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Blue euclase from Zimbabwe – a review

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ABSTRACT: Blue euclase from Mwame, Hurungwe District, Zimbabwe, which was first collected in the late 1970s has recently been available for study. This paper presents information on mineral inclusions for the first time and the complex surface morphology of the crystals is shown in a series of photomicrographs.

Keywords: euclase, inclusions, pegmatite, Zimbabwe

Introduction

Euclase, a rare beryllium mineral ($\text{BeAlSiO}_4(\text{OH})$), occurs worldwide as a late-stage hydrothermal mineral often associated with beryl and other beryllium minerals in a variety of host rocks, usually quartz veins, granitic pegmatites or greisens.

Although euclase can occur as a primary mineral, more usually it is secondary in origin formed by replacement of other beryllium minerals.

First recorded from Brazil in 1785 (Dana, 1892; Bastos, 1969), euclase has been found more recently from sources in Colombia, Russia, Tanzania and Zimbabwe; spectacular crystals have been described from all these localities. Of less importance gemmologically, occurrences with small crystals or non-transparent types of euclase have been recorded from New Zealand, USA (Sharp, 1961), Europe, Guyana, Sri Lanka (Deen, 1984), Kashmir, Mozambique, Uganda and Namibia.

Euclase occurs in a range of colours including pale green, pale to medium blue, medium greenish blue, pale yellow and colourless; the gemmological interest in the crystals from Zimbabwe is for the deep azure colour.

Euclase in Africa

Tanzania

Spencer (1934) first described euclase from Africa. Spectacular crystals were found with quartz in pegmatite at Lukangasi Mica Claims, 8 km south of Mikese Station, Morogoro District. The largest of these crystals measuring 72 x 38 x 35 mm (*b* axis direction) is in the collection of the Natural History Museum, London. It is described as being white and cloudy but bluish green and transparent on the face parallel to *b*. Other crystals were sold in the 1930s to collections in the USA (Pough, 1991; *see also* Dirlam *et al.*, 1992; McKie, 1955).

Mozambique

A reference to the occurrence of euclase from Muiane pegmatite, Alto Ligonha District, was made by von Knorring *et al.* (1964). This pegmatite was mined for microcline and tantalite and was an important source of gem beryl, producing both aquamarine and pink beryl; it was also noted for giant crystals of microcline. Two crystals, apparently similar in morphology to the Zimbabwean euclase were described, one was used for analysis, and the other reportedly weighed about 20 gm. No



Figure 1: Partial euclase sheath on beryl crystal.
Photo: E.A. Jobbins

information was given about the accompanying minerals or the paragenesis of the euclase.

Namibia

A report by Beyer (1980) described colourless to slightly yellow crystals up to 5 mm long from Spitzkopje. The euclase grew freely on microcline together with quartz, green feldspar, fluorite, and the other beryllium

Figure 2: Group of euclase crystals, each about 10 mm across. Photo: E.A. Jobbins



minerals, herderite and bertrandite. Beyer inferred that the euclase formed after a first generation of beryl but was older than the tabular crystals of bertrandite. The associated euclase and herderite showed no signs of etching or dissolution and euclase was not considered to be the source of beryllium for a younger generation of beryl (aquamarine) which also occurred in the pegmatite.

Uganda

In a report by von Knorring (1962) on the mineralogy of pegmatites in Uganda, euclase was recorded in the Namapherere tin mine, Ankole. Beryl is a common minor constituent in all the pegmatites mined in south-west Uganda and at Kihandu mine, an unusual form of beryl with acute bipyramidal form has been pseudomorphed by muscovite and albite together with crystals of clear flaky bertrandite. No further information was found on this locality.

Zimbabwe

Euclase has been found in several of the pegmatites mined for mica since the 1920s and for beryl since the 1950s in the Mwame area 19 km NNE of Karoi, in northern Zimbabwe (Figures 1, 2, 3 and 4). These occurrences are described in more detail in this paper.

Euclase in Zimbabwe

History

Euclase was first recorded in Zimbabwe in 1952, from a location 16 km east of Mwame (Geological Survey, 1952) and again (Wiles, 1961) where it is mentioned in a review of the economic minerals of the Mwame Mica Fields, Hurungwe District. Mwame was formerly known as Miami, Urungwe District, Rhodesia or Southern Rhodesia; most references cited give the earlier names, which are used in this paper where relevant. Euclase is one of a group of rare beryllium minerals that had been found in pegmatites in this area; hurlbutite and herderite occur in the Grand Slam Beryl mine, phenakite in an unnamed beryl working and chrysoberyl in the Renda mine. No bertrandite

has been recorded. Only chrysoberyl and euclase have been exploited commercially.

The crystal aggregates and faceted gems of blue euclase described in 1978 (Gübelin) 1980 (Anderson) and in this paper, came from the Last Hope claims located on Haslemere and Momba Estates 13 km NNE of the town of Karoi. Recent information unsupported by geological reports refers to the production of some euclase specimens from the MWM claims, Haslemere and Momba Estates and from Trim, Mukwichi District. Both localities are within the general Mwame area. Samples of euclase at the Geological Museum, Harare, are recorded from the Eurythmic and Lion Hill claims, situated N and NNW of Mwame; the euclase from Last Hope claims, however, remains the most significant source for the blue variety.

Euclase specimens displayed in mineral collections at the Natural History Museum, London, and the National Museum of Scotland in Edinburgh, originate from the Last Hope claims.

Geology

The country rocks are sillimanite gneisses and sillimanite garnet schists; formed by high-grade metamorphism of former argillaceous sediments of the mid-Precambrian Piriwiri supergroup. There have been several metamorphic episodes, the most significant phase being the Palaeozoic to Proterozoic (400–650 Ma) event referred to as Miami metamorphism (Stagman, 1978).

Pegmatites are of two main groups representing distinct episodes in the metamorphic history of the area. An 'older' group, secretory in type and unzoned, are composed principally of plagioclase, quartz and some tourmaline and belong to a phase of sodic metasomatism; these are of no economic importance. The 'younger' group include the economic pegmatites and belong to a later potassic phase of metasomatism considered to be part of the Miami metamorphic event.

These pegmatites contain abundant microcline and may also have mica, beryl and other gem species. They are clearly associated with late kinematic intrusive

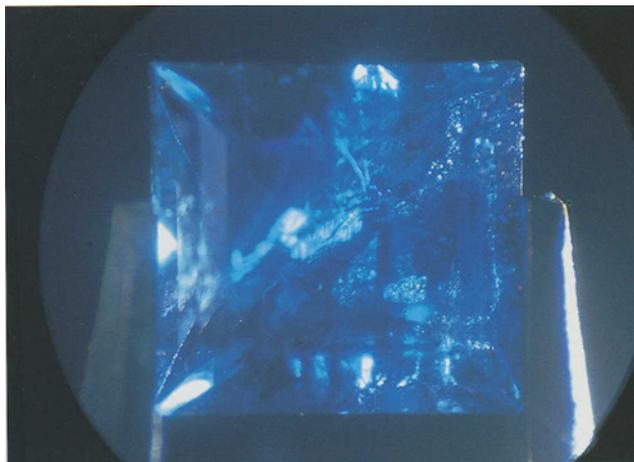
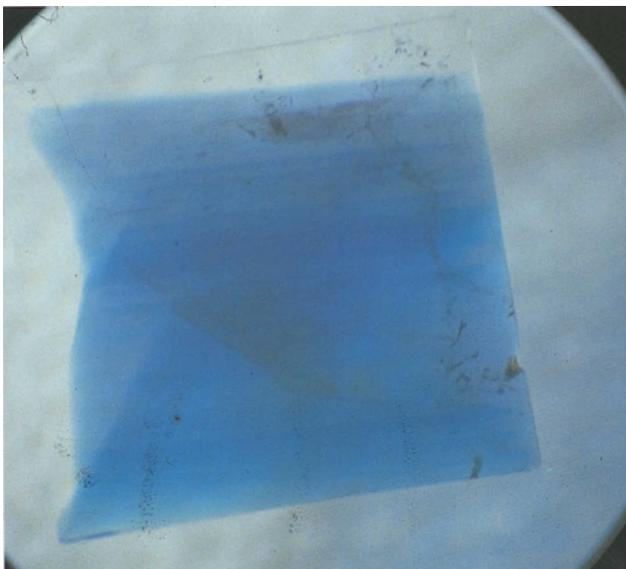


Figure 3: Faceted euclase, 4 mm across. Photo: S.M. Stockmayer

granite plugs termed the Miami Granites. Radiometric data gave K-Ar ages of 520 and 530 Ma on muscovite from the Catkin and Esquire pegmatites (Wiles, 1961) and K-Ar and Rb-Sr ages of 480 ± 20 Ma and 500 ± 20 Ma on biotite from the Miami Granites (Clifford *et al.*, 1967).

Figure 4: Faceted euclase of Figure 3 immersed to show the colour distribution. Photo: S.M. Stockmayer



The nature of the mineral content of these pegmatites is complex with source material not only derived from the granites but, in the case of the mica-bearing type, from assimilated country rock. The close association of the economic mica-bearing pegmatites and the nature of the enveloping country rocks demonstrates the metamorphic control. This was noticed by early prospectors and miners who called the country rocks 'kindly' schists which were host to 'mellow' mica-bearing pegmatites. In them, mica often formed large blocks perpendicular to the strike of the pegmatite in the contact and border zones.

Not only are pegmatites composite in derivation but also may contain simple or complex mineral zones. Late pneumatolytic activity, resulting in kaolinization of the feldspars, is considered to have provided a suitable environment for the crystallization of tourmaline, beryl and other species such as the blue topaz (St Ann's claims) and for

recrystallization and replacement of pre-existing beryl by secondary euclase. The mineralogical sequence of replacement was described in a preliminary report (Anderson, 1980).

