno between crossed polaroids (half closed).

TABLE 1. The physical properties of the seven faceted aquamarines and five rough crystals from Tongafeno, Madagascar

Cut or shape	Weight (carats)	Colour	Refractive index*	Double refraction	Specific gravity
Cabochon (flat base)	0.95	Medium blue	1.583-1.590	.007	2.730
Marquise	0.75	Medium-dark blue	1.582-1.590	.008	2.735
Cabochon (flat base)	0.42	Medium blue	1.582-1.590	.008	2.748
Brilliant	0.34	Medium-dark blue	1.583-1.590	.007	2.748
Pear-shaped	2.46	Medium-dark blue	1.583-1.590	.007	2.760
Baguette	1.50	Medium-dark blue	1.583-1.590	.007	2.766
Oval-shaped	0.77	Med.lt. bluish-green	1.582-1.590	.008	2.778
Rough crystals		Medium-dark blue	1.583-1.590	.007	No data
		Medium-dark blue	1.584-1.590^{2}	.006	
		Medium-dark blue	1.586-1.592	.006	
		Medium-dark blue	1.590-1.596	.006	

*The superscript number at the end of the refractive index, indicates the number of times these indices were encountered.

Gemmological properties

Table 1 gives the gemmological properties of 7 medium-dark blue aquamarines and 5 rough crystals from Tongafeno which were examined for this study.

Visual appearance

The medium-dark blue aquamarines from Tongafeno show a very strong dichroism similar in strength to that of cordierite. The two colours observed under a calcite dichroscope were medium-dark blue for the ε ray, and colourless for the ω ray. All aquamarines that have their table facet cut parallel to the *c*-axis show a medium dark blue colour. One which is oval shaped, has its table facet cut perpendicular to the *c*-axis, shows medium light bluish-green.

Most of these aquamarines are traversed by long canal-like inclusions which are reminiscent of 'rain', and these found parallel to the *c*-axis give to those gems a sleepy aspect.

Except for these long canal-like inclusions, the aquamarines are clean to the eye, and transparent.

Refractive indices

The refractive index determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. Only the table facets were tested and the indices obtained from the seven stones are ω 1.590 ε 1.583 to 1.582, giving a birefringence of .007 to .008 with optic sign (–).

A minute fragment taken from five different rough aquamarine crystals revealed under the polarising microscope the following indices: ω 1.590 to 1.596 ε 1.583 to 1.590, giving a birefringence of .006 to .007, with optic sign (–).

These refractive indices are very high for aquamarine, but seem to correspond to the mean value of those recorded from Zambia, the Isle of Elba, and the Brazilian Maxixe-type beryl (Tables 1 and 2).

Specific gravity

The specific gravities were obtained by hydrostatic weighing of the stones in distilled water using a Mettler electronic PL 300c carat scale, and the seven Tongafeno aquamarines were found to have specific gravities between 2.730 and 2.778; much higher than those recorded for aquamarines from the major localities, but again similar to those from Zambia, and the Isle of Elba (Tables 1 and 2).

Reaction to ultraviolet light

The stones, examined with a Multispec combined LW/SW unit remained inert. In this respect

TABLE 2. Physical properties recorded from aquamarines from other localities

Gem locality	Weight (carats)	Colour	Refractive index*	Double refraction	Specific gravity
Zambia[4]		Dark blue	1.575-1.582	.007	No data
		Dark blue	1.575-1.584	.009	
		Dark blue	1.579-1.587	.008	
		Dark blue	1.581-1.590	.009	
		Dark blue	1.584-1.593	.009	
		Dark blue	1.586-1.596	.010	
Rough crystals†		Deep sky blue	1.574-1.582	.008	2.701
		Deep sky blue	1.580-1.586	.006	2.718
		Deep sky blue	1.581-1.587	.006	2.724
		Deep sky blue	1.582-1.587[2]	.005	2.730
Zimbabwe†	1.32	Light greenish-blue	1.573-1.580	.007	2.710
Nigeria†	0.82	Light blue	1.568-1.572	.004	2.698
Brazil†	17.35	Light blue	1.564-1.570[1]	.004	2.685
	5.39	Light blue	1.565-1.570[2]	.005	2.690
	8.15	Light blue	1.566-1.570[1]	.004	2.689
	6.49	Light blue	1.566-1.572[1]	.006	2.695
	6.49	Light blue	1.567-1.572[1]	.005	2.690
	9.34	Light blue	1.568-1572[10]	.004	2.688
	11.80	Light blue	1.568-1.573[3]	.005	2.690
	11.11	Light blue	1.569-1.574[5]	.005	2.691
	13.06	Light blue	1.570-1.574[4]	.004	2.692
	9.01	Light blue	1.570-1.576[3]	.006	2.692
	0.80	Light blue	1.571-1.578[1]	.007	2.703
Maxixe-type[3]		Dark blue	1.584-1.592	.008	2.805
Isle of Elba[3]		Sky blue	1.585-1.591	.006	2.763
Pakistan[3]		Ink blue	1.599-1.607	.008	No data

* The superscript numbers at the end of the refractive index, indicates the number of times these indices were encountered out of 5 rough crystals from Zambia, and 32 faceted aquamarines from Brazil.
† Physical properties recorded by the author.

the aquamarines from Tongafeno, like aquamarines from other localities show no reaction to ultraviolet light.

Spectroscopic analysis

The absorption spectra seen through a Gem Beck Spectroscope Unit, showed a strong absorption 400-410 nm, a set of three lines centred at 430, 620, 630 nm, and then another strong absorption 640-700 nm.

Microscopy

The inclusions were examined under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting, depending on whether internal or external features were to be examined.

The most characteristic inclusion, and nearly always present, consisted in different lengths of dense canal-like needles oriented parallel to the *c*-axis (Figure 4), and giving a 'rain-like' effect. Sometimes, many isolated black pinpoints (crystallites) were observed. Two-phase inclusions in the form of a squarish shape were also present, and in one stone a three-phase inclusion has been noticed accompanied by other more complex three-phase and multiple-phase inclusions consisting of gas, liquid, and many solid inclusions (Figures 5 & 6).

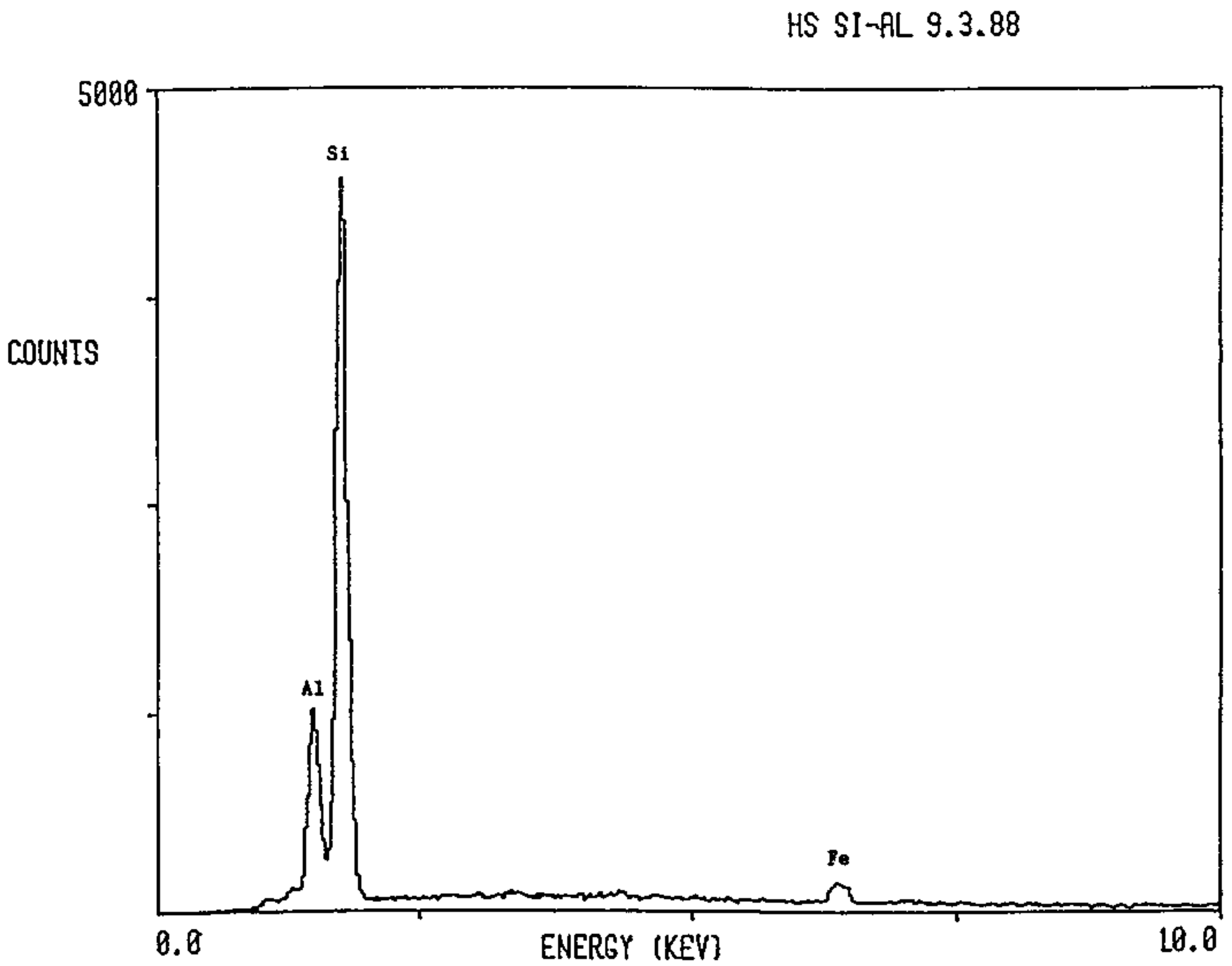

Fig. 8. Energy-dispersive qualitative spectra of the aquamarines from Tongafeno.

The complex three-phase inclusions have been observed on a horizontal Eickhorst Gemmoscope while the stone was immersed in benzyl benzoate.

Notice how the solid inclusions react while the stone is between crossed polaroids, by giving different polarising colours due to their crystallographic orientations. These inclusions were proved anisotropic, but unfortunately could not be determined (Figure 7).

Chemical analysis

Chemical analysis for the Tongafeno aquamarines were obtained through qualitative analysis by dispersion energy, which revealed the presence of aluminium, silica and iron (Figure 8).

It is interesting to note that the small amount of iron present in these aquamarines is probably responsible for the medium-dark blue colour, but of more gemmological value, of the distinct absorption line centred at 430 nm observed under the Gem Beck spectroscope unit.

Summary and conclusion

The aquamarines from Tongafeno due to their characteristic dichroism, inclusions, absorption spectrum, and high physical properties are remarkable and readily differentiated from those from other localities. However, as the colour of these stones is due to the presence of iron, as in all true aquamarines, it seems appropriate to give these the variety name 'aquamarine', despite the fact that they are not sky-blue, or sea-green, or pale green with decided tinges of blue.

In the case of the Maxixe-type beryls, such a name should not apply, since the colour is probably due to activation of a colour centre through irradiation, or a defect in the structure, but not to the iron present in a too small amount to be responsible for the colour[5].

There is also an inversion of the colour absorption. While in all 'true aquamarines' the colour is vehicled by the ε ray, in the Maxixe-type beryls the colour is vehicled by the ω ray.

Last but not least, the colour of the Maxixe-type beryls is not stable and fades in light. For all these reasons, such varieties should be called either Maxixe-type beryls, or blue beryls, rather than aquamarines.

A similar situation occurs when distinguishing between emeralds and green beryls. In this case the identification is based on the presence of chromium lines in the absorption spectrum. If these lines are present, then it is an emerald, and on the contrary, it must be a green beryl.

Acknowledgements

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A fourteenth century crown

Amanda Gray, FGA

London

Fig. 1. The 'English Crown' displayed at the Schatzkammer of the Residence Museum, Munich. *Photo by permission of Bayerische Verwaltung der Staatlichen Schlösser, Gärten und Seen.*

One of the highlights of the spectacular Age of Chivalry Exhibition at the Royal Academy, London, was the beautiful fourteenth century 'English Crown'. This has not returned to England since it left in 1401, as part of the dowry that Blanche, the daughter of Henry IV, took with her on her marriage to Ludwig III of Bavaria. This is how it came into the possession of the Wittelsbach family, and it is now displayed in the newly refurbished Schatzkammer of the Residence Museum, in Munich, West Germany. Gemmologically the stones are of no great merit; however the combination of colours in their layout is aesthetically very pleasing. From a historical standpoint the crown is of great interest.

On examining crowns over the ages they appear to fall into three distinct categories. The single circlet, the two tier type and the ones which had closed-in tops. This crown falls into the second category, and, despite its fragile appearance it is in very good condition. The lower section of the crown consists of 12 rosettes which support 12 golden lilies of alternating heights. The lower rosettes are made up of a circular gold ring base within which is an enamelled hexagon which contains some fine gold tracery work. At the centre of each is a sapphire. These are of a pale blue colour and are mostly oval cabochon bead-shape. Some have been drilled through the centre, implying re-use of the stones.

They are held in position by gold claws. One of the stones is a flat hexagonal shape and appears to be a sliver from a trigonal corundum crystal. The colour of the enamel alternates between translucent red and blue and is overlaid with small white flowers made up of dots of opaque enamel. Each point of the hexagon is set with either a pale ruby cabochon stone, of almost pebble-like appearance, or a cluster of four drilled pearls with a tiny diamond octahedron in a rub-over mount in the centre. The red enamelled hexagons have rubies at the tops, and the blue ones have the pearl clusters. The interplay of the blue, red, pearls and gold is extremely effective and is repeated in the layout on the upper part of the crown. The taller lilies have three carved gold trefoil leaves with beaded edges at the top, with a cabochon ruby in their centre surrounded by four cabochon sapphires. At the very tip of the highest leaf there is a three-pearl cluster with a tiny diamond crystal in its centre, and another four-pearl and octahedron diamond cluster on the stem of the lily with a further sapphire and ruby below it. There are two pairs of small carved gold leaves, also in a trefoil design, sprouting from the sides of the stem. A single pearl protrudes from the lower points of the large leaves. The pearls are in good condition; apparently some restoration work was carried out in 1925, so it is possible some were replaced then. Their creamy colour stands out well against the gold. The smaller lilies have a sapphire in the centre of four rubies and either a ruby or an emerald with a single pearl on the stem. In contrast to the four pearl and diamond clusters which the larger lilies have at the tips of the upper leaves, these smaller lilies have a single pearl which is suspended on a gold wire from the upper leaf.

An interesting feature of the crown is the fact that it is possible to fold it for travelling purposes and it has its own fitted case. Between the rosettes are exquisitely decorated blue enamel plaques with delicate gold tracery overlay – these are the sections where the crown folds. They are even enamelled on the reverse with a small flower. Each rosette is also numbered 1 – 12 so that each lily can be fitted into the correct position.

There has been much speculation as to when the crown was made and for whom. In the late fourteenth century many of the portraits of the Virgin Mary depicted her wearing a crown of this style, e.g. Gerard David's 'Virgin' in the National Gallery. This style is also seen on other queens of the period as well as Blanche. As mentioned above, it came to Bavaria when Blanche married Ludwig III in 1401. Henry IV had spent six months arranging this marriage which he felt would be a politically beneficial alliance between England and Germany. However, as Blanche died in 1409 this was rather short lived.

Prior to the crown leaving England in 1401, it had been in the possession of Henry IV and is mentioned in 1399 in an inventory of jewels, gold and silver plate, which was to be transferred from the Treasury to the King's personal chamber. This collection had previously belonged to Edward III, Richard II and his Queen Anne, the Duchess of York, the Duke of Gloucester and Sir John Golafre (who was a Knight of the Chamber). This inventory does not give any precise indication of the crown's previous ownership and it is not possible to be certain that it belonged to any of these people. However, several of the 339 items listed belonged to Anne of Bohemia and it is possible that she brought it with her when she married Richard II in 1382.

