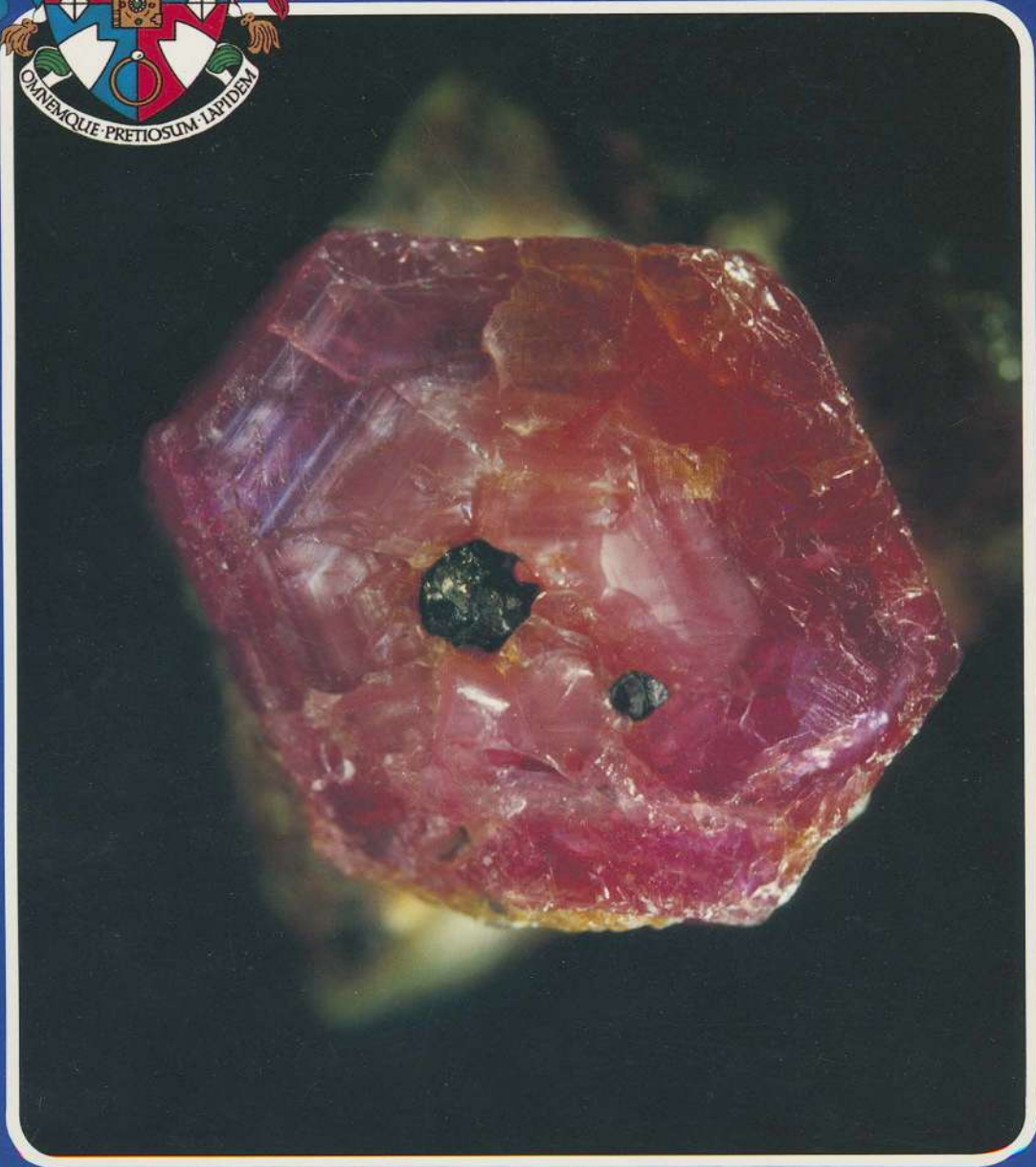
Volume 22 No. 8. October 1991

The Journal of Gemmology



THE GEMMOLOGICAL ASSOCIATION AND GEM TESTING LABORATORY OF GREAT BRITAIN

OFFICERS AND COUNCIL

Past Presidents:
Sir Henry Miers, MA, D.Sc., FRS
Sir William Bragg, OM, KBE, FRS
Dr. G.F. Herbert Smith, CBE, MA, D.Sc.
Sir Lawrence Bragg, CH, OBE, MC, B.Sc., FRS
Sir Frank Claringbull, Ph.D., F.Inst.P., FGS
Vice-President: R. K. Mitchell, FGA

Council of Management
D.J. Callaghan, FGA
N.W. Deeks, FGA
N.B. Israel, FGA
E.A. Jobbins, B.Sc., C.Eng., FIMM, FGA
I. Thomson, FGA
V.P. Watson, FGA
K. Scarratt, FGA: Chief Executive
R.R. Harding, B.Sc., D.Phil., FGA: Director of Gemmology

Members' Council

A. J. Allnutt, M.Sc., Ph.D., FGA
C. R. Cavey, FGA
P. J. E. Daly, B.Sc., FGA
T. Davidson, FGA
R. Fuller, FGA
J.A.W. Hodgkinson, FGA
D. Inkersole, FGA
B. Jackson, FGA
G.H. Jones, B.Sc., Ph.D., FGA
H. Levy, M.Sc., BA, FGA
J. Kessler
G. Monnickendam
L. Music
J.B. Nelson, Ph.D., FGS, F. Inst. P., C.Phys., FGA
PG. Read, C.Eng., MIEE, MIERE, FGA
I. Roberts, FGA
E.A. Thomson, Hon. FGA
R. Velden
D. Warren
C.H. Winter, FGA

Branch Chairmen:
Midlands Branch: D.M. Larcher, FBHI, FGA
North-West Branch: W. Franks, FGA

Examiners:

A. J. Allnutt, M.Sc., Ph.D., FGA
L. Bartlett, B.Sc., M.Phil., FGA
E. M. Bruton, FGA
C. R. Cavey, FGA
A.T. Collins, B.Sc., Ph.D
A. E. Farn, FGA
R. R. Harding, B.Sc., D.Phil., FGA
E. A. Jobbins, B.Sc., C. Eng., FIMM, FGA
G. H. Jones, B.Sc., Ph.D., FGA
D. G. Kent, FGA
P. Sadler, B.Sc., FGS, FGA
K. Scarratt, FGA
E. Stern, FGA
Prof. I.Sunagawa,D.Sc.
M. Virkkunen, M.Phil., FGA
C. Woodward, B.Sc., FGA

Editor: E. A. Jobbins, B.Sc., C.Eng., FIMM, FGA
Editorial Assistant: Mary A. Burland
Curator: C. R. Cavey, FGA

The Gemmological Association and Gem Testing Laboratory of Great Britain
27 Greville Street, London ECIN 8SU
Telephone: 071-404 3334 **Fax: 071-404 8843**

The Journal of Gemmology

VOLUME 22

NUMBER EIGHT OCTOBER 1991

Cover Picture

Cross section of ruby crystal with massive rutile inclusion. (Plate 5, 'The growth of rubies in south-east Kenya' by R.M. Key and J.O. Ochieng, p.484).

ISSN: 0022-1252

An unusual assembled inclusion specimen

Robert C. Kammerling and John I. Koivula

Gemological Institute of America, Santa Monica, California 90404, USA

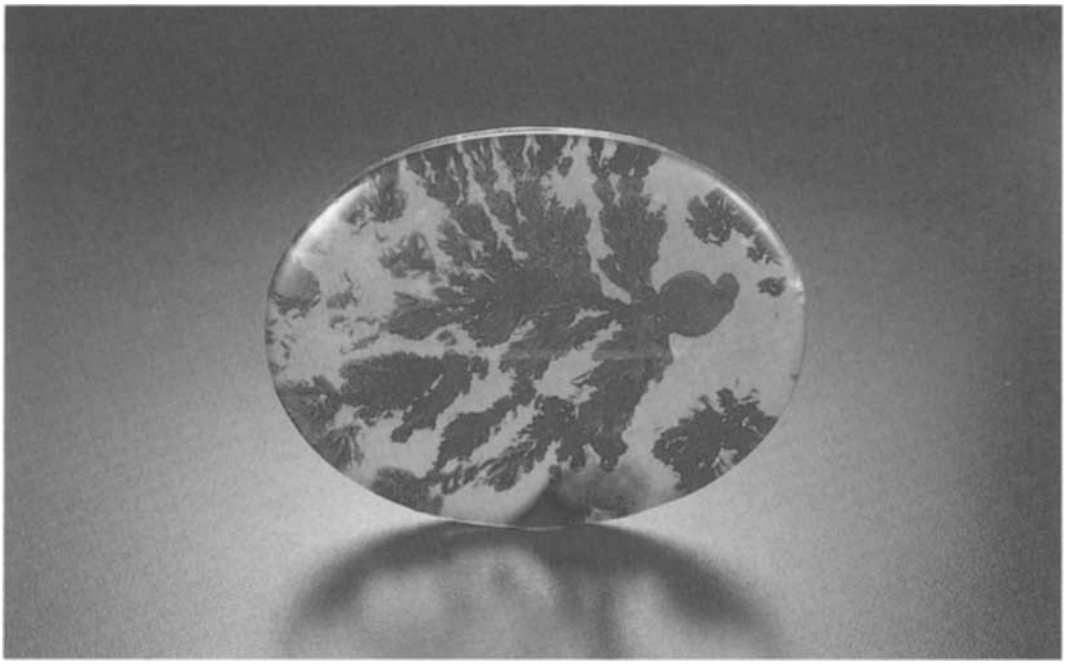


Fig. 1. This assembled agate specimen weighs 61.39 carats and measures 39.00 × 30.45 × 6.42mm. Photograph by Robert Weldon, Gemological Institute of America.

Abstract

This article reports on an assembled stone consisting of glass and dendritic agate components.

Introduction

Inclusions are an important feature in gemstones for a number of reasons. For the diamond grader, the presence of a minute inclusion, just visible with 10x magnification, can set the clarity grade and greatly affect the stone's value. Although often less closely scrutinized from an evaluation standpoint, 'eye-visible' inclusions can also have a significant effect on the value of a coloured stone (in this regard, 'blemishes' on pearls are also an important consideration).

Additionally, features detected under magnification are of concern in gem identification. With the proliferation of new synthetics and the growing availability of so-called 'sophisticated' man-made gems, inclusions are usually the most reliable – sometimes the only – means of determining the nature of a gem. No longer is it just a question of natural vs. Verneuil synthetic ruby. Today we face the possibility of having to identify flux synthetic rubies; flux blue, pink and orange sapphires; synthetic opal in a variety of body colours and patterns to their play-of-colour; synthetic alexandrite and even cat's-eye alexandrite; and the list goes on. Furthermore, even when we do determine, for

 ISSN: 0022-1252

example, that a ruby is natural, we may then have to determine whether or not it has been heat-treated to modify colour and/or clarity, or had surface cavities filled with a glass to improve appearance and add weight.

Inclusions (and related structural features) are also important in that they are responsible for some of the most intriguing gems, those which display optical phenomena. Were it not for fine, parallel acicular crystal inclusions in chrysoberyl, there would be no cat's-eye stones; but for intersecting, oriented rutile 'needles' there would be no star rubies and star sapphires. There would be no sunstone or aventurine feldspars had not minute hematite or copper crystals precipitated out in these gem materials.

Altered inclusion specimens

Occasionally we also come across gem materials that have been treated with the apparent purpose of fabricating or altering inclusions. Two such fabricated specimens the authors have examined were colourless quartz crystals with man-made 'three-phase' inclusions. Thin, tubular columns had been drilled in from their bases and had been partially filled with a liquid. The final touch – 'phase three' – was a minute faceted gem; in one specimen this 'solid phase' was a blue gem, in the other, a bright red stone. Each stone had its base sealed with what appeared to be a mixture of epoxy resin and quartz fragments (Koivula and Kammerling, 1989).

In 1986 the authors first saw faceted colourless as well as blue topaz containing brownish yellow acicular inclusions. First described as 'rutilated' topaz, it was later shown that the inclusions were limonite-stained etched dislocation channels (Koivula, 1987). Late in 1988 one of the authors was shown similar material in which the inclusions were a dark red-brown and which reportedly had been altered by heat treatment. Subsequent investigation showed that the heating had altered the limonite staining to hematite, changing the colour of the inclusions and making them more prominent (Kammerling and Koivula, 1989).

Also seen occasionally are translucent to semi-translucent chalcedonies containing large, apparently artificially induced dendritic inclusions. It is believed that the gems are first soaked in a copper solution, after which an electric current is applied in order to precipitate out a dendrite of elemental copper (Dunn *et al.*, 1981; Koivula and Misiorowski, 1986; Koivula and Kammerling, 1989). The copper solution is also probably responsible for the blue-green body colour of such treated gems. There is also a brief mention in the literature of an agate cabochon on the back of which dendrites were engraved and then filled with a black substance (Nassau, 1983). Equally germane to this discussion are 'most agate doublets'. These are produced by precipitating out manganese oxide dendrites within gelatine on a glass plate and then gently heating to remove excess water; another glass plate is then cemented on top and assembled stones fashioned from the composite piece (Webster, 1983).

Description of specimen under investigation

In the spring of 1990, a resident gemmology student at the Gemological Institute of America in Santa Monica donated a most interesting assembled stone for examination. The specimen, a very shallow-domed oval single cabochon (Figure 1), had been purchased at the Tucson Gem and Mineral Show in February, where it was represented as a dendritic agate; there was no indication from the vendor that the piece was assembled or in any other way altered. The stone, which weighs 61.39 carats and measures 39.00 × 30.45 × 6.42mm, is essentially colourless and almost transparent where inclusions are not present. It exhibits an attractive pattern of dark reddish to greenish brown dendrites in the type of general pattern which in the US trade is referred to as 'plume' structure (Figure 2). One small, irregular area has a dark yellowish brown colour with wavy, agate-like banding.

When examined from the side, the assembled nature of the piece becomes obvious (Figure 3). The top consists of a very transparent, colourless convex cap joined to a flat, light grey, semi-transparent to translucent base.

Magnification

When examined under magnification the cap appears virtually inclusion-free. Between the cap and base there is a fairly thick (approximately 0.5mm) transparent, colourless layer containing many minute, spherical gas bubbles (Figure 4). Using a straight metal pin and very little pressure it was easy to both scratch and indent this layer, which we believe to consist of an epoxy or similar synthetic resin (or perhaps a 'gel-type' cement). Some of this epoxy-like material runs out over part of the cap and some irregular drops of what appears to be this material are found on the cap near the separation plane. The entire base of the stone is also coated with this material; several scratches (Figure 5) and other irregularities (Figure 6), some resembling human fingerprints, are noted on the coating. The base section, which is approximately 1.2mm thick, contains (in addition to the dendritic inclusions already described) some irregular, wispy, milky-white areas, some of which show typical 'botryoidal' or 'fortification agate' structure (Figure 7).

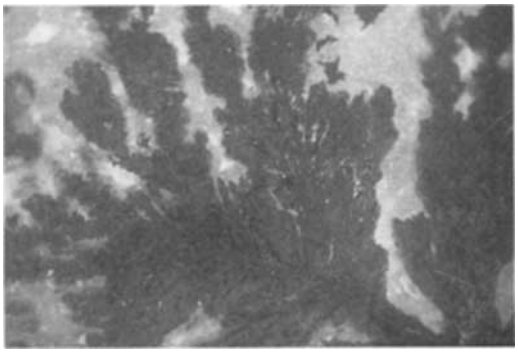


Fig. 2. The dendrites in the assembled stone exhibit an attractive 'plume' structure. Photomicrograph by John I. Koivula. Magnified 3x.

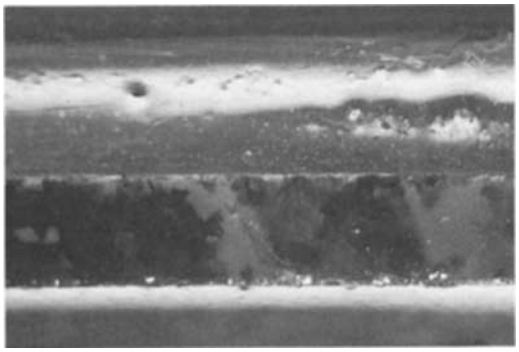


Fig. 3. When examined from the side, the assembled nature of the stone becomes obvious. Photomicrograph by John I. Koivula.

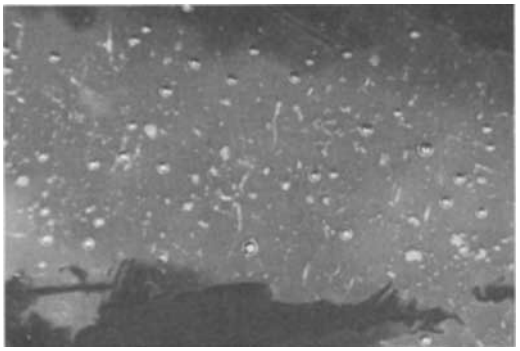


Fig. 4. Numerous minute, spherical gas bubbles can be seen in the colourless cement layer between the cap and the base. Photomicrograph by John I. Koivula. Magnified 40x.

Fig. 5. A scratch can be seen in the colourless coating on the base of the assembled agate. Photomicrograph by John I. Koivula. Magnified 10x.

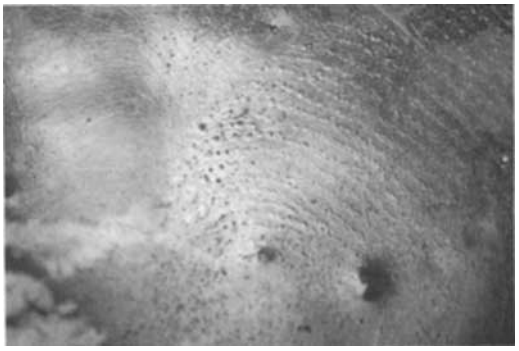


Fig. 6. Irregular surface features, probably human fingerprints, were also noted on the coated base. Photomicrograph by John I. Koivula. Magnified 5x.

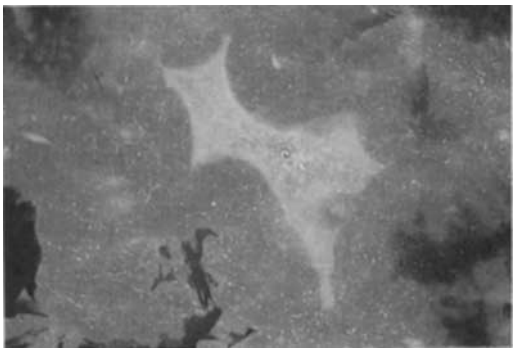


Fig. 7. The typical agate structure was detected in some areas of the agate base. Photomicrograph by John I. Koivula. Magnified 30x.

Gemmological properties

A spot refractive index reading taken on the apex of the cap with a Duplex II refractometer revealed a value of 1.51, while a flat-facet type reading on the base gave a value of 1.56. No birefringence or pleochroism was noted, and no absorption features were detected using a Beck prism spectroscope mounted on a dual direct-transmission/fibre-optic illuminator base. When examined face-up in the polariscope between crossed polaroids the stone exhibited an aggregate reaction; when examined through the side, parallel to the separation plane, the cap gave a singly refractive reaction while the base gave an aggregate reaction. Through the careful use of hardness pencils it was determined that the cap had a Mohs hardness of approximately 5½.

Viewed face-up under long-wave ultraviolet radiation, no fluorescence was detected; when examined parallel to the girdle plane, however, the epoxy-like layer was seen to fluoresce a bright bluish white. Viewed face-up under short-wave ultraviolet light, the stone fluoresced a moderate chalky yellow; examined from the side, however, it was seen that the cap was fluorescing a strong chalky yellow, the epoxy-like layer fluoresced a moderate chalky bluish-white and the base was inert. Interestingly, when viewed through the base of the cabochon the yellow fluorescence of the cap was masked.

Conclusion and discussion

Based on the above test results, it was determined that the specimen was a glass and dendritic ('plume') agate doublet, the two components being joined with a colourless cement layer. Although it would appear inconsistent with the identification of the base section, the 1.56 RI obtained for this component was probably due to the thickness of the coating on the base, that is, the reading was that of the epoxy and not of the underlying chalcedony. In the authors' experience, this reading is in the range of some synthetic casting resins with which they have experimented.

One might ask why anyone would go to the bother of producing such an assembled stone. Dr Emmanuel Fritsch of the GIA Research Department offered one possible explanation, stating that only in a relatively thin section might the agate base have exhibited the desired 'plume' effect; the assemblage allowed this effect to be seen in a larger (and perhaps more durable) stone. Another possible explanation is that, as with some turquoise and opal, the finished piece may merely have been too thin to have offered adequate durability, hence the assemblage.

Acknowledgement

The authors would like to thank Mr Pieter Bennett for bringing the assembled 'plume' agate specimen to their attention and for donating it to the GIA Permanent Collection.

References

Dunn, P.J., Bentley, R.E., Wilson, W.E., 1981. Mineral Fakes. *Mineralogical Record*, **12**, 4, 197-219.

Kammerling, R.C., Koivula, J.I., 1989. Thermal Alteration of Inclusions in 'Rutilated' Topaz. *Gems & Gemology*, **25**, 3, 165-7.

Koivula, J.I., 1987. The Rutilated Topaz Misnomer. *Gems & Gemology*, **23**, 2, 100-3.

Koivula, J.I., Kammerling, R.C., 1989. Gem News: Man-made 'Inclusion' Specimens. *Gems & Gemology*, **25**, 1, 45-6.

Koivula, J.I., Misiorowski, E., 1986. Gem News: Electrically Treated Chalcedony. *Gems & Gemology*, **22**, 4, 246.

Nassau, K., 1983. *Gemstone Enhancement*. Butterworth & Co. (Publishers) Ltd., London.

Webster, R., 1983. *Gems, Their Sources, Descriptions and Identification*. 4th Edition revised by B.W. Anderson, Butterworth & Co. (Publishers) Ltd., London.

[*Manuscript received 18 April 1990.*]

Contributions to a history of gemmology Carl Peter Thunberg and Ceylon gemstones

John Sinkankas, Ph.D., GG, FMSA

San Diego, California 9109, USA

The literature of antiquity frequently mentions the gem riches of Ceylon, today known as Sri Lanka, but only in the 18th century, did a modern, trained scientist, Peter Carl Thunberg (1743-1828), Swedish medical doctor and naturalist, systematically collect and describe its gemstones. The account first appeared in a narrative of his voyage to the Far East and elsewhere, *Resa uti Europa, Africa, Asia... 1770-1779*, published in Uppsala, Sweden, 1788-93. He briefly describes four non-gem minerals and twenty gemstones which herein are affirmed as to identity or suggested as being different from the species to which assigned by Thunberg.

Biographical note

Carl Peter Thunberg was born at Jönköping on 11 November 1743 where in his youth he attended local schools then entered the University at Uppsala for his higher education. Here he obtained his doctorate in medicine in 1770. While at Uppsala he studied under the celebrated naturalist Carolus Linnaeus (1707-1778) who made him his protege and declared him to be his most promising student. From this master of natural history he received the inspiration to devote almost his entire life to studies in the natural sciences with greatest emphasis on botany. However, immediately after leaving the university he travelled to Paris to further study medicine for one year. Here he received an invitation from the Dutch East Indies Company to act as surgeon and naturalist in their colony at Cape Town, South Africa. Setting sail from Europe he arrived at the Cape in April 1777, and for a period of almost three years assiduously collected over 3,000 species of plants, of which over 1,000 were new to science.

An opportunity now came his way to travel farther to Japan, again acting in similar official capacities. He boarded ship in 1775 and after stops in the Dutch East Indies eventually arrived at the island of Deshima in Nagasaki Harbour to which place the Dutch were confined by order of the Japanese government. Despite restrictions placed on travel and social exchanges Thunberg managed to assemble a large collection of native flora, especially plants that were used for food or in the native economy, which proved to be the next largest collection after that formed earlier by Engelbert Kaempfer (1651-1715) also a visitor to Japan in 1690. Thunberg's collection was dispatched to Sweden and formed the basis for his monumental *Flora Japonica*, 1784, in which treatise he described over 300 previously unknown plants. He left Japan in December 1776, stopping during his voyage home in Batavia, Colombo, Cape Colony, and London, in the last city making the acquaintance of a number of scientists, including Sir Joseph Banks (1743-1820). He arrived in Sweden in 1779 and in 1781 was appointed demonstrator in botany at Uppsala, and then succeeded his mentor, Linnaeus, as Professor of Botany in 1784. Thunberg founded a botanical garden at Uppsala and gave to his university his large collection of natural history objects. In addition to the Japanese botany mentioned, he also wrote *Icones plantarum Japonicum*, 1794-1805, *Prodromus plantarum*, 1800, and *Flora Capensis*, 1807-1812. He first described the remarkable South African plants known as the proteas while the genus, *Thunbergia*, containing 65 species and much cultivated in warmer climes, was named in his honour. His travels proved popular reading and were published in German, 1792-4, in English, 1794-5, and in French, 1794. After a useful and productive life, Thunberg died at Tunaberg, near Uppsala, on 8 August, 1828.

Historical accounts of Ceylon gemstones

This pleasant, tropical island, lying immediately south of the Deccan Peninsula of India, has been identified by various names as Serendib, Taprobane, and others (Yule, 1871; Gübelin, 1968; Casson, 1989). Its gem treasures were known for some centuries prior to the Christian era as is made clear in the *Periplus of the Red Sea*, or sea-trader's guide to the Red Sea and other Near East waters, a new translation of which has been made by Casson (1989, esp. pp. 230 ff). By the beginning of the first century traders knew of numerous animal, vegetable, and mineral products of the region, all of

 ISSN: 0022-1252

which were exchanged among Greek, Roman, Egyptian, and Moslem merchants. Well into the Christian era the fame of Ceylon's riches spread throughout the civilized world but the first reliable eyewitness account appears to be that of Marco Polo (1254-1324), famed Venetian adventurer, who visited the island on his return trip from China sometime between 1292, when he left China, and 1295 when he arrived in Venice.

Polo writes (Yule, 1871): "Now I will... tell you of the most precious article that exists in the world. You must know that rubies are found in this Island and in no other country in the world [*sic*] but this. They find there also sapphires and topazes and amethysts, and many other stones of price. And the King of this Island possesses a ruby which is the finest and biggest in the world; I will tell you what it is like. It is about a palm in length, and as thick as a man's arm; to look at, it is the most resplendent object upon earth; it is quite free from flaw and red as fire. Its value is so great that a price for it in money could hardly be named at all. You must know that the Great Khan [Kublai Khan, 1216-1294] sent an embassy and begged the King as a favour greatly desired by him to sell him this ruby, offering to give for it the ransom of the city, or in fact what the King would. But the King replied that on no account whatever would he sell it, for it had come to him from his ancestors".