The Last Hope pegmatite, located 8 km SW of Mwame, was first pegged for mining mica sometime soon after 1920. The pegmatite intruded along a normal fault, discordant to the foliation of the host gneiss, and displaced a barren tourmaline pegmatite. Late faulting and movement related to the nearby intrusive Miami Granite produced bent beryl crystals and buckled mica in some local pegmatites and faulting is demonstrable in some of the larger euclase crystals. Small-scale fissuring of euclase crystals has resulted in fractures, later filled with fine-grained mica and iron-stained clay.

During its productive life, the mine was exploited for mica on five levels, the fifth level at 85 m below surface; the longest drive was on the third level and had total length of 347 m. The width of the pegmatite ranged from 1.5 to 4 m. Mining ended in 1959 with a total production of cut mica of 225 tonnes. Only a small amount of beryl, 0.44 tonnes, was declared in 1953 but this may have originated from nearby claims. This production of beryl included blue and yellow varieties; there was no gemstone industry at the time and all production was classed as commercial.

The section of pegmatite from which euclase was collected is a few metres west of one of the old mine shafts. The pegmatite is approximately 2.5 m wide, strikes parallel with the country rocks but dips more steeply. It is simply zoned with marginal areas containing 'fish tail' mica developed perpendicular to the strike of the pegmatite, together with anhedral quartz, iron-stained kaolin and tourmaline. Beryl crystals were located in the core in a matrix of iron-stained kaolin, muscovite and quartz; this zone was also penetrated by 'blows' of quartz. Euclase occurs with the beryl as well as in association with quartz (Fey, 1978).

The euclase samples were extracted loose from soil and overburden by digging, hand-sorting and washing the rubble. Single, doubly terminated crystals and crystal

212 *Figure 5: Euclase crystal with mica 'booklet' projecting from base and showing 'hour glass' colour distribution. Photo: S.M. Stocklmayer*



aggregates were released from the reddish clay soil by washing, while other crystals were loosened from the vugs of massive samples. The excavation was small and covered only a few metres and mining stopped when barren quartz was exposed. The pit was refilled and never reopened. Before these claims were officially pegged and worked, illegal mining at the site accounted for the appearance of samples in 1977 and early 1978.

Crystal morphology

The Last Hope euclase occurs in two distinct habits; in crystal aggregates and massive. Massive euclase is intimately associated with beryl and progressive replacement of beryl by euclase can be demonstrated in a series of petrographic sections (*Figure 1*).

Euclase in bladed, flattened and blocky habits may be present on the surface of beryl crystals as a sheath. In other samples replacement of beryl has been complete and perfect pseudomorphs have resulted, preserving hexagonal prismatic form; one of these measures 115 mm across. The outer surface of the pseudomorph may also be coated with massive white translucent quartz and white mica (*Figure 5*) and may be cavernous with vugs lined with euclase crystals. Some massive euclase has small straight gashes in the surfaces; these penetrate to a depth of several mm and it seems likely that they were occupied by mica booklets. Feldspar occurs on the surface of some samples but is not common.

The crystals of euclase of this massive type each cover several cm and can be seen surrounding and traversing areas of relict beryl. The remnant beryl has ragged borders and is penetrated by numerous veinlets of euclase in optical continuity, providing clear evidence for progressive replacement of the beryl. These large anhedral euclase crystals commonly contain inclusions of small quartz crystals, perfectly hexagonal prismatic in form and random in distribution, producing a sieve texture. No strain patterns were evident in the enclosing euclase. Mica inclusions are



Figure 6: Euclase crystal with a euhedral quartz crystal on its surface. Photo: S.M. Stocklmayer

rare, and confined to the veins traversing the beryl or between crystals of euclase.

The blue colour of euclase is evident in thin section under plane polarised light (PPL) and pleochroism is distinct from blue to colourless. The blueness occurs in small patches with no apparent pattern to its distribution.

The beautiful specimen crystals of euclase occur commonly as groups of well-formed terminated prisms, patchily transparent and blue with colourless zones. Some of the crystals appear cloudy, with surfaces encrusted with quartz (*Figure 6*). The development of euclase seems to be partly concurrent but generally later than the quartz; quartz crystals may have an encrustation of euclase and similarly crystals of euclase contain quartz euhedra which comprise the most common mineral inclusion.

The largest well-formed euclase crystal in the group of specimens studied measured 74 mm x 42 mm x 47 mm (*b*-axis); however, this is exceptional and most of the terminated crystals are less than 10 mm in their largest dimension. The deep-blue colour that appeared patchy in thin section may display a coherent pattern in certain



Figure 7: 'Hour glass' colour distribution or zonation in a euclase crystal. Photo: S.M. Stocklmayer

zones of the crystals. The most intense blue is seen as a series of vertical planes, parallel to the a-faces (100) perpendicular to the b-face (010) and diminishing in length towards the crystal centre. Viewed from the direction of the b-face this produces a distinct 'hour glass' colour distribution (Figures 5 and 7). Viewed from the direction of the a-faces a

Figure 8: Complex surface morphology of a zone between the a and c axes of a euclase crystal. The view is taken looking down a and shows the terracing. Photo: R. Huddleston

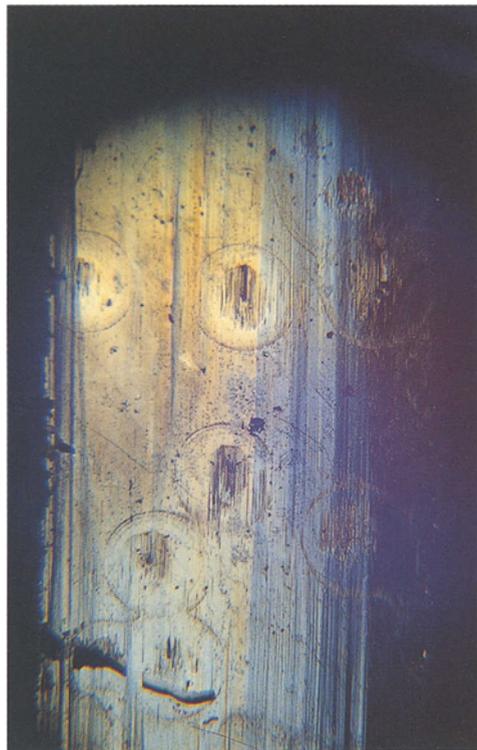
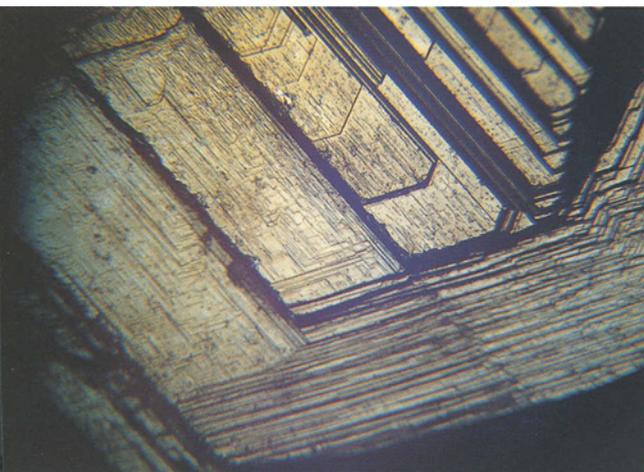


Figure 9: Circular depressions on a (100) face of euclase. Photo: R. Huddleston

chevron pattern of intense blue is often seen at the crystal apices more or less parallel to the (011/021) prisms (clinodomes).

Euclase crystals are monoclinic prismatic in habit, almost equant, slightly flattened parallel to (100) with perfect cleavage (010). Crystals comprise broad pinacoids (100) and (010) and prisms (011) and (021); the latter are usually featureless and unmarked. In contrast the c-zone intergrowths between vertical prisms (hk0) and pinacoids (010) are commonly striated (Figure 8), and in the complex zone between the a and c crystallographic axes (hkl, h0l) terracing is common. An unusual feature comprising a series of circles with micropit centres was found on the (100) face of one euclase crystal (Figure 9). The circular features may be the result of solution activity.