It is very difficult to trace the work of goldsmiths of this period. Kings and nobles often employed their own craftsmen in their courts. Two of the techniques used on the crown suggest a French origin. Firstly, the enamelling is typical of the work carried out in France in the latter part of the fourteenth century, and secondly the gold beading on the leaves is similar to some examples found on rings in the hoard of jewellery which had been deposited in 1349, at Colmar in France. However, if the crown was made in Bohemia for Anne, it could have been made in Prague by French trained craftsmen; alternatively it may have been made for her in Paris. However, there are fourteenth century examples of similar enamelling and gold beading on English pieces (for example on the Oxwich brooch displayed at the same exhibition), and therefore this evidence is by no means diagnostic, and the origin of this interesting crown therefore remains obscure. Our interest is sufficiently held in appreciating the design and interplay of colours, and in speculating who has worn the crown through the ages!

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The four optical attributes of a diamond

James B. Nelson, Ph.D., FGS, C.Phys., F.Inst.P., FGA

McCrone Research Institute, 2 McCrone Mews, Belsize Lane, London NW3 5BG

Abstract
The four separable optical attributes of a diamond, lustre, brilliance, fire and sparkliness are treated in terms of physical optics. Other gemmological matters of interest which are derivative of these properties are discussed in some detail. These are (1) the possible improvements in 'liveliness' by adopting an odd-number symmetry cut, (2) the Brewster angle refractometer, (3) the effects of adventitious matter adhering to pavilion facets and (4) the possible benefits and disadvantages of depositing pure aluminium films on the pavilion facets. A brief description is given of two instrumental arrangements for demonstrating all the effects discussed. The article concludes with a plea for the standardization of descriptive English terms for brilliant cut diamonds.

If an inclusion-free diamond has been smoothly polished with its 58 facets placed at angles characteristic of the modern round brilliant-cut style, it can then exhibit its four most prized optical attributes. These are lustre, brilliance, fire and sparkliness. There is a fifth, which, apart from coloured diamond fancies, most prizes those stones which show the closest approach to a colourless body colour.

Lustre

This is the amount of white light specularly reflected from the individual surfaces of the table and crown facets alone, relative to the amount of white illuminating light falling directly on these surfaces. This measure is termed reflectance. It varies in a complex manner with the angle of incidence (i) of the illuminating ray. When i = o°, its value is given by the equation:–

$$R = \frac{I}{I_o} = \frac{(n-1)^2}{(n+1)^2}$$

where R is the ratio between the intensity of the light reflected (I) from a flat perfectly polished surface, to that of the incident light intensity (I_o). The refractive index is (n). The ratio R is usually expressed as a percentage, i.e. 100 R. The angle of reflection is always identical to the angle of incidence. If the n value for diamond is inserted in this equation, the value for R is found to be 0.172 (or 17.2%) when i = o°. For comparison, quartz has an R value of 0.046 (or 4.6%) when i = o°. When i = 90° the value of R for the polished surfaces of *all* substances becomes unity (or 100%).

Brilliance

This is a measure of the relative amount of light, which on entering the stone, can be twice totally reflected from the pavilion facets back to the observer only by way of the table or crown facets. Only white, or near-white (weakly-dispersed) light is being considered here.

If the number of the total reflections possible is reduced then there will of course be an increased loss of brilliance through forwards light leakage (as with a 'fisheye' cut) or from sideways leakage (as with a 'lumpy' cut). These rays cannot reach the eyes of the viewer.

Fire

This is a spectral effect produced by the complex prismatic nature of the diamond's flat facets. The size of the effect depends on the particular geometry of the table and crown facets and on their relative areas. A white light ray, on entering the stone by way of the table or crown facets, can, if its direction is appropriate, be totally reflected and this reflected white ray be split up into its constituent spectral colours. These rays emerge from the table and crown surfaces as flashes of fully-saturated (i.e. spectral) colours. The effect was first named 'fire' by Tolkowsky[2].

The effect, of course, depends mainly on the total number of those refracted rays capable of being totally reflected by the pavilion's facets and subsequently being spectrally dispersed by the table and crown facets.

The magnitude of the effect also depends on the high dispersion of the refractive indices of diamond, which for the region lying between the Solar spectrum lines B (wavelength = 687 nm) and G (wavelength = 431 nm) has the value 0.044.

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The most popular diamond substitutes or simulants have been those whose B-G dispersions are not too far removed from diamond's 0.044. The most acceptable of the natural stones, colourless zircon, has the value of 0.038. Among the colourless synthetic stones which have been sold as simulants are YAG (0.028), GGG (0.045) and CZ (0.061), the last-named of which is now by far the most used. Other colourless or near-colourless synthetic stones such as strontium titanate (0.200) and rutile (0.300) have also been marketed, but their very high dispersions produce such intense and spectacular 'fires' that they are held to be unappealing or even garish to the informed eyes.

Should it become possible to produce large colourless monocrystals of the beta-modification of silicon carbide (SiC) by a relatively inexpensive process, this material would probably displace CZ as the most favoured simulant. It possesses a cubic structure, a very high Mohs's hardness (9½), a large **n** (about 2.65; therefore the high lustre of $R = 20.4\%$ at $i = 0°$) and a not too excessive fire-producing dispersion (0.110).

Sparkliness

This twinkling effect requires movement and is mainly proportional to the number of crown facets present. These facets produce only *colourless* surface reflections. The crown facet movements, which can be quite small in angular terms, bombard the observer with myriads of tiny flashes or scintillations of intense white light. The greater the size of a facet, the greater will be the perceived intensity of a reflection. There can be also another contribution to sparkliness. This originates from the smaller number of colourless, or near colourless, rays which can emerge from the table and crown facets through the agency of internal total reflections from the pavilion facets.

Unlike the previous three effects, the observation of sparkliness requires movement. The three possible movements can be either those of the illumination, or of the diamond, or of the observer or wearer.

For the illumination to be really effective, it must be derived from one or more high intensity, condensed-filament lamps. The use of long tube-like fluorescent or opal incandescent lamps seriously dampens the effect.

The diamond alone or in its setting may be moved by being displayed on a revolving table, or by the wearer of the diamond jewellery or by the now unfashionable use of 'tremblers' in jewellery design.

In the absence of movement of the light source(s) or of the diamond, it is only by the movement of the observer or wearer that the effect can be seen. Again, unlike the three other optical attributes, sparkliness cannot be captured on a still photograph of a stone.

Stone design options

It is clear that as the ratio of table 'spread' to total 'spread' is changed, so also will the relative proportions of brilliance, fire, sparkliness, and even lustre. A larger table means a more brilliant appearance. A smaller table produces greater fire. A trade-off is usually necessary to satisfy the prevailing fashion. At present, the trend seems to be towards whiter sparkles.

There are no set rules for cutting diamond rough to obtain the highest commercial yields. Each stone presents a compromise between the conflicting aims of size and beauty, with beauty often trailing as second best. If beauty is the first choice, then certain design principles have been established by practical experience over many centuries to produce the most pleasing optical effects[1]. Pavilion angles should be very close to 41° with crown angles close to 34°, with impeccable polish, flatness and eight-fold symmetry. Very small ('ticked') culets help to avoid breakage and increase brilliance.

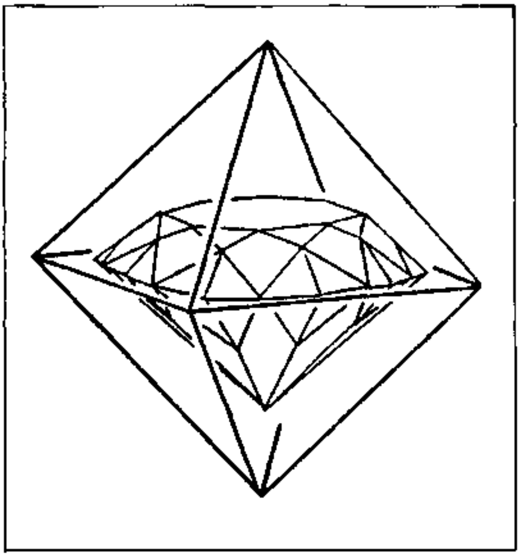

Fig. 1. Location of an 'ideal' round brilliant stone within an octahedral crystal, and cut to yield the largest possible girdle size.

Starting from an octahedral crystal such as shown in Figure 1, the cutting of an ideally-shaped diamond having a maximum girdle diameter would probably not give the best yield, particularly if an inclusion was badly located.

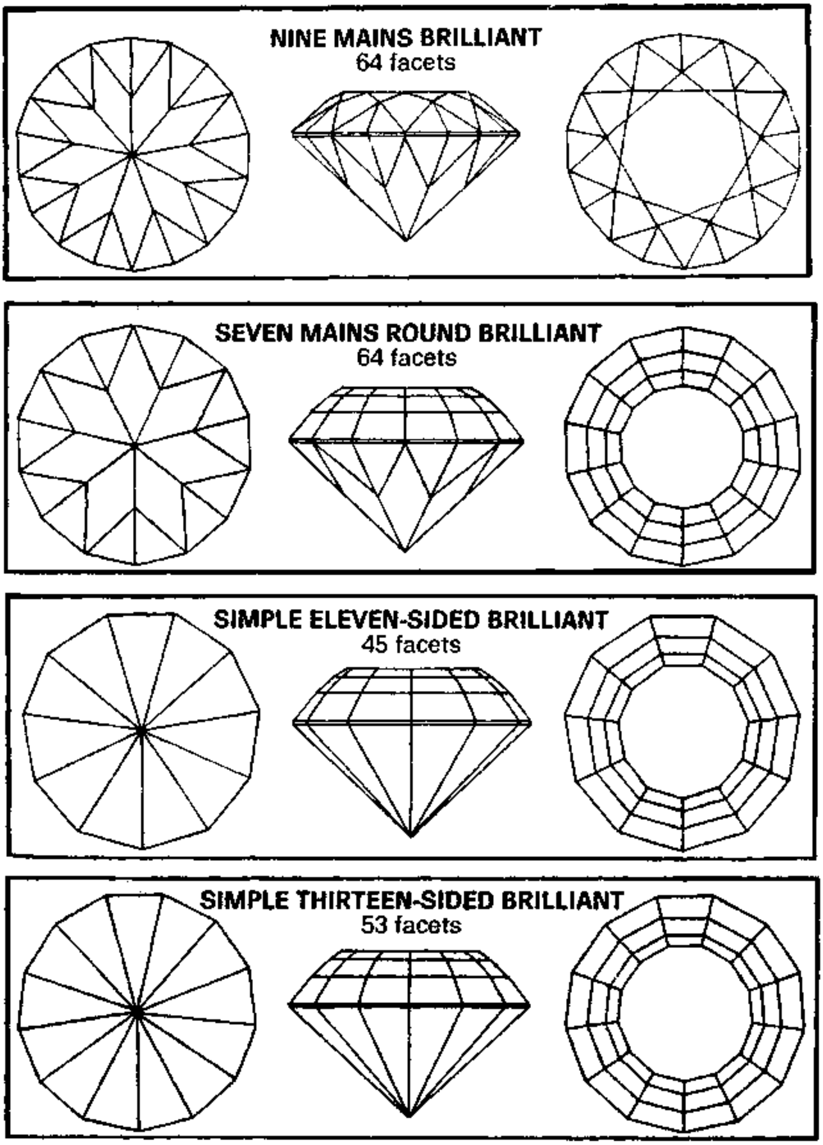

Fig. 2. Examples of round gemstones having mains facets with odd-numbered symmetries.

The physical optics of a round, brilliant-cut diamond

Much effort has been expended over recent years in trying to determine by calculation alone if it is possible to improve on the current generally favoured cutting angles and shapes of the round brilliant style[2-12]. The computer calculations have been concerned mainly with the two-dimensional angular relations of geometrical optics although there have been two attempts to introduce three-dimensional ray-paths and also involving light intensities[8-11]. One of these[11] however, only treats the situation where a wide, parallel light beam is directed to the diamond 'model' at $i = 0^\circ$.

The many simplifications needed to restrict the large numbers of parameters required for realistic computer predictions of 'optical goodness' have meant that the results have been of limited practical use to stone cutters.

It is clear that for some time yet, judgments of the 'optical goodness' or perhaps 'beauty or attractiveness' criteria will have to rely on subjective assessments of new stone designs by panels of experts in the trade. Indeed, it is highly probable that it will be the coloured gemstone faceters and diamond cutters producing actual exploratory cuts, rather than the computer scientists, who will discover real improvements in stone design.

Claims were made recently by two gifted professional faceters that if the eight-fold symmetry of the brilliant cut were changed to certain odd-number symmetries such as 7-fold or 9-fold, then this would result in a 'better return of brilliance' than the standard cut[13]. Crown and pavilion facets would, as usual, lie in common meridians.

To test this view, a faceter, W. Carss, cut a suite of stones having 16 different axial symmetries, ranging from 5-fold to 20-fold in 1-fold steps. The stones were of clear, colourless, synthetic quartz, each cut to a girdle diameter of 12 mm in the round brilliant style, but with stepped crowns. See Figure 2. The suite of stones was displayed to an audience of experienced faceters who were participating in a faceting symposium. Each member was asked to look at the gemstones carefully and decide which one each liked best. The largest number of viewers chose the 11-fold stone; the next largest chose the 13-fold stone[14]. Somewhat unexpectedly, no one had chosen any of the even-numbered symmetry stones.

It is clear that a design demonstrated in quartz would not necessarily be a useful guide for diamond. Even if it were so, the diamond trade would raise the strongest objections to such a radical change. It would be argued that an odd-symmetry cut, whilst not a serious production problem, would have to compete with immense quantities of existing octagonal-cut jewellery; matching lost stones with those of different geometries would not be possible.

Nevertheless, the novelty or rarity of cut, purely by itself, might find a welcome niche within the traditional market.

The general interaction of light beams with transparent media

In spite of the poor performance of computer ray-path tracing leading to 'optical goodness' assessments, it is perhaps helpful to gemmology students, lapidaries and others to know a little of the basic physical optics of faceted gemstones, and of diamond in particular.

Figure 3a is a schematic illustration of the interaction of a single monochromatic light ray falling at a point 0 on a flat, polished block of any isotropic, colourless, transparent material. The symbols E, N, R, D, s and p represent directions only. They are the symbols used internationally* following the fundamental optical studies of the German physicist, Paul Drude[15].

The angle EON is the angle of incidence (i) and is equal to NOR, the angle of reflection. The important plane, known as *the plane of incidence*, is that containing the incident ray E, the surface normal, N and the reflected ray R. This plane also contains D, the direction of the refracted ray (r) which has entered the block of material.

The relationship between the value of i, the value of r and the value of the refractive index n, of the material of the block is given by:

$$\frac{\sin i}{\sin r} = n$$

It is known as Snell's law.

Figure 3b shows the angular relationships of the various rays in the plane of incidence when the refractive index of the material is taken as n = 1.5, the approximate value for ordinary glass. The value of r = 3°20′ is that found from Snell's law when i is taken as i = 5°00′, an angle near normal incidence. Similarly, the value of r = 41°37′ is found when i = 85°00′, an angle near grazing incidence.

The middle diagram shows a special situation when the sum of i and r attains 90°. The value of i for the n = 1.5 glass at this particular angle is known as the Brewster angle and is given the special symbol ($\bar{i}$). Here $\bar{i}$ = 56°19′ and $\bar{r}$ = 33°41′ where ($\bar{i} + \bar{r}$) = 90°00′.

So much for the angular relationships. It is now necessary to examine the intensity variations.

Returning to Figure 3a it is seen that there are two directional symbols, (p) and (s) which have not yet been discussed.

The incident ray EO is assumed to be unpolarised. That is to say the transverse vibrations (of the electromagnetic theory of light) in the incident light ray have completely random directions. On being reflected at 0, these transverse vibrations become no longer random, but are partially resolved into two components. One of these is the p-component whose vibrations lie in the plane of incidence. The other is the s-component whose vibrations marked s-s, lie perpendicularly to the plane of incidence.