Yule (p.256) comments on the story of this enormous 'ruby' as told by others who in the past claimed to have some knowledge of it but offers himself no explanation as to the stone's identity even though it was probably obvious to Yule that it could not have been a true ruby. Alternatively, the stone could have been a large tourmaline crystal, possibly red in colour and from Burma where in modern times at least, very large rubellite crystals were found in the pegmatite mine at Sakangyi. Furthermore, Bauer (Spencer transl. 1904, p.371) notes that "two very fine specimens of crystallized rubellite from Burma are exhibited in the Mineralogical Gallery of the British Museum, one of these, remarkable for its size and shape, being seven inches high and six inches across, was given by the King of Ava to Colonel Symes when on an embassy to that country in 1795; the other, not so large, but of a fine deep colour, was presented to the Museum in 1869 by Mr C.S.J.L. Guthrie".

After Marco Polo the next eyewitness from Europe appears to be Jean Baptiste Tavernier (1605-1689), the daring French traveller-gem merchant, who made no less than six voyages to the Near East and into India, seeking and buying gems of great value for resale in Europe. His account makes fascinating reading and is still highly esteemed for its historical detail, gemmological information, and general accuracy. Its first edition, *Les six Voyages*, etc., appeared in Paris in 1676. Tavernier visited Ceylon from May 12 to July 25, 1648, noting that "there are only two places in the East where coloured stones are obtained, namely in the Kingdom of Pegu [Burma] and in the island of Ceylon" (Tavernier, Ball-Crooke transl., 1925, 2, 77). Further, "the other place in the East whence rubies and other coloured stones are obtained is a river in the island of Ceylon. It flows from high mountains which are in the middle of the island, and as the rains greatly increase its size – three or four months after they have fallen, and when the water is lowered, the poor people go to search the sand, where they find rubies, sapphires, and topazes. The stones from this river are generally more beautiful and cleaner than those of Pegu" (*ibid*, p.79). While Tavernier's first edition appeared in 1676 the information on India's and Ceylon's gemstones actually appeared beforehand in the 1665 edition of *Chappuzeau's Histoire des Joyeaux*, which, however, is said to be a pirating of information derived from Tavernier's 'original memoirs', according to Valentine Ball (Tavernier, Ball-Crooke edit, 2, 471-6). An English version of Chappuzeau is also known, published in 1671. Neither of the works contain any information which is not already in Tavernier.

Thunberg's visit

Apparently Thunberg's knowledge of Ceylon's gemstones was gained largely as a result of a several weeks stay at Matara, which gem district he visited in response to an urgent request for his medical attention to the wife of Count Rantzow, Dutch Comptroller of the 'factory' at Mature (as it was called). Thunberg states that "I daily made excursions in the vicinity of this place, and as the precious stones of the island are found and dug up more especially in these parts, I procured the proper intelligence, as well concerning the different kinds of them, as the manner in which they are sought for and made use of" (Engl. transl. p.215, ff.). He notes that the major part of gemstones are locally cut and sold afterwards in India, it being the occupation of the "poorer sorts of Moors to cut and polish them", referring here to the Moslems of Sri Lanka who until recently monopolized the lapidary treatment of native gemstones. Thunberg took care to buy both rough and cut stones, the rough to be preserved with other 'fossils', i.e., mineral specimens, which he collected during his travels. The non-gem species from Ceylon are few: an 'iron ore' found in the earth and clay and suggesting limonitic or goethitic concretions, mica in "large laminated masses... the slivers of this are used for ornamenting... umbrellas, made of large Talpat

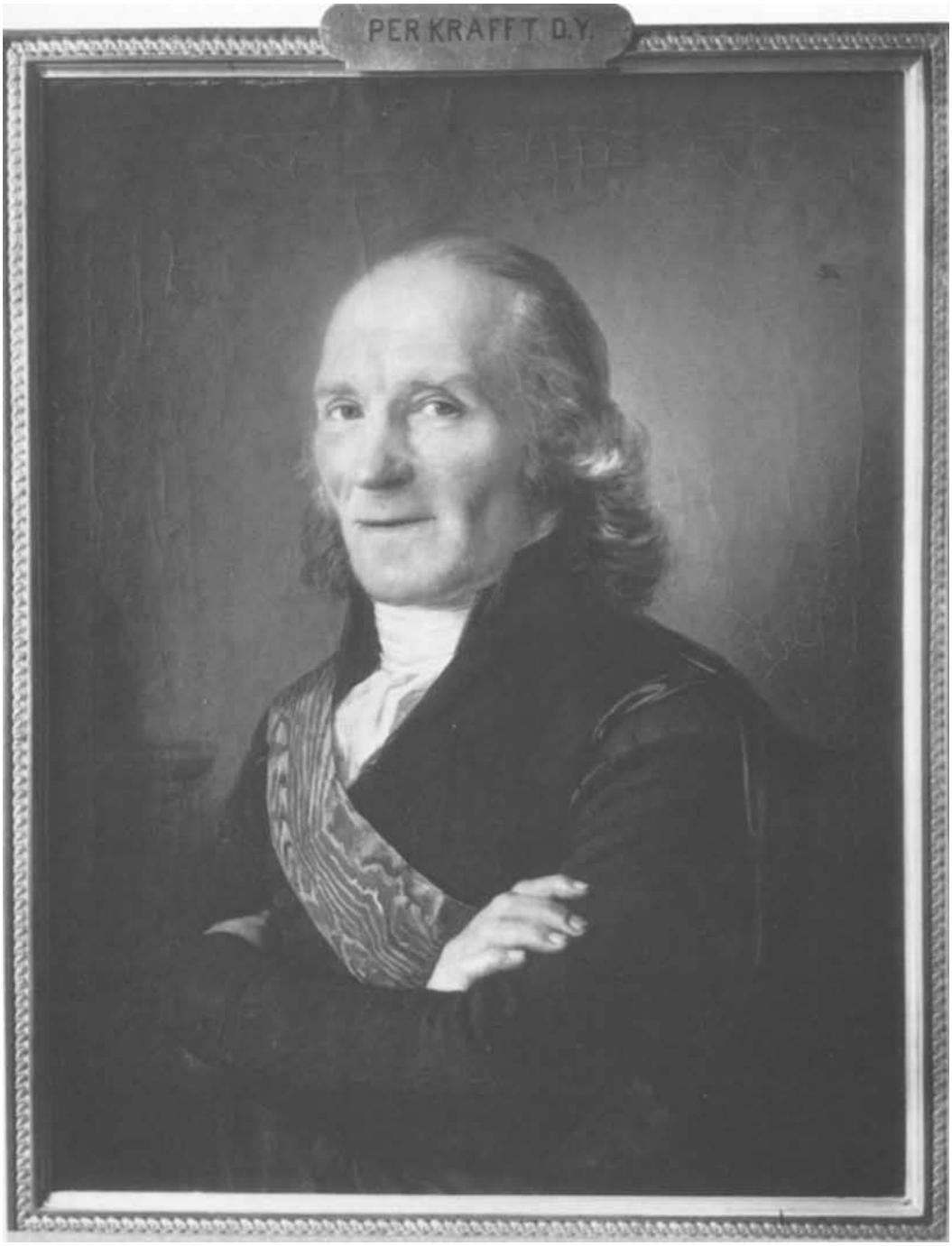


Fig. 1. Portrait (original in oils) of Carl Peter Thunberg by Per Krafft, The Younger, painted in 1808, now in the University of Uppsala, Sweden. Courtesy Dr. Kurt Boström.

(*Licuala*) leaves", 'plumbago' or graphite, and 'stahlstein, or crystallized pyrites (or siderite), "used for making buttons of".

The gemstones are as follows, with synonyms in English, Malabarese, Singhalese, and Swedish, the last added from Thunberg's article on same in the transactions of the Swedish Academy of Sciences (Thunberg, 1784). The first name is from the English translation (Thunberg, 1795).

Ruby: robyn, elinges chogeppu, lankaratte, rubin. "Genuine ruby".

Amethyst: scuandi (in Malabar. & Singhal.); Swedish like English. "Purple-coloured Mountain Crystal."

Robals: rauwa, rawa; granater. "Small transparent Garnets of dark-red colour".

Hyacinths: No synonyms given; "made to pass for rubies". The name is classically assigned to red zircon, which gemstone is abundant in Sri Lankan gravels in short prismatic tetragonal crystals and rounded pebbles.

Red Tourmaline: pania turemali, penni tourmalin; röd turmalin. "A quartz inclining to a red colour". As with other colours of zircon, called indiscriminately 'tourmaline', even today.

Blue Saphire: nilem, nile; blå saphir. "A genuine blueish coloured Saphire, frequently with blue spots", here probably referring to the many sapphire crystals in Ceylon gravels that display pigmentation only in patches, zones, or thin skin areas.

Blue Tourmalin: nile turemali (both Malab. & Singhal.); blå turmalin. "A Quartz, in colour inclining a little to blue".

Green Saphire: patje padian (both Malab. & Singhal.); grön saphir. "Genuine saphire".

Green Tourmalin: patje turemali (both Malab. & Singhal.), also called the "Maturese diamond", and noting that this name "is given to both Chrysolites with tetrahedral prisms, and even sometimes to the Chrysopras". In the Swedish version, Thunberg defines 'Grön Turmaline' as occurring in 'fyrsidig prisma', again almost certainly describing tetragonal crystals of green zircon. The 'chrysopras' used here is not further identified by Thunberg.

Topaz: puresjeragen, purperagen, but the latter is given in Thunberg's article as 'pusperagan'. "Genuine topaz".

Cinnamon-stone: komedegam (both Malab. & Singhal.); canelsten. "A fine flame-coloured or yellowish-brown garnet". Grossular.

Yellow Tourmaline or *Maturese Diamond:* kaneke turemali (both Malab. & Singhal.). "A Topez [*sic*] of a greenish-yellow colour", but most likely another colour phase of zircon; the second term for many years has been applied to zircons, especially from the Matara area, which have been heat-treated to drive off colour.

White Tourmalin or *Maturese Diamond:* sudu turemali (both Malab. & Singhal.). "Topaz of pale yellow colour", but Thunberg's Swedish gives it as 'gröngul', i.e., 'greenish-yellow'.

White Crystal: wille palingu, sudu palingu; hvit crystall. "Transparent and colourless mountain Crystal".

White Saphires or *Water Saphires:* willie padjan, sudu padjan; hvit saphir or vatn-saphir. "Small fragments and slivers of the most transparent white mountain Crystals".

Taripo: "a milk-coloured quartz".

Yellow Crystal: manjel palingu, kaha palingu. "A lighter coloured smoky Topaz". Citrine.

Brown Crystal: tillia palingu (both Malab. & Singhal.). "Smoky mountain Crystal, or a dark coloured smoky Topaz". Smoky quartz.

Black Crystal: karte palingu, kallu palingu. "Partly in Crystals, partly in fragments, is the Electrical Tourmalin of Ceylon". Apparently referring here to schorl.

Cat's Eye: wairodi (both Malabar. & Singhal.); kattöga. "Pseudo-Opal".

Commentary

The meagre descriptions above are augmented for some stones in the text that follows the listing, giving colour qualities of ruby and amethyst, and properties such as transparency and presence or absence of inclusions. Accurate identifications of gemstones, especially when in the form of rolled pebbles and lacking morphological clues, were not easy in the last part of the 18th century, and even when Thunberg enlisted the aid of Torbern Bergman it is obvious that mistakes still occurred. For example, in Thunberg's discussion of ruby (p.220), he states that "most of them are round and flat, from having been agitated and rolled about in the water", which is actually more likely to be the case with every other Sri Lankan alluvial gemstone than the ruby or sapphire. The corundum crystals of these gravels commonly display small to large remnants of crystal faces, and even when severely worn, they present general shapes that are readily identified as belonging to crystals of this species. The confusion in identity, or, rather, the application of the name 'ruby' freely to any reddish stone, causing such confusion, is typified in Thunberg's following remark in which he claims that "some [rubies] I have found crystallized with eight sides, of which four were broad, and four very small, and terminated by two points, consisting of four sides each", an excellent description of a typical doubly-terminated zircon crystal displaying first and second order prisms and the bipyramid but not of a corundum

crystal. Next he notes that "the Moors say that these approach nearest to the Diamond in hardness, and polish them, in order to render them fit for being set in rings", but now it seems obvious that the Moors [Moslems] are speaking of true corundums and not zircons, the difference in hardness between the two readily apparent to anyone who has applied them to the lapidary's grinding wheel.

The difficulties in identification that beset Thunberg and others in his day were to a large extent mitigated by the success of chemical analytical methods utilizing alkali fusions of hitherto intractable minerals, and from the fusions, now water-soluble, further isolating distinctive compounds – usually oxides such as 'silica', 'alumina', etc. Among the most successful analysts at the close of the 18th century and into the first years of the 19th century was Martin Heinrich Klaproth (1743-1817), characterized by Mary Elvira Weeks, *Discovery of the Elements* (Weeks, 1956, p.263) as "the most distinguished German mineralogical and analytical chemist of his time". Klaproth published his numerous analytical results in various journals but these are found conveniently collected in his *Beiträge zur chemischen Kenntnis der Mineralkörpers*, 6 volumes, 1795-1815, of which the first two volumes in the English edition are utilized here (Klaproth, 1801). Thus, on corundum, or "oriental sapphire", Klaproth disputes Bergman's analysis, in which the latter includes 35% silica, and after a lengthy description of his analytical procedure, arrives at his own analysis, essentially all alumina and only a little iron oxide and calcium oxide, which is nearly identical to currently accepted analyses for corundum. From this and other comparisons with the analyses of gemstone provided earlier by Bergman it becomes clear why even consultation with this contemporary of Thunberg did not always result in accurate identifications of the gemstones that Thunberg brought back from Ceylon. Before advanced methods of chemical breakdown became available there was little that mineralogists could do to identify many species which nether reacted before the blowpipe flame nor allowed attack by then available acids and reagents.

In his further discussion of Ceylon gemstones, Thunberg has little difficulty identifying amethyst in which the crystals are characteristically terminated, "some have six sides, and one hexagonal point" (p.222). However, the "robal", said to be dark-red, darker than ruby, is not further described and its identity must remain speculative. Thunberg's "hyacinths" that occur in "small yellowish-brown or reddish prisms" appear to be zircons, and the added remarks on "red tourmalin" that speak of crystals that "seem to have four similar sides on their oblong column, and a quadrangular pyramid", again apply best to zircon. Speaking of this species, it was Klaproth (p.175 ff.) who "discovered zirconia in 1789 while analyzing a zircon from Ceylon" (Weeks, p.543), further noting colours, crystal forms, and specific gravities, but giving credit to

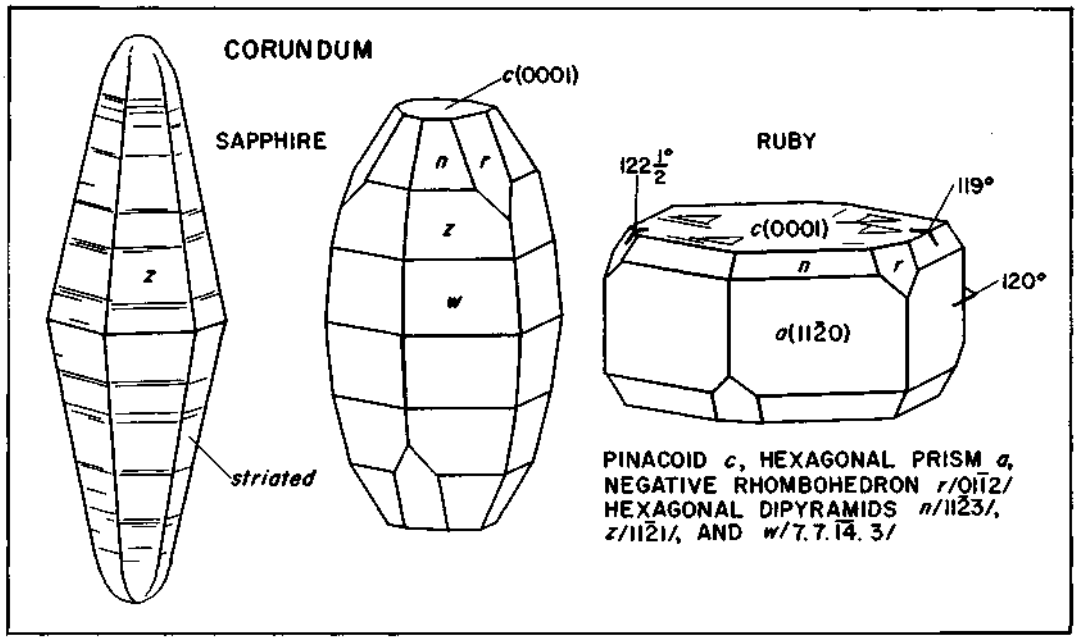


Fig. 2. Sapphire and ruby crystals, the sapphire at extreme left being particularly typical of those found in the gem grvels of Sri Lanka. From a drawing by John Sinkankas in his *Mineralogy*.

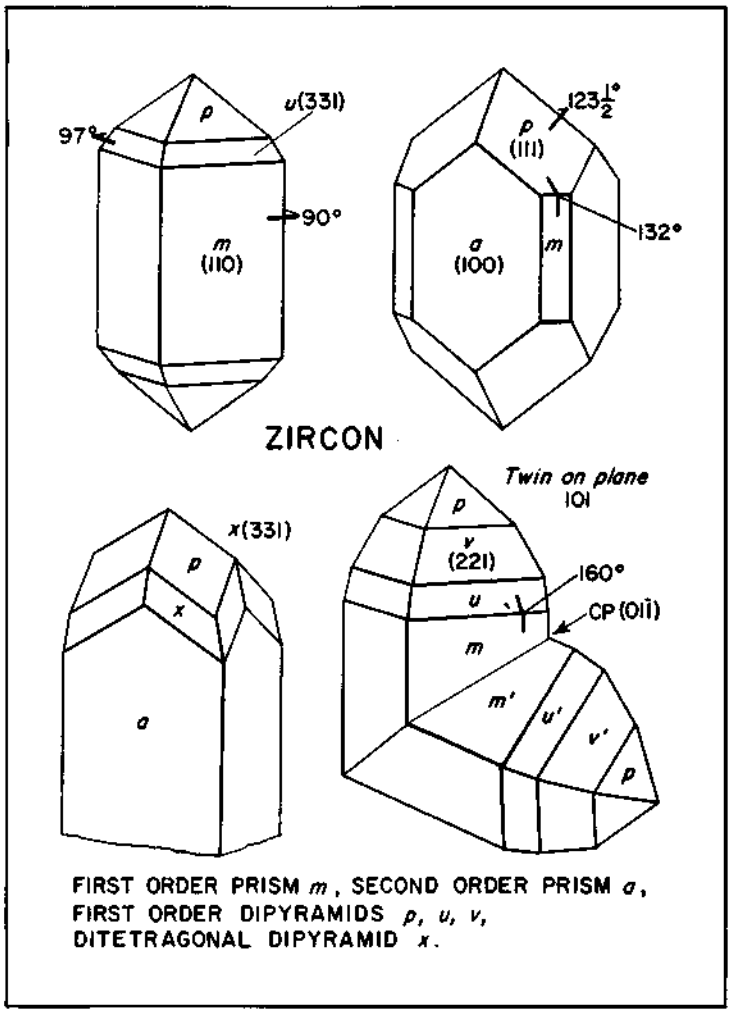


Fig. 3. Zircon crystals showing common forms, the upper two examples being noted very frequently among the crystals found in the gem gravels of Sri Lanka. From a drawing by John Sinkankas in his *Mineralogy*.

J.B.L. Romé Delisle (1736-1790) for being the first mineralogist to suggest that zircon was a distinct species. Klaproth also analyzed hyacinth from Ceylon (p. 195), noting again that erroneous analysis by Bergman (who failed to recognize the presence of zirconia) and determining that chemically it was the same as zircon.

Thunberg's "blue saphire" may also be misidentified because all specimens that he saw are claimed to be more uniformly coloured than amethysts, "all those which I saw had been worn smooth by their agitation in the water", and "all made use of, when cut, for buttons and rings". This description seems unlikely for true sapphire but could be applicable to iolite, aquamarine, or topaz. He repeats his previous statement that "blue tourmalin" is nothing but quartz with a tinge of blue. On the other hand, a green sapphire is reaffirmed as "geniune", while the "green tourmalin", again from his description of its crystals, is most likely to be zircon. Topaz is reaffirmed as genuine, and is said to occur "mostly in yellowish splinters", while the "cinnamon-stone", a term long applied to grossular from Ceylon "derives its name from its colour, which in some measure resembles the oil drawn from the best and finest cinnamon" (p.225).

The "yellow tourmalin" was never seen in crystals by Thunberg but only in alluvial stones "always worn smooth... from the size of a grain of rice to that of a pea". Nothing further is given as an aid to the identification of this gemstone. The so-called "white tourmalin", also called "Maturese diamond" from the town of Matara is certainly zircon and Thunberg provides some of our earliest knowledge of heat treatment of gemstones to improve their colour when he stated that this stone is "almost always the colour of milk, so that its transparency is not perfectly clear. For this reason it is frequently

calcined in the fire, in consequence of which the colour vanishes, and the stone becomes much clearer, although not perfectly white. It is then enveloped in fine lime, and burned with rice-chaff (oryza)." This is "Matara diamond" or colourless zircon known for hundreds of years by that name in the gem trade.

As to other stones in Thunberg's list, the "white crystal", is ordinary rock crystal, but "water-saphire" is certainly neither corundum nor iolite; under the above misnomer it has for many years masqueraded as corundum but here appears to be nothing more than a colourless zircon. Thunberg says it very much resembles the white crystal but is clearer and "is especially distinguishable by its hardness, in which it surpasses the Crystals." While this suggests corundum, Thunberg admits that he never could obtain any of these stones as crystals but only as "shapeless pieces, or else flat and rounded off, with rugged surface, full of small impressions like dots." Passing on to other "crystals" the kind called "taripo" is defined as milky quartz, while the yellow and brown crystals correspond to our citrine and smoky quartzes. But in the same breath Thunberg mentions "black crystal" which now appears to be schorl because he notes that some crystals display "six dissimilar sides and an obtuse triangular point," a fair description for many of the black to brown or reddish-brown strongly dichroic tourmaline crystals commonly found in Sri Lankan gem gravels, and in shape ranging from smooth ovate pebbles to some which are stubby prisms, doubly-terminated, to some which are practically compressed to wafer-like shapes with scarcely more than traces of prism faces. Thunberg notes that he "could not observe, that the Indians were acquainted with its electrical properties, which they never denote by the name of Tourmalin, but bestow that denomination upon several other species".

One of the stones on the list is the cat's-eye called a "pseudo-opal", which is neither chrysoberyl nor opal, but chatoyant quartz. He describes the stone as "a very hard stone, which approaches more or less white or green, and is semi-diaphanous, with a streak the breadth of a line in the middle, which streak is much whiter than the stone itself, and throws its light to whatsoever side this is turned. In this respect therefore it resembles a cat's-eye, whence it derives its name". The largest piece he saw was the size of a hazel nut. From further remarks it is plain that it is not chrysoberyl, the term "pseudo-opal", apparently being used in his time to describe certain varieties of quartz which bore some fancied resemblance to opal. In fact, Klaproth, who analyzed a specimen from "the coasts of Malabar", noted that its specific gravity was 2.625 as compared to 2.660 for a cut cat's-eye from Ceylon, and from the analyses established the material as almost pure silica (Klaproth, p.78 ff). Despite the evidence of hardness and irregular, splintery fracture, Klaproth suggested that "it would be more proper, in my opinion, to class it with the opals; among which also it was formerly reckoned under the names of Pseudopal, Cat's-eye-opal" (p.84).

Thunberg ends his amplifying remarks by noting that "the stone known in Europe under the name of Tourmalin, and celebrated for its electrical virtues, is not known by the same name by the Indians; but that they denote by the word Tourmalin, several stones, which possess not electrical properties, and which are even of different species, of different colours, and of different degrees of transparency". Regarding the genuine tourmaline of Ceylon, its pyroelectrical properties had been known long before Thunberg's collection of same as pointed out by R.W. Home (Aepinus, 1979) who notes that "samples of this stone had begun to be imported into Europe from Ceylon in the early years of the eighteenth century for use in jewelry. The Dutch and German jewelers who for many years enjoyed a virtual monopoly over the tourmaline trade soon discovered in working them that their stones possessed the remarkable property of attracting a coating of ash to themselves as they were heated in the fire". Thunberg's tourmaline specimens, in part, were turned over to his celebrated compatriot, Torbern Olof Bergman (1735-1784), chemist, mineralogist, pharmacist and professor in the university at Uppsala, who investigated them to the best of his ability and resources and then published the first adequate analysis of same and at the same time remarking on the strong dichroism, variations in properties, and crystal habits (Bergman, 1784). It was to Bergman that Thunberg turned for aid in identifying his Ceylon treasures, acknowledging that he "very kindly furnished me with their mineralogical names" (Thunberg, 1795, p.229).

In conclusion it is noted that another early report on Ceylon's minerals appeared in an article by John W. Webster who summarized a report by Dr John Davy, of England, that originally appeared in the fifth volume of the *Transactions of the Geological Society of London* (Webster, 1824). Davy noted that topaz is called "white sapphire" in Ceylon, that tourmaline is rare and met with by him only in honey-yellow specimens, and that cinnamon-stone garnet, although abundant, is found only in two places, namely Cotta and Belligam. He also noted that zircons of the Matara district receive the name "Matara diamonds" for their finest varieties. Davy claimed that "the natives of Ceylon are perfectly ignorant of the true nature of zircon, and sell the

yellow varieties as topazes of a peculiar kind, the green as tourmalines, the red as rubies, and the light grey as diamonds" (Webster, 56). In 1823, J.L. Bournon (1751-1825), the French mineralogist (hence *bournonite*), examined and described spinels from Ceylon, and suggested possible origins of the alluvial gemstones of that island, basing his remarks on the reports of J.B.L.C.T. Leschenault De Latour (1773-1820) who visited the island and the coast of Coromandel (Bournon, 1823).

Acknowledgement

My sincere thanks are extended to Dr Kurt Boström, of the Geological Institution of the University of Stockholm for obtaining the photographic reproduction of the portrait painting of Thunberg and for his encouragement in completing this project.

References

Aepinus, F.U.T. (Home & Connor), 1979. *Aepinus's Essay on the Theory of Electricity and Magnetism*. Introductory monograph and notes by R.W. Home; transl. by P.J. Connor. Princeton U. Press, Princeton, NJ. p.92-3 esp.

Bauer, M. (Spencer), 1904. *Precious Stones*. Transl. by L.J. Spencer. Charles Griffin, London.

Bergman, T.O. (Cullen), 1784. *Physical and Chemical Essays*. Transl. from the original Latin of Sir Torbern Bergman... by Edward Cullen. London: J. Murray. Esp. Dissertation XVI, on Ceylon tourmaline, p.120-33.

Bournon, J.L., 1823. *Observations sur quelques-uns des Minéraux, soit de l'Ile de Ceylan*. Londres: Chez Dulau.

Casson, L., 1989. *The Periplus Maris Erythraei*. Text with introduction, translation, and commentary by Lionel Casson. Princeton University Press, Princeton, NJ.

Gübelin, E., 1968. *Der Edelsteine der Insel Ceylon*. Gübelin: Lucerne.

Klaproth, M.H., 1801. *Analytical Essays towards Promoting the Chemical Knowledge of Mineral Substances*. T. Cadell, London.