Terracing has been described in equivalent zones in euclase crystals from

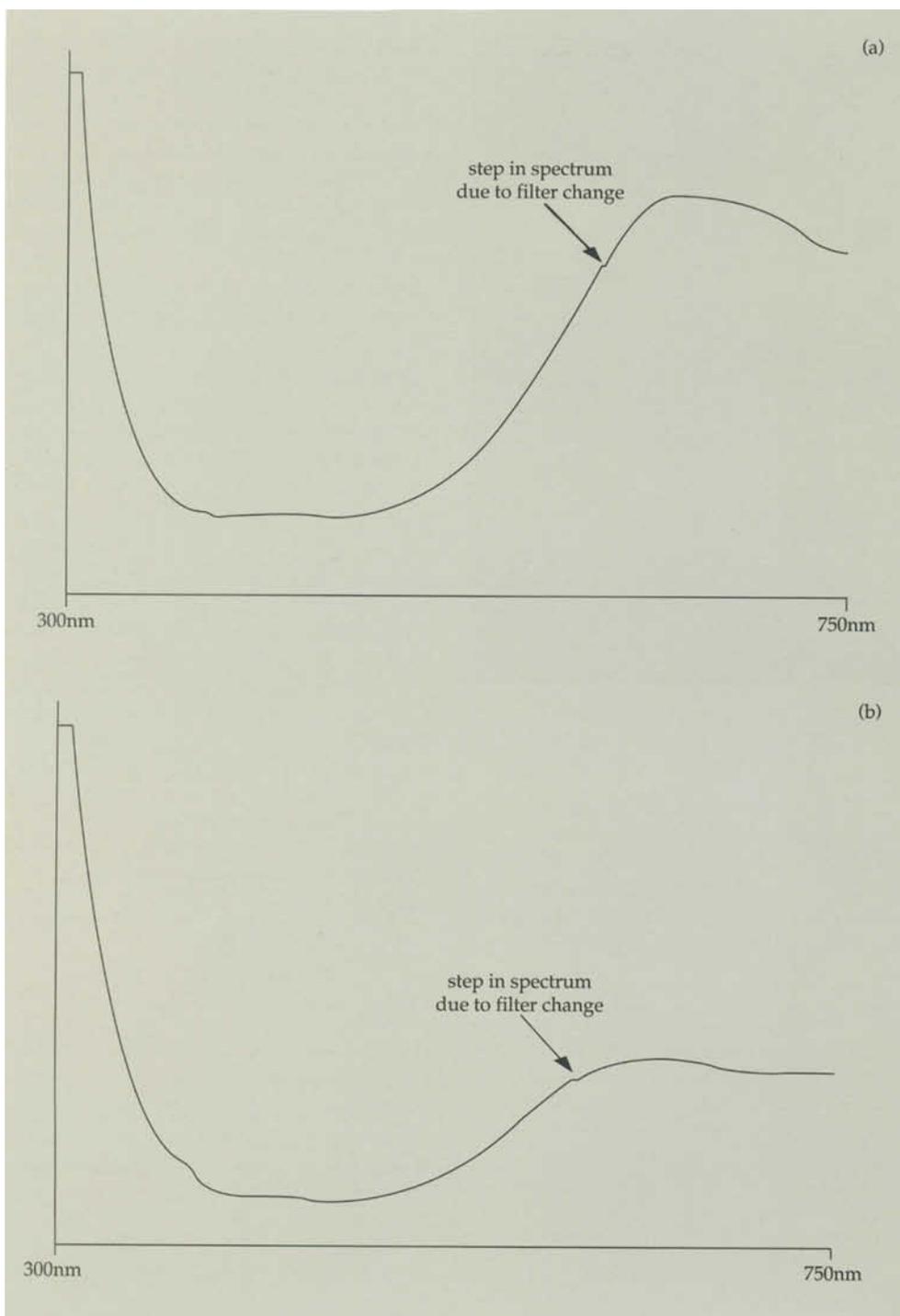


Figure 10: Absorption spectra (a) parallel and (b) perpendicular to the *c*-axis of a euclase crystal from the Last Hope mine.



Figure 11: Slender euhedral quartz crystal inclusions in euclase. Photo: S.M. Stockmayer

Brazil (Graziani and Guidi, 1980). The terraces have developed parallel to the junctions $(hkl)-(hk0)$ and $(hkl)-(100)$ and contain rows of discrete mineral inclusions. Micro pits are also a feature in the $(hk0)$ faces of some of these Brazilian crystals.

Optical features and chemistry

Euclase crystals are monoclinic, normal class and holohedral, with an axial ratio $a:b:c$ of 0.84:1:1.55. Refractive indices measured on a faceted stone were $\alpha - 1.652$, $\beta - 1.656$, $\gamma - 1.672$, all ± 0.001 (Na) with a birefringence of 0.020 which values are within the range recorded by Gübelin (1978). Trichroism is distinct from deep blue, to pale blue to colourless.

Specific gravity was measured in the range 3.06–3.13 (Gübelin, 1978), 3.075 (Anderson, 1980) but the crystals lack mineral homogeneity.

Analysis of euclase from the Last Hope claims using a MAC 5 - SA5 electron microprobe indicates that the blue zones contain 0.06% Fe as FeO; titanium was detected in only one blue zone near detection levels at 0.02% TiO_2 (Mattson and Rossman, 1987). These authors also inferred from a study of the beta-polarized spectrum that the colour can be attributed to charge transfer $Fe^{2+} - Fe^{3+}$ and $Fe^{2+} - Ti^{4+}$ transitions. A 670 nm spectral absorption band was assigned specifically to $Fe^{2+} - Fe^{3+}$ charge transfer.

Gübelin (1978) reported that colourless parts of the crystals contain 0.06% FeO and dark-blue parts contain 0.12% FeO and concluded that trivalent iron is the cause of the blue colour.

No absorption bands were visible in the hand-held optical spectroscope, the spectrum showing transparency in the 450 nm region. Figure 10 shows the results of a spectrophotometer scan on euclase from the Last Hope. The crystal was positioned first to transmit the light parallel to the c -axis and secondly in a position at right-angles to show the results produced by a combination of vibration directions. The broad transmission transparency in the blue region attains a maximum in the range 380–460 nm with a gradual increase in absorption in the red with a maximum in the range 650–670 nm.

Inclusions in euclase

Worldwide sources

There is little published information about inclusions in euclase.

In euclase from Santa do Encoberto, Minas Gerais, Brazil (Graziani and Guidi, 1980), black inclusions of hematite were noted along terraces of the crystal surfaces. Hematite and 'rounded' zircon grains are described as inclusions formed before the euclase, and subhedral opalite and rutile needles are considered as syngenetic. These inclusions were identified using an electron microprobe, as their small size precluded identification by optical means.

Photomicrographs of three-phase inclusions in euclase from Colombia have recently been reported (Duroc-Danner, 1996), and their appearance is reminiscent of inclusions in emeralds from the same country.

From various descriptions of occurrences of euclase worldwide, several pegmatite minerals are described in association with euclase, e.g. fluorite, muscovite, quartz, albite in Norway (Strand, 1953). However, none are reported to occur as mineral inclusions. These reports are of a geological nature where the study of inclusions was not carried out.

Zimbabwe

Gübelin (1978) examined a suite of faceted Zimbabwean euclase and described healed fissures with no particular orientation or distribution and epigenetic 'dry' fissures showing colour iridescence, but noted no mineral inclusions. Photographs of Zimbabwean euclase by Hochleitner (1989) showed crystal faces studded with quartz. The writer noted that only the colourless parts of the crystals are clear and that the blue zones contain liquids that make them cloudy and opaque. All crystals, including those of the finest quality, show colour zonation and this feature together with perfect cleavage (010) are potential problems in faceting the gem. When correctly orientated the faceted gem can appear a uniform blue, but oil immersion reveals the patchiness of the blue colour. Two-phase inclusions are common, but show no preferred distribution. Although terracing is a common feature of the external faces of the crystals, no feature equivalent to axial tubes common in beryl was seen.

Mineral inclusions

The range of mineral inclusions reflects the genetic mineral association of quartz, mica and euclase found in the surrounding rocks.

Quartz

Quartz is the most common inclusion (Figure 11). Clear and glassy crystals, usually doubly terminated, occur clustered on the

surfaces of euclase crystals as well as entirely enclosed within as a syngenetic generation of inclusions. These inclusions may form aggregations so dense that the host crystal appears cloudy. In a few crystals they also occur alone or in small groups. No crystallographic control of their distribution is apparent either macroscopically or microscopically.

Mica

The occurrence of white mica commonly encrusting the surfaces of the beryl pseudomorphs has already been discussed. Books of white mica are found on the surfaces of or partly enclosed by euclase crystals. In some crystals, laths of a dark coloured mica were found. Fine-grained white mica and clay minerals occur in fractures and negative crystals but further work is needed to identify the precise species.

Opaque minerals

Three kinds of opaque minerals have been seen as rare inclusions in euclase. Two occur as euhedral-subhedral equant grains, one type with yellow brassy metallic lustre, likely to be pyrite, the other with a grey-silver metallic lustre. In one crystal, dark mica foliae are associated with these grains. Grains of similar appearance were seen in some of the larger quartz crystals that are intergrown with euclase.

The third kind of opaque inclusion consists of groups of dark granules which appear red-brown in reflected light.

Discussion

The intimate association of euclase and quartz is constant and interesting. Their synchronous crystallization indicates that the conditions necessary for their formation are very similar and that some small fluctuations may determine which phase is developed; quartz occurs both as syngenetic inclusions in euclase and as surface encrustations. That the two minerals are physically compatible is shown optically by the lack of strain and stress-induced fissures around the quartz

within the euclase crystals. The surface encrustations are similar to the quartz-epidote-magnetite mineral 'dust' adhering to aquamarine described by Eppler (1963) who suggests temperature fluctuations as the likely cause for the vari-crystal shower.

Mining ceased at the Last Hope claims at the end of 1978. It is likely that further occurrences of euclase will be discovered but prospecting requires careful search by mineral collectors rather than commercial miners.

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Further aspects of the history of rose-cut diamonds

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ABSTRACT: The development of rose-cut diamonds in centres such as Antwerp and Amsterdam is discussed. Suggestions for a realistic terminology are made.

Introduction

In the recent treatise on historical diamond cuts (Tillander, 1995), I corrected early, long-lived, misunderstandings regarding the development of the brilliant cut, but did not pay the same attention to the obviously parallel situation with reference to the rose cut. Consequently I spent the summer of 1997 reading everything I could possibly find on this cut.

My prime disclosure is that the rose cut cannot have been developed from surviving primitive hexagons by gradually adding facets. In the Dutch encyclopedia on diamonds of 1908 (Leviticus and Polak, 1908) I found the clear statement that both the hexagonal and square rose cuts had been experimental only and turned out to have been abortive. Consequently neither could have served as a starting point. Max Bauer, writing in 1896 and 1909, and Karl Schlossmacher initially in 1932 in the sequence named 'Edelsteinkunde', were the ones who established the concepts about rose cuts. Ever since, they have been uncritically repeated. It is therefore high time to correct early misunderstandings.

Development of the rose cut

Since the early fifteenth century, beginning in Bruges, the Flemish cutters have been unequalled creators of a great

variety of new diamond cuts. Consequently it is likely that they will also have hit on the idea of stepping cleavages and other suitable rough, a trick which, since the mid-sixteenth century, they had successfully performed on crystals not thick enough for perfect table cuts. This stepping was found to disperse light entering from above and consequently to increase the light effects, but also, by trial and error, they went on to create the ideal facings and proportions.

We may never be able to find out when the prototypes were created, including their original outline and height proportions, if these events coincided with the catastrophic and destructive invasions by the Spaniards. In addition, the following depression forced many cutters to re-establish in Amsterdam and records are often lost in such movements. In these circumstances, serial production of this new cut would have been postponed. This was consequently the beginning of diamond cutting in Amsterdam, but we do not know which of the two competitors will have been in the position to market the full range of rose cuts in large quantities, if not both.