*E = Einfallswinkel, meaning 'angle of incidence'.
N = Normal, meaning 'perpendicular to surface'.
R = Reflexionswinkel, meaning 'angle of reflection'.
D = Durchfallen, meaning 'transmitted'.
s = Senkrecht, meaning 'perpendicular to a plane'.
p = Parallel, meaning 'in the same plane'.

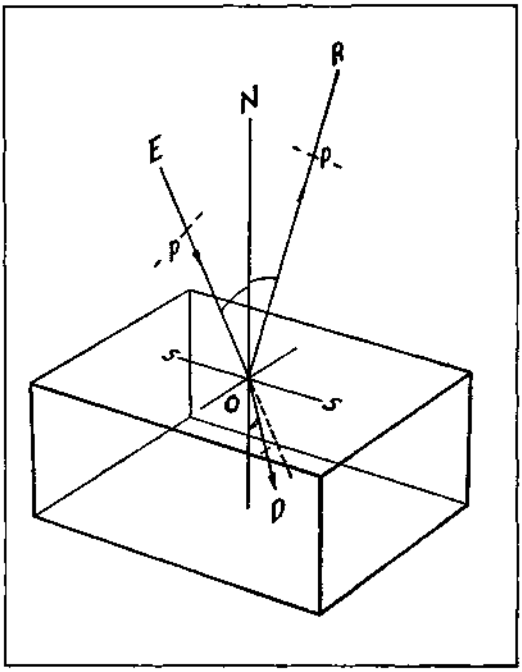

Fig. 3a. Illustration of the paths taken by a single monochromatic light ray after striking a flat polished block of a transparent, colourless, isotropic material such as glass. The meaning of the symbols are given in the text.

Thanks to the work of Drude[15], the physical reasons for this behaviour have been elegantly explained in terms of the Clerk-Maxwell electromagnetic wave theory of light. Unfortunately, a simple explanation in terms of a model or analogue is hard to find. It must be sufficient, therefore, to present Drude's calculations of the light reflectances and transmittances of the two vibrational components in graphical form.

External reflections. The case of the externally reflected light, associated with lustre, will be described first. In Figure 4, for a polished diamond surface the percent reflectance, R, is plotted on the vertical axis and the angle of incidence i plotted on the horizontal axis.

The reflectance of the s-component (R_s) is seen to increase slowly at small values of i, but increases rapidly until at i = 90° (with EO lying parallel to the block's surface) R becomes equal to unity (R = 100%). This means that the block reflects all the light falling upon it at this angle, but of course in actual viewing conditions, this situation will seldom be realized.

The maximum viewing angle could probably be reached when i = 60°. This corresponds with an R value of 40%, compared with 18% at i = 10°, which is probably the minimum viewing angle.

The reflectance of the p-component (R_p), behaves quite differently. It decreases slowly for small values of i until it becomes zero at a particular value called the principal angle of incidence, designated $\bar{i}$, or Brewster angle. It is related to the refractive index n by the designated expression tan $\bar{i}$ = n. This situation, when (i + r) = 90°, is illustrated for the case of a glass of n = 1.5 in the middle diagram of Figure 3b and in Figure 5 for the case of diamond.

Referring to Figure 4, it can be seen that when i is increased beyond the Brewster angle of $\bar{i}$ = 67.54°, R increases very rapidly, until at i = 90°, R again becomes 100%.

Drude showed that the s-component of the reflected ray is only partially polarized at all i values. Some polarization of the reflected p-component ray occurs at all values of i, except at the Brewster angle, when it becomes completely polarized. The vibration direction of this completely polarized p-component ray at $\bar{i}$ = 67.54° lies perpendicularly to the plane of the page of Figure 5 and is indicated by the four dots on the reflected ray.

It is now clear that the nature of the R_s curve alone is responsible for the dramatic increase in lustre when i is increased, because it is only weakly polarized. If R_s and R_p were completely polarized at all values of i, then the mean of the two curves would be that observed by the eye, which of course cannot see polarized light directly. The calculated mean curve is that shown by the dashed line in

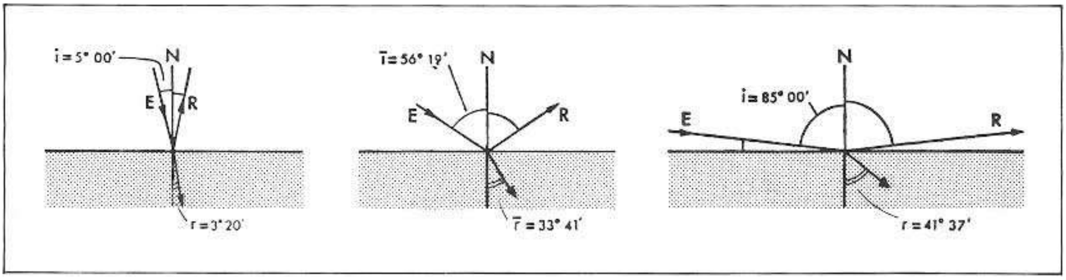

Fig. 3b. Illustrations of various ray paths in the plane of incidence, when the refractive index is taken as 1.5, the approximate value for ordinary glass. See text for explanations.

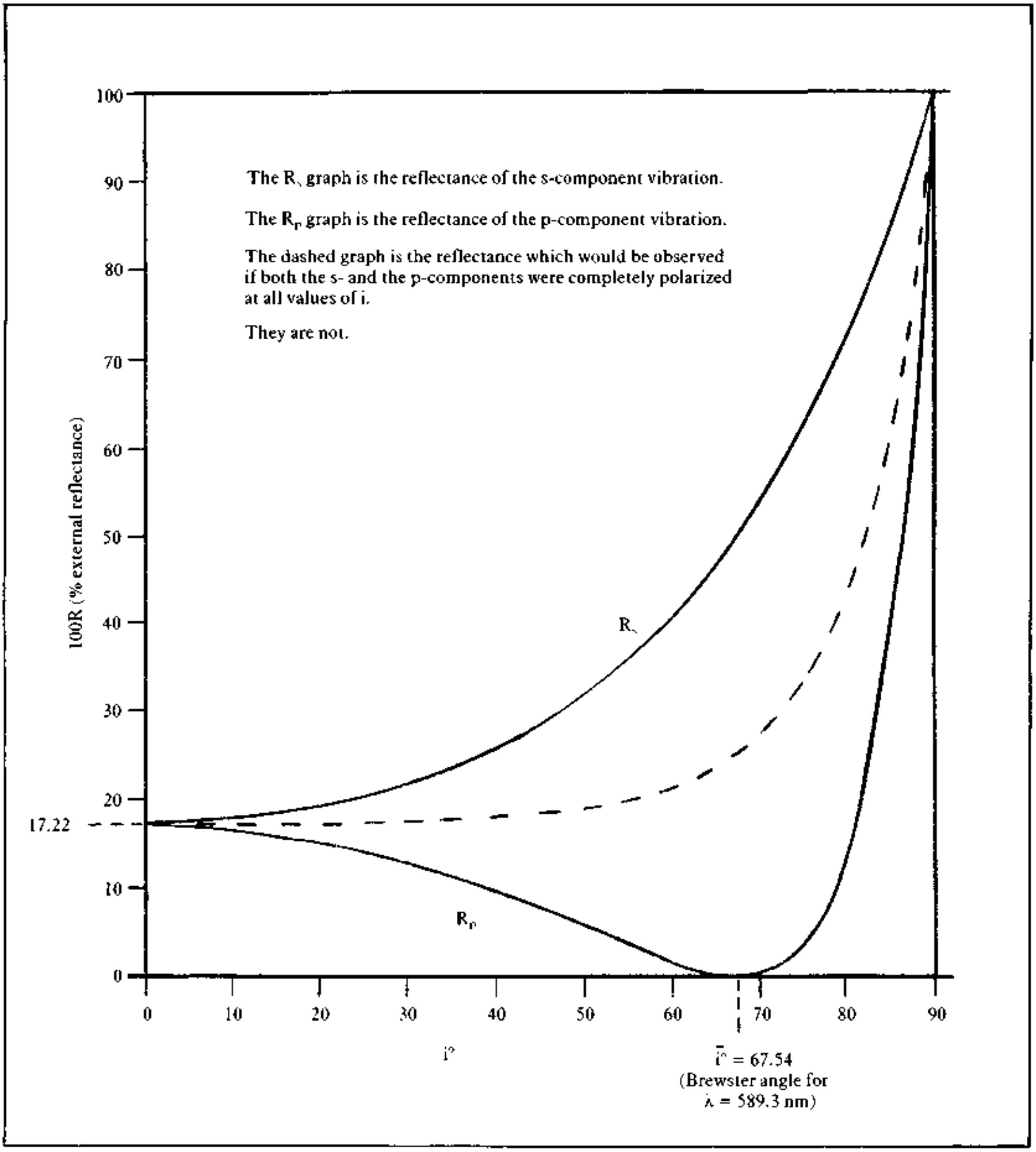

Fig. 4. Variation of the external reflectance, R, with the angle of incidence, i, from the surface of a polished diamond.

Figure 4. This indicates that there would be an almost imperceptible change in lustre for i values up to the practical limit of i = 60°. This does not happen.

Brewster angle refractometer

The relationship n = tan $\bar{i}$, is the basis of a proposed Brewster angle refractometer[16,17,18]. The particular value of such a device is that it requires no optical coupling liquid, so that it can cope with stones whose n values are higher than the n = 1.81 limit of conventional refractometers. Another virtue is that it is relatively insensitive to scratches and imperfections on the table's surface, a problem which bedevils all infra-red reflectometer measurements. It would be especially useful in checking diamond and coloured stone simulants.

The main obstacle to its accurate performance is the intrinsic difficulty in determining when R_p reaches its critical zero value at i. This null point is

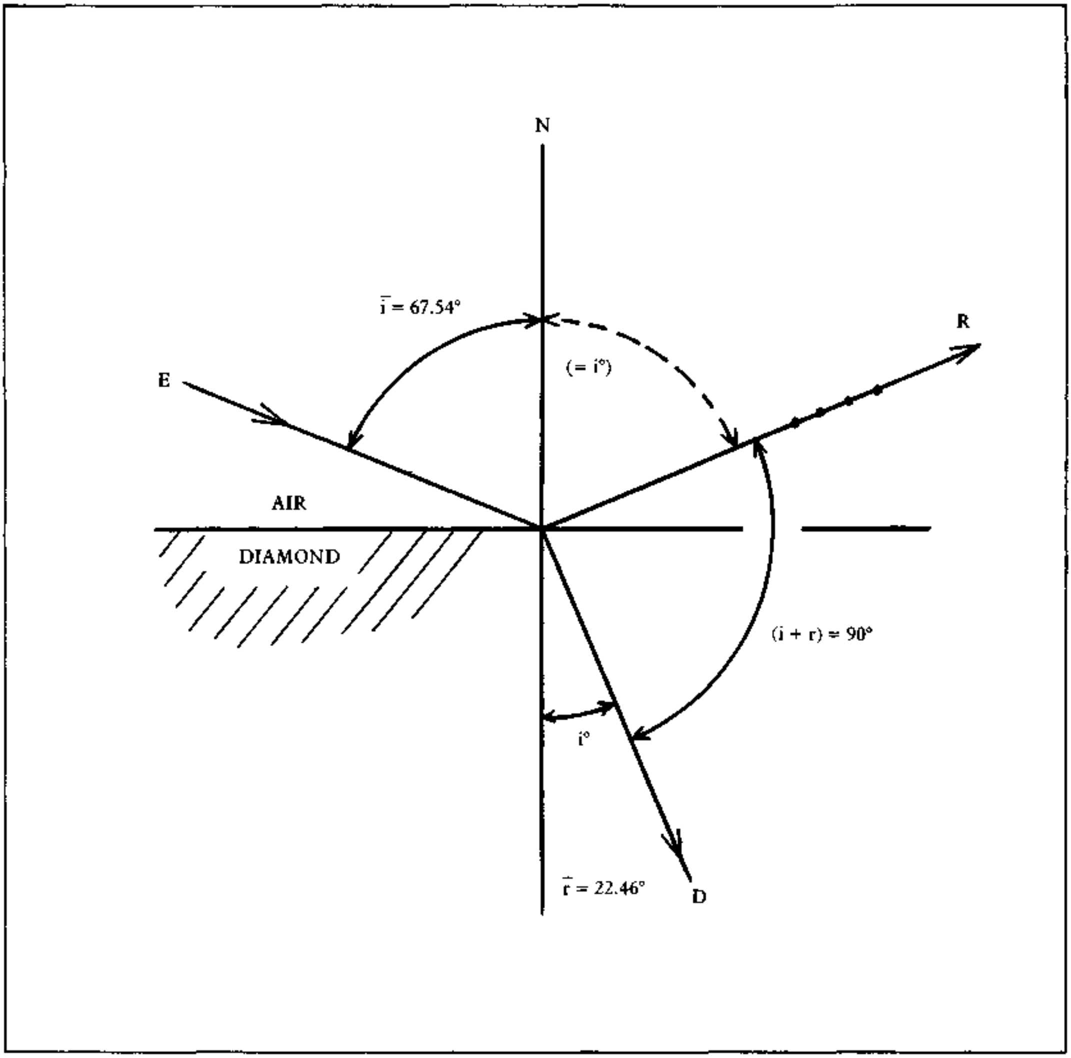

Fig. 5. The Brewster angle for diamond. For a λ of 589.3 nm. See text for explanation.

difficult to measure with the eye or even with a photocell, because of the shallow nature of the trough of the curve near the $\bar{i}$ position. However, by taking identical photocell readings on either side of the steeply-rising parts of the trough, this null point could be much more accurately determined. The mid-point of the i values would yield the correct $\bar{i}$ value, if an account was taken of the asymmetry of the trough. This is illustrated in Figure 6. The angular scale calibration would be simplified by the use of two calibrants. These could be a flat polished plate of CZ ($\bar{i}$ = 65.33°) and a basal plane growth face of alpha-silicon carbide ($\bar{i}$ = 69.31°). These would bracket the $\bar{i}$ value of diamond.

Internal reflections. Up to this point it has been the physics of the external reflections relating to lustre which have been discussed. It is now possible to examine those concerning the *internal* reflections of diamond. These are the rays which having penetrated the stone now proceed to leave it by way of the crown and table facets to produce the other two desirable attributes of brilliance and fire.

As the rays pass through (i.e. internally) the body of the diamond, they are reflected or refracted when they encounter the diamond-air interface.