Tavernier, J.B., 1676. *Les six voyages*... Gervais Clouzier, Paris, 3 vol.

Tavernier, J.B. (V. Ball), 1889. *Travels in India by Jean Baptiste Tavernier*... translated from the original French edition of 1676... 2 vol. MacMillan, London. A second edition, edited by W. Crooke, appeared in 2 vol. in 1925.

Thunberg, C.P., 1795-6. *Travels in Europe, Africa, and Asia*, made between the years 1770 and 1779... By Charles Peter Thunberg. 4 vols. C. Rivington, London. First edit. Upsala 1788-93; other edits. in French and German.

Webster, J.W., 1824. Geology and mineralogy of Ceylon. *Boston Journal of Philosophy and the Arts*, Vol. I, Boston. p.53-9.

Weeks, M.E., 1956. *Discovery of the Elements*. 6th ed. edit, by H.M. Leicester. Journal of Chemical Education, Easton. pp.263, 543.

Yule, H., 1871. *The Book of Ser Marco Polo, the Venetian*. Newly translated and edited with notes by Colonel Henry Yule. 2 vols. John Murray, London. II, p.254-6.

[*Manuscript received 14 March 1991.*]

The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones

Part 3: Examples for the applicability of structural features for the distinction of natural and synthetic sapphire, ruby, amethyst and citrine

Dipl.-Min Lore Kiefert [1] *and Dr Karl Schmetzer* [2]

[1] *Griffith University, Queensland, Australia*
[2] *Marbacher Str. 22b, D-8067 Petershausen, Germany*

Abstract

The application of diagnostic growth structures for the distinction of natural and synthetic optically uniaxial gem minerals such as corundum and quartz is discussed. Typical examples for the characterization of natural gem varieties of corundum and quartz are quoted, e.g. sapphires and rubies, amethysts and citrines from distinct sources are described by means of growth structures. In addition, their synthetic counterparts of some producers are compared using structural features of diagnostic value. Criteria, which are useful for the recognition of faceted gemstones as natural or synthetic are underlined. Gem materials described in detail are natural sapphires from alkaline host rocks (Australian, Nigerian, Cambodian and Thai sapphires), Chatham synthetic sapphires, natural rubies from Malawi, Knischka synthetic rubies, natural amethysts and citrines from different sources as well as synthetic amethysts and citrines from different producers.

Zusammenfassung

Die Anwendung von Wachstumsstrukturen zur Unterscheidung natürlicher und synthetischer Edelsteinminerale mit einer optischen Achse, wie Korund und Quarz wird beschrieben.

Typische Beispiele zur Charakterisierung natürlicher Edelsteinarten von Korund und Quarz werden erwäht, u.a. Sapphire und Rubine, Amethyste und Citrine verschiedener Herkunft werden beschrieben an Hand der Wachstumsstrukturen.

AuBerdem werden die synthetische Gegenstücke einiger Hersteller mit einander verglichen mittels struktureller Merkmale diagnostischer Art.

Nützliche Kriterien zur Erkennung geschliffener Edelsteine als natürlich oder synthetisch werden betont.

Ausführlichst beschriebene Edelsteine sind natürliche Sapphire ads alkalinen Muttergesteinen (australische, nigerianische, kamobschanische und thailändische Sapphire), Chatham synthetische Sapphire, natürliche Rubine aus Malawi, Knischka synthetische Rubine, sowohl natürliche Amethyste und Citrine verschiedener Herkunft, wie auch von verschiedenen Herstellern gezüchtete Amethyste und Citrine.

Resumen

Se discute la aplicación de marcas de crecimiento diagnosticas para la distinción entre minerales de calidad gema naturales o sintéticos que son opticamente uniaxicos, tales como el corindón y el cuarzo. Se facilitan ejemplos típicos para la caracterización de variedades naturales de calidad gema de corindón y cuarzo; por ejemplo, se describen mediante el uso de marcas de crecimiento zafiros y rubíes, amatistas y cuarzos citrinos de determinados yacimientos. Ademas, se comparan entre si muestras sintéticas de algunos fabricantes de estas gemas haciendo uso de caracteristicas estructurales de valor diagnóstico. Se subrayan criterios, que son útiles para distinguir entre gemas talladas naturales o sintéticas. Se describe con detalle los siguientes materiales de calidad gema; los zafiros naturales con origen en rocas alcalinas (Australia, Nigeria, Cambodia y Thailandia), zafiros sintéticos de Chatham, rubies naturales de Malawi, rubies sintéticos de Knischka, amatistas y cuarzos citrinos naturales de distintos yacimientos al igual que amatistas y cuarzos citrinos sintéticos de distintos fabricantes.

I. Introduction

In the first part of this publication (Kiefert & Schmetzer, 1991a) a detailed description of methods for the determination of characteristic crystal faces and growth structures in faceted

optical uniaxial gemstones by use of two simple auxiliary means is given. In the second part of this paper (Kiefert & Schmetzer, 1991b), the characterization of natural and synthetic emeralds by the use of growth structures and their application to practical problems of determinative gemmology is discussed in detail.

This third part of the publication will reveal some new examples for the application of the methods described in the first part, e.g. for the characterization of natural sapphires originating from alkali basalts or for the characterization of the most recent type of Knischka synthetic rubies. Additionally, a summary of results obtained by these methods, part of them already published in earlier issues of this journal, is presented, e.g. the recognition of Chatham synthetic sapphires or the distinction of natural and synthetic amethysts and citrines.

Figures 1-15 as well as Tables 1-3, which are occasionally referred to in this third part of the publication, are presented in the first part (Kiefert & Schmetzer, 1991a).

II. Natural sapphires from alkaline rocks

In connection with systematic investigations of sapphires from different localities, a great number of faceted sapphires and rough crystals from alkaline rocks as sources have been at the authors' disposal. The sapphires originating from alkaline source rocks were of Australian, Nigerian, Cambodian and Thai origin (cf. Vichit *et al.*, 1978; Jobbins & Berrangé, 1981; Keller, 1982; Coldham, 1985; Kiefert & Schmetzer, 1987). During these investigations the authors discovered a significant similarity in structural properties of sapphires originating from alkaline rocks, i.e. in most cases from alkali basalts. By measuring the crystal faces of the rough samples and comparing these common morphological properties with internal growth structures determined by the methods described, a correspondence between the external crystal faces and the internal growth structures was proven for all sources. Another common feature of all sapphires originating from alkaline rocks are their spectroscopic properties, which were found to be similar or almost identical for all samples from different localities examined (cf. Kiefert & Schmetzer, 1987; Schmetzer, 1987a).

All rough crystals from alkaline rocks reveal the basal pinacoid c {0001} and the hexagonal dipyramid z {$22\bar{4}1$} as dominant forms, and the positive rhombohedron r {$10\bar{1}1$} appears frequently. Subordinate forms, e.g. some other pyramidal faces or the hexagonal prism, differ only slightly from locality to locality [cf. Figures 3a, d]. The above mentioned three crystal faces dominate in cut samples as growth planes. In connection with growth planes of sapphires from alkaline rocks there is nearly always a strong blue, greenish-blue, bluish-green or yellowish-green colour zoning observable. However, the crystal faces, especially those of the dominant forms mentioned above, vary markedly according to their sizes for samples of different occurrences. Compared with sapphires from other types of host rocks, e.g. sapphires from Sri Lanka, the appearance of the hexagonal dipyramid z {$22\bar{4}1$} is only observable in sapphires from alkaline rocks in this significance [Figures 46-57].

Australian rough crystals, for example, show pyramidal habit with the hexagonal dipyramid z {$22\bar{4}1$} as dominant form. The basal pinacoid c {0001} is very small in these samples. The positive rhombohedron r {$10\bar{1}1$} as well as the hexagonal dipyramid n {$22\bar{4}3$} appear less frequently. Corresponding to this morphology, the dominant growth planes determined in the microscope with the above mentioned methods occur parallel to z ($22\bar{4}1$). In addition, growth planes parallel to the positive rhombohedron r ($10\bar{1}1$) as well as parallel to the basal pinacoid c (0001) are observed. Other growth planes such as faces parallel to the hexagonal dipyramids w ($11\bar{2}1$) and n ($22\bar{4}3$) appear occasionally, faces parallel to the second-order hexagonal prism a ($11\bar{2}0$) as well as parallel to the hexagonal dipyramids v ($44\bar{8}1$) and v ($44\bar{8}3$) are extremely rare [Figures 46-49, 51, 53, 55, 57].

For rough crystals of Nigerian sapphires, which showed well developed crystal faces, a typical morphology was determined as follows: the majority of the crystals reveal tabular habit with the basal pinacoid c {0001} and the hexagonal dipyramid z {$22\bar{4}1$} or with the crystal faces c, z and the positive rhombohredon r {$10\bar{1}1$}. In addition to the crystal faces mentioned above, sapphires with barrel-shaped habit reveal the hexagonal dipyramid n

Fig. 46. Growth structures in natural sapphire from Australia; planes parallel to c (0001) and r ($10\bar{1}1$). View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 16x.

Fig. 47. Growth structures in natural sapphire from Australia; planes parallel to c (0001), n ($22\bar{4}3$) and z ($22\bar{4}1$). View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 16x.

Fig. 48. Growth structures in natural sapphire from Australia; planes parallel to c (0001) and r ($10\bar{1}1$). View perpendicular to the c-axis, the c-axis runs almost vertically. Crossed polarizers. 16x. Figs. 46 and 47 as well as Figs. 47 and 48 are related by a rotation of 30° about the c-axis, Figs. 46 and 48 are related by a rotation of 60° about the c-axis.

Fig. 49. Growth structures in natural sapphire from Australia; planes parallel to c (0001), n ($22\bar{4}3$) and z ($22\bar{4}1$). View perpendicular to the c-axis, the c-axis runs diagonally from lower left to upper right. Crossed polarizers. 20x.

Fig. 46.

Fig. 47.

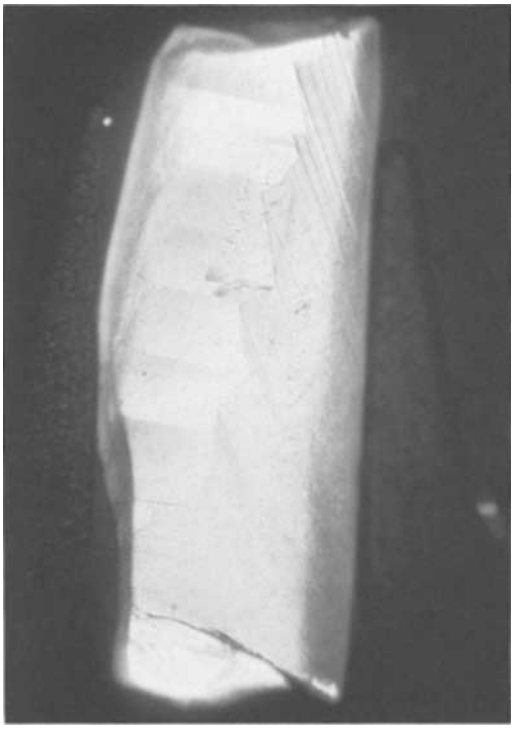


Fig. 48.

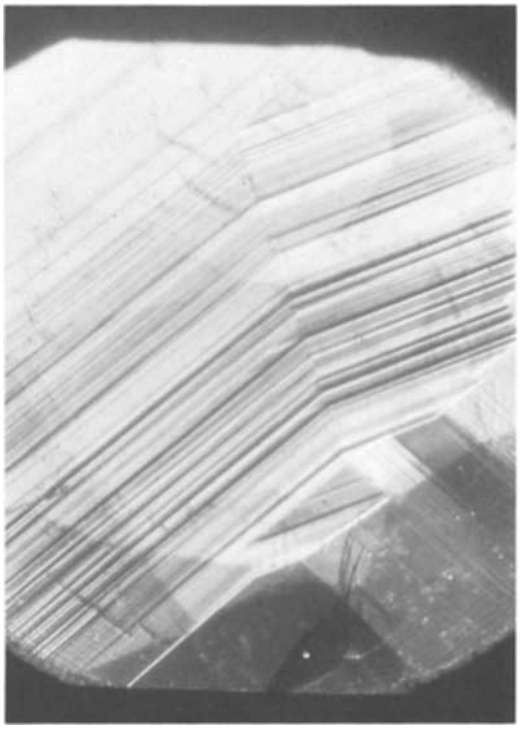


Fig. 49.

{22$\bar{4}$3} [Figure 3a]. Crystals with prismatic habit display the hexagonal prism a {11$\bar{2}$0} in addition to the forms mentioned above [Figure 3d]. The determination of growth structures in the microscope by use of the methods described, reveals that the growth planes are, according to the morphology of the rough crystals, mainly parallel to dominant crystal faces like the hexagonal dipyramid z (22$\bar{4}$1), parallel to the positive rhombohedron r (10$\bar{1}$1) and parallel to the hexagonal dipyramid n (22$\bar{4}$3) and parallel to the hexagonal prism a (11$\bar{2}$0) may occur [Figure 54, see also Kiefert & Schmetzer, 1987].

Cambodian sapphires available to the authors disclosed very rarely well developed crystal faces. The few crystals with preserved external morphology are described as follows: the majority of these samples reveal tabular habit with the basal pinacoid c {0001} and the hexagonal dipyramid z {22$\bar{4}$1}, occasionally the positive rhombohedron r {10$\bar{1}$1} is observed. This morphology corresponds to the morphology of part of the Nigerian sapphires [cf. Figures 3a, d]. Besides these forms part of the Cambodian sapphires reveal pyramidal habit with only the hexagonal dipyramid z {22$\bar{4}$1} as the crystal form. Occasionally tabular crystals with the second-order hexagonal prism a {11$\bar{2}$0} and the basal pinacoid c {0001} appear. In accordance with the examination of sapphires from Australia and Nigeria, the determination of internal growth structures of Cambodian sapphires in the microscope reveals that the most frequently appearing growth planes correspond to the external morphology of the crystals. These are the hexagonal dipyramid z (22$\bar{4}$1) as well as the basal pinacoid c (0001). As subordinate growth planes the positive rhombohedron r (10$\bar{1}$1), the second-order hexagonal prism a (11$\bar{2}$0) as well as the hexagonal dipyramids n (22$\bar{4}$3), w (11$\bar{2}$1), v (44$\bar{8}$3) and ν (44$\bar{8}$1) could be determined [Figure 50].

Among the investigated sapphires from Thailand, no rough crystals with well developed crystal faces were available. However, similar to the sapphires from the occurrences mentioned above, the dominant growth planes in the microscope are the hexagonal dipyramid z (22$\bar{4}$1) and the basal pinacoid c (0001). The frequency of other appearing growth planes is similar to that of Cambodian sapphires. The crystal faces observed are occasionally the positive rhombohedron r (10$\bar{1}$1) and the hexagonal dipyramid w (11$\bar{2}$1), and, less frequently, the hexagonal dipyramids n (22$\bar{4}$3) and v (44$\bar{8}$3) as well as the hexagonal prism a (11$\bar{2}$0) [Figures 52, 56].

In summary, the morphology of all natural sapphires originating from alkaline rocks is dominated by the basal pinacoid c {0001} and the hexagonal dipyramid z {22$\bar{4}$1}. In addition, the positive rhombohedron r {10$\bar{1}$1}, the second-order hexagonal prism a {11$\bar{2}$0} as well as different hexagonal dipyramids n {22$\bar{4}$3}, w {11$\bar{2}$1}, v {44$\bar{8}$3} and ν {44$\bar{8}$1} may occur as more or less subordinate forms. Sapphires from alkaline rocks often occur with a thick tabular habit, but barrel-shaped, pyramidal or prismatic crystals were also found, and sapphires with a habit intermediate between these three basal morphologies were also examined.

At present, no hexagonal dipyramids with the exception of n (22$\bar{4}$3) and no second-order hexagonal prisms a (11$\bar{2}$0) were observed as crystal faces of flux-grown synthetic sapphire (cf. section III). Thus, the presence of at least one of these growth structures indicates a sapphire of natural origin. Among several hundreds of faceted samples examined, part of them without characteristic mineral inclusions, each of those natural sapphires originating from alkaline rocks disclosed characteristic growth structures and, consequently, were determinable as natural using the above mentioned criteria.

III. Growth structures and twinning in flux-grown Chatham synthetic blue sapphires

All different syntheses of corundum produced by the flux method show a distinct, limited number of crystal faces, which are easily determinable with the methods described by the authors. Due to the composition of the flux as well as other variable growth conditions, which are applied for the production of the individual synthesis, the number of crystal faces vary for the different commercial productions of corundum. For example, the common crystal faces of Chatham synthetic rubies are c, r, d, and n [cf. Table 1]. In rubies made by Kashan c, r, and n appear as crystal faces, and Knischka synthetic rubies reveal the crystal faces c, r, d, n, and γ. The morphology of synthetic rubies produced by Ramaura consists of c, r, and d (cf. Schmetzer, 1986).

An important feature for the distinction of natural and synthetic rubies is the absence of prism and some pyramidal faces in synthetic stones, whereas the negative rhombohedra d and γ never appear in natural samples (cf. Schmetzer, 1986).

Flux-grown Chatham synthetic sapphires are described here in some detail and will be compared with natural sapphires from alkaline rocks (cf. section II). For the investigation of structural properties of Chatham synthetic blue sapphires, both rough crystals and faceted stones were available (cf. Kiefert & Schmetzer, 1988). The rough samples were found to consist of single crystals and twinned individuals. Twinning is easily recognizable due to the re-entrant angles of the samples. The crystal faces which were identified in both untwin-

Fig. 50. Growth structures in natural sapphire from Pailin, Cambodia; planes parallel to c (0001) and r ($10\bar{1}1$). View perpendicular to the c-axis, the c-axis runs vertically. 25x.

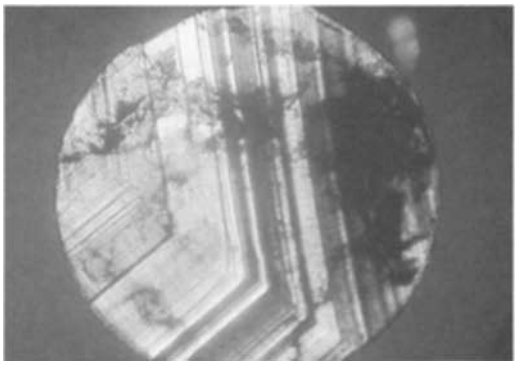


Fig. 52. Angled growth structure in natural star-sapphire from Thailand; planes parallel to the hexagonal prism faces a and a' ($11\bar{2}0$) form an angle of 120°. View parallel to the c-axis. Crossed polarizers. 26x.

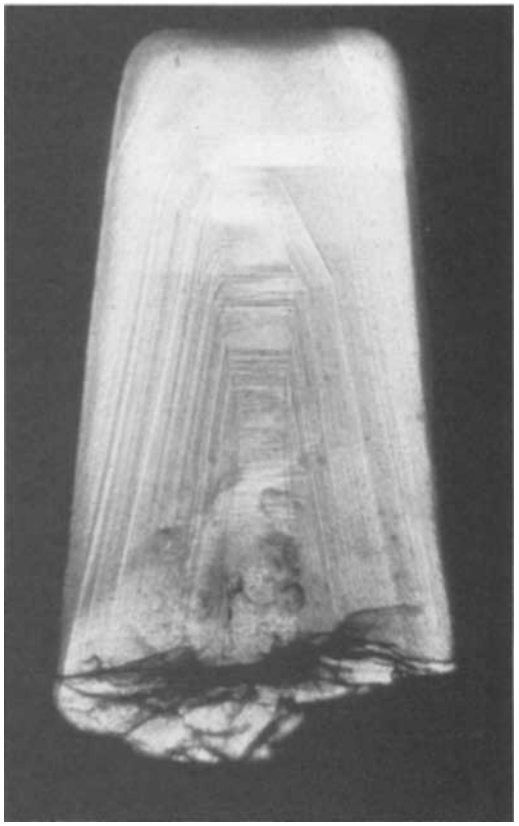


Fig. 51. Growth structures in natural sapphire from Australia; planes parallel to c (0001), n ($22\bar{4}3$) and z ($22\bar{4}1$). View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 20x.

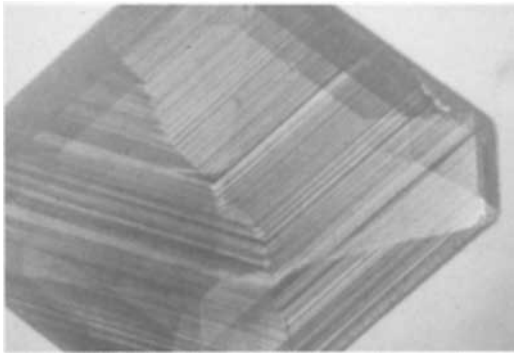


Fig. 53. Angled growth structure in natural sapphire from Australia; planes parallel to the hexagonal dipyramids z and z' ($22\bar{4}1$) form an angle of 121.1°. View 10.4° inclined to the c-axis. 20 x.

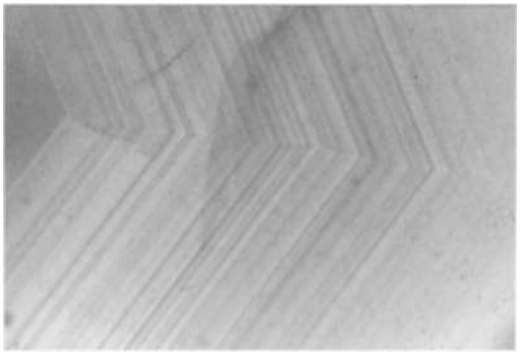


Fig. 54. Angled growth structure in natural sapphire from Nigeria; planes parallel to the hexagonal dipyramids z and z' ($22\bar{4}1$) form an angle of 121.1°. View 10.4° inclined to the c-axis. 25x.

ned and twinned crystals are identical, the samples displayed tabular to rhombohedral habit with the basal pinacoid *c* {0001}, the positive rhombohedron *r* {10$\bar{1}$1}, the negative rhombohedron *d* {01$\bar{1}$2} and the hexagonal dipyramid *n* {22$\bar{4}$3} as predominant forms, as well as the negative rhombohedron γ {0115} as subordinate form [Figures 3b, c, f]. Occasionally, an oscillatory development of both negative rhombohedra *d* and γ was observed causing parallel striations on these crystal faces. No prism faces were detected. All single and repeatedly twinned individuals (cyclic twinning) were contact twins with the second-order hexagonal prism *a* {11$\bar{2}$0} as composition plane and the first-order hexagonal prism *m* {10$\bar{1}$0} as twin plane [Figure 3c].

In the immersion microscope, families of straight parallel growth planes were determined which reflect the external morphology of the crystals. These growth faces are parallel to the predominant external forms, i.e. parallel to *c* (0001), *r* (10$\bar{1}$1), *d* (01$\bar{1}$2), and *n* (22$\bar{4}$3) [Figure 58]. The composition planes *a* {11$\bar{2}$0} of the individuals, which are related by reflection twinning on {10$\bar{1}$0} are also observable in the gem microscope without having problems [Figures 58, 59].

The most significant difference between Chatham synthetic sapphires and natural sapphires from alkaline rocks is the absence of the hexagonal dipyramids, e.g. *z* {22$\bar{4}$1}, in Chatham synthetic sapphire, which is one of the most characteristic crystal forms in natural sapphires from alkaline rocks. On the other hand, the negative rhombohedra *d* {01$\bar{1}$2} and γ {01$\bar{1}$5} of Chatham synthetic sapphires were never observed in natural sapphires.

Another important difference, which can easily be identified by the method used by the authors, is one distinct type of twinning, which is found only in flux-grown synthetic sapphires. The only kind of twinning in natural sapphires from alkaline rocks is lamellar twinning on the positive rhombohedron *r* (10$\bar{1}$1). This kind of twinning is very common in all natural sapphires, but was recently also observed in some Chatham synthetic flux-grown sapphires [Figure 60]. However, in Chatham synthetic sapphires, an additional type of twinning occurs. The twinned individuals are related by reflection twinning across (10$\bar{1}$0) with the second-order hexagonal prism *a* (11$\bar{2}$0) as composition plane. These composition planes occur as single growth lines, which are diagonally passing through the rough or faceted crystals, and consequently are determinable by the methods used by the authors without any difficulties [Figures 58, 59; see also Kiefert & Schmetzer, 1988].

The production of Chatham synthetic sapphire is supposed to be similar to the production of flux-grown Chatham synthetic rubies. According to their morphology, both syntheses are most probably produced by using the same or almost identical compositions of fluxes, which was confirmed by chemical investigations of residual flux material in rough and faceted samples. Both syntheses, ruby and sapphire, reveal twinning across (10$\bar{1}$0), which is not known for natural corundum. The only difference between Chatham synthetic ruby and Chatham synthetic sapphire is the occurrence of small faces of the negative rhombohedron γ (01$\bar{1}$5) in synthetic sapphire, which so far was not found in synthetic ruby.

IV. Natural ruby from Malawi

Corundum from Malawi was already mentioned in earlier publications (Rutland, 1969; Grubessi & Marcon, 1986), but in recent months larger quantities of high quality rubies from this source have been found on the market. Rough crystals show tabular habit, the basal pinacoid *c* {0001} is observable on both sides of the crystals. There were, however, no pyramidal, rhombohedral or prismatic faces exposed because all rough crystals were irregularly broken on all sides perpendicular to the basal pinacoid. According to the most recent microscopic investigations of the present authors, several types of this kind of ruby exist. Part of these rubies frequently reveal no characteristic mineral inclusions, but have definite diagnostic growth structures.

An example, which was investigated by the authors using the methods described in part 1 of this paper, was a cut ruby from Malawi of excellent quality weighing 2.60 ct. This particular stone was free of any characteristic mineral inclusions. The determined growth structures were the basal pinacoid *c* (0001), the hexagonal prism *a* (11$\bar{2}$0), the hexagonal dipyramid *n* (22$\bar{4}$3) as well as the positive rhombohedron *r* (10$\bar{1}$1) [Figures 61-63]. In other words: the determination of internal growth structures revealed an external morphology similar to the crystal drawn in Figure 3e. According to the complete determination of all growth structures with the methods introduced here, this stone can definitely be classified as natural ruby because of the absence of growth structures parallel to *a* (11$\bar{2}$0) in all types of commercially available synthetic rubies.

V. Most recent commercial production of Knischka synthetic rubies

Several generations of synthetic rubies with different habits were produced by Prof. P.O. Knischka of Steyr, Austria. For example, Knischka synthetic rubies of the last experimental generation

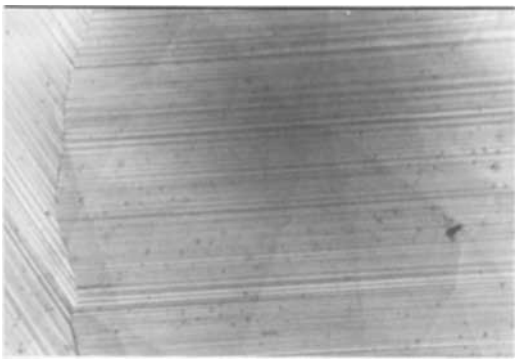


Fig. 55. Angled growth structure in natural sapphire from Australia; planes parallel to the hexagonal dipyramids w and w' $\{11\bar{2}1\}$ form an angle of 124.0°. View 20.1° inclined to the c-axis.