In any case we find that from 1625 rose cuts had already been available for some time. They were, however, simply described as faceted diamonds (faucets by some) and named as rose cuts only by the end of the seventeenth century. This was the reason

Some notes on Thomas Cletscher 1598–1668

Cletscher was Crown Jeweller to Prince Frederik Hendrik in the Hague, a specialist in gem setting and a financier. In 1625 he began to reproduce diamond cuts in jewellery, which in various ways passed through his hands. For some undisclosed reason he concentrated on the 'new-fangled' rose cuts. Although he omitted mentioning the provenance of the diamonds, Cletscher's collection of drawings fortunately turned out to be the prime and priceless source of reliable information on cuts from 1625 onwards. On his fifty drawings of jewellery with roses he depicts a wide range of roses (sometimes classified into seven types on the basis of facet pattern), every conceivable outline and a great variety of applications, many fairly soon abandoned.

Most pages of Cletscher's notebook have gone astray, but those surviving in the Museum of Boymans-van Beuningen in Rotterdam, suffice as a source of information about early rose-cut jewellery. More details on jewellery of the period can be found in the book *Juwelen en Mensen* by M.H. Gans published in 1961.

why they had only occasionally been mentioned in this period as 'a rose fashioned out of one crystal'. As late as 1673 such a cut was described as 'an oblong, thin diamond with large facets and a flat bottom'. Any earlier documentation of rose cuts has not yet been found. Those rose cuts present in earlier jewellery, such as on the Fellowship Pendant in the Grünes Gewölbe (see Tillander, 1995, p. 54) are now found to be later replacements of some insignificant stones (such replacement was a regular habit also in the Schatzkammer in Munich). At some (so far unknown) stage, rose cutting was obviously introduced also in Amsterdam, but the cutters appear not to

have been competitive enough with the Antwerp cutters. When the river Schelde was closed in 1648 Antwerp was forced to rely exclusively on Amsterdam for deliveries of rough. In order to put a stop to Antwerp's supremacy the Amsterdam dealers offered only rejection qualities such as coloured, flawed and hard-to-master goods. The victims of this treatment did not, however, give up. On the contrary, the situation was excellently mastered. First of all the height of the rose had to be substantially lowered, foils were adopted for reducing the effects of off-coloured rough, and finally inclusions were disguised by switching some facet ridges. Contrary to what has been alleged, they retained the full number of facets, except on stones too small to accommodate them. The cutters in Amsterdam simply concentrated on higher quality and larger sizes with near to ideal proportions, but nevertheless continued to produce some stones with irregular outlines. These circumstances prevailed at least until 1668 when there was a generally chaotic market situation and Holland reduced its diamond trade to a minimum. At that time Antwerp would then most likely have found some kind of access to the developing London market for rough of any quality.

The terms Antwerp and Amsterdam as applied to rose cuts were, even though incorrectly defined, relevant, but only for a relatively short period. In practice they differed mainly in that the former were considerably shallower, being described as spread roses. Recently, on a two-day visit to Moscow, I was shown their entire collection of thousands of roses, mostly spread. Not one of them had less than the standard number of facets, obviously with the exception of the exceedingly small ones. On reflection, this is not really surprising because it would take more time to leave open spaces than to apply regular facets all the way round.

The rose cuts were originally based on cleaved dodecahedral crystals. The two halves of the cleaved crystal formed the initial point of departure for the cutter. They resemble consequently the shape of a

flat-bottomed triangular cupola. Quite obviously this called for a pattern of faceting with threefold symmetry. It also explains the variety of regular and irregular outlines which, for weight-saving reasons, followed the outlines of the rough.

With the introduction of brilliant cuts, roses gradually lost their popularity and most of the large ones were refashioned into brilliants. Small roses were mostly used as complementary stones surrounding central brilliant cuts and coloured gems. By the nineteenth century they were already out of date, but occasionally rehabilitated for specific purposes. In Fabergé jewellery about 1900, costly gems were totally excluded and, on visiting the Green Vaults in Dresden, Carl Fabergé will no doubt have been influenced by the specific charm of minor roses, set in succession, and decided to try this arrangement out on his Easter eggs. On Fabergé's platinum and gold egg of 1914 the cost price paid for the extraordinary number of 1782 roses was only 75 kopeks each. Even so, this amounted to only 5 per cent of the total cost of material used in its manufacture. The size of the stones is generally below 1 mm, but there are three larger irregular lozenges on the outsize crown each with six more or less rectangular facets round their bases.

Summary of rose cuts

Rose cuts may be considered in three main categories:

1. Gothic roses

Flat-bottomed diamonds with a great variety of facet shapes, mostly trihedral, created in the early fifteenth century and still popular throughout the sixteenth (see also Tillander, 1995, pp 45–52);

2. Renaissance roses or rosettes

Combination of from 4 to 16 pavé-set and pavilion-based diamonds marketed as complete settings which may easily be fixed on any suitable piece of jewellery (see also Tillander, 1995, pp 87–98);

3. Baroque roses or simply rose cuts or roses

Flat-bottomed, stepped diamonds with triangular facets in threefold symmetry, a crown with six facets coordinating with the outline of the stone and, in principle, 18 facets at the base (see also Tillander, 1995, pp 45, 52 and 54–63).

Conclusion

The ultimate reason for this paper is, however, to influence the gemmological institutions the world over in their use of suitable terminology when referring to rose-cut diamonds, to refrain from unhelpful or even incorrect statements such as 'originating in India', 'double roses' or 'rounds only'.

There is also no sense any longer in naming roses Antwerp or Holland roses, since at times both centres delivered whatever type their customers were looking for. It is far clearer and more understandable to describe a rose as high or spread.

In future, gemmologists should be able to correctly name most historic cuts and give full exposure and value to their interest as collectors' items.

I finally suggest that both gemmologists and historians refrain from using the trade vernacular 'polished'. In most other languages polishing stands for 'the final touch on the scaife'. Several authors have already replaced 'polished' with 'fashioned' or 'faceted'. Neither of these latter terms can be misunderstood.

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Kyanite in diamond identified by Raman analysis

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ABSTRACT: This paper describes the identification of kyanite and garnet as inclusions in a round brilliant-cut diamond. Kyanite is a very rare inclusion in diamond, and this is the first time Raman analysis has been used to make such an identification. It is an effective analytical technique and both the host diamond and inclusions remain undamaged.

Introduction

In 1994, during the routine examination of a 0.65 ct round brilliant-cut diamond to determine its clarity grade, gemmologist Gary Roskin of Los Angeles, California, noticed what appeared to be a small blue crystal inclusion just under the table facet near the edge of the diamond's crown. Since this was the first blue mineral inclusion in a diamond that he had seen, he contacted one of the authors (JIK) and, with the permission of the owner, submitted the gem for further examination.

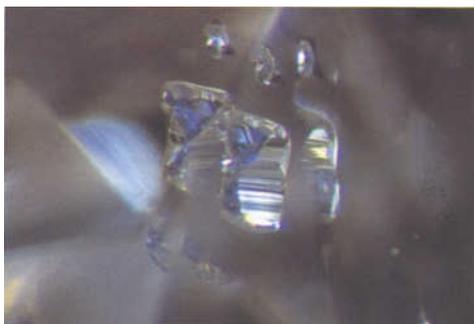
Under magnification it was noted that the diamond actually contained three blue crystals ranging in size from 0.15 to 0.42 mm in largest dimension. The diamond also contained several transparent colourless crystals and an orange crystal measuring 0.3 mm in length. While the two smallest blue crystals were very pale in colour, the largest one showed a rather intense blue when viewed at a slight angle to the plane of the table, through the edge of the crown (Figure 1).

Polarized light microscopy revealed that the blue crystals were doubly refractive, as were the colourless crystal inclusions. But no signs of double refraction were observed in the orange crystal. The pleochroism of the

largest blue crystal was weak, showing blue and violet. Previous descriptions in the literature (Prinz *et al.*, 1975; Meyer and Tsai, 1976) indicated that this inclusion might be kyanite, which is a very rare inclusion in diamond. It was also thought that the isotropic orange crystal was a garnet and, if both these interpretations proved to be correct, it is likely that the diamond came from an eclogite.

By coincidence, N. Sobolev from Novosibirsk, Russia, was visiting the GIA and was able to examine the stone. He also concluded that in all probability the blue crystals were kyanite and that the orange

Figure 1: This 0.42 mm blue inclusion in diamond was identified as kyanite by laser Raman microspectrometry.



crystal was an eclogitic garnet. He based this conclusion on his observations of similar-appearing kyanites he had examined from xenoliths of eclogite and grosspydite (a rock composed of *grossular pyroxene* and *disthene* – or kyanite). Sobolev also stated that this diamond was a significant stone because of its inclusions and suggested that the diamond be purchased for destructive analysis, to determine if the blue inclusions were in fact kyanite. Such analysis procedure would require burning the diamond away in oxygen, or some other destructive technique, to free the mineral inclusions so that they could then be identified.

A price was settled on and the stone was purchased from the pawn shop that owned it in Kenmore, New York. However, since a very strong case for rarity had been made, it was decided that the stone would not be destroyed but would be held intact until the technology needed to identify the inclusions non-destructively became available at the GIA. With the recent acquisition of a Renishaw Raman Imaging Microscope System the non-destructive identification of the inclusions in this diamond has now become possible.

Experimental

In preparation for laser Raman microspectrometry with the Renishaw system, the diamond was first cleaned in acetone and then carefully examined under magnification. This was done to determine which of the blue inclusions was closest to the surface, and which orientation of the stone would be the most advantageous for the analysis. It is an advantage to direct the laser as near perpendicular to a facet as possible so that its traverse through the host gem to the inclusion is as short as possible.

As it was relatively near the surface (less than 1 mm) and it presented a large blue-coloured target area through the edge of the crown, the largest blue inclusion was chosen for Raman analysis. The diamond was placed in a special mount on a glass microscope slide with the chosen target area of the diamond in parallel alignment with

the plane of the glass slide. This allowed the inclusion to be focused with minimum risk to the surface of the 50x objective lens of the Leica targeting microscope.