To distinguish these internal reflections from the external reflections, a change in nomenclature must be made. The incident ray, now originating

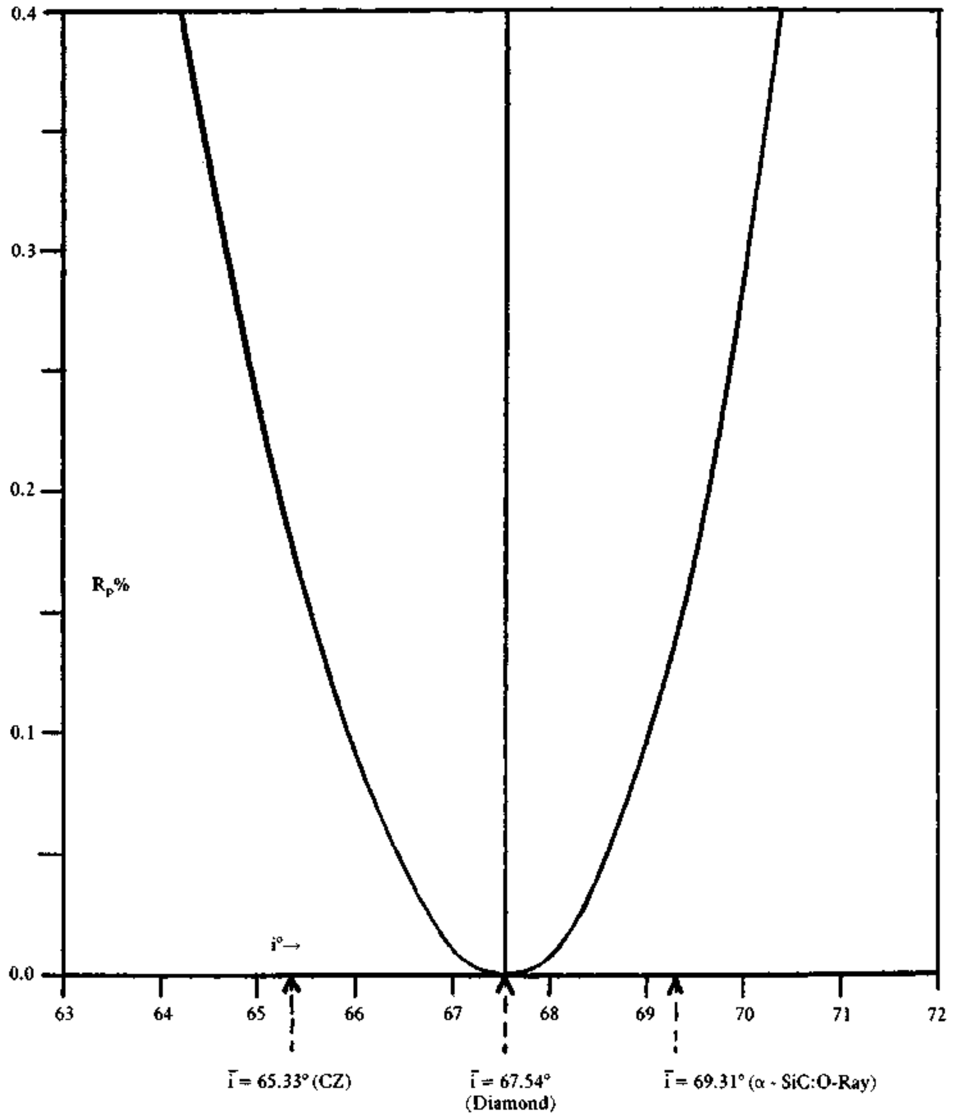

Fig. 6. Calculated reflectance profile of the Brewster angle trough for diamond. The ī angles are shown for two possible refractometer scale calibrants. For a λ of 589.3 nm.

within the body of the diamond, must preserve its identity and be termed i. However, it is now an internal ray so that it has to be distinguished from the previously discussed external ray, i. This is done by the algebraic convention of 'priming' it, by giving it the symbol i′. The associated refracted ray is also symbolized by r′. They are spoken of as 'i prime' and 'r prime'.

The behaviour of the internally reflected rays is presented in Figure 7 in the same way as that shown in Figure 4 for the externally reflected rays.

It is seen that R'_s rises progressively to R′ = 100%, whilst R'_p descends and reaches R′ = 0% at the internal Brewster angle ($\bar{i}'$) at 22.46°. It then rises very steeply until it reaches R′ = 100% at an i′ value of 24.42°. This is the

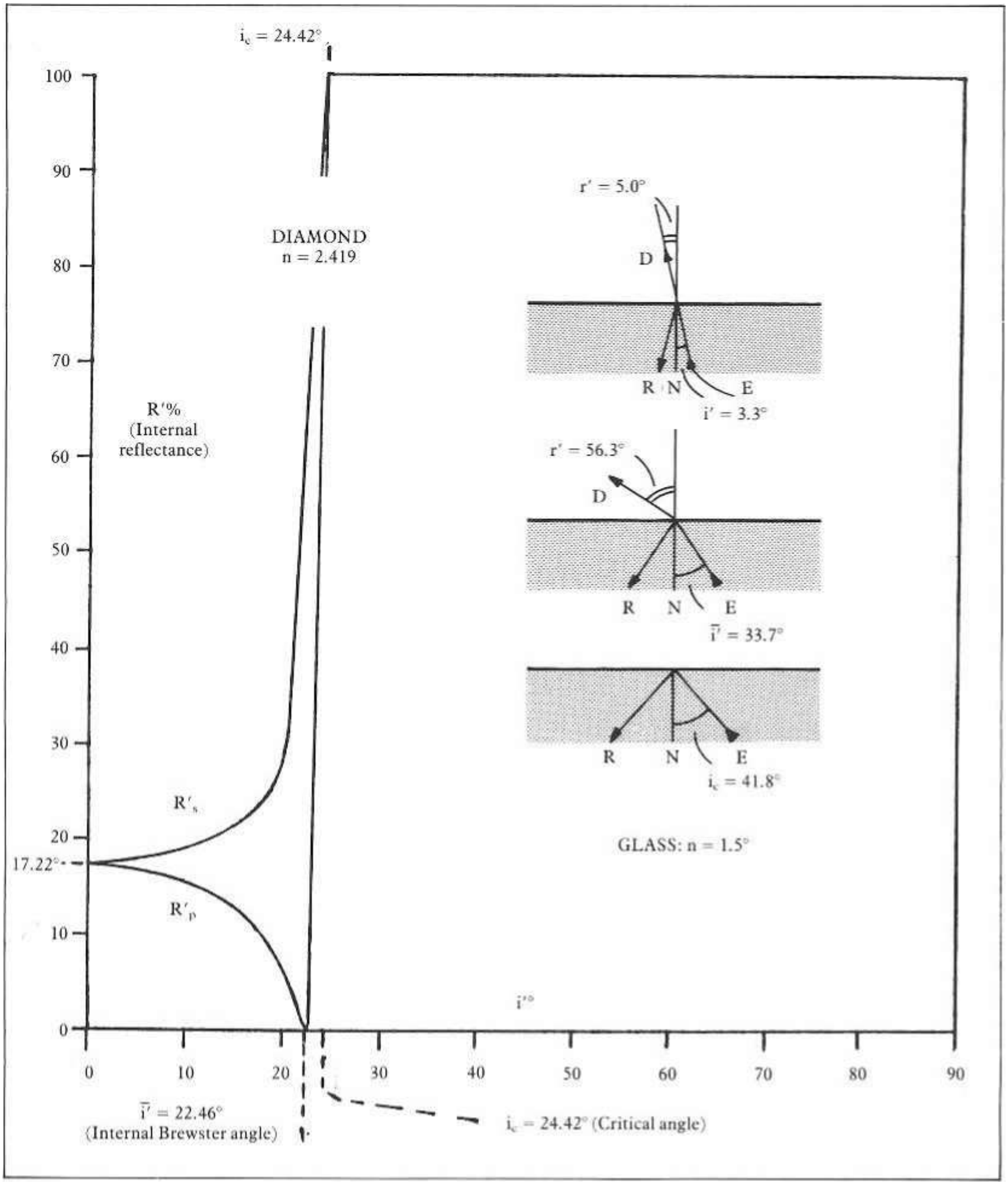

Fig. 7. Variation of the internal reflectance, R', with the angle of incidence, i', from a polished diamond surface. *Inset:* Illustrations of various ray paths in the plane of incidence, for rays originating within the denser medium (here, a glass with n = 1.5).

all-important *critical angle*, designateed i_c (no 'prime' is needed here). It is related to n by:

$$\sin i_c = \frac{1}{n}$$

When i' increases beyond this point right up to 90°, R' remains unchanged at 100%. In other words from i' = 24.42° to i' = 90°, the diamond-air interface behaves as a perfect reflector of light. The attributes of brilliance and fire hang entirely upon the phenomenon of the critical angle. Otherwise pavilion facets would have to be silvered or aluminised.

It is perhaps useful here to help clarify these somewhat involved descriptions. To this end, the inset of Figure 7 returns to the case of the glass of n = 1.5.

The top diagram shows that Snell's law is not followed when the incident ray travels from the dense medium (glass) to air. (Compare with Figure 3b, first diagram.)

The middle diagram shows that when $(i' + r') = 90°$, the *internal* Brewster angle conditions prevail, giving an internal Brewster angle $\bar{i}'$ of 33.7°. It should be noted incidentally that this internal Brewster angle is not the same as the *external* Brewster angle of $\bar{i} = 56.3°$ (see Figure 3b, second diagram, and Figure 5).

The bottom diagram shows the situation at the critical angle i_c when the internal incident ray cannot pass across the glass-air boundary.

Reverting to diamond, one of the questions which frequently crops up during discussions of diamond grading is this. Why are the undispersed rays from the stone's interior so much more intense than the external ones?

The answer is now probably apparent. The diamond shape is such that the major proportion of the source light entering the crown and table facets is totally reflected (R' = 100%) as colourless or weakly-dispersed light. The remainder appears as refracted fire or is lost because a small proportion of the light fails to be totally reflected in spite of the low i_c, and leaks out through the sides and back of the stone.

There is however some loss of the totally reflected colourless light due to a different cause. Let it be supposed that light enters the table at $i = 0°$. It will suffer a loss of intensity of 17.22% (Figure 4), which is the amount of light specularly reflected, thus reducing the transmitted light to 82.78%. After twice being totally reflected, the light then passes across the diamond-air boundary, with a second loss of 17.22%. In this manner, the incident light of say 100% intensity, is returned to the viewer as light having an intensity of only 68.53% $(0.8278 \times 0.8278 \times 100)$.

In relation to this emergent totally-reflected colourless light, the proportion of light contributed by the lustre is still modest. For example, Figure 4 shows that unless the angles between the light source, the stone's crown or table facets and the viewer can reach high values of i, (say $i = 60°$) the R_s values will not rise much higher than 40%.

Other effects which diminish brilliance and fire

There is a more practical matter which is seldom mentioned in discussions of the relative contributions of lustre and brilliance to a stone's 'life'. It is the dulling effect which occurs when adventitious substances adhere to the pavilions of diamonds in diamond-set jewellery.

Diamond jewellery owners are advised by the trade to clean their possessions as a matter of routine. However, jewellery repairers, dealers and valuers and gem-testing laboratories all testify to the fact that this advice is not taken seriously. The words 'disgusting state', 'shocking condition' and other more forceful expressions, are often heard from these quarters.

To be fair, the trouble arises from the inaccessibility of the pavilion facets. Soaps and detergents are totally ineffective unless accompanied by some scrubbing action. Ultrasonic baths are effective but are seldom possessed or used by jewellery owners. The crown and table facets usually do not escape the almost constant cleansing attentions which come from ordinary day-to-day wear and because they are not hidden from view.

Is this dulling effect not exaggerated? If not, what are the physical reasons for it?

The effect is indeed real, and can be linked to two specific mechanisms. So far as lustre and sparkliness are concerned, these attributes are scarcely affected because they originate mainly from the crown and table facets. On the other hand, brilliance and fire derive solely from the total reflections occurring at the pavilion's facets. Any interference with this phenomenon will be bound to change the magnitude of these attributes.

Let it be imagined that a diamond's pavilion facets are covered with a thin, clear, colourless, uniform film of natural skin oil (sebum) having an n value of 1.455. Its presence will result in a shift of the critical angle of a clean pavilion from $i_c = 24.42°$ to an $i_c = 43.42°$ for the sebum-coated pavilion. This means that there will be fewer totally reflecting rays available to participate in the production of brilliance. The resulting brilliance will resemble that of an equivalent cut fluorite ($i_c = 44.14°$), a water opal ($i_c = 43.42°$) or a silica-glass stone ($i_c = 43.23°$). The fire will be diminished proportionally.

A practical and simple experiment is worth trying. Choose two well-proportioned, colourless, CZ round brilliants which approximately match in size (girdle diameter of about 10mm or greater). Dip only the pavilion of one of them in either glycerine (n = 1.45) or medicinal paraffin (say Nujol with n = 1.46). A side-by-side comparison of the dipped with the undipped clean stone usually demonstrates quite effectively the reality of the dulling effect.

The dulling does not end with the adhesion of a film of clear liquid of low n value. The adhering undisturbed sebum oil is a very good collector of a large variety of microscopic particles. This results in the formation of a paste which is capable of strongly diffusing and scattering any light which strikes it.

The author examined micro-samples of this material taken from the pavilions of gemstones set in many pieces of much-used jewellery. Using the analytical techniques of polarised light microscopy[19] alone and with dispersion-staining techniques[20], he was able to identify many of the constituent particles. These were found to be corn starch grains, very short fibres of human hair and cotton, talc particles, dried blood cells, epithelial cells (dandruff and dead skin cells), perfect microscopic cubes of common salt (presumably a product of perspiration), light-brown spheres of resin (from hair sprays), calcium palmitate aggregates (soap curd) and spindle-shaped particles of the brown iron mineral goethite (alpha-$Fe_2O_3.H_2O$). The presence of this last-named iron-bearing mineral was surprising, but not after reading an account of its presence on the *crown and table facets* of a constantly worn diamond finger ring[21].

In appearance, the soft, sticky pastes were never white, or even grey, but varied from light brown to deep brown and, in one instance, almost red. One can well imagine the powerful tinting effect which these impurities can confer on a stone's colour appearance. Even the colours of the metal alloys used as mountants can be picked up by the stone.

Is there a remedy? The question which inevitably must arise is this. Why are the pavilions of diamond brilliants not routinely covered with a shielding deposit of vacuum-evaporated pure aluminium? The body colour of the stones would of course, take on the colour of aluminium, but as its whiteness is virtually indistinguishable from pure white, this is hardly worth further consideration. What is worth pondering upon is the complete preservation of the stone's body colour which this process would ensure. As colour is an attribute which is especially dearly paid for, why should a 'D-colour' stone not remain forever a 'D-colour' without having to concern oneself about its pavilion's cleanliness? Another benefit would be that there would be less rigour needed in keeping to the classical pavilion cutting angles. With a coating, even a 'fish-eye' stone would not leak light.

It is not difficult to see why this coating strategem is presently regarded as distasteful. The eighteenth-century habit of gluing silver foil around the pavilion facets is now viewed as a rather nasty practice. For one thing, grease and dirt often became trapped between unstuck foil and the stone. For another, the silver became tarnished from sulphur dioxide in the environment, resulting in a film of black silver sulphide. Neither of these things enhanced the stone's beauty.

More recently, this unpopularity was reinforced because such treated stones, even though of good quality, were likened to those used in costume jewellery. These articles made much use of cheap pastes with moulded pavilion facets which were silvered and over-coated with protective lacquers.

Should this coating practice ever be seriously resurrected, it would have one commercially awkward consequence. It would make it impossible to assess *visually* small differences in the body colours of diamonds. The only way to view the stone would be the 'table up' direction, which is that showing the maximum fire. This strong fire would completely mask the feeble body colours of the Cape Series and make nonsense of accurate colour assessments. It would be possible to measure the body colour by non-visual means, but such electronic devices are expensive.

Again, there remains the all-important question of acceptability. Like the over-intense fire of strontium titanate, the effect would probably be regarded as 'unnatural'.

Demonstration units

The foregoing descriptions of the separate interactions which happen when a single theoretical pencil of light falls upon a diamond are far from easy for an individual to grasp and a computer to present. The use of this single ray and its progress to, through, and out of a two-dimensional diamond cross-section profile is an enormous simplification of the innumerable pathways actually taken by the infinite assembly of light beams impinging on a real three-dimensional stone. Then why bother, one is entitled to ask? The answer probably is that by breaking the problem down into little bits or steps, much better insights *might* follow.