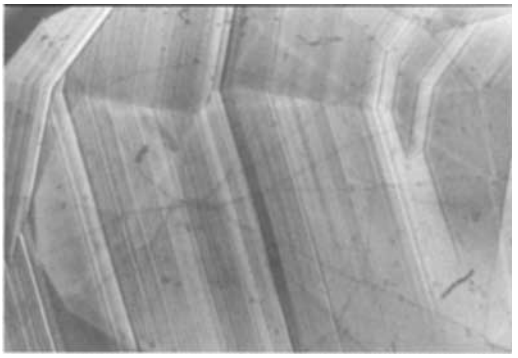


Fig. 56. Angled growth structure in natural sapphire from Thailand; planes parallel to r $(10\bar{1}1)$, n and n' $\{22\bar{4}3\}$ form angles of 154.0°. View about 30° inclined to the c-axis. 30x.

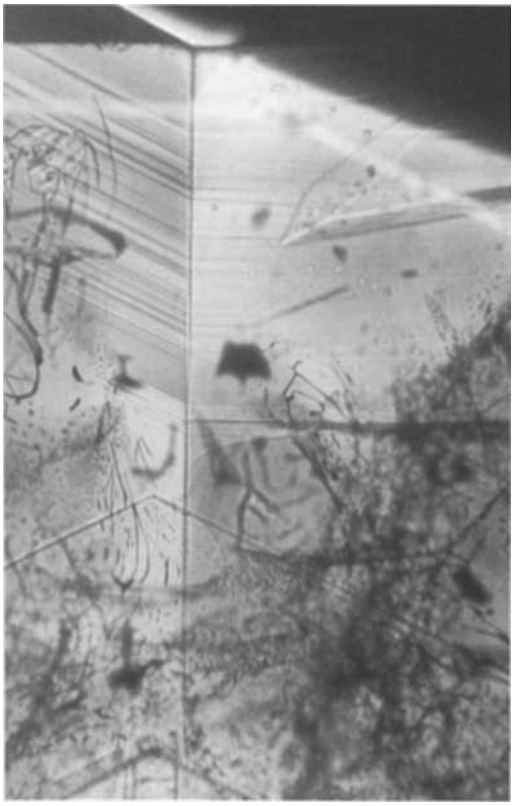


Fig. 58. Growth structures and twinning in flux-grown Chatham synthetic sapphire; growth sectors confined to the rhombohedron r $(10\bar{1}1)$ [right part] and the hexagonal dipyramid n $(22\bar{4}3)$ [left part] are divided by a twin boundary parallel to a $(11\bar{2}0)$. View about 30° inclined to the c-axis. 40x.

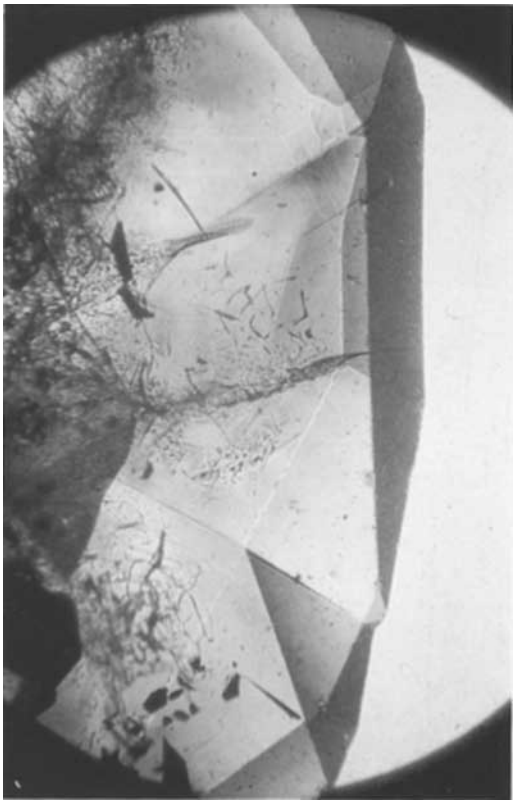


Fig. 59. Growth structures and twinning in flux-grown Chatham synthetic sapphire; repeated twinning across $\{10\bar{1}0\}$ with two composition planes a and a' $\{11\bar{2}0\}$ observable. View parallel to the c-axis. 24x.

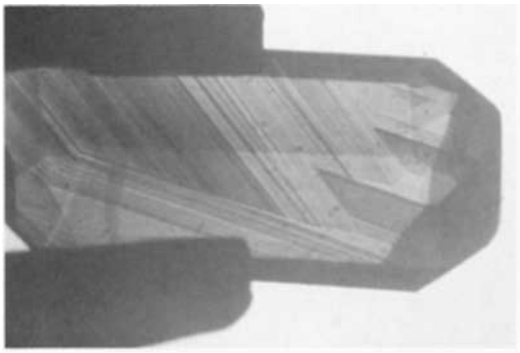


Fig. 57. Angled growth structure in natural sapphire from Australia; planes parallel to $r(10\bar{1}1)$ and $n(22\bar{4}3)$ form an angle of 154.0°. View about 30° inclined to the c-axis. 30x.

Fig. 60. Twinning in flux-grown Chatham synthetic sapphire; intercalated lamellae of corundum in twin position on r $(10\bar{1}1)$. View 32.4° inclined to the c-axis. 40x.

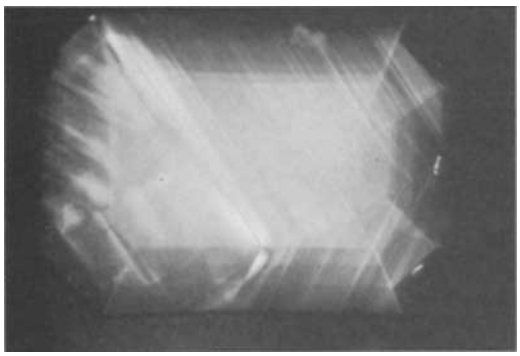


Fig. 61. Angled growth structure in natural ruby from Malawi; planes parallel to the hexagonal prism faces a and a' $\{11\bar{2}0\}$ form an angle of 120°. View parallel to the c-axis. Crossed polarizers. 16x.

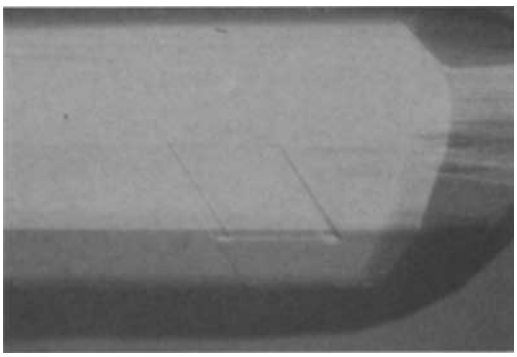


Fig. 62. Growth structure in natural ruby from Malawi; planes parallel to c (0001) and $r(10\bar{1}1)$. View perpendicular to the c-axis, the c-axis runs vertically. 20x.

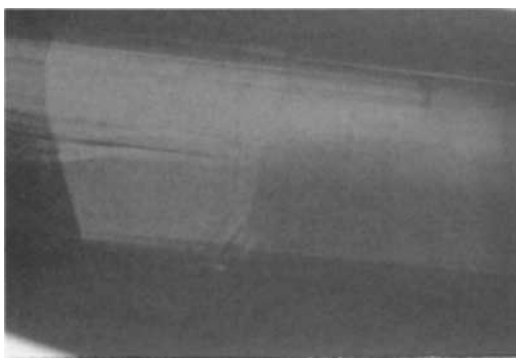


Fig. 63. Growth structure in natural ruby from Malawi; planes parallel to c (0001), n $(22\bar{4}3)$ and a $(11\bar{2}0)$. View perpendicular to the c-axis, the c-axis runs almost vertically. 26x. Figs. 62 and 63 are related by a rotation of 30° about the c-axis.

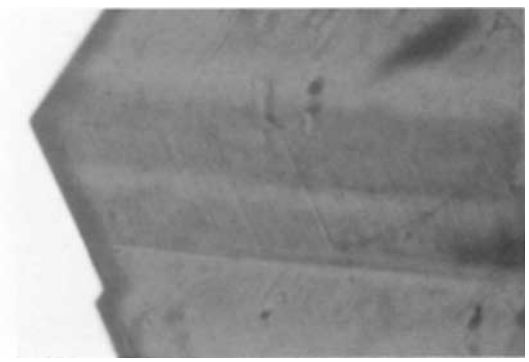


Fig. 65. Growth structures in Knischka synthetic ruby; oscillating planes parallel to n $(22\bar{4}3)$ and $\bar{n}$ $(2\bar{2}43)$ form angles of 122.4°. View perpendicular to the c-axis, the c-axis runs vertically. 35x.

reveal the crystal faces c {0001}, r {10$\bar{1}$1}, d {01$\bar{1}$2}, n {22$\bar{4}$3} and γ {01$\bar{1}$5} and, consequently, show a certain similarity to Chatham synthetic sapphires and rubies [cf. Figures 3b, f; see also Galia, 1987]. There is, however, a diagnostic feature commonly observed in all generations of Knischka synthetic rubies, which is due to the composition of the flux, part of which always contains a certain percentage of a tungsten-bearing compound (cf. Schmetzer, 1987b). This diagnostic feature of the synthetic rubies made by Knischka is the oscillatory growth of the second-order hexagonal dipyramids n {22$\bar{4}$3} and $\bar{n}$ {2$\bar{2}$43}, causing parallel striations on the external crystal faces (cf. Knischka & Zirkl, 1986). If these oscillatory striations of n and $\bar{n}$ become very dense, the external habit of the crystals is similar to prismatic, i.e. a dense repitition of n and $\bar{n}$ can simulate the presence of the second-order hexagonal prism a (11$\bar{2}$0).

A new type of commercial production of Knischka synthetic rubies has been grown since autumn 1986 and marketed since about 1987 (Knischka, 1989). An important component of the flux in this production is still a tungsten-bearing compound. In this new generation of Knischka synthetic rubies, crystals with columnar habit and a length of up to 6 cm are grown [Figure 64]. These crystals reach a weight above 100 ct. The surface of these columnar appearing crystals is formed by the oscillatory grown faces n (22$\bar{4}$3) and $\bar{n}$ (2$\bar{2}$43). In faceted samples, besides feathers of residual flux material, the oscillatory occurrence of n (22$\bar{4}$3) and $\bar{n}$ (2$\bar{2}$43) is distinctly recognizable in the immersion microscope [Figures 65-67]. This oscillation of the two pyramidal faces n and $\bar{n}$, forming angles of 122.4°, is easily observable in the view perpendicular to the optic axis, with a rotation of the crystal about the 360° vertical axis of the sample holder as described in the first part of this publication. Consequently, a significant and diagnostic feature is now available for synthetic rubies of that particular generation of Knischka synthetic rubies. Similar or identical growth structures were never observed in natural stones up to now.

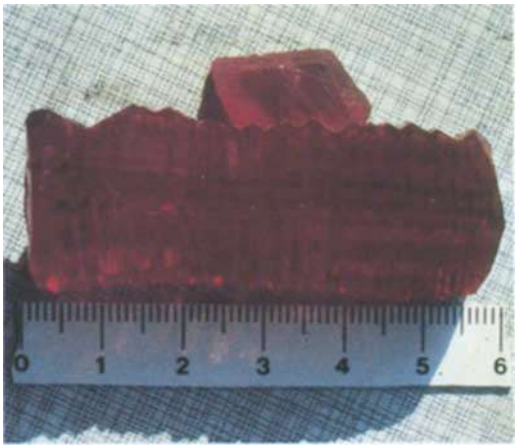


Fig. 64. Rough crystal of Knischka synthetic ruby of the most recent commercial production revealing columnar habit. Photo by courtesy of the producer.

VI. Natural amethyst and citrine

Structural properties like growth planes and twinning of both natural as well as synthetic amethyst and citrine have already been discussed in detail in earlier issues of this journal (Schmetzer, 1986, 1989; Lind & Schmetzer, 1987). In these earlier articles, however, only part of the now available methods used for these investigations were applied. Therefore, a summary of the most significant results, obtained by the methods discussed in the first part of this paper, is presented.

In all rough samples of natural amethyst and heat-treated natural amethyst (citrine) examined, only the positive rhombohedron r (10$\bar{1}$1) or the major rhombohedron r (10$\bar{1}$1) in combination with the minor rhombohedron z (01$\bar{1}$1) were observed [Figure 5]. The first-order hexagonal prism m (10$\bar{1}$0) is subordinate if present at all, and of small size only.

Natural amethysts as well as heat-treated amethysts frequently disclose growth planes in the form of sharp lamellar structures, often connected with a distinct colour zoning. The colour zoning parallel to the positive and negative rhombohedra r and z is violet in natural amethyst and yellowish-brown in heat-treated natural amethyst (citrine). Growth planes, which are commonly parallel to the rhombohedral faces, form three characteristic angles of diagnostic value. Structures parallel to two positive rhombohedral faces r and r' {10$\bar{1}$1} form an angle of 94.2° [Figure 68], growth planes parallel to the positive rhombohedron r (10$\bar{1}$1) and the negative rhombohedron z (01$\bar{1}$1) form an angle of 133.7° if both faces are adjacent [Figures 69,70], and an angle of 76.4° if they are opposite to each other [Figure 71].

Besides lamellar colour zoning parallel to the rhombohedral growth planes, natural amethyst and heat-treated natural amethyst (citrine) often reveal another kind of colour zoning in the areas confined to the positive and negative rhombohedra. The areas confined to the positive rhombohedron r {10$\bar{1}$1} in natural amethyst have a dark violet colour, i heat-treated natural amethyst (citrine) they show an intense yellow to brownish colour, whereas in the areas confined to the negative rhombohedron z {01$\bar{1}$1} the colour is a lighter violet or a lighter yellowish-brown, respectively [cf. Figure 69].

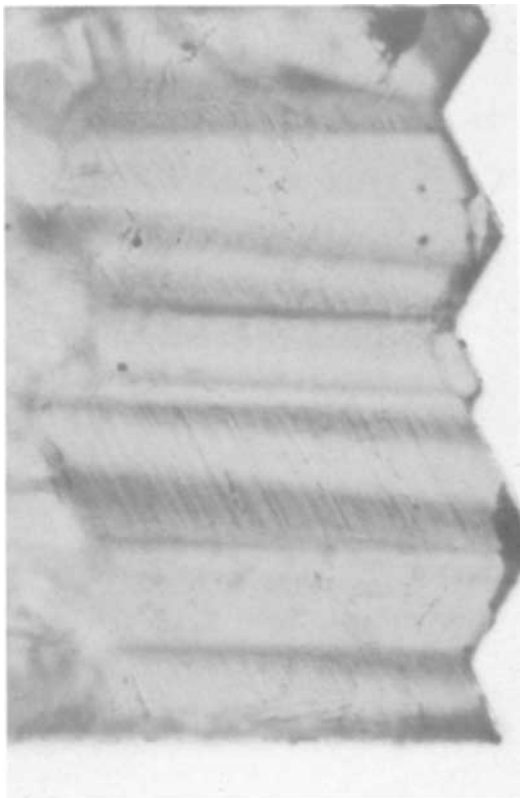


Fig. 66. Growth structures in Knischka synthetic ruby; oscillating planes parallel to n $(22\bar{4}3)$ and $\bar{n}$ $(2\bar{2}43)$ form angles of 122.4°. View perpendicular to the c-axis, the c-axis runs vertically. 25x.

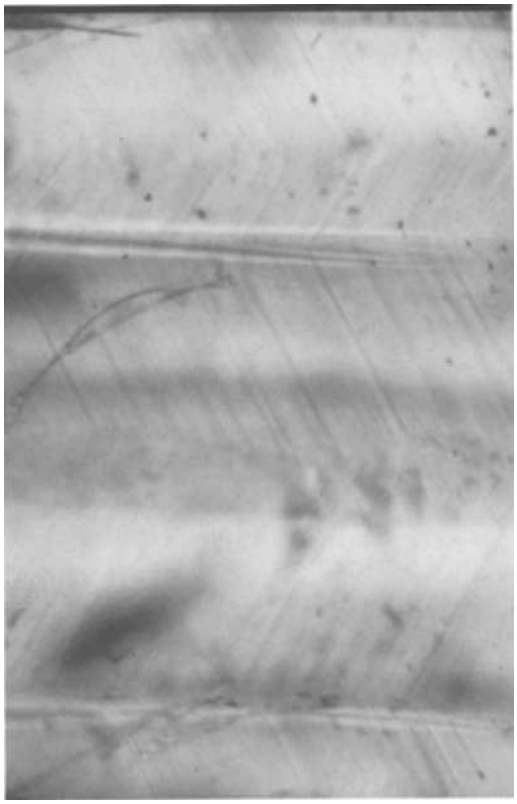


Fig. 67. Growth structures in Knischka synthetic ruby; oscillating planes parallel to n $(22\bar{4}3)$ and $\bar{n}$ $(2\bar{2}43)$ form angles of 122.4°. View perpendicular to the c-axis, the c-axis runs vertically. 40x.

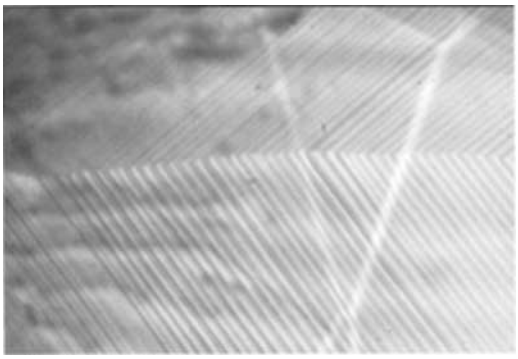


Fig. 68. Angled growth structure in natural amethyst from Brazil; planes parallel to the positive rhombohedra r and r' $\{10\bar{1}1\}$ form an angle of 94.2°. View 38.2° inclined to the c-axis. 60x.

Fig. 69. Angled growth structure in natural amethyst from Uruguay; adjacent planes parallel to the positive rhombohedron r $(10\bar{1}1)$ and parallel to the negative rhombohedron z $(01\bar{1}1)$ form an angle of 133.7°; growth sectors confined to the positive rhombohedron r [below] are dark violet, growth sectors confined to the negative rhombohedron z [above] are light violet in colour. View 38.2° inclined to the c-axis. 35x.

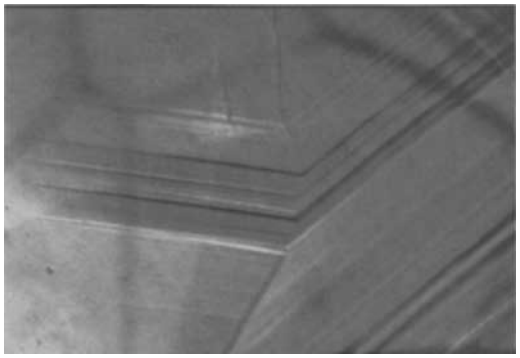


Fig. 70. Angled growth structure in natural citrine (heat-treated amethyst) from Brazil; adjacent planes parallel to the positive rhombohedron r $(10\bar{1}1)$ and parallel to the negative rhombohedron z $(01\bar{1}1)$ form an angle of 133.7°. View 38.2° inclined to the c-axis. 40x.

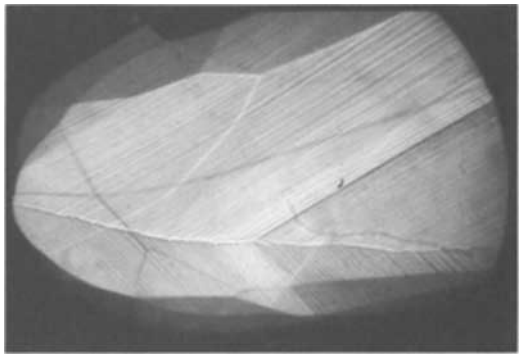


Fig. 71. Angled growth structure in natural citrine (heat-treated amethyst) from Brazil; opposite planes parallel to the positive rhombohedron r $(10\bar{1}1)$ and parallel to the negative rhombohedron z' $(01\bar{1}1)$ form an angle of 76.4°. View perpendicular to the c-axis, the c-axis runs horizontally. Crossed polarizers. 26x.

Polysynthetic twinning of the Brazil law, which is also a characteristic feature of natural amethyst and heat-treated natural amethyst (citrine) will not be discussed in this paper (cf. Schmetzer, 1986, 1989). However, it has to be mentioned, that in heat-treated natural amethyst an alteration of twinning may occur, which is connected with the development of orientated brown striations, which are also useful as diagnostic criteria.

In contrast to natural citrine obtained by heat treatment of natural amethyst, in natural untreated citrine the first-order hexagonal prism m $(10\bar{1}0)$ is clearly developed (cf. Schmetzer, 1989). The crystal forms determined are the first-order hexagonal prism m $\{10\bar{1}0\}$ and the positive rhombohedron r $\{10\bar{1}1\}$ or, in other crystals, the forms m $\{10\bar{1}0\}$, r $\{10\bar{1}1\}$, and the negative rhombohedron z $\{01\bar{1}1\}$. The angles formed by different crystal faces are identical with those of natural amethyst. In addition, an angle of 141.8°, formed by the two crystal faces m and r or by m and z may also occur.

In natural untreated citrine, growth structures occur occasionally in broader distances than in natural amethyst. In cut samples, few single growth planes can be observed, which may form characteristic angles as listed in Table 3. Twinning in natural citrine is occasionally present in form of inserted bodies or plates of quartz in an orientation different from the host crystal.

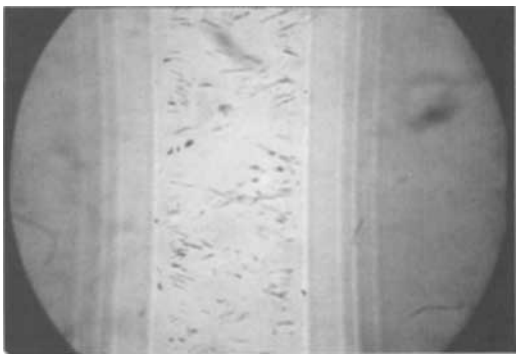


Fig. 72. Growth structures in hydrothermally-grown synthetic citrine from USSR; residue of the seed orientated parallel to the basal pinacoid c (0001) in the centre, growth planes and colour zoning parallel to the boundary seed/synthetic citrine. View perpendicular to the c-axis, the c-axis runs horizontally. Crossed polarizers. 30x.

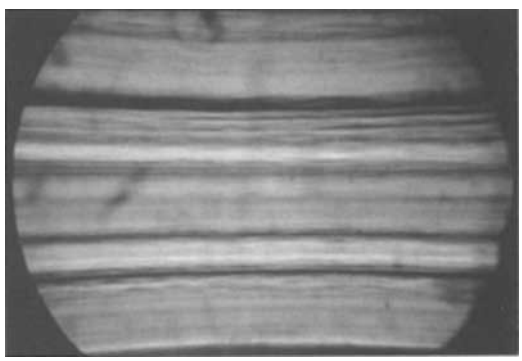


Fig. 73. Growth structures in hydrothermally-grown synthetic citrine from USA; growth lines parallel to the basal pinacoid c (0001). View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 32x.

VII. Synthetic amethyst and citrine

Synthetic amethyst is commercially grown by using seed plates cut parallel to the positive rhombohedron r $(10\bar{1}1)$ or parallel to the negative rhombohedron z $(01\bar{1}1)$. The main crystal growth habitually is parallel to the seed plate, which means, parallel to one rhombohedral face. Parallel to this single dominant rhombohedral face, i.e. parallel to the seed plate, in different samples examined all

stages of growth structures between no zoning and an intense lamellar zoning as observed in natural amethyst are observable. However, it has to be underlined that only in the single dominant growth direction parallel to the seed plate distinct growth structures as well as colour zoning are observable. No characteristic angles between this dominant rhombohedral face and other growth structures, i.e. other rhombohedra, were observed so far in faceted samples.

In synthetic amethyst, a distinct type of twinning may occur occasionally (Lind & Schmetzer, 1987). In samples of this particular type, triangular shaped twinned areas are incorporated into the normally untwinned host crystal. These acute-angled zones are easily recognizable under crossed polarizers.

Different types of commercially produced synthetic yellow quartz are grown with seed plates orientated parallel to the basal pinacoid *c* (0001). In some of the samples growth structures parallel to the seed plate, parallel to the basal pinacoid *c* (0001), in connection with colour zoning were observable [Figures 72, 73] (Schmetzer, 1989). This type of growth structure is neither existent in natural amethyst or heat-treated natural amethyst (citrine) nor in natural untreated citrine, because the basal pinacoid *c* (0001) does not appear as a growth plane in natural quartz. An additional characteristic feature of synthetic citrine is the lack of polysynthetic twinning as it is commonly observed in natural amethyst and heat-treated natural amethyst (cf. section VI).

VIII. Conclusions

As described in detail in this third part of the paper, the consequent determination of growth structures using the easily available microscopic methods introduced in part 1 of the publication reveals a great number of characteristics which can be used as diagnostic criteria for the distinction of natural and synthetic gem minerals. These additional diagnostic features can be extremely helpful in cases, in which no unequivocally diagnostic inclusions are available in the faceted gemstone under investigation. The methods described can easily be made available for every gem testing laboratory and the techniques of examination can be learned by use of some characteristic samples within a few days. Hopefully, the application of the techniques described will lead to an improvement of the methods by other colleagues as well as to some further developments in the recognition of characteristic criteria which can be applied to problems of practical gem testing and gem identification. In general, the microscopic determination of growth structures and twinning can reveal criteria, which are of comparable value for the gemmologist as the investigation of chemical or spectroscopic properties.

References

Coldham, T., 1985. Sapphires from Australia. *Gems & Gemology*, **21**, 130-46.

Galia, W., 1987. Eine neue Generation synthetischer Rubine von P.O. Knischka unter Verwendung natürlicher Nährsubstanz. *Z. Dt. Gemmol. Ges.*, **36**, 19-31.

Grubessi, O., Marcon, R., 1986. A peculiar inclusion in a yellow corundum from Malawi. *J. Gemm.*, **20**, *163-5*.

Jobbins, E.A., Berrangé, J.P., 1981. The Pailin Ruby and Sapphire Gemfield, Cambodia. *J. Gemm.*, **17**, 555-67.

Keller, P.C., 1982. The Chanthaburi-Trat Gem Field, Thailand. *Gems & Gemology*, **18**, 186-96.

Kiefert, L., Schmetzer, K., 1987. Blue and yellow sapphire from Kaduna Province, Nigeria. *J. Gemm.*, **20**, 427-42.

Kiefert, L., Schmetzer, K., 1988. Morphology and twinning in Chatham synthetic blue sapphire. *J. Gemm.*, **21**, 16-22.

Kiefert, L., Schmetzer, K., 1991a. The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones. Part 1: General considerations and description of the methods. *J. Gemm.*, **22**, 344-54.