Using the continuous scan feature, the Raman system was set up for 10 complete scans of the inclusion. The 514 nanometre argon ion laser was used to obtain the Raman spectrum shown in *Figure 2*. The search programme was then employed using the Raman software in conjunction with the Renishaw digital spectral library. The computer selected a spectral match for kyanite.

As a back-up to this result, to ensure the integrity of the identification, a cabochon of kyanite was also analysed with the Raman system using the same laser strength and the same number of scans. Once again the computer match from the Renishaw digital spectral library was for kyanite. The resulting spectrum obtained from the cabochon is shown in *Figure 3*. The strengths of the major peaks for kyanite vary slightly due to the host's matrix effect in the case of the inclusion, and the difference in optical and crystallographic orientation between the cabochon and the inclusion. However, all the major kyanite peaks are present, and their positions are identical, proving that the largest blue inclusion in this diamond is kyanite.

To complement the genetic picture of this diamond, the orange isotropic crystal (*Figure 4*) was also examined with the laser Raman microspectrometer. The result of this analysis confirmed what was already suspected, that this inclusion was a garnet, and its orange colour is a strong indication that the host diamond is eclogitic rather than from a peridotite (where the associated garnets are chrome pyrope and pale to deeply coloured red to purplish-red).

Conclusion

Kyanite is the high-temperature, high-pressure member of the trimorphous mineral group of kyanite, andalusite and sillimanite. It is known to occur in diamondiferous eclogites and on this basis it is not surprising to find kyanite as an inclusion in diamond.

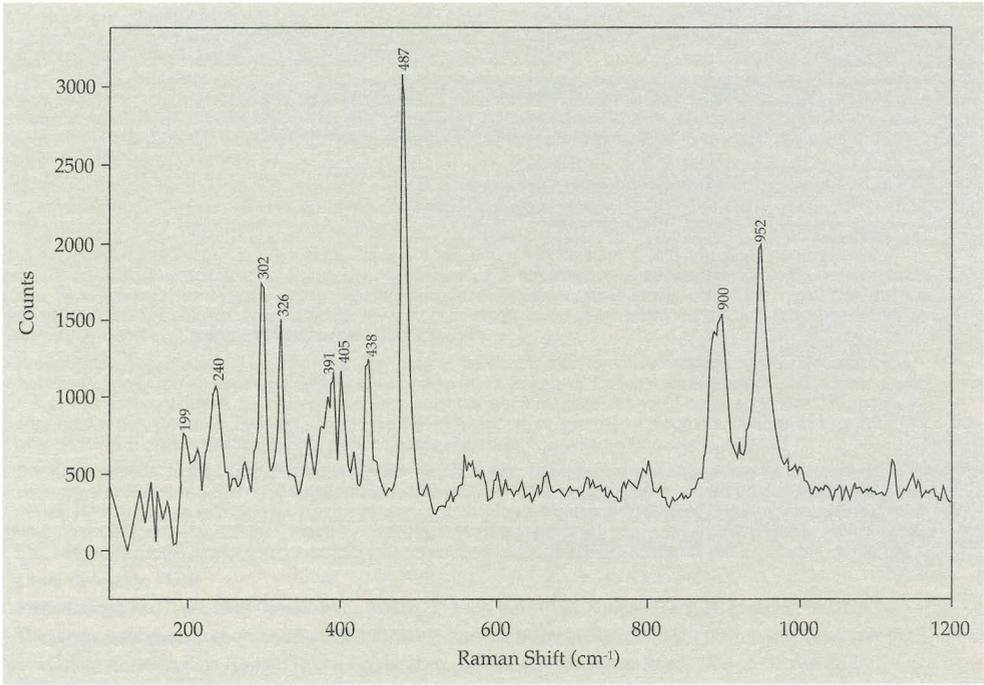


Figure 2: The Raman spectrum obtained from the kyanite inclusion shown in Figure 1.

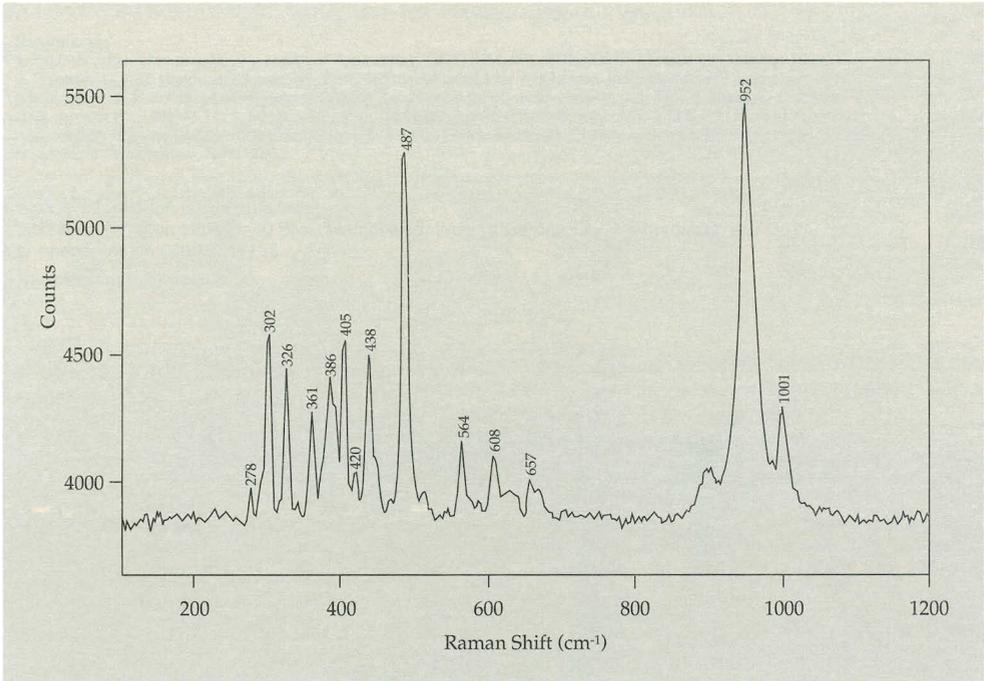


Figure 3. Raman spectrum from a kyanite cabochon used as a reference standard.

But kyanite in diamond is apparently very rare. This rarity may be partly illusory and due at least in part to the fact that the smaller the inclusion of kyanite in diamond, the lighter it is in colour, to the point that the smallest appear colourless. This fact is well demonstrated by the inclusions in the diamond described in this paper. This size-to-colour dependence would make smaller kyanite inclusions very difficult to recognize. Since most mineral inclusions in diamonds are quite small, some kyanite inclusions have probably been overlooked because they are so small and lack a distinctive colour.

The authors were able to find only two previous reports of such an occurrence. The first description is provided by Prinz *et al.* (1975) who reported a crystal of about 1 mm in size exposed on the surface of a cut stone from an unknown locality. According to Meyer and Tsai (1976) this identification '... must be viewed with caution,' however, because 'Unfortunately, the identification by Prinz *et al.* was of the kyanite on a cut surface of a diamond'. In the second description, Harris and Gurney (1979) reported finding a kyanite inclusion in a diamond from the Premier Mine.

This paper also shows that it is possible, in certain instances, to identify mineral inclusions in a diamond without burning, cutting, grinding or breaking the host to expose an inclusion at the surface, which has been a necessary practice in research for many years. Raman analysis, however, is by no means the complete answer to inclusion investigation. If inclusions are too deep in their host then they cannot be identified in this manner. Laser Raman microspectrometry also does not give details of chemistry comparable with those from an electron-microprobe, and it cannot provide precise structural information like that provided by X-ray diffraction. However, it does leave the



Figure 4. Reflected three times, and measuring only 0.12 mm, this orange garnet is in the same diamond as the kyanite.

host intact to be re-examined and enjoyed at any time in the future.

Acknowledgements

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Tourmaline: morphological and compositional variations during the growth history of uvite single crystals

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ABSTRACT: Surface microtopographs of crystal faces, internal textures and associated compositional variations have been investigated on single crystals of uvite from Brumado, Bahia, Brazil. From the surface microtopographic observations of major faces, it is demonstrated that the uvite crystals grew by the spiral growth mechanism, and the growth rate in the positive direction was about twice as high as in the negative direction. Based on the investigations of internal textures including growth sectors, sector boundaries and growth banding, the morphological and compositional evolution during the whole growth history was analysed, and four stages where morphological changes took place were distinguished. In the first stage, crystals were bounded principally by r and $r'\{10\bar{1}1\}$, but in the second stage $[010]$, $[110]$ and $[100]$ sections (probably corresponding to either r and r' or r and m , $m'\{10\bar{1}0\}$) appeared, which was associated with an increase of Mg contents. The appearance and development of $a\{11\bar{2}0\}$ faces at the third and fourth stages were associated with a decrease of the uvite component. At the earlier stages of growth, the uvite component was high, and the dravite component increased in the later stages, reflecting compositional changes of the fluid formed by the action of granitic fluids on the original carbonate rocks. There was no partial dissolution at any period during the growth history nor was there any excessive increase of the driving force at the latest stage, and the whole growth proceeded and terminated rather gently.

Keywords: compositional variation, growth history, growth mechanism, morphological evolution, single crystal, tourmaline, uvite

Introduction

Tourmaline is a mineral which typically shows morphological, compositional and colour changes during its growth history. In sections cut perpendicular or parallel to the elongation of a prismatic crystal of elbaite of pegmatitic origin, such changes

are typically seen in the form of sector or colour zoning and growth banding. Beautiful examples may be seen in the monograph by Benesch (1990).