The author felt that some additional insights might be gained if an analogue machine was designed and made to observe directly these separate ray pathways, in two dimensions at least. Such a device was built, and it was found to be most helpful in demonstrating the predictions of the paper arguments and indeed considerably more. For one thing, it did confirm the view that adhering paste does cause internal light scattering and diffusion and which also frustrates those rays capable of total reflection not only once but several times. Indeed, the author has put this phenomenon to serve a useful purpose in connection with the quantitative measurement of gemstone body colour. The method was termed by him, 'frustrated multiple internal reflection'.[22,23,24]

Description of the ray-path tracer

Three plates of optical quality glass were cut and polished to represent the central axio-symmetrical planes of round brilliants, simulating 'ideal', 'fisheye' and 'lumpy' cuts. Made of colourless glass

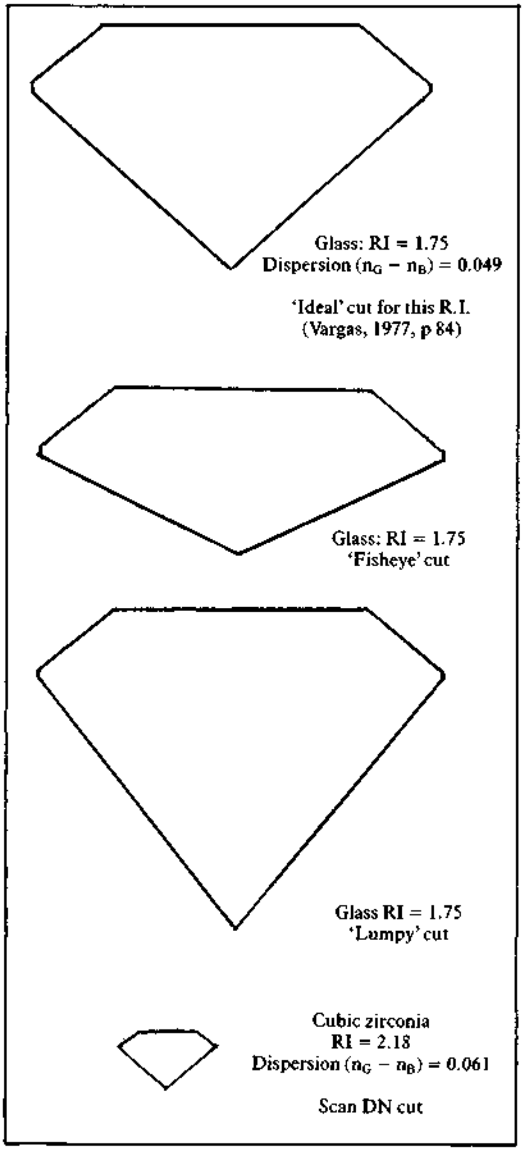

Fig. 8. Brilliant-type shaped plates cut in optical glass and cubic zirconia. Used in the ray-path tracing device shown in Figure 9 for visualizing ray paths in the meridional planes of 'ideal', 'fisheye' and 'lumpy' cuts.

having an n_D of 1.754 and an ($n_G - n_B$) disperson of 0.049, the profiles all had girdle 'diameters' of 100mm, with identical crown dimensions.

They were intended to demonstrate the behaviour of a single, thin parallel ray of white light as it enters and leaves the profile. Each stationary profile can be illuminated by the ray, either by varying the ray's angle of incidence continuously from +70° to −70° or by translating the whole profile bodily across the ray. Both angular and

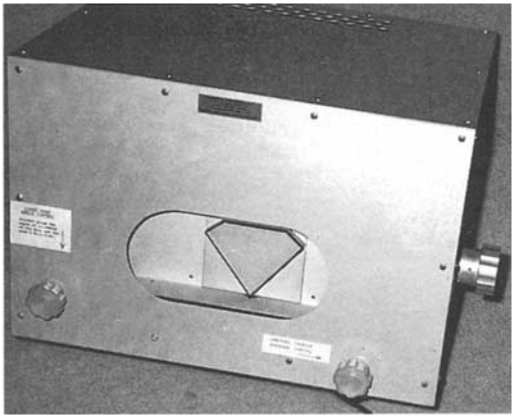

Fig. 9. Analogue optical device for visualizing ray paths in 'ideal', 'fisheye' and 'lumpy' profiles. The left-hand knob controls the angle of the incident ray and the right-hand knob controls the traverses of the profiles. The side knob brings each of the four profiles into view.

linear crown-scanning movements can be made simultaneously, providing any one of an infinite number of easily visible ray paths.

In this way it was found possible to trace visually the entire path of the ray, both externally and internally and to compare the ray paths of each profile.

A fourth profile made of colourless cubic zirconia, of a 'diameter' of 25mm and of Scan DN shape was also included in the assembly because its n value of 2.18 serves as a more realistic approach to diamond than that of glass. The four profiles are illustrated in Figure 8.

The optical effects which can be exhibited on each profile are those of Fresnel (i.e. surface) reflection, Brewster angle, internal (total) reflection, refraction, dispersion, internal (inclusion) scattering, external scattering (from adventitious matter optically adhering to the pavilion), light leakage and the unexpected observation of secondary and ternary internal ray paths.

If the ambient light level is unacceptably high, it is possible to use a colour television camera and monitor system. This has been found to be a particularly effective measure. All external light can be suppressed and the intrinsic contrast-control features of a television presentation can be exploited.

A photograph of the unit is shown in Figure 9.

Unit for separately demonstrating the four attributes

It was also felt that it might be helpful to be able to demonstrate visually the separate effects of lustre, brilliance, fire and sparkliness, using an actual polished diamond.

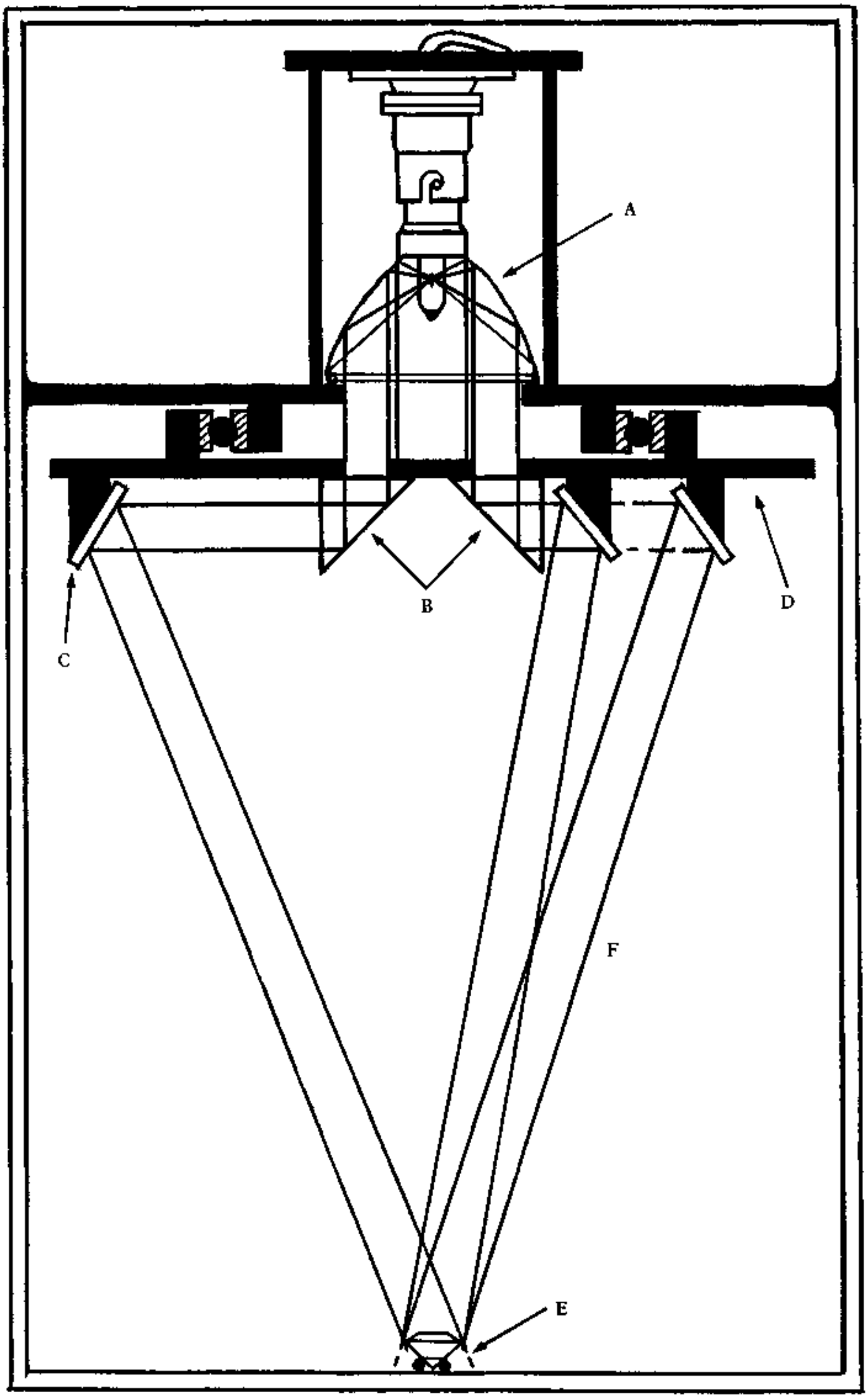

Fig. 10. Optical device for separately demonstrating the four optical attributes of a round, brilliant-type diamond.
Key to sketch

A. Quartz-halogen parabolic reflector lamp producing a single parallel beam of white light.

B. Three glass prisms, mounted 120° apart, for conducting three selected parallel beams on to three inclined mirrors.

C. Three mirrors angled so as to direct simultaneously each of the beams on to a faceted diamond at angles of incidence (i) of 10°, 20° and 30°

D. Rotating optics assembly mounted on a large ball-bearing. The assembly is rotated continuously at about 50 rpm by means of a small electric motor (not shown).

E. Diamond supported 'table-up' by means of a small black, rubber O-ring.

F. Vertical white screen for viewing the moving reflections.

As a first experiment, a diamond was placed on a rotating turntable and illuminated by three light beams from point sources. This was not found to be a suitable arrangement for separating the attributes.

A second experimental arrangement proved to be successful. Here, the diamond was kept stationary. It was again illuminated by three point sources of light, but this time the three focused beams were rotated together. They were directed on to the diamond but at different angles (10°, 20°, 30°). By placing a white reflecting screen behind the diamond, it was found to be possible to separate visually all four attributes. The device is shown in Figure 10.

On rotating the light beam assembly, the white scintillation spots on the screen were seen to originate from crown and table facets only. They were therefore the lustre's contribution to sparkliness.

These lustre scintillations were seen to be fairly well angularly separated from the spectral scintillations arising from dispersion. There were also white scintillations mingled with the dispersive fire. These white flashes were obviously linked with the brilliance contributions.

Taken together, the unit was able to demonstrate quite clearly the separation of the four prized optical attributes of diamond.

Problems in nomenclature

Almost every discussion of a diamond's appearance uses different descriptive terms. These cause much confusion which is further increased when English terms are translated into other languages or vice versa.

The four attributes discussed here are real properties each of which is capable of being quantitatively assessed by machines, if so required. Indeed Andrychuk[25,26] has described and used an electronic arrangement for such measurements on faceted gemstones. Again, he gives the attributes different names and compounds them to yield new terms relating to his 'quantitative performance parameters'.

Undoubtedly, the time has come for the international body of the diamond trade to encourage the standardisation of, at least, the English qualitative compound terms. The following are proposed.

Brilliancy = lustre + brilliance
Scintillation = fire + sparkliness
Liveliness = lustre + brilliance + fire + sparkliness

Acknowledgements

The author wishes to thank both Mr Eric Bruton and Mr R. Keith Mitchell for their generous and helpful comments on various aspects of this article.

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Gemmological Abstracts

Ashbaugh, C.E.III, 1988. Gemstone irradiation and radio-activity. *Gems & Gemology*, 24, 4, 196-213. 14 figs in colour.

This excellent survey of the effects, intensities and sources/methods of irradiation, both natural and artificial, on the range of gem materials treated today, is by a senior lecturer on Nuclear Energy at UCLA.

We exist in a 'sea' of low level radiation of which some 82% is from natural sources. Certain gem materials contain radio-active elements, e.g. uranium and thorium in zircon and a few much rarer stones. Of the remaining 18% which can be said to be man-made, less than 1%, surprisingly, is due to fall-out.

Diamond, topaz, beryl, tourmaline and kunzite are among the stones artificially treated by various laboratory radiations. No methods for detecting resultant colour changes are given.

The author goes on to discuss the health and the legal aspects of marketing irradiated gems which may retain residual radio-activity for years after treatment and concludes that this raises very complex issues, and that current US regulations appear to be unrealistic. R.K.M.

Balfour, I., 1988. Famous diamonds of the world, XXXVI. The McLean diamond. *Indiaqua, 51*, (1988/3), 145-7.

An avid collector of jewellery, Mrs Evalyn Walsh McLean's named acquisitions included the Hope diamond, the 14.37 ct kite-shaped Star of the South, the Star of the East and a cushion-cut 31.26 ct diamond which became known as the 'McLean'. During the period of the Depression, many of her jewels saw the inside of New York pawn shops. However, after her death Harry Winston bought the entire collection, and in 1950 sold the McLean to the Duchess of Windsor. When the Duchess's jewels were auctioned by Sotheby's in 1987, the McLean diamond was bought for $3,153,333 by Mr Katsuji Takagi of Japan. P.G.R.

Balfour, I., 1989. Famous diamonds of the world, XXXVII. Little Sancy. *Indiaqua*, 52, (1989/1), 147-8.

Nicholas de Sancy was a French financier who is remembered for giving his name to the famous 55.23 ct pear-shaped diamond which can be seen in the Louvre in Paris. However, he was also the owner of another sizeable diamond of around 30 ct which came to be known as the 'Little Sancy' or the 'Beau Sancy'. After his death, the Little Sancy was sold to Frederick Henry, Prince of Orange. Eventually the gem came into the possession of Frederick I of Prussia and became the premier stone in the Crown Jewels of Prussia. When last heard of the Little Sancy was displayed in a simple pendant in the Royal Prussian House in Bremen. P.G.R.

Balfour, I., 1989. Famous diamonds of the world, XXXVIII. Richelieu. *Indiaqua*, 52, (1989/1), 148.

Owned by one of France's outstanding statesmen, Cardinal Richelieu, the Richelieu diamond was a rose-cut heart-shaped stone weighing around 19 ct, and took its name as soon as it became part of the French Crown Jewels. When Richelieu died he was succeeded by that other great collector of stones, Cardinal Marazin. The last mention of the Richelieu diamond was that it was set with the Marazins IV, V and VI in one of three pairs of earrings. The diamond was stolen in 1792, and no trace of it has been found since then. P.G.R.

Balfour, I., 1989. Famous diamonds of the world, IX. Harlequin. *Indiaqua*, 52, (1989/1), 149.

No satisfactory reason has been found for the name 'Harlequin' that was applied to this 22 ct pear- shaped diamond. The stone was originally set in a bejewelled decoration created for Karl Alexander, Duke of Wurtemberg. Today it is owned by the Federal Republic of Germany. P.G.R.

BALFOUR, I., 1989. Famous diamonds of the world, XI. Dresden White. *Indiaqua*, **52**, (1989/1), 149.

Despite the fame of the unique 41 ct 'Dresden Green' diamond, the largest diamond mounted in the Saxon Crown Jewels is, however, the 49.71 ct cushion-cut 'Dresden White'. After being safely stored in the Fortress of Konigstein during World War II, the Crown Jewels, including the Dresden White, were removed by the Russians to Moscow, but in 1958 they were returned to Dresden where they are now on display. P.G.R.

BANK, H., 1988. Gemmologische Kurzinformationen. Durchsichtiger, geschliffener, gelber Milarit aus Rössing, Namibia. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 143, bibl.

This note deals with a transparent, cut, yellow milarite from Rössing in Namibia. This stone was first described by M. O'Donoghue. Values are slightly different. E.S.

BANK, H., 1988. Gemmologische Kurzinformationen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 75-80. (a) Sternskapolith von Sri Lanka, Id., 76-8; (b) Hocklichtbrechender grüner Apatit von Rössing, Namibia, Id., 78-9; (c) Glas für Leucit ausgegeben, Id., 79-80.