Kiefert, L., Schmetzer, K., 1991b. The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones. Part 2: Examples for the applicability of structural features for the distinction of natural emerald from flux-grown and hydrothermally-grown synthetic emerald. *J. Gemm.*, **22**, 427-38.

Knischka, P.O., 1989. Personal communications.

Knischka, P.O., Zirkl, E.J., 1986. Knischka-Rubine der nullten bis dritten Generation mit steigender Zahl präsenter Kristallflächen als Funktion von Wachstumsparametern. *DGKK Mitteilungsblatt*, Nr. 43, Juli 1986, 25-31.

Lind, T., Schmetzer, K., 1987. New investigations of synthetic amethysts produced in Japan. *J. Gemm.*, **20**, 274-7.

Rutland, E.H., 1969. Corundum from Malawi. *J. Gemm.*, **11**, 320-3.

Schmetzer, K., 1986. An improved sample holder and its use in the distinction of natural and synthetic ruby as well as natural and synthetic amethyst. *J. Gemm.*, **20**, 20-33.

Schmetzer, K., 1987a. Zur Deutung der Farbursache blauer Saphire – eine Diskussion. *N. Jb. Miner. Mh.*, 1987, 337-43.

Schmetzer, K., 1987b. Production Techniques of Commercially Available Knischka Synthetic Rubies – An Additional Note. *Aust. Gemmol.*, **16**, 192-4.

Schmetzer, K., 1989. Methods for the distinction of natural and synthetic citrine and prasiolite. *J. Gemm.*, **21**, 368-91.

Vichit, P., Vudhichativanich, S., Hansawek, R., 1979. The Distribution and Some Characteristics of Corundum-Bearing Basalts in Thailand. *J. Geol. Soc. Thailand*, **3**, *M4-1 – M4-38*.

[Manuscript received 3 May 1989.]

The growth of rubies in south-east Kenya

R.M. Key [1] *and J.O. Ochieng* [2]

[1] British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA.
[2] Mines and Geological Department, PO Box 30009, Nairobi

Abstract

Gem quality rubies from south-east Kenya, associated with small ultramafic intrusions, formed during a late Precambrian allochemical metamorphism under upper amphibolite or granulite facies conditions. PT estimates for the metamorphism from two-feldspar thermometry indicate temperatures of between 630 and 670°C at pressures in excess of 7 kbars. The red colour of the rubies, as well as the green and blue body colour of co-existing tourmalines and kyanites respectively, are all due to very high amounts of Cr_2O_3 in these minerals. Growth colour bands in the rubies reflect variations in their crystal matrix Cr_2O_3 and TiO_2 contents. Exsolved rutile needles formed during cooling to cut across the colour bands and may be related to decompression.

Introduction

The first discovery of corundum in south-east Kenya, at Kinyiki, was announced in the Annual Report for 1936 of the Geological Survey of Kenya. Small quantities of gem-quality sapphires were recovered from soils and gravels derived from corundum-bearing wall-rock to an ultramafic (dunite) intrusive (Parkinson, 1947). It was in 1973 that the first rubies were found in south-east Kenya, in the Mangari area, by two American geologists, John Saul and Elliott Miller (Figure 1). The Mangari ruby deposits are now known to be amongst the world's richest and Hughes (1990) notes that East Africa in general has the potential to become the future centre of world ruby mining. In order to facilitate future exploration for new ruby deposits the present study is an attempt to elucidate the physical conditions under which the rubies in the Mangari area were formed. John Saul provided samples of ruby and its rock matrix for optical and chemical investigations. The mineral phases of the ruby deposits were examined in thin sections and electron microprobe analyses of polished thin sections provided the chemical compositions of the main minerals.

Geology

The Mangari ruby deposits occur at the contacts of small ultramafic intrusions with metasediments of the Kurase Group (Pohl *et al.*, 1977, after Saggerson, 1962). Psammitic gneiss is the dominant metasediment with marble and graphitic schist intercalations. Gem quality vanadiferous grossular garnets ('tsavorite') occur in the graphitic schists; these deposits have been described in a previous paper (Key and Hill, 1989). The area around Mangari comprises flat, poorly exposed, scrub-covered country. Bedrock is concealed beneath layered superficial deposits of sand and black cotton soil above kunkar (secondary limestone). Prior to the ruby mining operations, the Mangari ultramafics were not exposed and are consequently not shown on the original regional geological map of Walsh (1960). Similar ultramafics are best seen in northern Kenya in the Baragoi area (Figure 2). The local geology of the Mangari area is described by Walsh (1960) with Pohl *et al.*, (1977). Bridges (1982) and Hughes (1990) providing descriptions explicit to the ruby mines.

On a regional scale the ruby deposits occur within the late Precambrian Mozambique Orogenic Belt which underlies much of East Africa between Ethiopia and Mozambique. The Mozambique Orogenic Belt developed as a result of Neoproterozoic collision between a western continental plate (Tanzanian Craton) and an eastern 'Kibaran' plate. Shelf sediments and oceanic volcanics were laid down during an initial extensional phase and subsequently disrupted by major folding and associated ductile shearing and thrusting. This collision-related deformation resulted in tectonic interfingering of different lithologies and lithostratigraphic units. Regional metamorphism at amphibolite to granulite facies, as well as crustal melt igneous intrusion, accompanied deformation. The rubies formed during this event.

At the end of the Precambrian, meridional transpressive shearing and folding was again accompanied by regional metamorphism (greenschist to amphibolite facies) with crustal melt igneous intrusion.

Regional uplift throughout Cambrian times

 ISSN: 0022-1252

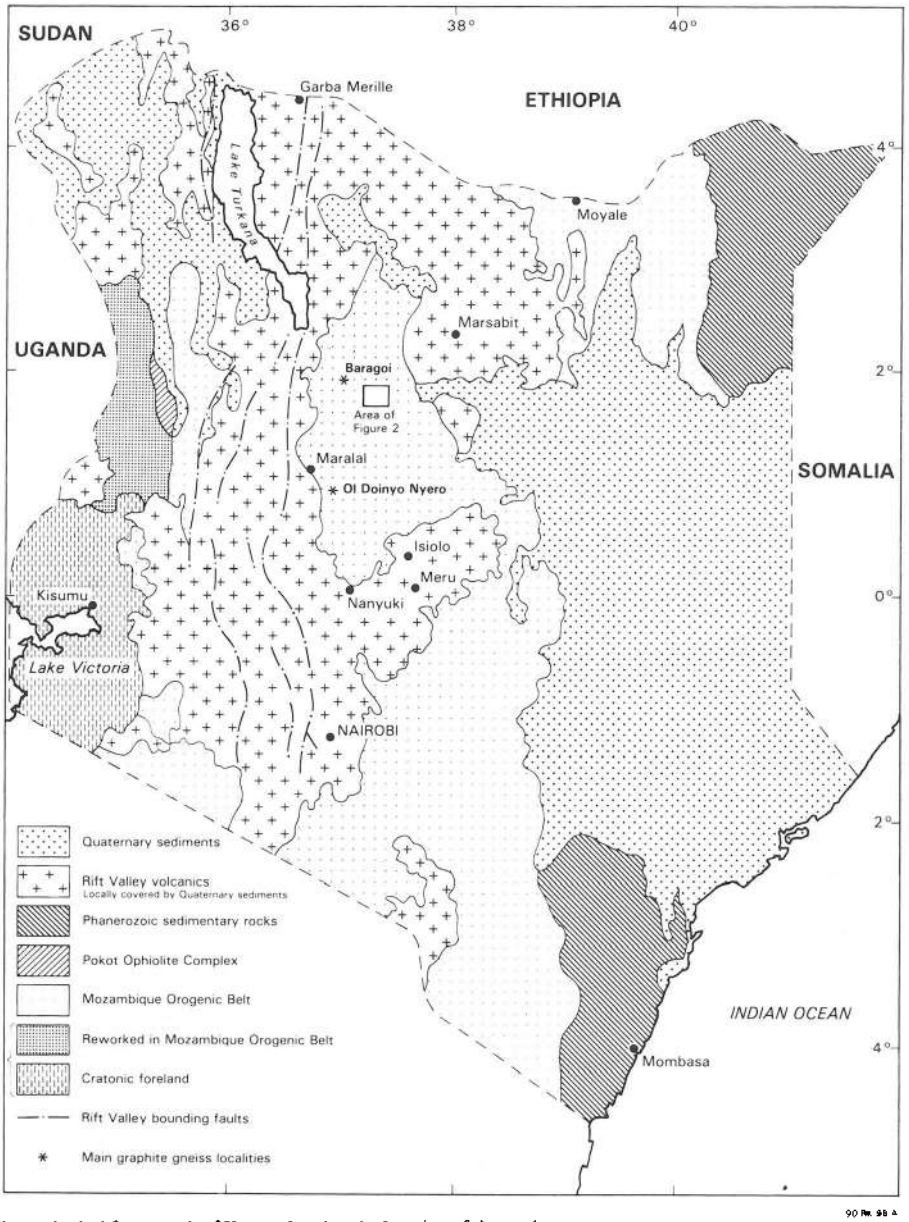


Fig. 1. The geological framework of Kenya showing the location of the study area.

accompanied orogenic cooling. Recent reviews of the Mozambique Orogenic Belt are given by Cahen *et al.*, (1984), El Gaby and Greiling (1988), Shackleton (1986), and Key *et al.*, (1989).

According to Pohl and Horkel (1980) the corundum deposits (in bedrock) of south-east Kenya are of the following four types.

1. Desilicated plumasitic pegmatites in ultramafic bodies.
2. Desilication zones at the contacts of the ultramafics and metasedimentary country rocks.
3. In aluminous metasediments (not economically important).
4. In marbles, associated with red spinel (not economically important).

These authors note that the Mangari rubies result from complex desilication processes between small ultramafics (altered talc – enstatite – tremolite/anthopyllite – chlorite rocks) and intrusive pegmatites or paragneisses (see also Hughes, 1990). The rubies are associated with plagioclase, mica, tourmaline and kyanite in the pegmatites and with

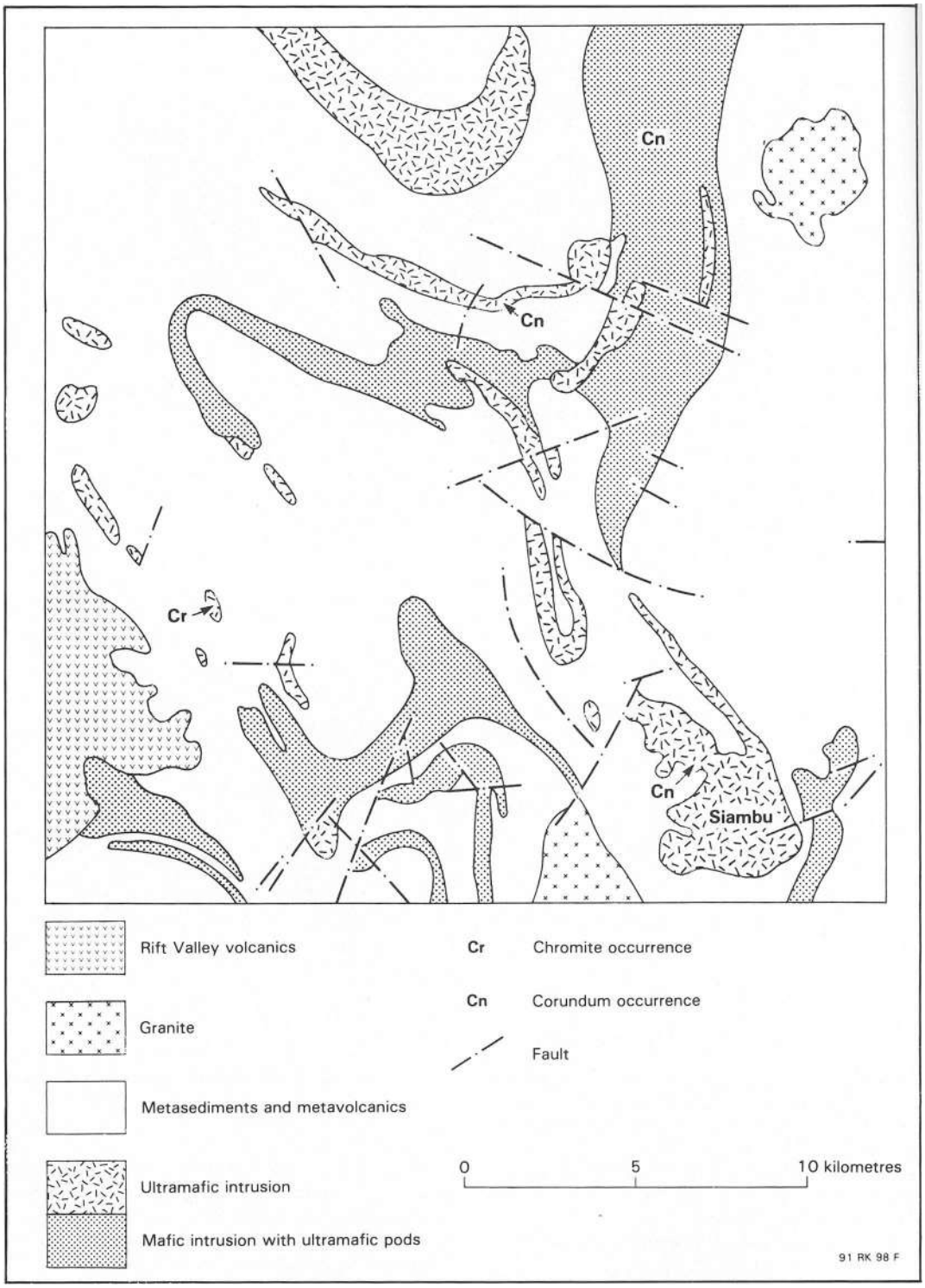


Fig. 2. Details of the geology of a well exposed area of north-central Kenya, near Baragoi, which illustrates the typical outcrop shape of ultramafic bodies in the Mozambique Orogenic Belt.

Plate 1. Colour zoned ruby with marginal white corundum rim. The diameter of the sample is about 2cm.

kyanite/sillimanite, tourmaline and mica aggregates in the desilicated gneisses. All the mineral phases formed during the regional metamorphism which controlled the desilication processes.

Mineralogy

The following ruby-bearing assemblages occur in the examined samples,

Ruby + muscovite + plagioclase (oligoclase – andesine) + xenotime* (sample 4)
Ruby + phlogopite (sample 5)
Ruby + muscovite + kyanite + plagioclase (sample 5b)
Ruby + phlogopite + plagioclase (andesine) (sample 7)
Ruby + margarite – paragonite + plagioclase (bytownite-labradorite) + tourmaline + graphite (sample 8)

*Identified on the electon microprobe

Ruby + muscovite + phlogopite + plagioclase (andesine) + K-feldspar + tourmaline + kyanite + zircon (sample 8)
Ruby + muscovite + plagioclase (oligoclase) + K-feldspar + zircon + xenotime (sample 9)
Ruby + margarite + tourmaline (sample 11)
Ruby + muscovite + pyrite + spinel (sample 12)

Ruby forms idioblastic hexagonal prisms and elongate hexagonal spindles up to several centimetres in diameter and mostly with a strong colour zoning mimicking the prism faces. This zoning is best seen in sections cut parallel to the basal pinacoid and comprises white, pink and red sharp and diffuse bands (see Plate 1). Polysynthetic twins enhanced by long, white boehmite, AlO(OH), needles (Hughes, 1990) cut across the colour zoning (see Plate 2). Rutile needles orientated parallel to the faces of the hexagonal prism to intersect at 120° are ubiquitous. The needles also cut the colour

Plate 2. Twin planes in ruby cutting across the colour zoning. White boehmite needles may be aligned in the twins (Sample 6). Field of view about 0.8mm by 1mm.

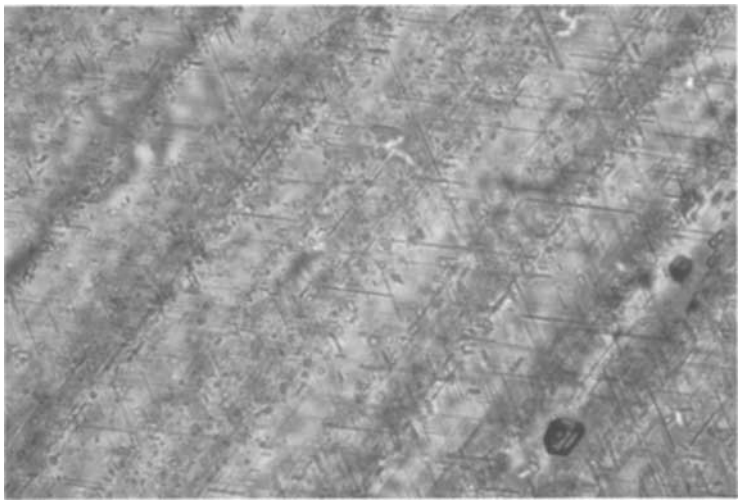


Plate 3. Oriented rutile needles and equant mica inclusions in ruby. Note that the rutile needles cut across the colour banding (Sample 3). Field of view about 3mm by 4mm.

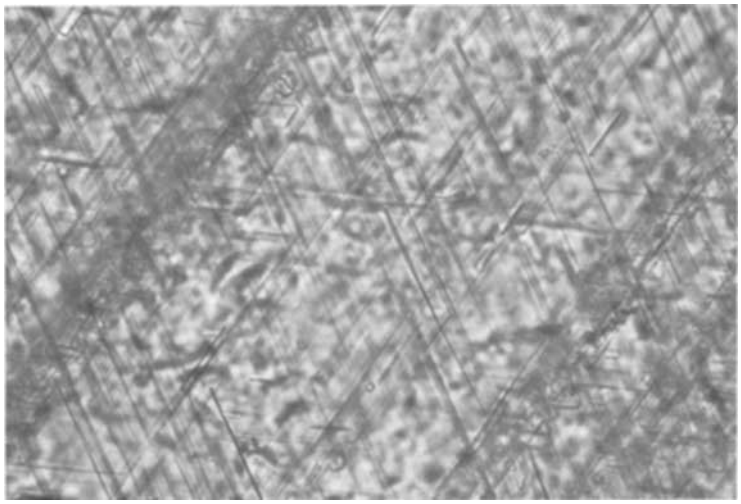


Plate 4. Close up of Plate 3. Field of view about 0.8mm by 1mm.

Plate 8. Mesoperthite with white albite spindles in K-feldspar. Sample 9. Field of view about 0.8mm by 1mm.

banding (see Plates 3 and 4). Less common inclusions are small, colourless to pale green chrome-muscovite plates (see Plates 3 and 4). One sample comprised a red, translucent ruby with massive rutile grains embedded in its centre (Plate 5 – see cover picture). The rutile needles formed after the colour banding and are regarded as exsolution features produced during cooling of the rubies (see also Hughes, 1990). Their distribution is influenced by the distribution of TiO_2 in individual grains and a close examination of Plates 3 and 4 shows that there is a strong concentration in the darker bands of rutile needles aligned parallel to the banding. The microprobe data confirm that the dark bands are enriched in crystal matrix TiO_2 relative to the lighter bands (see below).

Ruby appears to be in equilibrium with the other phases although marginal margarite plates may be replacive (see also Harding and Scarratt, 1986). Plagioclase is more abundant than K-feldspar; both minerals form an equigranular groundmass with accessory zircon and xenotime (Plate 8). The plagioclase grains are commonly polysynthetically twinned but the K-feldspar is untwinned with rare mesoperthitic textures (Plate 8). Tourmaline and kyanite form poikilitic grains in the presence of feldspar. They have strong green (tourmaline) and blue (kyanite) body colours (Plates 6 and 7). Graphite forms isolated typically ragged blades (Plate 9).

The mineral phases are generally unaltered as can be seen in the various plates. There is local marginal alteration of ruby to margarite and minor sericite replacement of the feldspar. The absence of fluids in the rocks following high grade metamorphism may have prevented major retrogression during cooling. Sillimanite has been recorded after kyanite in south-east Kenya (Pohl and Niedermayr, 1978) which indicates that the cooling history was not isobaric. Pressure release on cooling may explain the pronounced orientation of exsolved rutile in the rubies, caused by slight expansions of the ruby lattice.

Chemistry

The various mineral phases were chemically analysed on the Edinburgh University Cameca Camebax electron probe micro-analyser operating at an accelerating potential of 20 kv, with a probe current, as measured in a Faraday Cup, of 20 nanoamps (see Key and Hill, 1989). Standards used in the calibration were as follows: wollastonite for silicon and calcium, jadeite for sodium, corundum for aluminium, periclase for magnesium, rutile for titanium, orthoclase for potassium, and the artificial compound MgF_2 for fluorine. Other elements (vanadium, 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 analyses occur at single points within individual grains and the point fluorescence during analysis provides instant confirmation of the nature of certain analysed minerals. Rubies have a red fluorescence under the probe beam; chrome-rich (mean value of 0.424% Cr_2O_3) kyanite also has a red fluorescence which changes to pale blue in the presence of significant titanium (0.127-0.152 % TiO_2).

Ruby analyses

Tables 1 and 2 summarize the results of the ruby analyses. It is apparent from these tables that the main chromophore is Cr_2O_3. In the unzoned rubies the mean Cr_2O_3 content varies from 0.391 to 0.963% with the highest values in the best quality

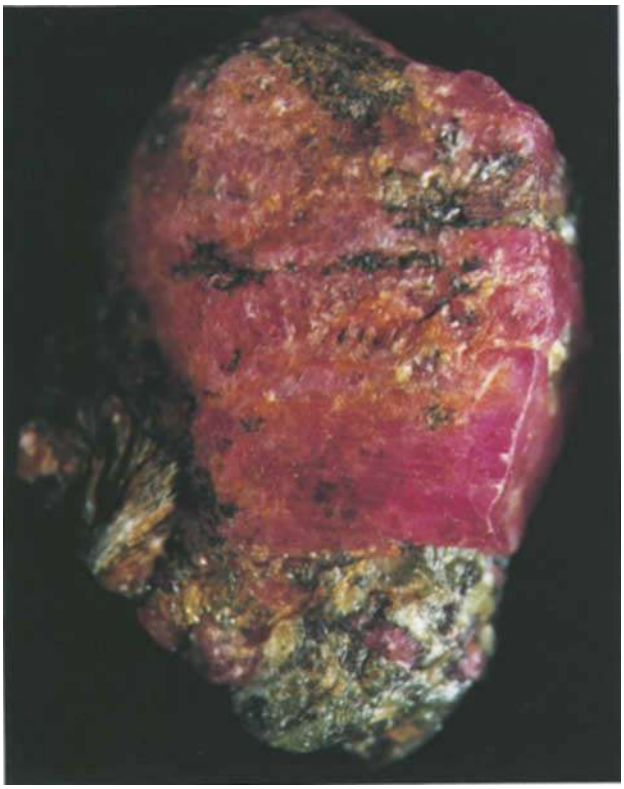


Plate 6. Green tourmaline and ruby cluster. Size of specimen about 3cm.

Plate 7.
Blue kyanite and ruby. Size of specimen about 3cm.

Table 1: Mean ruby analyses for unzoned rubies

	Sample 7	Sample 8b	Sample 11	Sample 8	Mangari*	Umba*	Morogoro*
Al_2O_3	99.546	99.336	99.803	99.647			
Cr_2O_3	0.963	0.920	0.447	0.391	1.10-1.80	0.01-0.10	0.060-0.090
TiO_2	0.029	0.030	0.016	0.024		0.006-0.020	
V_2O_5	0.039	0.027	0.009	0.027	0.000-0.003	0.002-0.01	0.004
FeO	0.017	0.008	0.013	0.010	0.060-0.50	0.10-0.25	0.010-0.020
Total	100.594	100.321	100.288	100.099			
n	5	2	5	4			

Values in weight %
n – No. of analyses
* From Hughes (1990), Umba and Morogoro are in Tanzania

(reddest) stones. The chrome values are slightly lower than those reported by Hughes (1990) for Mangari rubies but are still higher than rubies from adjacent parts of Tanzania. The ultramafic intrusions are thought to be the original source of the chromium as these rocks have high Cr_2O_3 and locally, in Kenya, host podiform chromite (Key, 1987). Iron contents are very low which is reflected by the lack of brown tints to the Mangari rubies – one of the reasons that they are so prized as gemstones. Vanadium contents are also very low in the rubies and all the other mineral phases.

The internal colour banding of dense or partly translucent ruby grains is reflected by variable Cr_2O_3 and TiO_2 contents (Figure 3 and Table 2). The darker (redder) bands have higher Cr_2O_3 values relative to adjacent paler bands and the overall mean Cr_2O_3 value for the dark bands is significantly higher than the corresponding figure for the light bands (0.571% compared with 0.400%). The same is true for the distribution of TiO_2 (0.286% mean value for dark bands and 0.168% mean value for light bands). The colour banding is regarded as a primary growth feature; diffusion of Cr_2O_3 and TiO_2 in the ruby crystal matrix. As shown earlier, the TiO_2 at least in part, was exsolved during cooling as orientated needles.

Other minerals

Table 3 presents the mean chemical analyses of the main mineral phases associated with ruby. All the micas have significant Cr_2O_3 values. In particular the muscovites have mean Cr_2O_3 values of 0.447% with the bright green fuchsitic micas having mean Cr_2O_3 values of 3.130%, and the highest individual analysis of 5.925% Cr_2O_3. For reference, Deer and others (1970) record maximum values of about 6% Cr_2O_3 for fuchsite. The fuchsite inclusions in the Mangari rubies have the highest Cr_2O_3 values.

The green body colour of the tourmaline (Plate 6) is due to Cr_2O_3 (mean value 0.478%) and not V_2O_5 (mean value 0.061%). Therefore the vanadiferous tourmalines reported to occur in south-east Kenya are unlikely to come from Mangari. This is supported by field evidence (J. Saul, pers. comm.). Similarly the blue body colour of the kyanite blades (Plate 7) is due to Cr_2O_3 (mean value 0.424%). The chrome content of the kyanites is amongst the highest ever reported. Altherr and others (1982) record values of 0.139% Cr_2O_3 for Tanzanian kyanite which they regard as exceptionally high. Table 4 shows two ICP (inductively coupled plasma) spectrometry analyses of tourmalines from Mangari. These analyses are similar to the microprobe analyses and they also provide data on the boron contents of the tourmaline.

The most common plagioclase phases have compositions in the oligoclase-andesine range. Albite occurs as late overgrowths or as lamellae within mesoperthites (Plate 8). The most calcic plagioclases are associated with margarite and tourmaline and the host rock must consequently have been relatively calcic. Barium was detected in the K-feldspar grains but was not quantitatively analysed.