Tourmaline is also a representative polar, hemimorphic crystal. It shows different development of faces in positive and

negative directions of the *c*-axis. Usually one end is terminated by trigonal pyramidal faces, whereas the other end is characterized by a basal face. One may often find a group of tourmaline crystals all pointing in the positive direction or all in the negative direction, but only rarely does one find a group with the two directions coexisting. In previous works on polarity of tourmaline crystals, somewhat controversial observations have been reported; some papers reported that the growth rates were higher in the positive direction, whereas other papers reported the higher growth rates for the negative direction (Dietrich, 1985). It is known that surface microtopographs of crystal faces can tell much about growth mechanism and the difference of growth rates in different directions (Sunagawa, 1988b), but such investigations on tourmaline have not been reported so far.

Tourmaline crystals typically showing morphological, compositional and colour changes in a single crystal, such as elbaite crystals of pegmatitic origin, usually have an elongated prismatic habit bounded by heavily striated vicinal prism faces, and the terminal faces are often corroded. These make elbaite crystals unsuitable for detailed observations of their as-grown features. Crystals formed in pegmatitic environments have usually been subject to repeated partial dissolution and re-growth processes during their growth histories. The evidence for such processes has been found in various pegmatitic minerals, e.g. beryl, topaz and quartz (see, for example, Sunagawa, 1982, 1984a, 1988a; Scandal, 1996), and pegmatitic tourmaline is no exception. It is probably due to this fact that the growth mechanism and process, as well as morphological and compositional changes of tourmaline crystals through their growth histories, have so far not been investigated in detail.

Uvite is the Ca end member of the dravite $[(\text{NaMg}_2\text{Al}_6\text{B}_3\text{Si}_6\text{O}_{27}(\text{OH},\text{F})_4)]$ – uvite $[\text{CaMg}_3(\text{Al}_5,\text{Mg})\text{B}_3\text{Si}_6\text{O}_{27}(\text{OH},\text{F})_4]$ series (Dunn, 1977). Dravite and uvite form a continuous solid solution through the coupled substitution $\text{Na}^+ + \text{Al}^{3+} \leftrightarrow \text{Ca}^{2+} + \text{Mg}^{2+}$, although the pure end member uvite has not yet been reported.

The composition is expressed in mole ratio of uvite and dravite end members. Although there is a report that Fe can be a component of this series, the name uvite is, in this paper, applied to those compositions with $\text{Ca} > \text{Na}$, since no Fe was detected in the samples.

Uvite crystals typically exhibit a flat rhombohedral (equant) to short prismatic habit terminated in both positive and negative faces. They show similar internal textures to those observed in elbaite. Uvite typically occurs in carbonate rocks contact metasomatized by an intrusion of acidic (granitic) magma (Dietrich, 1985) where the crystals often occur as isolated single crystals, not in a group. Such crystals are suitable for detailed investigations of their surface microtopographs and internal textures. In this paper, we report the results of investigations on the external morphology, surface microtopography of crystal faces, morphological and compositional evolution during the growth history of uvite single crystals from Brumado, Bahia, Brazil, purchased from a mineral dealer in Belo Horizonte. Altogether 15 crystals were investigated.

We intended to analyse how and by what mechanism the uvite crystals grew and how morphological and compositional evolution took place in the contact metasomatic environment. The methodology and results of the present analyses may be applicable, in essence, to the features commonly observed in other elbaite crystals of pegmatitic origin.

Crystal morphology and polarity

The uvite crystals are brownish-green in colour in transmitted light. They occur as doubly terminated and isolated single crystals with a flat rhombohedral (equant) to short prismatic habit bounded by well developed positive and negative trigonal pyramidal faces, $r\{10\bar{1}1\}$ and $r'\{01\bar{1}\bar{1}\}$, second-order prism faces $a\{11\bar{2}0\}$, and a basal face, $c'\{000\bar{1}\}$. Much smaller $m\{10\bar{1}0\}$ and $m'\{01\bar{1}0\}$, $\sigma'\{02\bar{2}\bar{1}\}$, $e'\{01\bar{1}\bar{2}\}$, and $t'\{21\bar{3}\bar{1}\}$ faces are also associated (Figure 1a). The well developed crystal faces are macroscopically

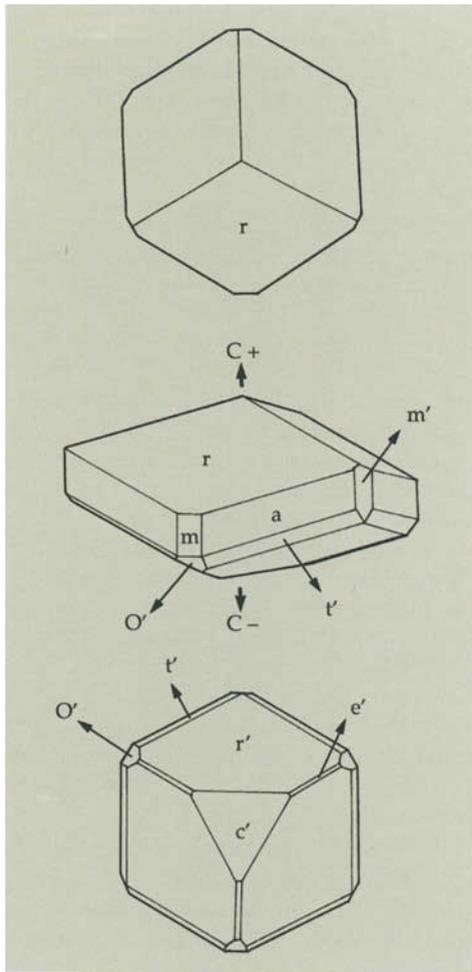


Figure 1: (a) Crystal figures. Orthogonal projection of positive (top) and negative (bottom) terminations, and (centre) clinographic projection. (b) Close-up photographs of positive (top) and negative (bottom) terminations of a crystal.

flat or striated, but microscopically show growth step patterns resembling the contour lines on a geographical map.

The polarity of the crystal was identified by Kundt's method (1883). Three $r\{10\bar{1}1\}$ faces appear on the positive termination, whereas on the negative termination $c'\{000\bar{1}\}$ and three $r'\{01\bar{1}\bar{1}\}$ faces appear. The prism zone consists of six well-developed, flat $a\{11\bar{2}0\}$ faces and six much smaller m and $m'\{10\bar{1}0\}$ faces. *Figure 1* shows the crystal figure and close-up photographs of a uvite crystal showing positive and negative terminations.

Tiny rhombohedral magnesite crystals are the only paragenetic mineral, suggesting a contact metasomatic origin of the specimens.

Surface microtopography

The surface microtopographs of all faces were observed by the differential interference microscope (DIM), which can reveal growth steps with step heights of the order of nanometers (Sunagawa, 1988b). The surfaces were coated with silver under vacuum to secure high reflectivity so that steps of one nanometre height could be observed.

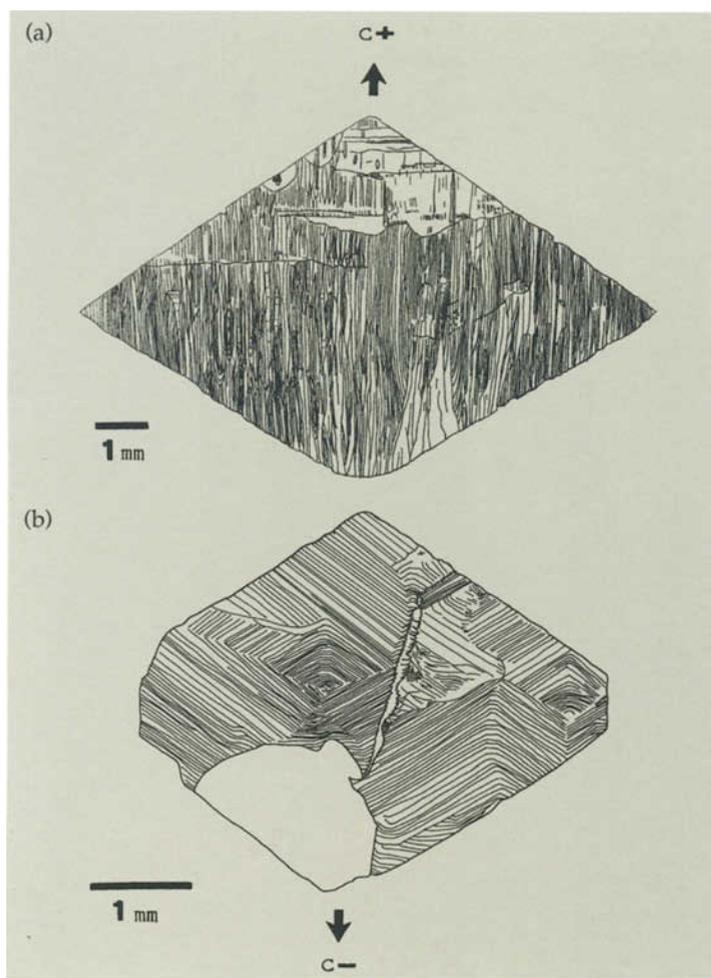


Figure 2: Surface microtopographs of positive (a) and negative (b) trigonal pyramidal faces, r and r' ; sketches prepared based on microscopic observations at low magnification.

Trigonal pyramidal faces, $r\{10\bar{1}1\}$ and $r'\{01\bar{1}\bar{1}\}$

Positive and negative trigonal pyramidal, r and r' , faces exhibit markedly different surface microtopographs, as can be seen in *Figure 2*. Although positive trigonal pyramidal r faces appear macroscopically as striated faces, they are microscopically featured by the development of growth hillocks having a very elongated spindle form with an aspect ratio larger than 10, whereas negative faces have a smaller number of growth hillocks with rhombic form concordant with the edges of the face. All of these features are as-grown features, and dissolution features, such as etch pits, were not observed.