Three short notes, all with bibliographies. Bank first deals with a star scapolite from Sri Lanka, then a high RI green apatite from Rössing in Namibia and lastly with a colourless glass which was offered as leucite. This stone came from Sri Lanka. E.S.

BANK, H., GÜBELIN, E., HENN, U., MALLEY, J., 1988. Alexandrit: natürlich oder synthetisch? (Alexandrite: natural or synthetic?) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 49-52, 4 figs, bibl.

An English version of this paper was published in the *Journal of Gemmology*, 1988, **21**, 4, 215-7. E.S.

BANK, H., GÜBELIN, E., HENN, U., SCARRATT, K., 1988. Rubin: natürlich oder synthetisch? (Ruby: natural or synthetic?) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 27-30, 8 figs (4 in colour), bibl.

The stone in question was a faceted ruby, 1.288 ct (6.0 x 6.0 x 4.15mm) from Nepal*. The authors identified the stone as natural, but there were some difficulties because of ambiguous features. E.S.

*The same ruby was described in *Journal of Gemmology*, 1988, **21**, 4, 222-6. – Ed.

BANK, H., HENN, U., 1988. Vergleichende physikalische, chemische und strukturelle Untersuchungen an vanadium-haltigen Grossularen aus Ostafrika. (Comparative physical, chemical and structural examinations of vanadium-containing grossularite from East Africa.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 69-74, 1 graph, 2 tables, bibl.

The work is based on seven grossulars from East Africa, the colour of which varied from pale yellow green to dark green and with RI ranging from 1.735 to 1.759. The results show a linear correlation between the vanadium oxide content, the lattice constants and relative densities with increasing RI. E.S.

BANK, H., HENN, U., LIND, TH, 1988. Rubine aus Malawi. (Ruby from Malawi.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 113-19, 8 figs (2 in colour), 3 tables, bibl.

The investigated rubies from Malawi showed a surprising variation in their RI, birefringence and density. These variations were correlated with their chromium and iron content. Mineral inclusions found were shown to be hornblende, plagioclase and zircon. Nothing is known as to quantity of rubies produced in Malawi, but colour intensity seems to vary widely. E.S.

BANK, H., PLATEN, H.v., 1988. Gemmologische Kurzinformationen. Blau gefärbter Magnesit als Lapis Lazuli-Ersatz angeboten. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 75-6, bibl.

A blue dyed magnesite which was offered as lapis lazuli is described in this short note. E.S.

BOURGEOIS, J., 1988. Caractéristiques des pierres rares. (Characteristics of rare stones.) *Revue de Gemmologie*, 97, 14-15.

Two tables give chemical composition, refractive index and birefringence, hardness and specific gravity, of a large number of less common gemstones. Stones in the second table are rarer than those in the first, and their birefringence is not given. M.O'D.

BOYAJIAN, W.E., 1988. An economic review of the past decade in diamonds. *Gems & Gemology*, **24**, 3, 134-54, 16 figs in colour.

In ten years diamond values have fluctuated dramatically and the GIA President has summarized events and causes with great authority and accuracy. This gemmology affects World economy and the GIA are doing a valuable service to the gem trade by publishing it.

De Beers organization is explained in detail and it is evident that they have manoeuvred skilfully to combat adverse influences which were beyond direct control. During early years of the decade financial and other pressures reduced demand and prices reached low ebb by 1985/86. Since then there has been an upturn and prices are recovering despite the Stock Market crash of 1987.

A final section on World Diamond Production serves to put the whole vast subject into perspective.

An important paper which should be widely read and well digested. R.K.M.

BRACEWELL, H., 1988. Gems around Australia. *Australian Gemmologist*, **16**, 12, 459-63, 14 figs in colour.

Early in the 1980s Hilda and Harold Bracewell undertook an extensive and fascinating circumambient journey by car around Australia specifically to visit as many gem localities as they could. The paper reports gem finds at the start of this journey, and it is hoped that a series will eventually cover the whole of their epic trip. R.K.M.

BROWN, G., 1988. Bamboo coral. *Australian Gemmologist*, **16**, 12, 449-54, 6 figs.

Deep water bamboo coral has been found with pink and gold corals in the Molakai Channel off Dahu, Hawaii. Bamboo coral so named because it occurs in white longitudinally striated stem sections segmented by flexible nodes of black coral. R.K.M.

BROWN, G., 1988. Gold coral revisited. *Australian Gemmologist*, **16**, 12, 473-7, 10 figs in colour.

A general survey of this Hawaiian golden coral which can be bleached to improve its colour, impregnated or coated with plastic in further efforts to fake its appearance. R.K.M.

BROWN, G., 1988. Zircon. *Wahroongai News*, **22**, 9, 17-21, 3 line figs.

A thorough resumé of this well-known gem drawn from half a dozen authoritative sources. [Miller indices for first and second order prisms are reversed.] R.K.M.

BROWN, G., 1988. The Egyptian emerald mines. *Wahroongai News*, **22**, 12, 24-6, sketch map.

A paper based on W.F. Humes' *Geology of Egypt*, published in 1934. These were probably the first emerald mines, dating from Ptolomeic and early Roman times. Their emeralds would today be considered pale, heavily included and low grade, but, with no better stones to compare, they were valued highly at the time. Mines at Zabara, Sikait, Nugrus and Um Kabu, are briefly described. They are probably exhausted now. R.K.M.

BROWN, G., 1988. Merensky, diamond and fossilized oysters. *Wahroongai News*, **22**, 12, 22-3, sketch maps.

A short paper based entirely on one by Dr Hans Merensky in 1909, on the diamond deposits of Luderitzland, German SW Africa, published a year after the discovery of the coastal diamond fields. Merensky found the diamonds associated with fossil oysters of the Cretaceous period. Diamonds were of good colour and quality, well crystallized but small, and showed evidence of having been transported by river and sea over very considerable distances, and concentrated by wind action. R.K.M.

BROWN, G., 1988. Phenakite. *Wahroongai News*, **22**, 12, 19-21, 2 figs.

A comprehensive account of this rare beryllium silicate, based on three authoritative sources. Mr Brown comments that this may be a rare gem, but it does appear often in practical examinations. R.K.M.

BROWN, G., SNOW, J., 1988. The diamond selector II. *Australian Gemmologist*, **16**, 12, 440-2, 3 figs.

An evaluation of a 9v diamond tester which beeps and indicates diamond by flashing red lights, and was found to work efficiently at ambient temperatures when used in accordance with instructions. R.K.M.

BROWN, G., SNOW, J., 1988. The Pool Emerald. *Australian Gemmologist*, **16**, 12, 443-9, 14 figs in colour.

A report on a new emerald synthetic marketed as low grade crystals from the Emerald Pool mine, near Poona, WA, transformed into stunningly beautiful emeralds by a secret process, suggests that these are hydrothermally grown synthetics with inclusions and gemmological properties virtually identical to those of Biron synthetic emeralds, produced by the same Perth company. They appear to be grown on seed plates, possibly using natural beryl from the designated mine, doped with V^{3+}, as feed material. R.K.M.

BROWN, G., SNOW, J., 1988. Gemmological Study Club lab reports. *Australian Gemmologist*, **16**, 12, 464-70, 21 figs in colour.

The team found that polymer infilling in treated Brazilian opals could be detected by transillumination [shining light through them].

Lapis Nevada, a thulite-diopside skarn rock rather like unakite in appearance, was investigated. SG 2.83 and RI which varies with mineral grain tested.

A metallic looking cabochon from Mt Biggenden Mine was shown to be a rock composed of bismuthinite, chalcopyrite, quartz and calcite.

Emmaville emeralds, the first found in Australia, had SG 2.68, RI 1.570-1.575 and seem to be coloured more by vanadium than by chromium.

Oval Mabe pearls are being imitated by coque-de-perle cut from nautilus shell, dyed, filled with coloured cement and backed by mother-of-pearl. Further imitations have been seen which are made from hemispherical pieces of the shell of a Philippine land-snail. This is thin and is strengthened with a black pitch-like substance which gives a silvery iridescence.

A ring of aventurine moss agate was examined; amethyst crystal earrings with mobile bubbles are described; calcite beads are thought to have been quench crackled in a brown dye; an attractive green glass with bubbles and spherical devitrification aggregates, morphologically like wollastonite, is described. R.K.M.

Dietrich R.V., White, J.S., Nelen, J.E., Chyi, K.-L., 1988. A gem-quality iridescent orthoamphibole from Wyoming. *Gems & Gemology,* **24,** 3, 161-4, 3 figs in colour.

Describes an attractive iridescent multi-colour rock, mostly brown and golden, identified as ferroanthophyllite with considerable goethite and garnet, cemented by opal. Similar material from Greenland compares. Density varies with mineral mixture and for similar reasons, and opacity, optical constants are not easy to obtain, but upper RI of 1.667 is suggested. R.K.M.

Epstein, D.S., 1988. Amethyst mining in Brazil. *Gems & Gemology,* **24,** 4, 214- 28. 16 figs in colour.

A beautifully illustrated account of visits to Marabá and Pau d'Arco in Pará, and to Rio Grande do Sul. Each area is geologically different and mining methods vary accordingly. Much amethyst from the first and last of these localities is heated to make the rarer citrine, a change achieved at Marabá by the crude expedient of burying the amethyst in sand in a steel wheelbarrow over a wood fire. Other amethyst localities exist in Brazil, but these three are the most productive and are probably the major world sources of the gem today. R.K.M.

Friedman, D., 1988. Specular heat treated garnet. *Australian Gemmologist,* **16,** 12, 477.

An Indian very dark purple-red garnet, RI 1.803, was heated to 720°C to lighten the colour, but was found to have acquired a 'silvered' surface of what is thought to be specular hematite as a result of the heat. R.K.M.

Fritsch, E., Shigley, J.E., Stockton, C.M., Koivula, J.I., 1988. Detection of treatment in two unusual green diamonds. *Gems & Gemology,* **24,** 3, 165-8, 4 figs in colour.

Two irradiated greyish-green diamonds had H1b and, in one, H1c absorption bands in the near-infrared. First time these have been seen in green diamonds although they are common in irradiated, annealed yellow or brown ones. Believed these stones have been irradiated, annealed or irradiated again. Colour alone would not prove treatment. Fluorescence and spectroscopic data given. Another green diamond examined later yielded both infrared lines. R.K.M.

Fryer, C.W. (Ed.), Crowningshield, R., Hurwit, K.N., Kane, R.E., 1988. Gem Trade Lab notes. *Gems & Gemology,* **24,** 3, 169-74, 16 figs in colour.

A synthetic alexandrite had 'oily' appearance and many colourless transparent rounded inclusions of pin-point size, new to the investigator; stone proved synthetic by infrared spectrum. Dyed spangles in amber were unexpectedly both red and green. [Is this so unusual? I have a similar specimen and have seen others in the past.] A black opaque Chinese 'onyx', RI 1.702-1.728, SG approximately 3.35, identified as the monoclinic pyroxene augite by X-ray diffraction. A calcareous concretion with honeycomb structure and a conchyolin spot had sheen effect and was evidently of mollusc origin.

Three green diamonds were examined, each with different testing characteristics; one with bluish transmission colour showed Cape absorption spectrum with slight chalky fluorescence under LUV and faint yellow phosphorescence; SUV gave similar colours but weaker; a natural green. Second and largest stone had 498/504 and 594nm lines strongly developed proving irradiation, and gave strong greenish-yellow fluorescence under LUV and chalky green under SUV, with flight yellow phosphorescence in each. Smallest stone, dark bluish-green, had no detectable absorption lines but gave vague 'smudge' centred at 500nm when cooled; fluoresced weakly, chalky greenish-blue in LUV and similar weaker colour in SUV; non-conducting of electricity; another natural coloured stone.

An opal with ironstone base had a wavy junction typical of a genuine stone, but the backing had been cemented on with epoxy resin tinted to match. A cabochon 'golden jade' from Wyoming had a vague RI of 1.44 and a hint of a second much higher one; in 2.57 liquid it suspended lop- sidedly, suggesting rock with two or more components; X-ray diffraction revealed goethite and hematite at the 'heavy' end and a spessartine pattern for the light end, suggesting that this was another opal-bonded orthoamphibole of the type described by

Dietrich *et al.*, in this issue of *Gems & Gemology.*

A large South Seas type cultured pearl had very thick nacreous layer which drastically reduced the expected X-ray fluorescence. A synthetic ruby had surface inclusions of flux, but time prevented identifying the flux. Two stones with sagenitic inclusions of black tourmaline proved to be quartz and, far less usually, fluorite. A sapphire with symmetrical abrasions on the pavilion is thought to have been worn next to a three-stone diamond ring. A brown synthetic star sapphire was identified, a first for the West Coast Lab. An almost colourless taaffeite exceptionally fluoresced a chalky yellowish-green under LUV, rather like a colourless synthetic spinel, which could be confusing if no other test had been done. A greyish-brown transparent lithium-iron manganese phosphate was identified as triphylite, RI 1.689-1.695, SG about 3.40, no fluorescence, but absorption at 410, 425, 450- 460, 470, 485-498 and a weak band at 540-590; X-ray diffraction proved this new recruit to occasionally faceted minerals. R.K.M.

Fryer, C.W. (Ed.), Crowningshield, R., Hurwit, K.N., Kane, R.E., Hargett, D., 1988. Gem Trade Lab notes. *Gems & Gemology,* 24, 4, 241-6. 18 figs in colour.

Dull beads in an otherwise polished black onyx necklace were opaque and found to be agate, painted to imitate the dyed beads.

'Diamond' crystals were identified as cubic zirconia, cut skilfully to convincing dodecahedral and octahedral shapes. Brown radiation stains seen in a pale yellow diamond were difficult to interpret, but may have related to inclusions at the surface which had pulled out in polishing, not known whether stains were artificially induced. A badly burned diamond had an unusual 'melted' scar indenting its table, again cause unknown. [Abstractor wonders whether burn was due to a high voltage spark discharge?]

Dyed green hydrogrossular was found by absorption and colour filter tests; a chess set purporting to be mammoth ivory was shown to be made from walrus tusk.

Grey irradiated cultured pearls showed the shell nuclei darkened but the nacre coating remained white; irradiation darkens freshwater shell but does not affect salt-water shell or nacre; also it can enhance freshwater Biwa type pearls to iridescent blacks which are more attractive than the dyed blacks. Very unusually a necklace of ten pear-shaped pearls proved to be thinly cultured over drop-shaped beads; it is understood that pear-shaped cultured pearls usually have round nuclei since pear-shaped beads tend to kill the oysters; the pear shape normally occurs accidentally or is induced by using round beads with a tissue culture method.

An exceptionally large faceted flux-grown ruby of 17 ct was seen at the East Coast Lab; synthetic 'topaz blue' spinels were identified. A warning is given that lost natural rubies, etc., may have been replaced by synthetics in otherwise genuine old pieces of jewellery. R.K.M.

Furui, W., 1988. The sapphires of Penglai, Hainan Island, China. *Gems & Gemology,* 24, 3, 155-60, 7 figs in colour.

An important alluvial source of sapphires covers about 25km^2 in the NE of this tropical island; material similar to that found at Chantaburi, dark but good blue up to 30mm in size, RI 1.761-1.769, SG 3.99 to 4.02, strongly pleochroic, marked colour zoning and silk; heat-treatment lightened colour to good indigo blues with little zoning. [Faceted stone illustrated looks cloudy.] Prospects excellent. R.K.M.

Garcia Guinea, J., Rincón Lopez, J.M., 1988. Vidrios y materiales vitroceramicos artificiales de interes gemológico. (Glassy and artificial glass-type ceramics of gemmological interest.) *Boletín del Instituto Gemológico Espanõl,* 30, 22-36, 11 figs in colour.

22 glassy ceramics obtained from lithia glasses containing manganese, chromium, vanadium or cadmium oxides, are examined for their possible gemmological interest. Their properties are given. M.O'D.

Hänni, H.A., 1988. Certitude de la détermination de l'origine des gemmes. (The certainty of determining the origin of gemstones.) *Revue de Gemmologie,* 97, 4-5. 3 figs in colour.