Metamorphism

Previous work in south-east Kenya has shown that the grade of the regional metamorphism within the Mozambique Orogenic Belt attained upper amphibolite or granulite facies conditions (see Pohl and Niedermayr, 1978; Key and Hill, 1989). The peak temperature of the progressive metamorphism in this area has been established as greater than 550°C and possible over 750°C. Thus, Arneth and others (1985) deduced that the metamorphism took place at temperatures of between 550°C and 650°C based on carbon isotope studies of the graphitic metasediments. Key and Hill (1989) concluded that the peak temperature of metamorphism was at least 750°C based on mineral assemblages in the grossular deposits of Mgama Ridge. Similar temperatures were established by Sarbas and others (1984) who, from their studies of the grossular garnet-bearing assemblages, concluded that peak temperatures exceeded 650°C. Pressures during metamorphism

Table 2: Mean analyses (in weight %) of a single zoned ruby from Mangari (see Figure 3)
2A Light toned bands

	1	2	3	4	5	6	7	8	9
Al_2O_3	99.540	99.634	99.735	99.453	99.718	99.985	99.870	99.849	99.741
Cr_2O_3	0.427	0.414	0.372	0.385	0.362	0.343	0.336	0.302	0.400
TiO_2	0.041	0.065	0.064	0.146	0.057	0.047	0.046	0.054	0.168
V_2O_5	0.003	0.020	0.012	0.000	0.022	0.009	0.022	0.009	0.017
FeO	0.000	0.011	0.011	0.010	0.005	0.019	0.020	0.012	0.011
Total	100.011	100.144	100.194	99.994	100.164	100.403	100.294	100.226	100.337
n	3	3	13	2	4	7	3	2	7

n – No. of analyses
9: mean analyses for 7 bands in sample 9

(Table 2 cont'd: Mean ruby analyses for dark toned bands (see Figure 3)
2B Dark toned bands

	10	11	12	13	14	15	16	17	18	19	20
Al_2O_3	99.311	99.181	99.625	99.727	99.336	99.683	99.409	99.646	99.777	99.502	99.351
Cr_2O_3	0.619	0.523	0.505	0.489	0.475	0.415	0.377	0.367	0.330	0.294	0.571
TiO_2	0.126	0.528	0.064	0.122	0.140	0.374	0.318	0.205	0.285	0.478	0.286
V_2O_5	0.017	0.034	0.043	0.010	0.010	0.044	0.016	0.030	0.011	0.012	0.024
FeO	0.006	0.008	0.011	0.002	0.006	0.012	0.006	0.015	0.020	0.012	0.018
Total	100.079	100.274	100.248	100.350	99.967	100.528	100.126	100.263	100.423	100.298	100.250
n	3	5	3	3	2	3	4	9	2	4	5

10: mean analyses for 7 bands in sample 9

Table 3: Mean mineral analyses (excluding ruby)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Na_2O	0.487	2.404	0.234	4.318	0.563	9.951	9.412	7.628	4.435	2.639	1.059	1.655	0.014
SiO_2	45.617	35.067	40.921	41.070	44.863	67.429	63.069	59.424	52.333	48.226	63.475	37.462	36.917
K_2O	10.518	0.209	8.692	0.460	9.940	0.684	0.181	0.159	0.051	0.033	14.173	0.042	0.009
Cr_2O_3	0.447	0.133	0.371	0.00	3.130	0.016	0.016	0.020	0.018	0.015	0.001	0.478	0.424
F	0.046	0.016	0.556	0.039	0.219	0.040	0.00	0.093	0.055	0.00	0.037	0.166	0.038
Al_2O_3	36.271	45.754	22.609	43.971	32.239	21.437	22.836	25.371	29.816	32.216	18.256	33.688	62.672
CaO	0.008	9.251	0.036	2.331	0.007	0.395	4.168	7.071	11.219	14.279	0.008	1.771	0.006
V_2O_5	0.262	0.020	0.060	0.00	0.487	0.00	0.029	0.015	0.00	0.014	0.001	0.061	0.017
MgO	0.560	0.075	17.821	0.171	1.662	0.225	0.010	0.018	0.002	0.014	0.009	10.339	0.044
TiO_2	0.156	0.023	0.590	0.018	0.331	0.008	0.016	0.012	0.018	0.008	0.005	0.313	0.078
MnO	0.015	0.006	0.037	0.00	0.031	0.009	0.010	0.018	0.004	0.013	0.009	0.016	0.003
FeO	0.162	0.024	0.040	0.019	0.034	0.014	0.003	0.014	0.019	0.009	0.007	0.042	0.037
Total	94.549	92.982	91.969	92.397	94.506	100.206	99.793	99.732	97.969	97.466	97.574	86.032	100.253
n	9	6	9	2	7	2	3	6	1	3	3	11	7

Values in weight %
n = No. of analyses
1. Muscovite
2. Margarite
3. Phlogopite
4. Paragonite
5. Fuchsite
6. Albite
7. Oligoclase
8. Andesine
9. Labradorite
10. Bytownite
11. K-feldspar
12. Tourmaline
13. Kyanite

(A complete list of analyses is available from the authors)

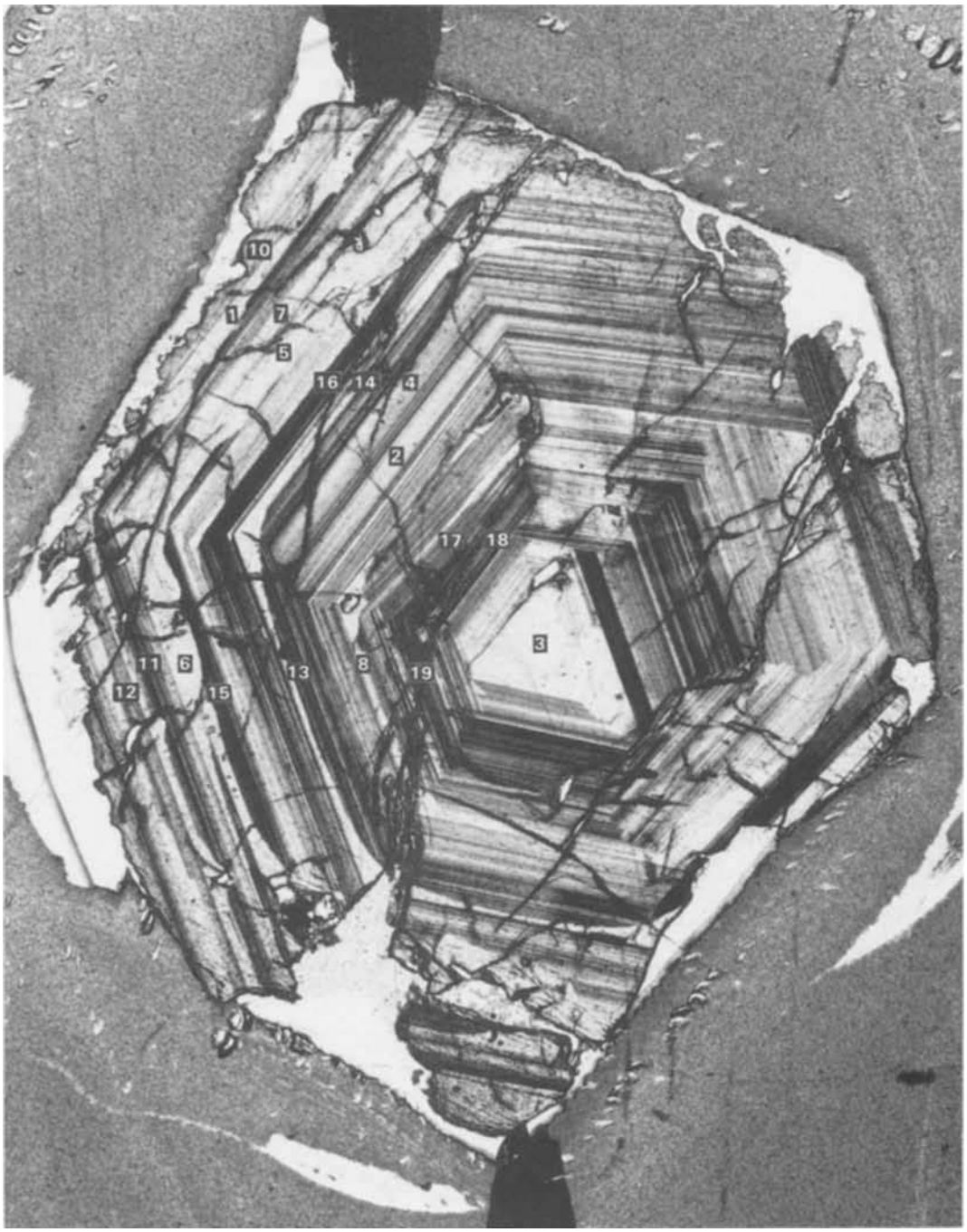


Fig. 3. The analysed ruby with the locations of the analysed pale and dark bands shown in Table 2.

Table 4: Two ICP analyses of tourmaline grains from Mangari

	Tourmaline 3	*Tourmaline 10*
SiO_2	39.30	38.13
Al_2O_3	29.86	30.04
TiO_2	0.35	0.30
Fe_2O_3	0.31	0.42
MgO	9.95	10.82
CaO	2.40	1.57
K_2O	0.35	0.13
Na_2O	1.82	1.66
MnO	0.02	0.02
P_2O_5	0.04	0.04
B_2O_3	9.17	9.73
Cr	840 *ppm*	1030 *ppm*
Zn	280 *ppm*	75 *ppm*

are not so well constrained and have been estimated at greater than 5 kbars with no upper limit yet established. Gneisses bearing two pyroxenes are recorded by Walsh (1960) from the area south of the Taita Hills, to support the conclusion that the metamorphism attained granulite facies conditions.

In the present study it is possible to estimate the PT conditions of the metamorphism during which ruby-formed, by two methods. A direct method uses the compositions of co-existing plagioclase and K-feldspar. Thus Haselton and others (1983) provide the following formula:

$$T_K = \frac{(X_{Or}^{AF})^2(18810 + 17030\,X_{Ab}^{AF} + 0.364P) - (X_{An}^{Pl})^2(28230 - 39520\,X_{Ab}^{Pl})}{10.3\,(X_{Or}^{AF})^2 + 8.3143 \ln\left\{\frac{(X_{Ab}^{Pl})^2(2 - X_{Ab}^{Pl})}{X_{Ab}^{AF}}\right\}}$$

Where T_k = Temperature (°C)
P = Pressure (bars)
X = Various mole fractions in the ternary system, orthoclase (Or)-albite (Ab)-Anorthite (An). AF and Pl refer to alkali feldspar and plagioclase respectively.

This equation is preferred to other two-feldspar thermometers because it takes in to account the anorthite content of both plagioclase and K-feldspar which is significant in the Mangari feldspars. Using the feldspar analyses summarised in Table 3 in the above formula provides temperatures of between 630°C and 670°C irrespective of pressure. The presence of kyanite as the Al_2SiO_5 polymorph indicates that pressures must have exceeded 7 kbars in this temperature range (Holdaway, 1971). These PT conditions agree with previous work as listed earlier.

An indirect approach to ascertaining the PT conditions of the metamorphism is provided by experimental data on the stability of the mineral assemblages. Altherr and others (1982) concluded that corundum in the Morogoro area of Tanzania formed in a metamorphism with temperatures of about 695°C at 7.7 kbars pressure (assuming an activity of H_2O of 1). This was based on the assemblages, albitic plagioclase + muscovite + phlogopite + corundum and albitic plagioclase + kyanite or sillimanite + phlogopite. These assemblages occur at Mangari. However, no account of the effect of the presence of CaO in the mineral phases was taken by Altherr and his co-workers. The very detailed study by Cartwright and Barnicoat (1986) on corundum-bearing restites from Scotland does discuss the effect of CaO. They note that the assemblage, corundum + K-feldspar + white mica + plagioclase + kyanite + liquid, indicates temperature of around 800°C with pressures of about 12 kbars. The PT conditions at Mangari cannot be exactly specified beause of the non-stoichiometric compositions of the mineral phases at Mangari and because of the unknown composition of the fluid phases. However, it can be concluded that the present study has confirmed that the Mangari rubies formed during a metamorphism which reached granulite facies conditions, defined as temperatures in excess of about 650°C irrespective of pressure, see Miyashiro (1961) and Zwart (1967).

It is relevant to note that Maesschalck and Oen (1989) show that Sri Lankan rubies, found in similar rocks to the Kenyan rubies, formed under very similar conditions to those specified in the last two paragraphs. They record that the rubies formed during a metamorphism with a temperature of about 630°C and pressures of about 5.5 kbars. Rubies in Tanzania are also found in areas of the Mozambique Orogenic Belt which preserve granulite facies mineral assemblages (Malisa and Muhongo, 1990).

Plate 9. Equigranular plagioclase grains with ragged graphite flakes (centre of plate) and tourmaline intergrowths (yellow). Sample 8. Field of view about 3mm by 4mm.

Plate 10. Two ruby grains (one strongly twinned) with idioblastic tourmaline and interstitial margarite. Sample 11. Field of view about 3mm by 4mm.

Plate 11. Several ruby grains with interstitial tourmaline. Sample 11. Field of view about 3mm by 4mm.

Plate 12. Intergrowth of muscovite with ruby; plagioclase grains clustered in lower left hand corner of the plate. Sample 9. Field of view about 3mm by 4mm.

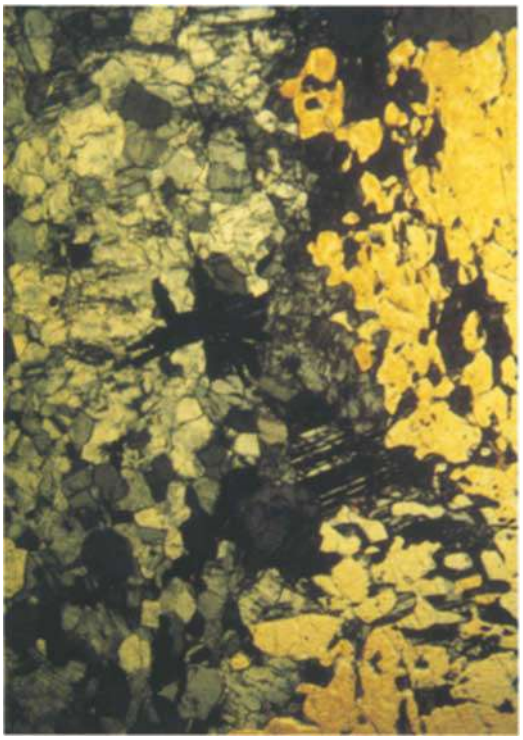


Plate 9

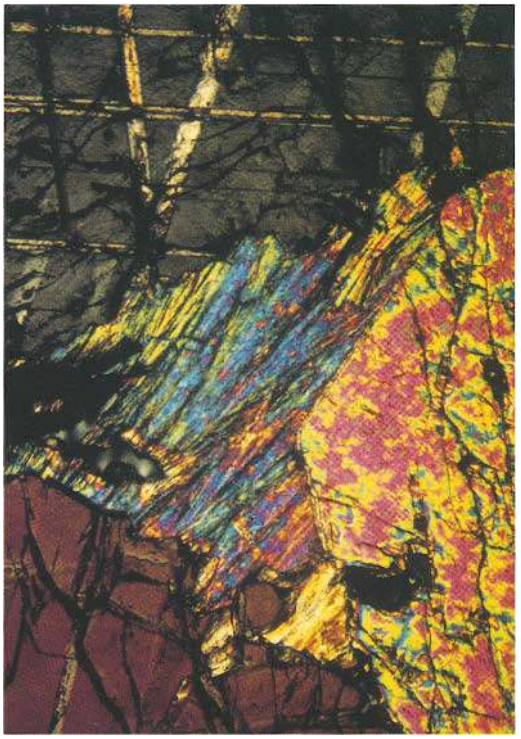


Plate 10

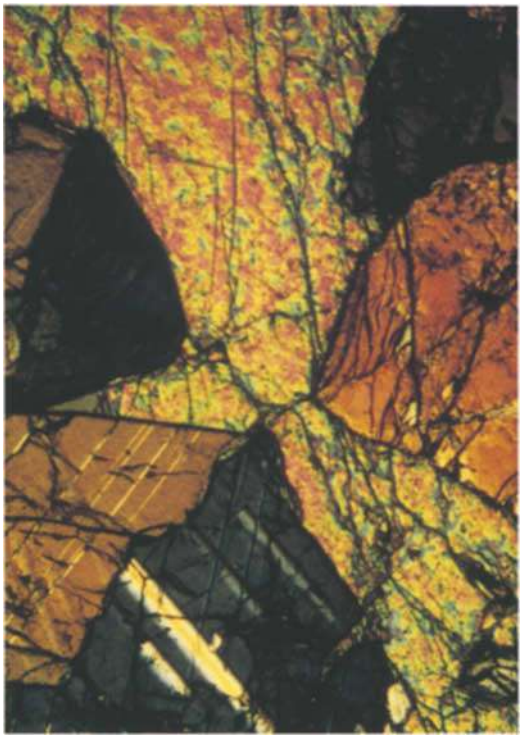


Plate 11

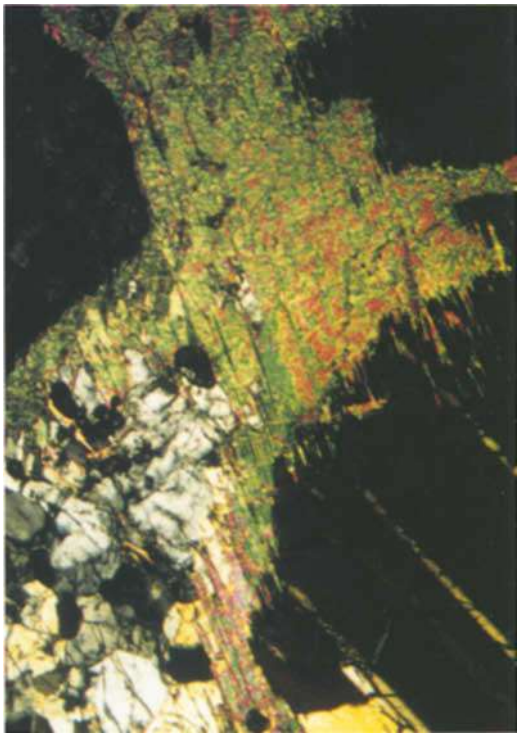


Plate 12

Conclusions

1. The Mangari rubies formed during regional metamorphism under upper amphibolite to granulite facies conditions: minimum temperatures of between about 630 and 670°C and pressures in excess of 7 kbars.
2. The pink and red body colours of the rubies are due to high values of Cr_2O_3 in the ruby matrix and low values of FeO. Titanium is present in significant amounts which is partly reflected by the ubiquitous presence of exsolved rutile needles. Vanadium is only present in trace amounts.
3. The strong colour banding is due to variations in the chromium and titanium contents of the rubies.
4. Chromium is also the chromophore in green tourmaline and in blue kyanite associated with the rubies. The ultramafic rocks associated with the rubies provided the chromium.

Future work

Many ultramafic intrusions in south-east Kenya do not appear to have marginal ruby deposits. There is an obvious need to compare the composition of the barren ultramafics with ruby-related ultramafics in order to see if there are chemical differences between the two sites. The chemistry of the ultramafics must significantly affect the desilication process which formed ruby.

Acknowledgements

This paper is published with the permission of the Director of BGS (NERC), and the Commissioner of Mines and Geology, Nairobi. The authors are indebted to Dr Peter Hill of Edinburgh University for his help with the probe analyses. Dr John Saul not only provided all the ruby samples but was a source of much useful information. He is sincerely thanked for his positive contributions to this project which was partly funded by the British Council.

References

Altherr, R., Okruch, M., Bank, H., 1982. Corundum and kyanite-bearing anatexites from the Precambrian of Tanzania. *Lithos*, **15**, 191-7.

Arneth, J.D., Schidlowski, M., Sarbas, B., Goerg, V., Amstutz, G.C., 1985. Graphite content and isotopic fractionation between calcite-graphite pairs in metasediments from the Mgama Hills, southern Kenya. *Geochimica and Cosmochimica Acta*, **49**, 1553-60.

Bridges, C.R., 1982. Gemstones of East Africa. *International Gemological Symposium Proceedings* (1982), 266-75.

Cahen, L., Snelling, N.J., Delhal, J., Vail, J.R., 1984. *The geochronology and evolution of Africa*. Clarendon Press, Oxford.

Cartwright, I., Barnicoat, A.C., 1986. The generation of quartz-normative melts and corundum-bearing restites by crustal anatexis: petrogenetic modelling based on an example from the Lewisian of north-west Scotland. *Journal of Metamorphic Petrology*, **3**, 79-99.

Deer, W.A., Howie, R.A., Zussman, J., 1970. *An introduction to the rock forming minerals*. 6th edition. Longman Group Ltd., London. 528pp.

El Gaby, S., Greiling, R., 1988. *The Pan-African belt of northeast Africa and adjacent areas: tectonic evolution and economic aspects of a late Proterozoic orogen*. F. Vieweg and Sohn, Wiesbaden, 369pp.

Harding, R.R., Scarratt, K., 1986. A description of ruby from Nepal. *Journal of Gemmology*, **20**, 3-10.

Haselton, H.T., Hovis, G.L., Hemingway, B.S., Robie, R.A., 1983. Calorimetric investigation of the excess entropy of mixing in analbite-sandine solid solutions: lack of evidence for Na, K short-range order and implications for two-feldspar thermometry. *American Mineralogist*, **68**, 398-413.

Holdaway, M.J., 1971. Stability of andalusite and the aluminosilicate phases diagram. *American Journal of Science*, **271**, 97-131.

Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann 336pp.

Key, R.M., 1987. Geology of the Maralal area. *Report, Mines and Geological Department, Kenya*, **105**, 93pp.

Key, R.M., Hill, P.G., 1989. Further evidence for the controls on the growth of vanadium grossular garnets in Kenya. *Journal of Gemmology*, **31**, 412-22.

Key, R.M., Charlsley, T.J., Hackman, B.D., Wilkinson, A.F., Rundle, C.G., 1989. Superimposed Upper Proterozoic collision-controlled orogenies in the Mozambique Orogenic Belt of Kenya. *Precambrian Research*, **44**, 197-225.

Maesschalck, A.A., Oen, I.S., 1989. Fluid and mineral inclusions in corundum from gem gravels in Sri Lanka. *Mineralogical Magazine*, **53**, 539-45.

Malisa, E., Muhongo, S., 1990. Tectonic setting of gemstone mineralisation in the Proterozoic metamorphic terrane of the Mozambique Belt in Tanzania. *Precambrian Research*, **46**, 167-76.

Miyashiro, A., 1961. Evolution of metamorphic belts. *Journal of Petrology*, **2**, 277-311.

Parkinson, J., 1947. Outlines of the geology of the Mtito Andei-Tsavo area, Kenya Colony. *Geological Survey of Kenya, Report 13*.

Pohl, W., Horkel, A., 1980. Notes on the geology and mineral resources of the Mtito Andei-Taita area (southern Kenya). *Mitt. osterr. geol. Ges.*, **73**, 135-52.

Pohl, W., Niedermayr, G., 1978. Geology of the Mwatate quadrangle (sheet 195/2) and the vanadium-grossularite deposits of the area. *Report 11, Kenya – Austria Mineral Exploration Project*. 89pp.

Pohl, W., Niedermayr, G., Horkel, A., 1977. Geology of the Mangari ruby mines. *Report 9, Kenya – Austria Mineral Exploration Project*. 70pp.

Saggerson, E.P., 1962. Geology of the Kasigau-Kurase area. *Geological Survey of Kenya, Report 51*.

Sarbas, B., Goerg, W., Amstutz, G.C., Schmetzer, K., Bank, H., 1984. Zur genese ostafrikanischer Grossularvorkommen. *Z. Dt Gemmol. Ges.*, **33**, 48-62.

Shackleton, R.M., 1986. Precambrian collision tectonics in Africa. In: M.P. Coward and A.C. Ries (Editors), *Collision Tectonics*. Blackwell, Oxford, pp 329-49.

Sweatman, T.R., Long, J.V.P., 1969. Quantitative electron probe microanalysis of rock forming minerals. *Journal of Petrology*, **10**, 332-79.

Walsh, J., 1960. Geology of the area south of the Taita Hills. *Geological Survey of Kenya, Report 49*. 26pp.

Zwart, H.J., 1967. The duality of orogenic belts. *Geologie en Mijnbouw*, **46**, 283-309.

[*Manuscript received 12 January 1991.*]

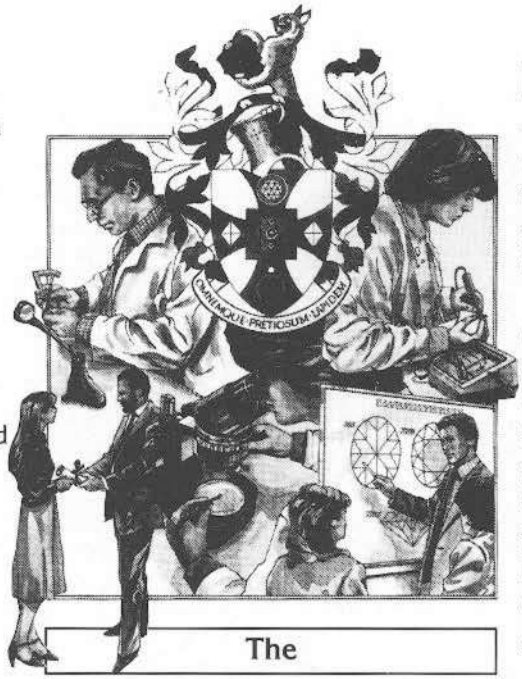
F.G.A.

your key to the fascinating world of Gemmology

The Gemmological Association and Gem Testing Laboratory of Great Britain has been actively involved in the very beginning of Gemmology as an independent science.

Today, the Association takes pride in its international reputation as a learned society dedicated to the promotion of gemmological education and the spread of gemmological knowledge.

The Association's coveted Fellowship is a mark of excellence only bestowed upon individuals who successfully undertake the Association's written and practical examinations covering all aspects of gemmology as a science.

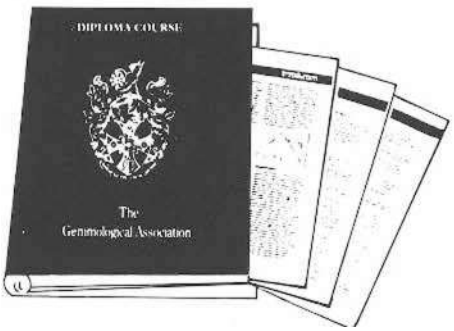


The Gemmological Association and Gem Testing Laboratory Of Great Britain

The Gemmological Association's course has been specially compiled into a series of teaching modules that are both readable and lavishly illustrated.

Together they provide a comprehensive step-by-step guide to the fascinating world of gemmology and an opportunity to earn the coveted initials FGA – Fellow of the Gemmological Association.

To find out more complete the coupon below and we will immediately forward the Association's 1991 prospectus giving full details of this unique course



Please complete and return to the Gemmological Association Training Scheme.
27 Greville Street, London EC1N 8SU England Tel: (071) 404 3334. Fax (071) 404 8843

Name

Position

Company

Address

Telephone

Paper Gems

J. Eadie

North Glasgow College (Barmulloch Campus), 186 Rye Road, Glasgow G21 3JY

Figs. 1-3 A selection of postage stamps depicting gem crystals and cut stones, mining activities and corals.