Growth hillocks on positive r faces are elongated parallel to the shorter diagonal of the face, i.e. $[211]$, which is the reason for the macroscopic appearance of striations. Under high magnification, they can be seen to be elongated growth hillocks, with plateau tops. On such plateau tops, a number of extremely thin circular growth steps are discernible, aligning in the direction perpendicular to the elongation of the growth hillock, i.e. in the $[010]$ zone. Some of the circular growth steps show spiral patterns with a half or a couple of turns. This is seen in a high-magnification DIM photograph, *Figure 3a*, and the corresponding sketch, *Figure 3b*, where circular steps are indicated by arrows. Although the

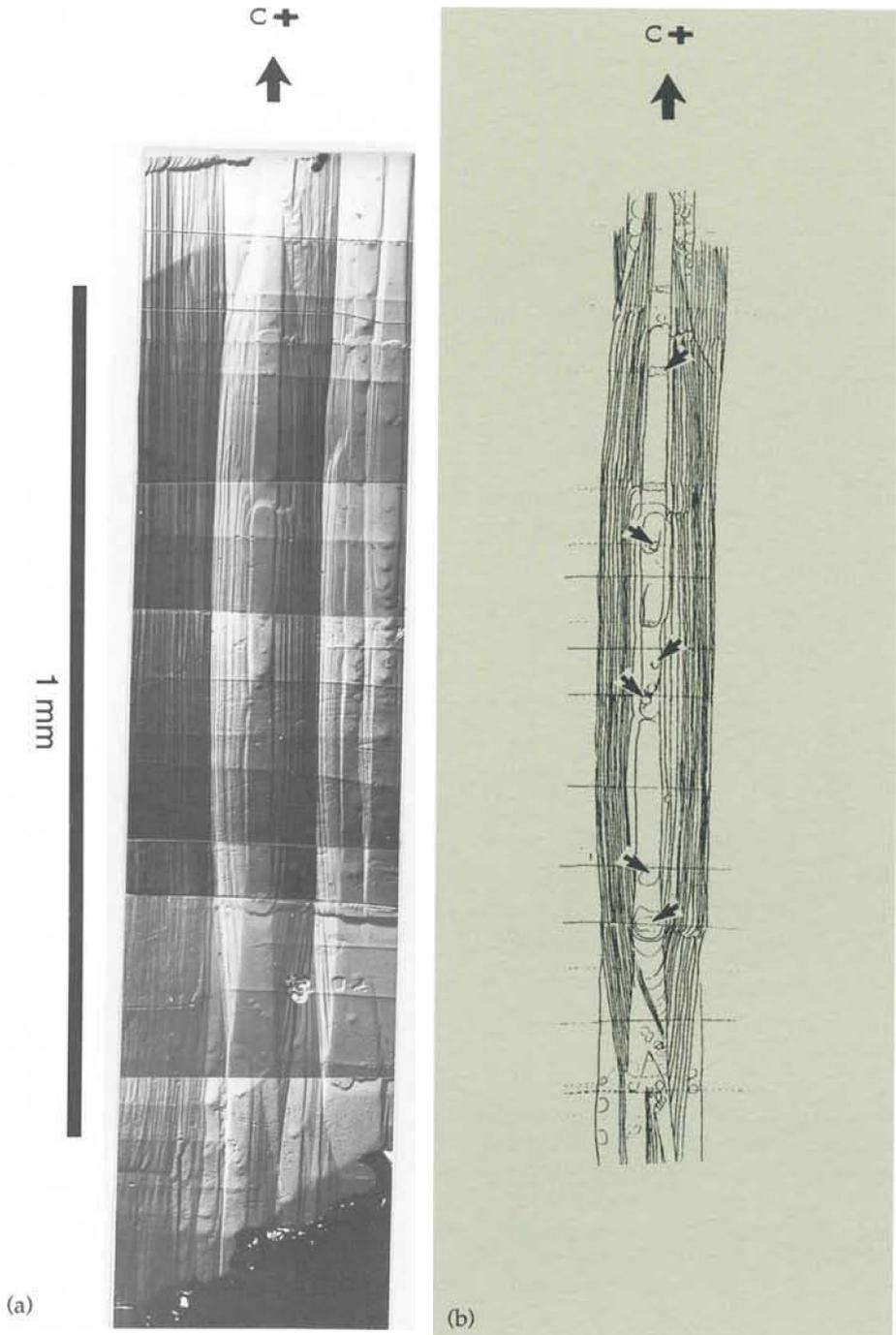


Figure 3: (a) High-magnification photomicrograph taken on a differential interference microscope (DIM) showing growth hillocks on a positive trigonal pyramidal r face, and (b) the corresponding sketch. Small arrows indicate elemental circular growth steps. Straight lines are faint cracks running perpendicular to the elongation of growth hillocks.

height of the circular growth steps could not be measured directly, it is safe to assume that they are elemental steps with the height of the $d\{10\bar{1}1\}$ lattice spacing, judging from the visibility under DIM (Sunagawa, 1988b).

On the side slopes of elongated hillocks, growth steps are seen with an average step separation of $2.6\ \mu\text{m}$, whereas the average step separation in the elongation is $11.3\ \mu\text{m}$. It follows from these observations that the positive trigonal pyramidal r faces grew most probably by the spiral growth mechanism, and that elemental growth spirals took a circular form, rather than polygonal or elongated spindle forms at their centres. The elongated spindle form of the growth hillocks develops through interaction and merging of circular growth spirals.

In contrast to the above, on the negative trigonal pyramidal r' faces, rhombic growth hillocks are seen. The hillocks show plateau tops, with two sides which are steeper toward the direction of negative polar axis and two gentler sloping sides in the positive direction. Even on the steeper side, the average step separation is more than $5\ \mu\text{m}$, more than twice that on the positive trigonal pyramidal r faces. It was not possible to confirm the presence of elemental growth spirals on the plateau top, but it is reasonable to assume that the growth hillocks are spiral hillocks from their morphologies.

Circular or rounded morphology of growth steps on positive trigonal pyramidal r faces in contrast to the rhombic morphology on negative trigonal pyramidal r' faces, and twice the average step separation on r' compared with r can be taken as an indication that the growth rate in the positive direction was more than twice that in the negative direction.

Prism faces, $a\{11\bar{2}0\}$ and m and $m'\{10\bar{1}0\}$

The second-order prism faces $a\{11\bar{2}0\}$ develop as much larger faces than the first-order prism faces m and $m'\{10\bar{1}0\}$ (Figure 1). On the $a\{11\bar{2}0\}$ faces, rectangular growth hillocks are seen, whereas the m and m' faces show either simple striations or undulating surfaces with no step pattern. Rectangular growth hillocks on the $a\{11\bar{2}0\}$ faces are

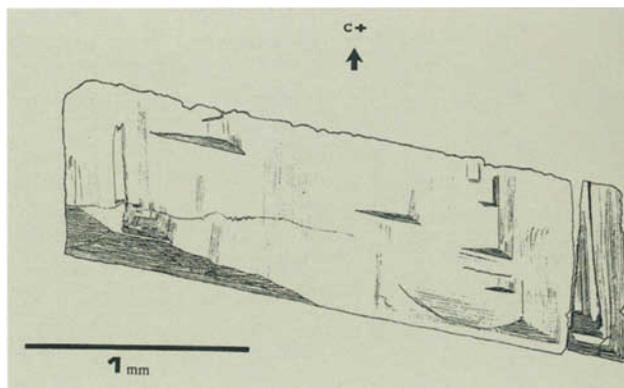


Figure 4: A sketch of growth hillocks on an $a\{11\bar{2}0\}$ face.

concordant with the outline of the face (Figure 4); they exhibit gentler sloping sides towards the positive direction and steeper ones in the direction of the negative axis which is towards the edge with the neighbouring m or m' face (see Figure 4).

Basal face, $c'\{000\bar{1}\}$ and minor faces

The basal face is an undulating face with many polygonal cavities resulting from detachment of magnesite crystals, and does not show any step patterns. Other minor faces, $o'\{02\bar{2}\bar{1}\}$, $e'\{01\bar{1}\bar{2}\}$, $t'\{21\bar{3}\bar{1}\}$ are rough, showing no step patterns.

Internal textures

Method of observation

Sections perpendicular to and parallel to the c -axis of a crystal were prepared to observe internal textures under a polarizing microscope, and to investigate variations in chemical compositions using an electron probe micro analyser (EPMA). Both point analyses (at 7 points) and line scans along six lines were made on the two sections.

Section perpendicular to the c -axis

More than 40 photomicrographs were taken to prepare a mosaic photograph to visualize the internal textures. Each photograph was taken at a slightly rotated position from the extinction to reveal the

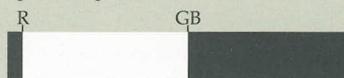
Table I: EPMA point analyses of a uvite crystal together with gemmological data.

Stage	1		2		3			4	9	
Point	1	2	3	4	5	6	7	8	9	
wt %										
SiO ₂	37.45	37.63	37.39	37.71	37.45	37.28	37.93	36.01	36.17	
TiO ₂	0.57	0.53	0.60	0.52	0.64	0.48	0.52	0.55	0.66	
Al ₂ O ₃	29.54	28.61	28.84	28.80	28.45	28.49	30.29	26.36	28.87	
Cr ₂ O ₃	0.08	0.06	0.07	0.06	0.04	0.03	0.08	—	—	
FeO	0.06	0.02	0.02	0.02	0.07	0.05	0.01	0.49	1.65	
MnO	0.00	0.03	0.00	0.01	0.00	0.01	0.00	—	—	
MgO	13.36	14.00	13.76	13.49	13.84	13.52	13.16	14.90	12.23	
NiO	0.01	0.00	0.00	0.05	0.02	0.00	0.00	—	—	
CaO	4.15	4.53	4.23	3.79	4.10	3.62	2.65	5.09	2.81	
Na ₂ O	0.66	0.53	0.63	0.74	0.67	0.76	1.18	0.35	1.26	
K ₂ O	0.02	0.03	0.01	0.00	0.00	0.00	0.02	—	—	
Total	85.90	85.97	85.55	85.19	85.28	84.24	85.84	83.75	83.65	
Uvite %	78	82	79	74	77	73	56	91	50	

NB: Corresponding growth stages 1 to 4 are shown. Positions of analytical points are shown in Figure 5. 8 and 9 show maximum and minimum data of uvite component in Dunn (1977). Contents of B, F, OH were not determined.