The article reviews the various features which can indicate to the gemmologist the geographical origin of a particular specimen. Corundum and beryl are considered. M.O'D.

Heflik, W., Sobczak, T., 1988. Gemmologische Kurzinformationen. Rodingit – ein Schmuckstein von Jordanòw in Niederschlesien, Polen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* 37, 3/4, 144-5.

This note describes a rodingite from Jordanow in Lower Saxony, Poland. This white, ornamental stone with green inclusions is a rough grained grossular-vesuvianite rock, hardness 6-7, SG 3.40-3.47, RI 1.710-1.730. E.S.

Henn, U., 1988. Untersuchungen an Smaragden aus dem Swat-Tal, Pakistan. (Investigation of emeralds from the Swat Valley, Pakistan.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* 37, 3/4, 121-7, 13 figs, 2 tables, bibl.

The most important emerald occurrences in Pakistan are in the upper Swat Valley. Chemical and physical data from five finds in the Swat Valley are compared (Makhad, Charbagh, Gujar Kili, Mingora I and II). Talc, calcite/dolomite, pyrite, chromite and molybdenite were found as mineral inclusions, besides liquid feathers, two-and three-phase inclusions and growth tubes. E.S.

HENN, U., MALLEY, J., BANK, H., 1988. Untersuchung eines synthetischen Alexandrits aus der UdSSR. (Investigating a synthetic alexandrite from the USSR.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 85-8, 5 figs (2 in colour), bibl.

The synthetic alexandrite from Russia weighed 0.71 ct with a definite colour change from green to red with a slight violet tinge. It was shown to be flux-grown. Analyses showed it to have a considerable content of gallium as well as chromium and iron. Feathers of flux residue in which the elements bismuth and sulphur were detected, are typical features for the distinction from natural alexandrites. E.S.

HICKS, W. (ED.), 1988. The Pool emerald –(F),(T), or (R)? *Australian Gemmologist*, **16**, 12, 478-9.

A further note on this 'new' synthetic emerald which questions the validity of some aspects of the promotional literature. R.K.M.

KEELING, J.L., TOWNSEND, I.J., 1988. Gem tourmaline on Kangaroo Island. *Australian Gemmologist*, **16**, 12, 455-8 & 470, 5 figs and map.

Gem tourmaline was found in the early 1900s in the Dudley pegmatite on this island near Adelaide. Mostly shades of green and blue with some pink 'water-melon' crystals. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems & Gemology*, **24**, 3, 176-81, 9 figs in colour.

Diamonds

Angola. Unita guerillas find huge deposits of diamond and plan to develop them.

China. A 32.79 ct diamond from Shandong Province will probably be cut in China.

Tanzania. Mwadui mine, formerly the Williamson, to take power from Kidatu hydro-electric plant and should double dwindling output.

Namibia. Rich deposit of diamonds discovered off coast near Luderitz may lead to cutting plant opening in that city.

USA. Murfreesboro, Arkansas, diamond deposit thought to contain $1000 million of diamonds.

Coloured stones

East Africa. Pyrope-spessartine garnets were bluish green by fluorescent and a good red by incandescent light. Colour change due to 1% of V_2O_3 rather than to chromium.

Washington State. Orange to dark yellowish-brown grossular garnets mined near summit of Vesper Peak.

New Mexico. Fine transparent moonstone from Black Range is suitable for faceting. A known locality for 50 years.

Alaska. Fine nephrite in large boulders found at Dahl Creek above Arctic Circle. Slabs sawn on site, worked at Anchorage or in Idar-Oberstein.

Oregon. Contra luz opal with considerable play of colour, and hydrophane found.

Sri Lanka. Clinozoisite, anhydrite and sapphirine reported.

Canada and Greenland. Sapphirine from Fiskenasset, Greenland, found with other gem species. Similar formations at Somerset Island, Canadian Arctic, also yielded sapphirine and other gems.

Australia's Northern Territory. Reports gem zircon in a range of colours from Harts Range near Alice Springs.

Pearls are being thinly cultured on coloured (blue or green) nuclei made from powdered and sintered shell with an inorganic dye. Colour shows through the nacre attractively.

Sydney University physicist, David McKenzie, has made an amorphous, glass-like, carbon which readily scratches diamond and could have important commercial applications.

Synthetic quartz complete with seed plate is being used to carve 'health' pyramids in Korea. Spheres also reported. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems & Gemology*, **24**, 4, 248-53. 9 figs in colour.

Diamonds.

China. A Hong Kong firm is to open a diamond polishing factory at Shunda, Guangdong Province.

India. Renewed activity reported from diamond field at Panna, N. India, and in Andhra Pradesh.

Diamonds with artificially filled cracks which were radio opaque to X-rays [white patches on film], ruling out silicone previously suggested as the filling medium. Rectangularly stepped tubes seen in a small diamond were thought to be laser drillings [going round sharp corners?], but absence of relieved inclusions suggests that these very unusual tubes were natural.

Diamond thin-film deposited from vapour is being explored by several firms. Most processes need high temperatures, but Beamalloy Corp of

Ohio have found an ion-beam enhanced deposition technique which can coat super-hard carbon [diamond?] onto plastics. GIA are backing attempts to do this on gems such as emerald and opal to study their properties and gemmological implications.

Coloured stones

A pink stone with RI 1.718 sold as garnet was shown to be spinel, but had it been near colourless, inclusions would have been needed to separate them.

Tsavorite is again being mined in East Africa.

A new find of quartz in the Poona area of India shows the 'Lowell Effect', iridescence around the minor rhombohedral faces, first seen in amethysts from Uraguay.

Smoky quartz with radiating rutile inclusions is reported from Inyo Co., California.

Quartz crystals coated with an ultra-thin film of gold give an attractive blue which is being promoted as 'Aqua Aura'. The coating is too thin to affect RI or SG which are those normal for quartz. [Abstractor understands that this so far can be done only with piezo-electric minerals, e.g. quartz or tourmaline.]

Some Umba River sapphires have been found with heat induced haloes around solid mineral inclusions, suggesting that they have been colour treated.

The 'American Golden' citrine, 22 982 ct, cut by Leon M. Agee and currently the largest known faceted stone, has been donated to the Smithsonian Institution, Washington DC.

A 15.97 ct Burma ruby sold by Sotheby's, New York, fetched $3 630 000, the highest price ever for a coloured stone.

Synthetics

The Siberian Academy of Sciences at Novosibirsk has grown synthetic beryl |by| hydrothermal means in a number of colours. Red (Co), blue (Cu), pink (Mn) and purple (Cr/Mn) crystals were grown on colourless seeds of beryl and are illustrated. Not known whether these will come onto the commercial market, but their absorption spectra should identify them if they do.

The Pool synthetic emerald. Further comments on the promotional literature, and a report that this has now been modified to admit that they are hydrothermally grown, but maintaining that the basic material used for the synthesis is from the Emerald Pool mine. R.K.M.

Koivula, J.I., Kammerling, R.C., 1988. A gemological look at Kyocera's synthetic star ruby. *Gems & Gemology*, **24**, 4, 237-40. 6 figs in colour.

A discussion and examination of the Inamori star rubies which are semi-transparent, of good colour and have convincingly natural looking stars. The flat semi-polished bases give them a synthetic look, but roughed and rounded they would be even more deceptive. Strong red fluorescence to UV and a chalky overtone with SUV; microscope showing exceptional fineness of rutile needles compared with the coarser ones in the natural stars; white smoke-like patterns seen in all five stones, all underline synthesis, while the infrared spectrum shows no water, suggesting a high-temperature melt process. Chemical analysis by X-ray fluorescence showed no gallium, which should have been present in any natural corundum. R.K.M.

Koivula, J.I., Shigley, J.E., Fryer, C.W., 1988. A gemological look at clinohumite. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 53-5, 2 figs in colour, 2 tables, bibl.

The Gemological Institute of America was given a rough crystal and a small faceted stone of clinohumite from the Pamir Range in the Soviet Union. Properties were identical to those previously recorded. There were primary and secondary liquid and gas inclusions. Strong zoning, specially in the cut specimen. In polarized light the rough crystal showed twinning. E.S.

Müllenmeister, M.S., 1988. Neuentdecktes im Dominikanischen Bernstein. (New finds in Dominican amber.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 1-25, 37 figs in colour, bibl.

While Baltic amber is often cloudy, Dominican amber is usually transparent and can show well preserved inclusions. Best viewed when immersed in benzyl benzoate as these substances have nearly the same RI (1.54). The beautiful photomicrographs show many curious palaeontological organisms, as well as multiple phase inclusions, some being inorganic, such as sand and even raindrops, as well as air bubbles. UV brings out a blue fluorescence in blue amber, probably caused by finely distributed burnt wood particles. The interior of one blue amber shows fissures which are filled with pyrites. E.S.

Ncube, A.N., 1988. Occurrences of gemstones and ornamental stones in Zimbabwe. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 139-42, 1 map.

Short survey of gemstones and ornamental stones in Zimbabwe and their geological setting. E.S.

Pearson, D.G., Davies, G.R., Nixon, P.H., Milledge, H.J., 1989. Graphitized diamonds from a peridotite massif in Morocco and implications for anomalous diamond occurrences. *Nature*, 338, 60-2, 5 figs.

Octahedral and other cubic forms of graphite, interpreted as pseudomorphs after diamond, have been found in garnet pyroxenite layers in the Beni Nousera peridotite massif, northern Morocco. The occurrence demonstrates that fragments of highly diamondiferous mantle are tectonically emplaced into the continental crust and thus providing a source for diamond different from the usual kimberlite/lamproite vulcanism. M.O'D.

PLATEN, H.v., 1988. Zur Genese von Korund in metamorphen Bauxiten und Tonen. (On the genesis of corundum in metamorphic bauxites and clays.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 129-37, 4 graphs, 2 tables, bibl.

During the formation of the bauxites, selective accumulation of Al_2O_3 takes place together with other oxides which contribute to the coloration of the corundum. During the metamorphic formation of the corundum from diaspore, isomorphic replacement by the colouring oxides becomes difficult as reaction temperature lies at approximately 400°C. In metamorphic clays which are undersaturated in SiO_2 corundum is formed from dioctahedrical mica minerals. At low pressures muscovite, paragonite and margarite react to form feldspar components, corundum and vapour. At high pressures, the alkali-micas produce SiO_2-rich melt and corundum. Corundum can also be formed at low temperatures when muscovite and chlorite produce biotite. E.S.

SCHWARZ, D., BANK, H., HENN, U., 1988. Gemmologische Kurzinformationen. Neues Smaragdvorkommen in Brasilien entdeckt: Capoeirana bei Nova Era, Minas Gerais. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 146-7.

This paper deals with a newly discovered emerald occurrence in Brazil: Capoeirana near Nova Era, Minas Gerais. The material is comparable to that obtained from the Belmont Mine, with similar inclusions. Alexandrites and high quality aquamarines are found in the district. E.S.

SCHWARZ, D., EIDT, TH., COUTO, P.A., 1988. Die Smaragde des Minengebietes Socotó, Bahia, Brasilien: Vorkommen und Charakteristika. (The emeralds of the mining district of Socoto, Bahia, Brazil: their occurrence and characteristics.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 89-112, 26 figs (6 in colour), 8 tables, bibl.

The region is described in detail. There are granite batholiths whose pegmatites (source of Be) intruded the rock of the Serra de Jacobina and contacted an iron and chromium rich zone, forming the emeralds. RI varies from 1.597 to 1.582 and 1.567 to 1.590, birefringence from 0.007 to 0.009. SG 2.67 – 2.72. Inclusions show growth tubes and channels, regions with elevated concentration of inclusions, colour zones and growth striations, also fractures and fissures, fluid inclusions, two- phase but rarely three-phase inclusions. A number of mineral inclusions were identified. Mining is primitive, each owner marking his claim and supervising the work. Apart from these workings, groups of older men, women and children work and sieve the discarded material looking for emeralds. Altogether about 4000 people are assumed to be working in the district. E.S.

SMITH, K.L., 1988. Opals from Opal Butte, Oregon. *Gems & Gemology*, **24**, 4, 229- 36. 11 figs in colour.

Among the several varieties found, contra-luz, crystal and hydrophane opal are commercially the most important. Contra- luz displays its colour only when light shines through the opal. Much material crazes badly on exposure to dry air. Very slow drying may obviate this in about half the mined material. Oven-drying in wet sand yields about 25% uncrazed. The water content varies through the stone and causes uneven shrinkage and crazing. R.K.M.

THOMPSON, R.J., 1988. Jewels for a crown: the gemstones of Pakistan. *Australian Gemmologist*, **16**, 12, 471-2, 2 figs in colour.

A brief and imaginative eulogy of the gem minerals of the Hindu Kush, Karakoram and Himalayas. R.K.M.

WABER, N., FRIEDEN, T., HÄNNI, H.A., IFF, R., NIGGLI, E., 1988. Zur Farbveränderung von Korunden bei Hitzebehandlung. (Colour changes in corundum through heat treatment.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 57-68, 6 graphs, 1 table, bibl.

The experiments were made with 17 colourless or only slightly coloured sapphires from Ratnapura, Sri Lanka. They were heat treated for six hours at 1720±10°C in an argon atmosphere. Six sapphires became blue, three an intense cornflower blue. Four stones turned out smoky coloured, while in seven sapphires zoning in blue and brown became apparent. The stones were carefully examined under a microscope before and after treatment, but no special features explaining results were found. Absorption spectra of the stones after treatment are reproduced. E.S.

Book Reviews

BAUMGÄRTEL, R., QUELLMELZ, W., SCHNAIDER, H., 1988. *Schmuck-und Edelsteine.* (Jewellery and gemstones.) VEB Deutscher Verlag für Grundstoffindustrie, Leipzig. pp. 300. Illus. in black-and-white. DM60.

Forming part of the series *Monographienreihe Nutzbare Gesteine und Industrieminerale*, this is a cheaply but well produced book describing a large number of gem minerals with details of their physical and chemical properties and their occurrence. Characteristic crystals are shown for most species and their optical directions are given in some cases. There is a table giving trade and varietal names and identification tables with a good bibliography. Details seem well up-to-date though some of the species included will scarcely ever be seen in cut form. Reproduced from typewriting, the book nevertheless makes a good impression as have others from this state publishing house and for those who can read German it can be highly recommended. M.O'D.

FEDERMAN, D., 1988. *Modern jeweler's gem profile: the first sixty.* Vance Publishing Corporation, Shawnee Mission, Kansas. pp. 131. Illus. in colour. £25.00.

The book describes sixty of the best-known gem species, each of which is illustrated in full page colour facing the description which gives up-to-date details of discovery and marketing. The information given appears to be accurate and is certainly presented in a clear and interesting way. The book will look good in the shop and it is clearly intended to be used in this way. The fine colour photographs are by Tino Hammid, who has made a special study of gemstone photography. M.O'D.

GERE, C., MUNN, G.C., 1989. *Artists' jewellery.* Antique Collectors' Club, Woodbridge. pp. 244. Illus. in colour. £29.95.

This welcome book describes jewellery made by the Pre-Raphaelites and their followers down to the workers in the Arts and Crafts movement, thus covering the late nineteenth and early twentieth centuries. The introductory chapter discusses the links between art and fashion and leads naturally into a further discussion of the role of art, this time in relation to commerce. The Romantic and Aesthetic fashions are then examined with particular reference to the work and influence of William Morris and A.W. Pugin.

D.G. Rossetti makes his appearance in chapter five which concentrates upon a period in which the taste for naturalism began to develop. Ruskin was lecturing on 'Natural ornament' in 1853 and the representation of plants in jewellery probably dates from that time though its incorporation into general fashion came in the 1880s. This chapter gives some interesting sidelights on parts of Ruskin's career. By the late 1880s the first signs of what came to be known as the craft revival could be seen and a good deal of work was carried out in Birmingham.