Stamp collecting is one of the world's most popular hobbies but because of the prodigious issues of world stamps, most philatelists now resort either to collecting a single country or the classics, or in more recent times collecting stamps based upon a theme or topic. For a gemmologist the topic 'Gem Crystals' seems to be an obvious choice. These are to be found on stamps displaying the crystal form, the faceted gem or both.

There are some two hundred stamps featuring gem crystals and as expected the most common gem crystal, quartz and its varieties are to be found on no less than 32 stamps. For a collection unmounted mint stamps are preferable although in some cases cost might preclude this, and v.f.u. (very fine used) may be substituted. Sometimes the requisite stamp cannot be bought singly from the dealer but can only be purchased as part of a set of stamps.

Other topics which may be of interest to the gemmologist are:

1. varieties of coral (approximately 150 stamps);
2. diamonds and associated material such as mining, treatment plant, grading, etc (approximately 30 stamps).

Any reader who would like a list of stamps on any of the above mentioned topics may obtain a free copy from the author at the above address.

Happy collecting.

[*Manuscript received 14 June 1991.*]


LESOTHO
10c
LESOTHO
20
15
LESOTHO
RSA 15c
1271
SWA
SWA
20c
SWA
SWA 25c
RSA 20c
1275


BRITISH VIRGIN ISLANDS
Coral Reefs USA 15c
Coral Reefs USA 15c
Coral Reefs USA 15c
Coral Reefs USA 15c
BRITISH VIRGIN ISLANDS
BRITISH VIRGIN ISLANDS
BRITISH VIRGIN ISLANDS

Emeralds from Colombia (Part 3)*

George Bosshart

Gübelin Gemmological Laboratory, Maihofstrasse 102, CH-6000 Lucerne 9, Switzerland

Abstract

A condensed historical and mining survey is followed by a compilation of the most notable crystals of Colombian emeralds ever found and of the details of their chemical composition. A summary of the elemental substitutions and their effects on the outlined range of gemmological data is given.

Special emphasis is placed on the cause of the famous, vividly green coloration, i.e. on the selective absorption of orange-red and violet light, dictated by minor contents of the chromophoric elements Cr and V substituting for Al^{3+} in octahedrally coordinated sites of the beryl lattice (Cr ≈ V, with the Cr/V ratio found to be ranging from 4.5 to 0.5, in extreme cases from about 10 to 0.1). Iron, however, has barely been detected in the UV/VIS absorption spectra of Colombian emeralds. Though generally present in slightly larger amounts than Cr^{3+} iron does not recognizably influence the colour (little Fe^{2+} and possibly some Fe^{3+} positioned in the axial channels of the ring-silicate structure).

A detailed presentation of the currently known internal characteristics (inclusions and growth structures) is supplemented by a discussion of identification problems with treated emeralds and the disclosure of the treatment during transactions in the wholesale and retail trade.

Allocation of the emeralds to individual Colombian mines on the basis of inclusion patterns does not appear possible in most instances. However, the differentiation of Colombian emeralds from other natural emeralds (such as those from the Panjsher Valley exhibiting very similar (s,l,g) three-phase inclusions) or from difficult, modern hydrothermal and flux synthetics is shown to be feasible by a combination of microscopy, refractometry, and absorption spectrometry (UV/VIS and NIR/MIR), assisted by chemical analysis only in the most difficult cases. Safe identification of authenticity, treatment, and origin of emeralds, however, is increasingly becoming the task of the experts in the specialized laboratory.

The mineralogical definition of emerald as a yellowish to bluish-green variety of natural beryl is shown to be valid for any Cr and V-containing variety except possibly the rare, absolutely chromium-free (V,Fe)-beryls (modification of the former definition of type II emerald): in many of the preferred Colombian emeralds, chromium is clearly dominated by vanadium (Cr/V ratio < 1). However, chromium has a higher efficiency of coloration than vanadium and a much higher one than iron ions in the various substitutional and interstitial lattice sites of beryl. Cr influences colour even at very low trace levels.

An extensive and up-dated selection of literature, covering all aspects cited, completes the synopsis.

*This is a paper has been published in *The Journal* in three parts. The complete bibliography was presented with Part 1.

The introduction to this review is based on the study of a fraction of the extraordinarily extensive literature on Colombian emeralds.
The main part of the paper (Part 2) contains data collected and findings achieved over many years in the SSEF Laboratory in Zurich.
Part 3 deals with the difficulties encountered in identifying treated emeralds and with the disclosure necessary when selling them and will discuss the possibilities of differentiation between Colombian and other natural emeralds and the synthetic emeralds.

Treatments

D. *Oil, ultrasonic and heat treatment*

A few inevitable words to the subject of *'oil treatment'*. Regrettably it is not true that only a small number of Colombian emeralds are improved in appearance. In principle all fractures and fissures are subjected to filling with colourless oils, Canada balsam etc. Success is largely dependent on the quality of the emeralds. Qualitatively good emeralds cannot show an improved appearance simply because they do not possess oilable (surface-reaching) tension cracks. For objective quality assessment, emeralds should be de-oiled before any transaction is finalized (Figure 22). Oil removal is easily achieved with warm acetone. These fracture fillings are not permanent. They readily evaporate or alter in other ways, either chemically or optically (oxidation in air, reaction with alcohol, soapy water, cosmetics etc., Figures 23 and 24). Ultimately there is a general need for subsequent retreatment.

According to laboratory experience, the private owner may be puzzled by the deteriorated appearance of the oiled emerald sold to him as untreated. He may even become annoyed by the slow or sudden 'generation' of shockingly flashing cracks, as he can prove that he did not damage the emerald. The experience with his 'sensitive' emerald can make him so sceptical that he is deterred from buying other gemstones. Any explanation by the jewellery staff after the sale to the effect that oil treatments have long become customary will definitely provide little solace. North-American sales personnel seem to be better trained with respect to disclosure of gemstone treatments than the European trade.

New treatment methods have recently made progress. Open cracks are permanently filled and do not turn turbid (but may appear blue in transmitted light and show orange flashes in reflected light). These techniques make use of artificial resins and hardeners and similar stabilizing substances.

It must be stated that emeralds are not necessarily endangered by the use of *ultrasonics*. Beryls are not more brittle or friable than many other gemstones. They even lack a proper cleavage. The reaction of emeralds to any mechanical stress is dependent – as in the case of oil treatment – primarily on their quality. Every kind of gemstone with definite tension and cleavage cracks presents a higher risk than a fine stone without flaws. But even these can be damaged under extreme circumstances, for instance when a sharp girdle of a diamond baguette exerts pressure on a set emerald (Figure 25).

Emeralds are also no exception when required to tolerate high temperatures (≥700°C), irregular *influence of heat* and thermal shock during jewellery work. The weak basal cleavage in beryl then causes the stone to disintegrate into turbid slices. In these extreme conditions the internal pressure of the fluid inclusions or the intrinsic strain caused by inhomogeneous chemical composition or geotectonic stress can lead to a rupture of the stone. The coloration of emerald by chromium and vanadium, on the other hand, is largely resistant to heat and is not affected by irradiation.

Discussion

E. *Differentiation of Colombian emeralds from other emeralds and emerald substitutes* is easily managed as nearly every Colombian stone shows the characteristic jagged three- and multi-phase inclusions and definite growth structures, has low to (at most) medium refractive index and density values and exhibits no iron spectrum, with the exception of an occasional weak Fe^{3+} line at 374 nm or a trace of the Fe^{2+} band centred at about 800 nm. In addition, the absorption edge at the transition to the general absorption and the absorption minimum in the UV are at extraordinarily low wavelength positions.

However, three- and multi-phase inclusions are by no means found exclusively in Colombian emeralds. Resembling them the most are the healing fissures observed in Afghani and Pakistani emeralds. The expert can usually distinguish the patterns by various details. More effective identification properties of *Pakistani emeralds* are the high refractive index and density values (due to their elevated contents of Fe, Cr and alkalis) as well as the dissimilar mineral and wallrock inclusions (albite and carbonaceous shale in Colombian emeralds and talc, molybdenite, hematite, chromite, magnetite and recently also gersdorffite (NiAsS, cubic) in the Pakistani stones). Pyrite and carbonates are common to emeralds of both mining districts.

A greater problem of identification appear to be the *Afghani emeralds* from the Panjsher Valley, little known up to now. Their inclusions are similar to and their refractive index and density values hardly higher than the Colombian ones. However, the absorption spectrum is clearly different (Figure 4: UV absorption edge and minimum at higher wavelengths, distinct Fe^{3+} band at 374.5 nm plus Fe^{2+} bands at about 840 nm (*o*) and 800 nm (*e*); iron content of the Panjsher emerald of 0.789 ct confirmed by microprobe partial analysis).

The gemmological data of certain *Brazilian and Australian emeralds* are often congruent with those of the Colombian stones. But, because of their different types of inclusions, identification presents no more difficulty than that of emerald imitations (made of Cr-doped YAG, zirconia, glass) or of composite stones (e.g. soudé 'emeralds' made of quartz/green glass/quartz; emerald-green rough made of assembled and dye-filled crystals). On the other hand, modern flux and especially hydrother-

Fig. 23 Covering of oil, fat or Canada balsam on an extended tension crack in a Colombian emerald, transformed into a semi-solid, ugly-looking white crust. Width of photomicrograph about 0.40 mm.

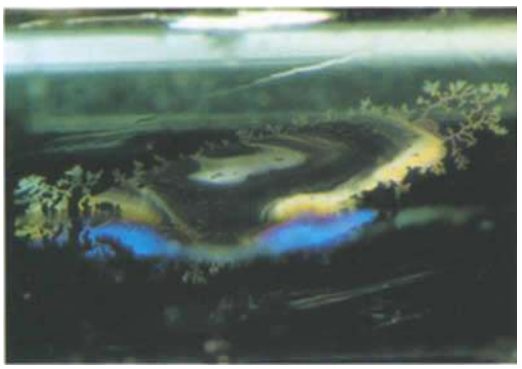


Fig. 24 Iridescent and greenish reflective oil film on a tension crack, in an advanced state of dendritic dessication. The owner of the emerald noticed the puzzling rainbow phenomenon one day with the bare eye. Length of oil film 2.2 mm.

Fig. 25 Extensive irregular breakage caused by the strong unilateral pressure of a diamond baguette on this emerald, formerly a centre stone in a ring. Development of breakage from the point of contact (the asymmetric indentation below the girdle) over the entire left crown side of this Colombian emerald, free from cracks and poor in inclusions. Length of the notch approximately 2.65 mm.

mal synthetics may pose problems which can no longer be solved except with the help of UV/VIS and near- and mid-infrared absorption spectra, chemical analyses and possibly ESR spectra.

While the *determination of origin*, based on the colour and microscopic, chemical and physical properties mentioned above, is comparatively simple for emeralds from Colombia, substantiation of the specific mine is nearly impossible.

Article 5 of the CIBJO Rules (1988) demands an unequivocal declaration as to emerald treatment with coloured oils or the permanent filling of cracks with artificial substances of the new generation.

Evidence of each and every kind of treatment with the microscope and UV lamp is often ambiguous. Iridescent reflection colours, for instance, are not specific: the orange flash on the fissure shown in Figure 13 looks very similar to those from 'Opticon' sealed cracks yet it is not due to this treatment. Systematic application of the CIBJO nomenclature regulations therefore is virtually impossible. Microspectrophotometric cathode-luminescence tests (Ponahlo 1989) could help here if they would facilitate differentiation of the various chemical compounds used.

Metal foils formerly applied to the pavilion of mounted emeralds are rarely encountered nowadays. They have not been durable, just like the modern green lacquers or iridescent coatings on emeralds, and are also recognizable at moderate magnification.

Many gemmologists and gemstone dealers do not appear in a 'moral' position to accept without contradiction the unintentionally broad mineralogical *definition of emerald* plainly as green beryl variety (i.e. without any restriction as to the hues and saturations of green). The author, nevertheless, insists on the fact that small quantities of Cr^{3+} (Al^{3+}oct.), being the cause of the green colour of all type I emeralds, appreciably participate in the coloration of type II emeralds also, due to the greater colouring effect of Cr than V or Fe. If there was a type of green beryl which might not be designated as an emerald, it should only be the V, Fe-beryls, absolutely free of Cr. Because of their chromium traces, most natural vanadium beryls, such as the ones from Eidsvoll (Mjösa Lake, Norway), Emmaville (New South Wales), Salininha (Bahía) or Gandao (Mohmand Agency, Pakistan), must be allocated to the emerald type II and should thus be called emeralds as well.

Acknowledgements

The author thanks the following gentlemen for constructive suggestions: Dr D. Schwarz, Ouro Preto (Brazil), now Idar-Oberstein, Mr W. Schäfer,

Ottobrunn, Dr K. Schmetzer, Munich, Dr W. Quellmalz, Dresden (Germany), Prof. Dr G. Niedermayr, Vienna (Austria), Prof. Dr E. Gübelin, Meggen, Prof. Dr H.A. Stalder, Berne, and Dr H.A. Hänni, Basle (Switzerland). Thanks are returned to the latter for figures 1, 7, 9-12, 14, 15, 19-23 and for the partial EMX analysis of the Panjsher emerald of Figure 4, and to D. Schwarz for the EMX data on the Gachalá emeralds. The author also appreciates the new chemical data on parisite specimens (e.g. on the inclusions pictured in Figure 13) worked out by Prof. Dr W.B. Stern, Prof. Dr R. Guggenheim (Basle) and Dr A. Peretti (Lucerne).

The original article 'Smaragde aus Kolumbien', published in the *Goldschmiede-Zeitung* (Rühle Diebener Verlag, Stuttgart, 1990, nos. 4,6,8), benefitted from the primary English translation by Mrs E. Stern, London, and reviewing of the final updated version by Mr E. Boehm, Los Angeles (presently Lucerne, Switzerland).

Corrigenda

On p.416 above, first column, 4th line, for 'that of chromium Fe^{3+}' read 'that of chromium and Fe^{3+}'.

On p.418 above, second column, line 13, for '(Figure 10)' read '(Figure 16)'.

[*Manuscript received 19 March 1990.*]

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

OBITUARY

Mr Johannes S. Hermans, FGA (D.1981), Delft, The Netherlands, died recently.

Mr Bjarne Jensen, FGA (D.1963), Bergen, Norway, died in October 1990.

Mr Gerald Leybourn-Needham, FGA (D.1980 with Dist.), Aston by Budworth, died in May 1991.

Mr Henry McNeilly, FGA (D.1929), Belfast, N. Ireland, died in February 1990.

Mr Akseli Valta, FGA (D.1973), Helsinki, Finland, died recently.

NEWS OF FELLOWS

On 12 June 1991 **Mr Michael O'Donoghue** gave a talk entitled 'Gemstones' to the Meopham Historical Society.

On 11 to 13 June 1991 **Mr Michael O'Donoghue** and **Mr Peter Reed** lectured at two courses held by the Precious Stone Training Services.

On 13 to 15 September 1991 **Alan Hodgkinson, David Larcher, Sharon Longden** and **Ken Stirton** participated in the National Exhibition of Time held at the British Horological Institute, Upton Hall, Nr Newark, Notts, with an exhibition of gem testing. The event proved to be very successful with a record attendance.

THE GIA INTERNATIONAL GEMOLOGICAL SYMPOSIUM

This very successful event was held in Los Angeles from 20-24 June 1991 in conjunction with the Conclave of the American Gem Society. There were over 1800 representatives (from 45 countries) from the international gemmological fraternity and the jewellery industry. The programme comprised four concurrent feature presentations all day Friday and Saturday with four concurrent panel discussions on the Sunday morning. As with most all-embracing conferences, the problem was to choose which *one* of the simultaneous lectures to attend – all four were always of considerable interest. British input was by K. Scarratt and E.A. Jobbins in the Gem Identification sessions, D.J. Callaghan and R.R. Harding in the Period Jewellery sessions, with K. Scarratt and P.G. Read participating in various Panel Discussions. E. Emms was involved in discussions on Diamond Grading.

For the enthusiastic gemmologist the Poster session provided excellent opportunities to view and to discuss with exhibitors the results of recent research and new discoveries. There were some 90 displays from a wide spread of countries.

To mark the Diamond Jubilee of the GIA, David Callaghan (our Chairman) presented to Bill Boyajian (GIA President) a Herbert Smith refractometer for their collection of historical instruments.

The evening functions were produced in the grand manner and included a fashion show hosted by cultured pearl interests from Japan and America and also a gala 'Maestro and Masterpieces: Italian Jewels of the Opera', a dinner party and display hosted by Italian jewellery organizations and the Platinum Guild International. Beautiful jewels, dresses and models! The overall theme was 'Facing the Future' and every aspect of gemstones and jewellery from the mine to the retail mall was featured. There was something for everyone in this superbly organized extravaganza – congratulations and thanks to the GIA.

MEMBERS' MEETINGS

London

On 2 July 1991 at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, a Pearl Evening was held. Mr Alan Jobbins gave an illustrated lecture on pearls, followed by reports from Nicholas Sturman on pearl testing by X-rays and Alan Clark on the newly devised Pearl Quality Report.

Midlands Branch

On 20 September 1991 at Dr Johnson House, Bull Street, Birmingham, a talk was given by Mr F. Deitch of Mikimoto entitled 'Pearls'.

North West Branch

On 18 September 1991 at Church House, Hanover Street, Liverpool 1, Dr J. Franks gave an illustrated lecture on the Smithsonian Museum.

FORTHCOMING MEETINGS

London

3-4 November 1991 Conference and Presentation of Awards

Meetings will be held at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, on the dates set out below. Full details and topics of lectures will be circulated prior to each meeting.

Tuesday 28 January 1992
Tuesday 10 March 1992
Wednesday 13 May 1992
Tuesday 9 June 1992
Tuesday 24 November 1992

Midlands Branch

Meetings to be held at Dr Johnson House, Bull Street, Birmingham. Further details from David Larcher on 021 554 3871.

15 November 1991	Mr J. Gosling. 'The Guyana Lapidary Project'
17 January 1992	Members' practical evening
21 February 1992	Mr Clive Burch. (Subject to be announced)
20 March 1992	Mr David Callaghan. (Subject to be announced)
10 April* 1992	Annual General Meeting followed by lecture

*NB. This meeting has been arranged for the second Friday of the month because of the Easter holiday.

North West Branch

Meetings to be held at Church House, Hanover Street, Liverpool 1. Full details from William Franks on 061-928 1520.

20 November 1991	Annual General Meeting
15 January 1992	David Pelham. 'On small gold mines'
19 February 1992	Helen Fraquet. 'Amber'
18 March 1992	Dr Jeff Harris. 'An aspect on diamonds'
17 June 1992	'Exchange and Mart'. Buying and selling of books, crystals and instruments, plus social evening
16 September 1992	Adrian Klein. 'Emerald'
21 October 1992	Dr Jamie Nelson. 'Optical attributes of a diamond'
18 November 1992	Annual General Meeting

GEM DIAMOND EXAMINATION 1991

In the 1991 Gem Diamond Examination 28 candidates qualified. The names of the successful candidates are as follows:

Ann M. Allnutt, Chislehurst.
Jose Miguel Bernad Soria, Zaragoza, Spain.
Gloria Blanch Papaceit, Barcelona, Spain.
Liza Boyadjian, London.
Anna Brooks, Watford.
Jose Antonio Casa Royo, Alfaro (La Rioja), Spain.
Ivan L. Charatan, Hackney.
Bruce J. Copestick, Harpenden.
Caroline E. Findlay, Edinburgh.
John Mainwaring Henry, Bolton.
David J. Hollanders, Maidenhead.
Yvonne Holton, Edinburgh.
Ana Ma Lopez Gracia, Barcelona, Spain.
Blancanieves Luzondo Olea, Tolosa (Guipozcoa), Spain.
Eduardo Moreno Rastrero, Logrono, Spain.
Brigitte C.E. Pfeiffer, London.
Trevor Rackley, Northampton.
Anna Ma Ruiz Domenech, Torredembarra, Spain.
Ahad Sayed, Brentford.
Louise Shafar, Glasgow.
Fatehchand Jivanlal Shah, London.
Evelyn Sim, Singapore.
Lesley Skinner, Stenhousemuir.
Stephen Spencer, Nottingham.
Kevin. G. Williams, Edinburgh.
Nean E. Wilson, Longniddry.
Michael Wright, Watford.
Mei Wan Wu, Harlow.

EXAMINATIONS IN GEMMOLOGY 1991

The 1991 Gemmology examinations were held at 62 centres in 26 countries throughout the world. 552 candidates sat the Preliminary Examination of whom 341 (61%) qualified and 429 candidates sat the Diploma Examination and 211 (48%) qualified, 17 with Distinction.

In the opinion of the Examiners, no candidate achieved the high standard required to warrant the award of the Tully Medal.

The **Anderson/Bank Prize** for the best non-trade candidate of the year in the Diploma Examination has been awarded to Peter J. Wates of Coulsdon, Surrey.

The **Diploma Trade Prize** for the best Diploma candidate of the year who derives his main income from activities essentially connected with the Jewellery trade has been awarded to Anura S. Edirisuriya of Dickwella, Sri Lanka.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination has been awarded to Wun Mo Seong of Daejon, Korea.

The **Preliminary Trade Prize** for the best Preliminary candidate of the year under the age of 21 at 1st June 1991, who derives her main income from activities essentially connected with the trade has been awarded to Anne Margaret Bailey of Rugby.

DIPLOMA

Qualified with Distinction

Ma Ester Alvarez-Palacios, Salinas (Asturias), Spain.
Rene Gerard de Winter, Amsterdam, The Netherlands.
Anura S. Edirisuriya, Dickwella, Sri Lanka.
Linda Lee Galloway, Hong Kong.
Rafel Ginebra i Molins, Vic, Spain.
Virginia Hogguer, Alphen aan den Rijn, The Netherlands.
Sandra J. Keating, Willowdale, Ont., Canada.
Alec J. Mason, Retford, Nottingham.
Rajendra A. Pattni, Nairobi, Kenya.
Simon Schmidt, London.
Carolyn L. Stewart, Hong Kong.
Stig E. Sundin, Bergen, Norway.
Peter J. Wates, Coulsdon.
Alison D. Williams, Abinger Common.
Hong Chung Wong, Hong Kong.
Qinfang Xue, Wuhan, China.
Mingxing Yang, Wuhan, China.

Qualified

Arlan R. Abel, Minneapolis, Minn., USA.
Suzanne Adams, Sutton.
Christopher Amo, Williamsville, N.Y., USA.
Evangelia Anastassiou, Maroussi, Greece.
Ekaterini Andersson, Athens, Greece.
Alexander Arbisman, Selsdon.
Henry N. Atkinson, London.
Sang-Duk Bae, Seoul, Korea.
Lisa J. Bailey, Birmingham.
Aristea Bakayianni-Sabou, Athens, Greece.
Chantal Ball Edwards, Cheltenham Spa.
Claire A. Barratt, Gillingham.
Frieda McNaughton-Bascombe, Hong Kong.
Vassilis Bassioudis, Thessaloniki, Greece.
Spencer Benham, Isle of Man.
Colette Z. Bensimon, London.
Benoit Bouvier, Cornwall, Ont., Canada.
Heather K. Boyd, Manchester.
Michelle A. Bradley, Norwich.
Anna Brooks, Watford.
Corrall E. Cage, London.
Daniel Waite Campbell, Bedminster.
Amalia Campomanes Eguiguren, Alicante, Spain.
Begona Campos Novergues, Valencia, Spain.
Andres Candela Alcover, Valencia, Spain.
Bonnie S.K. Chan, Hong Kong.

Chi Keung Raymond Chan, Hong Kong.
Nga Yee Chan, Hong Kong.
Mahaveer Singh B. Chauhan, Jaipur, India.
Kit Ling Connie Cheng, Hong Kong.
Siu Hing Cheng, Hong Kong.
Roy Shuk-Hung Chiu, Hong Kong.
Kam King Chow, Hong Kong.
Ourania Christaki, Volos, Greece.
Terence Y.W. Chu, Hong Kong.
Sucheta M. Chudawala, Bombay, India.
Tsz Kin Chung, Hong Kong.
Tony Cipriani, St Laurent, Quebec, Canada.
Sarah E. Clifton, Birmingham.
Janette M. Colborne, Brisbane, Qld., Australia.
Mark A. Colingwood, Bradford.
Stephanie Collins, New Malden.
Ian Combe, Haddington.
Martha D'Alessandro, Rio de Janeiro, Brazil.
Gamini De Silva, London.
P.V.D.P.R.F. Neelamanee De Silva, Moratuwa, Sri Lanka.
Stuart G. Dennis, London.
Ahsha Devnani, Kuala Lumpur, Malaysia.
Pablo Dhir, Nairobi, Kenya.
Setu Hasmukh Doshi, Bombay, India.
Valerie S. Egner, London.
Dora Pang English, Hong Kong.
George G. Evangelou, London.
Deborah Everest, Aldershot.
Carita L. Falck, Helsinki, Finland.
Lucia Ferrer Mas, Alicante, Spain.
Robert H. Fixter, Lincoln, Nebr., USA.
Sara E. Flint, Leeds.
Pui Man Foo, Hong Kong.
Brenda C. Foster, St. Albans.
Neil Franklin, Newcastle-upon-Tyne.
David E. Fromming, Aylesbury.
Hideali Fukushima, Tokyo, Japan.
Chung Min Newson Fung, Hong Kong.
Bauke G. Gaastra, Leiden, The Netherlands.
Lal Gajadeera, Boralesgamuwa, Sri Lanka.
Robert Ben-rong Gau, Taipei, Taiwan, China.
Elizabeth Georgiadou, Volos, Greece.
Maria K. Ghisi, Athens, Greece.
Sophia Gofa, Athens, Greece.
Enrique Gomez Lopez, Zaragoza, Spain.
Miranda J. Grant, Edinburgh.
Alan A. Green, Kidlington.
Christopher M. Green, Slough.
Rajasinghe S. Gunasekara, Colombo, Sri Lanka.
Wai Ming Ha, Kowloon, Hong Kong.
Rebecca Mary Anne Hare, Fleet.
Adrian L. Hendry, Stansted.
Peter G.A. Hobbs, Lavenham.
Elisabeth G. Hoogendoorn, Houten, The Netherlands.
Charlotte T. Hunter, Northampton.
Jacqueline Ichniowski, Ellicott City, Md., USA.
Yuko Ito, Kanagawa-ken, Japan.
Neerja Jain, Birmingham.
Thomas Ake Jakobsson, Huddinge, Sweden.
Cynthis C.V. Jameson, Bethesda, Md., USA.
Bindu Kejriwal, London.
Abdul Jabbar Khan, Bombay, India.
Priti Khimji, London.
Andree Killias, Hong Kong.
Hiroyuki Kimura, Tokyo, Japan.
Margaret A. King, Isle of Lewis.
Pik Sim Kwan, Hong Kong.
Mui Lak Margaret Lai, Hong Kong.
Jose Lajara Lopez, Valencia, Spain.
Radka Lalovska-Koundourou, Athens, Greece.
Kwong Ki Lam, Hong Kong.
Christina Keturah Lam-Pakstun, Brisbane, Qld., Australia.
Yan Wah Glady Lau, Hong Kong.
Mee Sim Lucia Maisie Lau, Hong Kong.
Carl Laurie-Lynch, Birmingham.
Padraic Lavin, Ballaghaderreen, Eire.
Isabelle Leblans, Ottignies, Belgium.
King To Lee, Hong Kong.
Mary F.A. Lee, Addlestone.
Annette I. Lehnert, Tiefenbach, Germany.
Janine Lentz, Veenendaal, The Netherlands.
Wing Sum Leung, Hong Kong.
Kam Yui Dick Li, Hong Kong.
Shang I. Liu, Hong Kong.
Mo Yu Lo, Kowloon, Hong Kong.
Ann Denise Long, Colchester.
Kok On Loong, Butterworth, Malaysia.
David C. McConnachie, Glasgow.
Katsuya Maeda, Kakogawa-shi, Japan.
Wing Han Windy Mak, Hong Kong.
Carina Manjavacas Canego, Barcelona, Spain.
James Gerard Mansfield, London.
Susana Marti Muntane, Barcelona, Spain.
Jacqueline N. Mathieson, Edinburgh.
Hiroshi Matoba, Nara-City, Japan.
Lisa Matthews, London.
Shilpa Mehra, London.
Reshma Mehta, Hong Kong.
Azmet F. Merchant, Bombay, India.
Mark Michallat, Shipley.
Beverly Mitchell, London.
Silvia Molera Reig, Barcelona, Spain.
Junko Mori, Hyogo Pref, Japan.
Stephanos Mourogiannis, Athens, Greece.
Hilda May-Mei Mueller, Karlsruhe, Germany.
Chee Keong Ng, Hong Kong.
Tahmineh Nikookar, West Vancouver, Canada.
Theresa A. Nolet, Sault Ste Marie, Ont., Canada.
Felipe Ortega Pino, Valencia, Spain.
Mamiko Oura, Tokyo, Japan.
Shing Chung Dominic Pang, Hong Kong.