The final chapter gives details of methods and techniques and there is a useful bibliography. This is a most attractive book; it incorporates many hitherto unpublished drawings, many in colour, and the standard of the photography is high. M.O'D.

GRABOWSKA, J., 1983. *Polish amber.* Interpress Publishers, Warsaw. pp.39. Illus. in black-and-white and in colour. Price on application.

A larger book than the pagination suggests (there is a large colour section at the back), this is a translation of a Polish original drawing on high-quality photographs from the Castle Museum in Malbork, the National Museum in Krakow, the National Museum in Warsaw, the Archaeological Museum in Gdańsk, The Archaelogical and Ethnographic Museum in Łódź, the Earth Science Museum in Warsaw, the District Museum in Tarnów, the State Art Collection in Dresden, the Treasury in Jasna Góra, Cathedral Treasury in Wawel [Krakow], and a church in Wegrów. These collections are not all well known in the west. The short text describes the finding and fashioning of Baltic amber in Poland with a commentary on the work of artists practising today.

This is a most attractive book and as material from Eastern Europe goes very quickly out of print, readers should look out for it wherever possible. There are said to be French, German and Polish editions. M.O'D.

GRIBBLE, C.D., 1988. *Rutley's elements of mineralogy.* 27th edn. Revised by C.D. Gribble. Unwin Hyman, London. pp. xii, 482. £12.95.

Rutley was first published in 1882 and the time had come for another revision after twenty years. Although the Rutley form has remained, the text is largely updated; in particular the silicates have a chapter to themselves in which they are described under a crystal-chemical classification. Dana order is used for non-silicates. More stereographic projections are used in the crystallography section and optical mineralogy has been completely revised.

In paperback this is still a useful book and the author's predilection for Scottish locations can be traced. Several undesirable names for gem minerals make an unwelcome reappearance and the upper limit for the specific gravity of lapis lazuli is given as 2.45. Location citations could have been better chosen. M.O'D.

JAFFE, H.W., 1988. *Crystal chemistry and refractivity.* University Press, Cambridge. pp. x, 335. Illus. in black-and-white. £55.00.

The book describes the composition of natural and synthetic crystals on the atomic level with emphasis upon the nature of chemical bonding. The relationships of atomic arrays, electronic structure and optical properties are discussed with particular attention being paid to refractivity. In the first part of the book the general principles of crystal chemistry are reviewed and the concept of refractivity introduced: in the second part examples of the structures and bonding of a number of minerals and artificial substances are presented with high-quality illustrations. Some previously unpublished data on refractivity and polarizability and their applications to mineralogical needs are given. Each chapter has its own bibliography. M.O'D.

NÉRET, G., 1988. *Boucheron.* Rizzoli, New York. Illus. in black-and-white and in colour. £60.00.

The book is subtitled *Four generations of a world-renowned jeweller,* and jumping ahead through the text to modern times it is clear that this celebrated firm has for long been in the forefront, not only of jewellery design but of large-scale projects such as that commissioned for the housing of the Iranian Crown Jewels in 1958. With branches in London, New York and Moscow, as well as in Paris, there can be few discerning jewellery buyers who will not be grateful for Frédéric Boucheron's foundation of the firm in 1858. From the first the clients included not only the rich but the flamboyant and it is good to see the book reflect this in its style and production. Three hundred pieces have been chosen to illustrate the firm's continuous alliances with the contemporary — for it has always been ahead of many of its more traditional competitors — and these are well shown on the pages (which are of good quality paper).

The book follows the history and work of the firm chronologically and there is a short bibliography. With the price of second-hand jewellery books today and with the prospect (one day) of severe limitations on paper supply serious students of jewellery and gemstones should be sure to build up their collections of the relevant literature now.

M.O'D.

O'DONOGHUE, M., 1988. *Crystal growth – a guide to the literature.* British Library: Science Reference and Information Service, London. pp. 67. £12.00.

This very useful guide is divided into the following sections: introduction, the Science Reference and Information Service, bibliographies, general topical works, journals, numerical data, conferences, crystal structures, phase relationships, solution growth, chemical vapour transport and solid phase growth), industrial crystallization, mixed crystals, ornamental and other uses of crystals, popular works, product availability, index (good). Some 23 pages are devoted to the literature of growth methods and this covers both Western and Russian technology – almost all are available in the British Library in London. The guide is an excellent start for anyone interested in crystal growth and is the third in a series by the same author. The earlier titles cover the literature of gemstones and mineralogy respectively. The high cost possibly reflects the somewhat limited appeal of the title and a consequently small print run.

E.A.J.

SALOMON, P., ROUDNITSKA, M., 1986. *Tahiti – the magic of the black pearl.* Tahiti Perle, Tahiti, French Polynesia. pp.221. Illus. in colour. Price on application.

Some may see this volume as a superior 'coffee-table' book promoting the black pearl of Tahiti – maybe it is, but it also contains much technical and historical detail not available elsewhere. The history of the local mother-of-pearl industry is recounted as is the development of the culturing of the black pearl along Japanese lines; there are many useful production statistics. The latter part of the book describes modern marketing and promotion and may be said to be somewhat poetic. It makes interesting reading, contains an abundance of facts and the photographs delight the eyes. E.A.J.

SCHWARZ. D., 1987. *Esmeraldas: inclusões em Gemas.* (Emeralds: inclusions in gemstones.) Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, Minas Gerais, Brazil. pp. xi, 439. Illus. in black-and-white and in colour. Price on application.

Despite the subtitle, this is a book about emerald in general since the chapter on inclusions takes up only the last section. Instead we have an exhaustive treatment of the mineralogy of the beryl group with particular reference to emerald; here the major occurrences are described with papers cited up to 1986 and a good deal of detail is given. After this section the different occurrences are classified on the basis of their genesis before notes are given on emerald synthesis.

Then comes the section on inclusions. These are described in what has come to be the traditional order of protogenetic, syngenetic and epigenetic. The various deposits are then discussed with reference to characteristic inclusions; synthetic emeralds are included at the end of this section. An appendix covers chemical analyses of Brazilian emeralds; new data on the Brazilian locality Santa Terezinha; emerald imitations; availability; gemmological microscopy and chemical composition of the minerals found as inclusions and an excellent bibliography.

Despite the somewhat low standard of production, this is a first-rate book and can be highly recommended. M.O'D.

Gemas do Brazil. (Gems of Brazil.) Mercedes-Benz do Brasil SA, Sao Bernardo do Campo, SP, Brazil, 1987. pp.130. Price on application.

This is a large-format limited-print prestige publication with coloured pictures of a number of species, some of which can scarcely be counted as ornamental but which nevertheless are attractively presented with captions and accompanying text in English and Portuguese. M.O'D.

A guide to fossicking in the Northern Territory. 2nd edn. Northern Territory Geological Survey, Darwin, 1986. pp.73. Illus. in colour. Australian $9.00.

A very-well produced and illustrated guide to the minerals to be found in the Northern Territory of Australia. The number of ornamental minerals is surprisingly large and includes quartz, garnet, epidote, tourmaline, zircon, prehnite, beryl, ruby and kyanite. M.O'D.

Opale Australijskie. (Australian opals.) Muzeum Ziemi, Warsaw, 1988. (Unpaged.) Illus. in colour. Price on application.

A short but attractive catalogue of the Australian opal collection of John and Zofia Benny-Wojciechowski, held at the Museum of the Earth, Warsaw, Poland, from May to August 1988. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

MEMBERS' MEETINGS

Midlands Branch

On 21 April 1989 at Dr Johnson House, Colmore Circus, Birmingham, the Annual General Meeting was held at which Mrs Janet S. Leek, FGA, and Mr John R. Bugg, LL B., FGA, were re-elected Chairman and Secretary respectively.

The AGM was followed by an illustrated lecture by Mr G. Millington entitled 'Inclusions in gemstones'.

North West Branch

On 19 April 1989 at Church House, Hanover Street, Liverpool 1, Mr Walter Wild, FGA, gave a talk on his collection of rare gemstones and brought along a selection for members to view.

On 17 May 1989, at Church House, Mr Ron Walledge gave a talk on opal mining.

On 23 May 1989, members visited De Beers Consolidated Mines, Charterhouse Street, London EC1, where a lecture was given by Mr Roger van Eeghen.

On 14 June 1989 at Church House, Mr Alan Hodgkinson, FGA, gave a lecture entitled 'Colourization of diamond'. He also displayed some of the rare gemstones from his collection.

COUNCIL MEETING

At a meeting of the Council held on 21 April 1989 at the Royal Automobile Club, 89 Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship

Slack, Richard D., Cardiff. 1984

Ordinary Membership

Baird, Renee, London.
Bradford, Nikki A., Hassocks.
Davies, Maria C., Bridgend.
Day, Michael P., London.
Deacon, Daren J., Brighton.
de Haulleville, Jonja, Bousval, Belgium.
Dimitriadie, Milyo M., Rhodes, Greece.
Edwards, Susan M., London.
Idris, Mustafa, Kaduna, Nigeria.
Komppa-Vigar, Leena M., Westoning.
Lipton, Heinz, London.
Litjens, R., Schoonhoven, The Netherlands.
Nieves Pinzon, Dario, Bogota, Colombia.
Panju, Zoher A., London.
Pomeroy, Terence L., Exeter.
Sage, Barbara L., Spalding.
Sorensen, Carsten, Rungsted Kyst, Denmark.
Sprague, Frances A., Exeter, Devon.
Wates, Peter J., Coulsdon.

THE CARNEGIE MINERALOGICAL AWARD

Dr John Sinkankas has been awarded the Carnegie Mineralogical Award for 1988. The prestigious award recognizes contributions which promote and improve the preservation, conservation and educational use of minerals and mineral collecting, ideals exemplified in the Hillman Hall of Mineralogy at the Carnegie Museum of Natural History. Dr Sinkankas was presented with a certificate of recognition, a bronze medallion and a cheque for $1500.

Dr Sinkankas' contribution of the fields of mineralogical and gemmological literature is legendary. John was born in 1915 in Paterson, New Jersey, a fortunate birthplace as he was collecting zeolite minerals at the famous Newstreat Quarry by the age of seven. At 21 he entered the US Navy and graduated the Pensacola Naval Air Station as an aviator. Travel abroad gave John numerous opportunities to observe gem mining, cutting and marketing as well as spare time aboard ship to work on his lapidary skills. After retirement from the Navy in 1961, Captain Sinkankas spent five years as research assistant in mineralogy at the Scripps Institution of Oceanography, served for a time as editor of the *Lapidary Journal* and started, with his wife Majorie, Peri Lithon Books, a business supplying antiquarian books in the earth sciences to collectors.

To date, Dr Sinkankas has published 11 books on mineralogy, gemmology, prospecting and lapidary art, among them the critically acclaimed *Gemstones of North America*, *Mineralogy for Amateurs* and, most recently, *Emerald and other Beryls*. He has also been a frequent contributor to popular and scientific journals, including the *Journal of Gemmology*.

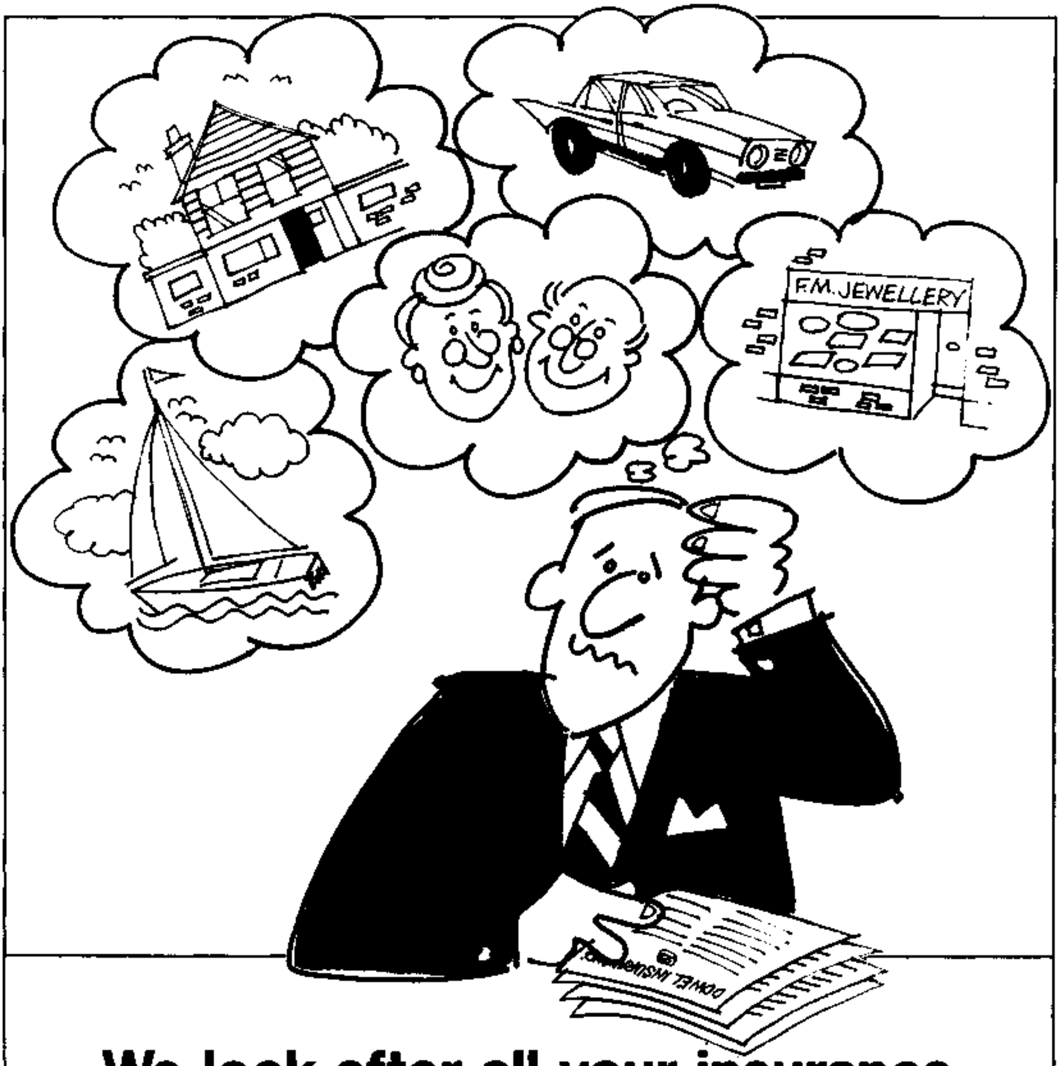
In 1982 John was given the Gemological Institute of America's Distinguished Associate Award at the GIA's first International Gemological Symposium. In the same year he was awarded a Doctorate of Humane Letters from William Paterson College, Paterson, New Jersey.

Throughout the years John and Marjorie assembled an extensive library of gemmological books and related literature, which, in 1988, was purchased by the GIA. Over the last year the GIA's existing library was expanded to accommodate the 8000 to 10 000 volume collection, and the Richard T. Liddicoat Library and Information Center has now been opened so that the Sinkankas Library can be used by researchers and other interested individuals.

FORTHCOMING MEETINGS

On **Wednesday 11 October 1989** at the Flett Theatre, Geological Museum, Exhibition Road, London SW7, a lecture will be given by Mr John I. Koivula, GG, FGA, of the Gemological Institute of America, Santa Monica, California.

The Reunion of Members and Presentation of Awards is to be held on **Monday 6 November 1989** at the Guildhall, London EC2. Mr R. Crowning-shield, GG, FGA, of the New York laboratory of the Gemological Institute of America will be presenting the awards.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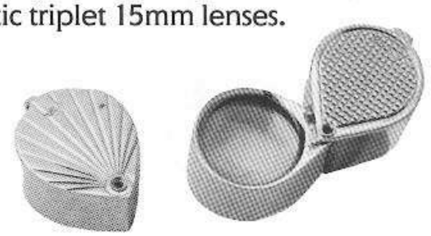

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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

Historical Note

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

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

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

Notes for Contributors

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

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

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

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