Roy John Pasini, N. Olmsted, Ohio, USA.
Pankaj Patel, London.
Sharon M. Peers, London.
Keith Penton, London.
Ma Angeles Pi Gregorio, Barcelona, Spain.
Richard J. Pool, York.
Cecilia Pople, Guildford.
Claire A. Redgrove, Selsey.
Janine Reimers, Johannesburg, S. Africa.
(Lesley) Clare Rigby, Bolton Abbey.
Ma Paz Roca Tudela, Valencia, Spain.
John W.S. Rogers, Stroud.
Neva Devi Rohmer, Hong Kong.
Alan F. Rowlands, Calgary, Alta., Canada.
Samuel J. Sabbagh, London.
Steven E. Sabbagh, London.
Tarja Aulikki Salmi, Helsinki, Finland.
Ramon Sanahuja i Ribo, Barcelona, Spain.
Jeannine Sanchez Comerma, Alicante, Spain.
Elisenda Santacreu Rull, Lleida, Spain.
Judy Shalvi, Hong Kong.
Yasushi Shinjo, Osaka, Japan.
Charlotte R. Simmons, Huntingdon, Md., USA.
Riita M. Spencer, Helsinki, Finland.
Hirofumi Takano, Toshimo-ku, Tokyo, Japan.
Mari Takeda, Tokyo, Japan.
Carol S. Tamblin, Liskeard
Ay Lin Tan, Penang, Malaysia.
Takako Tanigaki, Osaka City, Japan.
Audrey Tees, Glasgow.
Lucilla Thomas-Everard, London.
Sui Ching Tsang, Hong Kong.
Miwako Tsuda, Takarazuka City, Japan.
Kazuo Tsurita, Osaka, Japan.
Ma Victoria Uriarte Terol, Alicante, Spain.
Ma Victoria Uribe Molto, Alicante, Spain.
Hester van den Haak, Krimpen A/D Yssel, The Netherlands.
Michael J. Vaughan, Budleigh Salterton.
Vivianne M.M. Veenemans, Arnhem, The Netherlands.
Marco Vesters, s'Hertogenbosch, The Netherlands.
Mark Waller, Bradford.
Keith Walter, Peebles.
Simon J. Washbrook, Manchester.
Caron J. Wasserman, London.
Kathleen Webster, London.
Lizanne Welch, Taunton.
Andrew Wells, Banstead.
Eddy Wenting, Wehl, The Netherlands.
Siu Por Wong, Hong Kong.
Kit Yee Kitty Yeung, Hong Kong.
Machiko Yonehara, Hyogo Pref, Japan.
Marie-Claire M. Zander, Sao Paulo, Brazil.
Rafal Zebrowski, Toronto, Ont., Canada.
Linxia Zhang, Wuhan, China.
Fan Zhang, Wuhan, China.
Xinmin Zhao, Wuhan, China.
Johannes C. Zwaan, London.

PRELIMINARY

Qualified

Veli Sakari Aalto, Nairobi, Kenya.
Erling Skaar Aasen, Molde, Norway.
Sheik Rashid Ahmed Al-Kalifa, Bahrain.
Pedro A. Alcolea Rubio, Cartagena, Spain.
Nick Aldridge, Gravesend.
Julie A. Alford, Taunton.
Debra Arden, Ashton under Lyne.
Michael J. Armstrong, Whitley Bay.
In-Ryul Bae, Seoul, Korea.
Jin Yee Baek, Daejon, Korea.
Vinod K. Baid, London.
Anne M. Bailey, Rugby.
Maj-Britt Baker, Hove.
Frederik C.S. Bakker, Zwaagdijk, The Netherlands.
Pamela J. Ball, Hong Kong.
Michelle Banks, Exeter.
Frieda McNaughton-Bascombe, Hong Kong.
David A. Beavan, Bournemouth.
Victoria L. Bedwell, London.
Michelle L. Bellamy, Swansea.
Ma Dolores Belmonte Monino, Murcia, Spain.
Maria Benissi, Athens, Greece.
Deli A. Boerema, Beek en Donk, The Netherlands.
Cristian Bou Dominguez, Castellon, Spain.
Christine L. Bradford, Hassocks.
Nikki Bradford, Hassocks.
Antonio Brenes Lanza, Valencia, Spain.
Jordi Bruguera De La Pena, Barcelona, Spain.
Susan M. Buncher, Tai Po, NT, Hong Kong.
Denis Burrow, Gravesend.
Jae Kyoung Byun, Seoul, Korea.
Beverley A. Capper, Paignton.
Stuart M. Carter, Bristol.
Rafael Casal Bordes, Valencia, Spain.
Seung Yuen Samuel Chan, Hong Kong.
Wai Pin Chan, Hong Kong.
Kwai Hing Chan, Hong Kong.
Kwei Wing Fion Chan, Hong Kong.
Nga Yee Chan, Hong Kong.
Chan Siu Lily Chan, Hong Kong.
Hang Chau, Hong Kong.
Shun Chung Chau, Hong Kong.
Susannah Chenevix-Trench, Hong Kong.
Pin Hoo Cheng, Hong Kong.
Chi Ho Cheung, Hong Kong.
Kam Kwan Cheung, Hong Kong.
Mei Ping Liann Cheung, Hong Kong.
Laura Chiampesan, London.
Oi Han Esther Chin, Hong Kong.
Hang Sun Cho, Daejon, Korea.

Kyu Hyeon Cho, Daejon, Korea.
Yong-Sang Cho, Seoul, Korea.
Dong-Geun Choi, Seoul, Korea.
Kyung Sug Choi, Kwangju, Korea.
Meyeoung Yeoung Choi, Daejon, Korea.
Seog Hoon Choi, Kyungju, Korea.
Sook Kyong Choi, Pusan, Korea.
Pui Wing Choi, Hong Kong.
Chun Hung Chow, Hong Kong.
Shui Wah Chow, Causeway Bay, Hong Kong.
Lai Ying Chow, Hong Kong.
Wai Mui Chow, Hong Kong.
Philip J. Chown, Sevenoaks.
Helen E. Christian, Bolton.
Josephine A. Clayton, London.
Joseph Connelly, Edinburgh.
Carolyn Cooper, Hong Kong.
Ann Cordery, London.
Chusri Cox, Hove.
Jeremy P. Crabbe, Hong Kong.
Marta Crespo Vilaro, Barcelona, Spain.
Virginia Gai Cullen, Nairobi, Kenya.
DeeDee Cecilia Cunningham, Toronto, Ont., Canada.
Nita Daryanani, Hong Kong.
Frederic P. Daubechies, London.
Bryn Day, Oldham.
Kees de Boer, Beek (Ubbergen), The Netherlands.
Laurenria Melissa de Jongh, The Hague, The Netherlands.
Luisa De La Torre Lopez, Tarragona, Spain.
Asha Devnani, Kuala Lumpur, Malaysia.
Rosemary O. Dharmaratne, Colombo, Sri Lanka.
Birgit W.M. Doesborg, Schoonhoven, The Netherlands.
Setu Hasmukh Doshi, Bombay, India.
Lucy N. Downing, Fulham, London.
Alison Earnshaw, Tonbridge.
Siripala Edirimannege, Colombo, Sri Lanka.
Michelle L. Embleton, Basildon.
Gail Emslie, Hong Kong.
Nora Engel, Geneva, Switzerland.
John W. Faithfull, Leicester.
Joaquim Falco Rovira, Llanca, Spain.
Charoulla Fantis, Bethnal Green, London.
Abigail A. Farley-Howson, Aylesbury.
Juan J. Fernandez Jativa, Alicante, Spain.
Marisa Fernandez Perez, Barcelona, Spain.
James Clark Fernbach, Schenectady, New York, USA.
H.W.J. Fleuren, Polsbroek, The Netherlands.
Melissa Friedland, Omaha, Nebr., USA.
Suzy Fry, London.
Mary Mei Ling Fu, Hong Kong.
Ho Cheuk Fung, Hong Kong.
Arlen Der Garabedian, Hackney, London.
Pilar Garrigosa Laspenas, Barcelona, Spain.
Noel R. Geoghegan, Wellesbourne.
Anastasis L. Georgiou, Famagusta, Tricomo, Cyprus.
Stavros Georgiou, Lefkara, Cyprus.
Rafel Ginebra i Molins, Vic, Spain.
Valerie J. Goddard, Alford.
Francis G. Gray, Edinburgh.
Janette F. Green, Binley, Coventry.
Pauline Groeneveld, Giessenburg, The Netherlands.
Ilse C. Grondahl, Helsinki, Finland.
Yu Guimei, Wuhan, China.
Winfried Gutmannsbauer, Allschwil, Switzerland.
Wai Ming Ha, Kowloon, Hong Kong.
Sabine Haberli, Bottmingen, Switzerland.
Andrew D. Haigh, Nettleham.
Ingvald Harkestad, Bergen, Norway.
Richard J. Harris, Carlisle.
Orit N. Hayes, Manchester.
Jennifer V. Henricus, Hong Kong.
Suzanne C. Hicks, Yardley, Birmingham.
Po Mi Avis Ho, Hong Kong.
Jeung Hee Hong, Taegu, Korea.
Xie Hongzhi, Wuhan, China.
Sadayuki Hoso, Osaka City, Osaka, Japan.
Mark Hudson, Ickenham.
Helen S. Hughes, London.
Chak Lun Hui, Hong Kong.
Stephen J. Humphreys, Biggin Hill, Westerham.
Kyu-Young Hwang, Seoul, Korea.
Mi Hee Hwang, Daejon, Korea.
Soon Sun Hwang, Pusan, Korea.
Hiroyoshi Ishida, Takatsuki, Osaka, Japan.
Takeshi Iwata, Hyogo Pref, Japan.
Cynthis C.V. Jameson, Bethesda, Md., USA.
Myung Won Jang, Seoul, Korea.
D.A. Jayananda, Colombo, Sri Lanka.
Steven L. Jordan, Boston.
Julia Kalinin, Ealing, London.
Che Mei Kam, Hong Kong.
Hyun Sook Kang, Daejon, Korea.
Joo-Yeun Kang, Seoul, Korea.
Kyung Sil Kang, Pusan, Korea.
Kiron Kapila, Nairobi, Kenya.
Niilo Karkkainen, Espoo, Finland.
Sandra J. Keating, Willowdale, Ont., Canada.
Chen Kesheng, Wuhan, China.
Hee Souk Kim, Chonan, Korea.
Hei Jong Kim, Seoul, Korea.
Jee Sue Kim, Daejon, Korea.
Jong Pil Kim, Daejon, Korea.
Myoung Sub Kim, Taegu, Korea.
Apostolia Kiroudi, Athens, Greece.
Jacoba E. Klaassen-de Ruiter, Waddinxveen, The Netherlands.
Garfield D. Kneebone, Penzance.
Anya K. Koetsier, London.

Peter A. Kohn, Oxford.
Sarah Joy Ku, Hong Kong.
Leena Kuumola, Stockholm, Sweden.
Chi Ming Kwan, Hong Kong.
Ho Taeg Kwon, Pusan, Korea.
Anna-Maiji Lahtela, Hamina, Finland.
Tim Mui Lai, Hong Kong.
Sai Mui Lai, Hong Kong.
Yi Oi Lai, Hong Kong.
Tuovi Tellervo Laiti, Lahti, Finland.
Pun Ho Lam, Kowloon, Hong Kong.
Ka Loi Celine Lam, Hong Kong.
Suet Lai Lam, Hong Kong.
Yik Him Lam, Hong Kong.
Bernard Lang, Basel, Switzerland.
Barry Larkins, London.
Jorgen Larsen, Lannavaara, Sweden.
Hok Keung Lau, Hong Kong.
Ying Chi Lau, Hong Kong.
So Sum Angelina Jessica Law, Hong Kong.
Isabelle Leblans, Ottignies, Belgium.
Hyeon Jin Lee, Daejon, Korea.
Hyung Jeong Lee, Daejon, Korea.
Siu-Kuen Lee, Kowloon, Hong Kong.
Sook Jin Lee, Daejon, Korea.
Sun Sook Lee, Daejon, Korea.
Yong Woo Lee, Daejon, Korea.
Young Mee Lee, Daejon, Korea.
Ossi A. Leinonen, Viantie, Finland.
Michael T.Y. Leung, Hong Kong.
Man Tai Raymond Leung, Hong Kong.
Lai Ping Leung, Hong Kong.
Aggeliki Leventopoulou, Kalamaki, Athens, Greece.
Shek Kee Li, Hong Kong.
Soung Taek Lim, Seoul, Korea.
Ravindranath Liyanage, Colombo, Sri Lanka.
Mo Yu Lo, Kowloon, Hong Kong.
Sara Anne-Marie Lodge, Birmingham.
Kok On Loong, Butterworth, Malaysia.
Roberto Lopez De Alda-Saez, Tarragona, Spain.
Angel Manel Lopez i Calvo, Reus (Tarragona) Spain.
Cho Lin Arlene Luke Ting, Hong Kong.
Jane F. Luxton, Bath.
Edward J. McCarthy, Cambridge.
Malini P. McDonald, Tampa, Fla., USA.
Suzanne M. McDonald, Edinburgh.
Neil Reid McFarlane, Alloa.
Jane McIlleron, Bedfordview, S. Africa.
Jonathon N. McLelland, Bradford.
Janet E. McQueen, Lurgan, Co Armagh.
Chris M. Makoundoul, Stockholm, Sweden.
James G. Mansfield, London.
Luis Fernando Martinez Caravaca, Barcelona, Spain.
Juan Carlos Martinez Vela, Jumilla, Spain.
Stephen R. Mason, Birmingham.
Shilpa Mehra, London.
Reshma Mehta, Hong Kong.
Aiden Melarkey, Northampton.
John J. Melinn, London.
Samuel P. Meza, Glasgow.
John O. Mitchell, Istanbul.
Shuji Morikawa, Osaka City, Osaka, Japan.
Ma Dolores Morillo-Verlarde Taberne, Barcelona, Spain.
Brian A. Morris, Oswestry.
Kyung Ju Na, Daejon, Korea.
Liisa Nevalainen, Espoo, Finland.
Frances Newman, London.
Soon Hoh Ng, London.
Kwok Yin Ng, Hong Kong.
Tahmineh Nikookar, West Vancouver, BC, Canada.
Theresa A. Nolet, Sault Ste Marie, Ont., Canada.
Anthony L. O'Shea, Ruislip.
Graham A. Oakley, Wrangbrook, Pontefract.
Gemma Oldfield, London.
Ma Isabel Olias Pertusa, Barcelona, Spain.
Maung Thein Lwin Oo, Singapore.
Michele J. Orsi, London.
Antonio J. Ortega Marin, Cieza, Spain.
Bing Pang, Hong Kong.
Kyung Ok Park, Seoul, Korea.
Mi Kyeong Park, Pusan, Korea.
Jagdish Ishverbhai Patel, Wimbledon, London.
Rekha Mahesh Patel, Nairobi, Kenya.
Rajesh Jamnadass Pattni, Eldoret, Kenya.
Andrea Pawlyna, Hong Kong.
Elise E. Peios, Kingswood.
Monica Pereda Soler-Cabot, Barcelona, Spain.
Rosa Maria Perez Merchante, Valencia, Spain.
Maria Perpina Bomboi, Valencia, Spain.
Cecilia Pople, Guildford.
Jagdish Prajapati, London.
Susanne L. Preece, Trowbridge.
Louise C. Prior, London.
Graham S. Proffitt, Liverpool.
Julian Read, Goole.
Keith C. Reffell, Barnhurst.
Paul R. Rietveld, Bergen Op Zoom, The Netherlands.
Claudia J. Rijkelijkhuizen, Bosch en Duin, The Netherlands.
Chantal Rochat-Huguenin, Lausanne, Switzerland.
Franklin Rodriguez Ortiz, London.
Aarto Roppanen Tohmajarvi, Finland.
Ma Teresa Ros Gonzalez, Barcelona, Spain.
Ramon Rossell Ma Andorra La Vella, Spain.
John T. Rossiter, Weston-Super-Mare.
Ignasi Rubio Barris, Girona, Spain.
Kyeong Won Ryu, Daejon, Korea.
Ali Mohammed Safar, Bahrain.
Francesc Sancho Montserrat, Saut Bol de

Llobregat, Spain.
Jose Luis Santolaya, Barcelona, Spain.
Katja C. Schneider, East Twickenham.
Tay Sun See, Hong Kong.
Joung Hee Seo, Daejon, Korea.
Wun Mo Seong, Daejon, Korea.
Clara Ma Serra Molla, Valencia, Spain.
Nuria Serret-Pinacho, Barcelona, Spain.
Kul Bhushan Sharma, Lusaka, Zambia.
Hyun Kwon Shin, Daejon, Korea.
Wai Chung Siu, Hong Kong.
Cornelis Slui, Krimpen A/D Ijssel, The Netherlands.
Brendon James Smith, Swindon.
Chak Tong Anthony So, Hong Kong.
Jeong Sun Sohn, Seoul, Korea.
Gary Spanbok, London.
Riita M. Spencer, Helsinki, Finland.
Robert J. Stainton, Edinburgh.
Nick Stamatiadis, Athens, Greece.
Jonathon P. Stoner, Bradford.
Elizabeth Strachan, London.
Josephine Stuifzand, Twello, The Netherlands.
Hideko Sugihara, Osaka, Japan.
Ay Lin Tan, Penang, Malaysia.
Kati Tarma, Helsinki, Finland.
Maja Clarissa Te Velde, Langerak, The Netherlands.
Elizabeth Thompson, Leeds.
Bjorn T. Thorbjornsen, Bergen, Norway.
Johanna H. Thuis, Schoonhoven, The Netherlands.
Maria M. Tiilikainen, Ireland.
Sebastia Timoner Espuga, Terrassa, Spain.
Darren M. Topham, Brighton.
Peter J.B.C. Travis, London.
Ki Lun Allan Tsang, Hong Kong.
Wai Mo Tse, Hong Kong.
On Na Anna Tse, Hong Kong.
Kwok Wing Tse, Hong Kong.
Maria Tsipoura-Vlachou, Athens, Greece.
Keith A. Tucker, Ilkley.
William J. Tucker, Douglas, Isle of Man.
Lonneke van der Hulst, Krommenie, The Netherlands.
Geertruida J. Van Hillo, Almere-Buiten, The Netherlands.
Simone J.C. Van Keulen, Amsterdam, The Netherlands.
Hans T. Van Lamoen, Hertogenbosch, The Netherlands.
Lorraine Van Papen, Guildford.
Vasso Vassilakou, Athens, Greece.
John Vaughan, London.
Michael Vaughan, Whitby, Ellesmere Port.
Alida J. Velthoven, Uven, The Netherlands.
Miguel Angel Vila Llopis, Alzira (Valencia), Spain.
Errol J. Walker, Oldham.
Simon J. Washbrook, Manchester.
Caron J. Wasserman, London.
Maria J. Weisenborn, Den Bosch, The Netherlands.
Isabel H. White, Tunbridge Wells.
Cas Jelle Wiebinga, Amsterdam, The Netherlands.
Angelique C. Wijne, Schoonhoven, The Netherlands.
Catharina A.H. Winkelmolen, Schoonhoven, The Netherlands.
Man Yee Bess Wong, Kowloon, Hong Kong.
Ming Kin Wong, Hong Kong.
Miu Wan Mueller Wong, Hong Kong.
Jei-Sung Woo, Seoul, Korea.
Bik Yee Liza Woo, Hong Kong.
Yin Yung Wu, Hong Kong.
Zhang Yabin, Wuhan, China.
Young Mee Yi, Daejon, Korea.
So Ying Yin, Hong Kong.
Yoichi Yoshikawa, Kobe-shi, Hyogo Pref, Japan.
Byeong Mi Youn, Seoul, Korea.
Kwai Lan Catherine Yu, Hong Kong.
Chai Hung Teresa Yuen, Hong Kong.
Sun Ki Yun, Seoul, Korea.
Tak Yi Yung, Hong Kong.
Fabrizia Zanettin Barbin, Geneva, Switzerland.
Rafal Zebrowski, Toronto, Ont., Canada.
Liu Zhao, Wuhan, China.
Johannes C. Zwaan, London.

MEETING OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 12 June 1991 at E.A. Thomson (Gems) Ltd, Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship
Fan, Siu-Kam, Kowloon, Hong Kong. D.1989
Kangas, Anne K., Helsinki, Finland. D.1990.

Ordinary Membership
Cattell, Nicla M.L.V., Kettering.
Corbett, John A., Edgbaston.
Daryanani, Nita, Hong Kong.
Emmett, John L., Pleasanton, Calif., USA.
Pakzad, Mohammad A., London.
Parkinson, Frederick, Leighton Buzzard.

At a meeting of the Council of Management held on 17 July 1991 at 1 Burlington Gardens, London W1X 2HP, the business transacted included the election to membership of the following:

Fellowship
Reveliotis, Christos, Athens, Greece. D.1990.

Ordinary Membership
Ben-Zur, Eitan, London.
Carter, Stuart M., Bristol.
Cerins, Andris, Cambridge.
Comersford, Jessie, Alexandria, Egypt.
Grossman, Julie F., Hounslow.
Gunasekara, S., Boulder, Colo., USA.
Halai, Amy, Solihull.
Kassam, Sultan M., London.
Koundourou, Ratka, Athens, Greece.
Prajapati, Jagdish, London.

At a meeting of the Council of Management held on 21 August 1991 at 27 Greville Street, London EC1N 8SU, the business transacted included the election to membership of the following:

Ordinary Membership
Berreux, Cedric, La Chaux-de-Fonds, Switzerland.
De Granville, Francesca, Oklahoma City, Okla., USA.
Denson, Keith, Oldham.
Fox, Rosemary T., Brighton.
Gautama, Surinder, Ilford.
Milne-Buckley, Deborah J., Chertsey.
Salama, Susan F., Beckenham.
Schlussel, Joseph L., New York, NY, USA.
Thorbjornsen, Bjorn T., Bergen, Norway.
Tillakaratne, Adikari M.N.K., Kano, Nigeria.

Transfers – FGA to FGA, DGA
Allnutt, Ann M., Chislehurst. D.1962.
Boyadjian, Liza A., Heston, D.1989.
Charatan, Ivan L., London. D.1990.
Copestick, Bruce J., Harpenden. D.1990.
Findlay, Caroline E., Edinburgh. D.1988.
Henry, John M., Bolton D.1990.
Hollanders, David J., Nelson. D.1990.
Holton, Yvonne, Edinburgh. D.1986.
Pfeiffer, Brigitte C.E., Isleworth. D.1989.
Rackley, Trevor, Brackley. D.1990.
Shafar, Louise, Eaglesham. D.1990.
Sim, Evelyn, London. D.1990.
Skinner, Lesley, Stenhousemuir. D.1990.
Spencer, Stephen R., Woodborough. D.1990.
Williams, Kevin G., Edinburgh. D.1983.
Wilson, Nean E., Longniddry. D.1990.
Wright, Michael J., Watford. D.1990.

Transfers – Ordinary Membership to Diamond Membership
Blanch, Gloria, London.
Brooks, Anna T., Watford.
Sayed, Ahad, Brentford.
Shah, Fatechand J., London.
Wu, Mei W., Harlow.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 4 July 1991 at 87 Hatton Garden, London EC1, the business transacted included the election to membership of the following:

Gold Laboratory Membership
Roselaar & Co., c/o LDB, 100 Hatton Garden, London EC1N 8NX.
Bernard Schipper BV, Kalverstraat 36-38, 1012 PD Amsterdam, The Netherlands.
Richard Shepherd & Co., Suite 123, 100 Hatton Garden, London EC1N 8NX.

Ordinary Laboratory Membership
Charles Mathews (Lapidaries) Ltd., 7 Hatton Garden, London EC1N 8AT.

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.

Volume 22 No. 8. October 1991

The Journal of Gemmology

Contents

ISSN: 0022-1252

Produced by Green Belt Studios: Printed by Quadrant Offset, Hertford, England.

Volume 22 Numbers 1-8 1990-1991

The Journal of Gemmology

VOLUME 22
NUMBERS 1-8
1990-1991
INDEX

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Journal of Gemmology

VOLUME 22

NUMBERS 1-8 1990-1991

CONTENTS

INDEX

Compiled by Christine Woodward

Alphabetical arrangement is letter-by-letter.
Names of authors are printed in capitals, pages of abstracts and book reviews in italics.
Special usages:
above and *below* in cross-references indicate that the reference is to another subheading under the same heading, not a separate heading.
A number in brackets following a page number indicates that there is more than one reference to the subject on the page.

THE
GEM DIAMOND DIPLOMA

GAGTL have brought together the finest minds in the world of diamonds to produce the most comprehensive Gem Diamond home study course available. The course acknowledges the professionalism of the international diamond market and includes every aspect of gem diamond you will ever need to know.

Following an examination in theoretical knowledge and practical application – including grading of polished and rough, you may gain the Gem Diamond Diploma and be entitled to the special Diamond Membership of GAGTL. With DGA after your name your professionalism will be obvious for all to see

For further information please contact Louise Macdougall on 071-404 3334, or complete the reply form below.

To GAGTL Education Department, 27 Greville Street, London EC1N 8SU
Please send me details and an application form for the Gem Diamond Course.

Name:_____

Address:_____

_____

_____

_____

_____ Telephone: _____ JG 4/92

ISSN: 0022–1252

Produced by Green Belt Studios: Printed by Quadrant Offset, Hertford, England.