RI: 1.610–1.628
 SG: average 3.04
 Fluorescence: inert
 Chelsea colour filter: red
 Magnification: magnesite inclusions, liquid film

Birefringence: 0.018
 Pleochroism: dichroic (strong) green, yellowish-green
 Spectroscope: Cr lines are difficult to discern



internal texture most clearly. This procedure was necessary because optical properties, including extinction angles, vary from point to point even in a single crystal. This phenomenon in tourmaline crystals was reported as early as in the last century (Madelung, 1883), and more recently investigated by Foord and Mills (1978). Such variations in optical properties within a single crystal have been attributed to crystal growth processes, which itself is an interesting problem for further investigation. The problem has been treated in terms of 'vicinal sectoriality' by Chernov (1984), or 'intra-sectorial zoning' by, for example, Scandal (1996), but we shall not deal with this problem in the present paper.

Since the internal textures revealed on the mosaic photograph are too faint to be reproduced, only the corresponding sketch of the observed internal texture is presented in Figure 5. Boundaries of growth sectors (a sector formed by the growth of a particular face) and their changes during the growth history, as well as growth banding in some sectors are discernible under the microscope. From the observed pattern, there are three distinct features relating to the growth process of the uvite crystal.

First, there is no peripheral mantle portion with fibrous texture. Such mantles are common in pegmatitic tourmalines and their fibrous texture has been attributed to a rapid increase of driving force with a

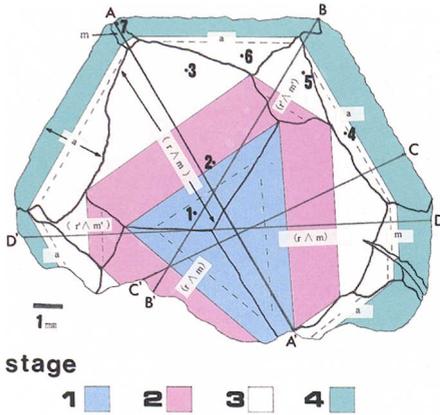


Figure 5: Internal textures (growth sectors, sector boundaries, directions of growth banding and growth stages) seen in a section perpendicular to the *c*-axis. Growth stages are shown by different colours, growth banding by dotted lines, and other boundaries by solid lines. Numbers correspond to analytical points in Table I. A–A', B–B', C–C' and D–D' are line scans. Arrowed solid lines indicate ranges of respective growth sectors, a , $r + m$, $r' + m'$.

consequent increase in growth rate and associated morphological changes at the final stage of crystallization (Sunagawa, 1984a,b, 1988a); this is a feature also commonly observed in the phenocrysts of volcanic rocks and in coated diamonds. Lack of a fibrous mantle in the uvite crystals is an indication that crystal growth proceeded rather gently from beginning to end of their growth history, keeping the polyhedral morphology. This indicates that there was no abrupt change in the growth parameters at the latest stage, which might have induced a drastic change of morphology from polyhedral to dendritic.

Secondly, no rounded discontinuous boundaries which intersect growth sectors were seen. This indicates that there were no periods of intermittent partial dissolution during the growth process of the uvite crystals.

Thirdly, from the sequence of changes in growth sector boundaries and growth banding, the following four stages have been distinguished. The morphological evolution

during the growth history of the uvite crystals may also be correlated with changes in their compositions.

1. The earliest stage 1, i.e. the central portion of the crystal, is characterized by a triangular outline bound by [010], [110] and [100] directions. In this stage, the most developed faces were positive and negative triangular pyramidal r and r' faces, and the habit was rhombohedral. Whether or not m and $m'\{10\bar{1}0\}$ faces were present cannot be concluded from this section only, but certainly no $a\{11\bar{2}0\}$ faces were present.
2. The second stage takes a hexagonal outline, bounded by [010], [110], [100], [100], [010] and [110] directions. It is not certain whether the six sectors corresponding to positive r and negative r' trigonal pyramidal growth sectors alone, or whether they are associated with the growth sectors of m and $m'\{10\bar{1}0\}$ faces.
3. The third stage takes a 12-sided outline, characterized by the development of $a\{11\bar{2}0\}$ faces.
4. In the final stage 4, narrow growth sectors corresponding to smaller m and $m'\{10\bar{1}0\}$ faces appear, in addition to the $a\{11\bar{2}0\}$ growth sectors.

Compositional variation

Table I gives the results of point analyses in the cross-section, together with corresponding growth stages, reference chemical data and gemmological data. The contents of the major oxides, SiO_2 , Al_2O_3 , MgO , CaO and Na_2O , and uvite mole % are given. It can be seen in Table I that Ca and Mg show concordant variation, whereas Al and Na show reverse variation with Ca and Mg, indicating coupled substitution. Figure 5 shows the analysis points and where the EPMA line scans (A–A', B–B', C–C', D–D') were carried out.

Figure 6 shows relative variation in contents of Mg, Ca and Na along each scan compared with the centre. From these variations, changes in uvite mole ratios have been calculated. From Table I and Figures 5 and 6, we note the following:

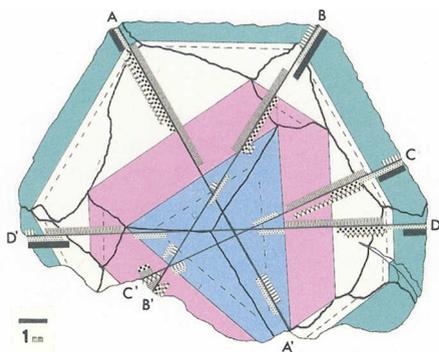


Figure 6: Compositional changes based on the results of EPMA line scans. Relative changes in the contents of Mg, Ca and Na are shown, taking the respective contents at the centre as standard. Boundaries of growth sectors and stages are also indicated.

1. At the boundary of the triangular outline of stage 1, there are slight decreases of less than 1% in Mg and Ca contents, i.e. the uvite component decreased temporarily.
2. In the second stage, an increase of Mg content (less than 1 wt% MgO) occurs simultaneously with the appearance of [100], [010] and [110] directions (corresponding to the growth sectors of r and r' , or $r+m$ and $r'+m'$). In these growth sectors, an increase of Ca and a decrease of Na, both being less than 1 wt% of the oxides, occur simultaneously with the increase of Mg. There is a general increase of the uvite component at this stage.
3. In the third stage, Mg and Ca start to decrease and Na increases only in the $a\{11\bar{2}0\}$ growth sectors, and this coincides with the appearance of this face. Meanwhile Mg continues to increase in the growth sectors corresponding to [010], [110] and [100], where an increase of Mg had already been noted in the second stage. In other words, the appearance of the $a\{11\bar{2}0\}$ growth sectors is closely related to a decrease in uvite and an increase in the dravite component.

4. In the fourth and final stage, the CaO content decreases by almost 2 wt%, and the Na_2O content increases by about 0.5 wt% (almost doubling), i.e. the uvite component sharply decreases in all growth sectors in the fourth stage.

In the sections parallel to the c -axis distinct growth sectors are not easily discernible under a polarizing microscope, and only faint features may be visible. However, from the results of EPMA analyses, the following compositional variations were established:

1. Compositional variation similar to that noted at the boundary between the second and third stages in the cross-section is present along the whole periphery of the crystal, with a constant width of less than ca. one-fifth of that of the prism. Mg and Ca contents decrease towards the periphery whereas the Na content increases, i.e. the uvite component decreases and the dravite increases both perpendicular and parallel to the c -axis, at the onset of the third stage, where $a\{11\bar{2}0\}$ faces started to develop.
2. The width of prismatic growth sectors is much narrower than those of trigonal pyramidal growth sectors, and limited to the peripheral portion, about one-fifth of the prism.
3. Judging from the compositional variation and the form of the growth sectors, the initial point of uvite growth is situated at about one-third of the length along the prism and closer to the negative end.

In *Figure 7a* and *b*, growth sector boundaries, growth stages and variations in uvite component are summarized and schematically illustrated, in sections perpendicular and parallel to the c -axis, respectively.

Discussion

Salient points revealed in this study are:

1. Uvite contents of the tourmaline changed from $Uv_{78} - Uv_{82} - Uv_{74} - Uv_{56}$ from the initial stage to the latest stage of growth of the single crystals.

- Morphology of the crystals changed from flat rhombohedral (or equant) bounded principally by $r\{10\bar{1}1\}$ and $r'\{01\bar{1}\bar{1}\}$ faces to short prismatic bounded by $r\{10\bar{1}1\}$, $r'\{01\bar{1}\bar{1}\}$, $c'\{000\bar{1}\}$ and $a\{11\bar{2}0\}$ faces during the growth history. Four stages were distinguished in the morphological evolution.
- The appearance and development of $a\{11\bar{2}0\}$ faces at the third stage are related to an increase of the dravite component. However, morphological changes in other stages are not directly or clearly related to compositional changes.
- The major portion of the uvite prism was formed by growth on positive and negative trigonal pyramidal faces, r and r' . Growth on the prism faces contributed to the volume of a uvite crystal by less than one-fifth in terms of the width of a prism.
- The growth rate along the c -axis in the positive direction was about twice as high as in the negative direction.
- The spiral growth mechanism operated most probably on both positive and negative trigonal pyramidal faces, r and r' , and also on second-order prism a faces, but probably did not on the $c'\{000\bar{1}\}$, m , $m'\{10\bar{1}0\}$ and other faces.

Based on the above summary, we will now analyse how uvite crystals grew and what were the causes for morphological evolution.

The chemical formulae of dravite and uvite are $\text{NaMg}_3\text{Al}_6\text{B}_3\text{Si}_6\text{O}_{27}(\text{OH},\text{F})_4$ and $\text{CaMg}_3(\text{Al}_5\text{Mg})\text{B}_3\text{Si}_6\text{O}_{27}(\text{OH},\text{F})_4$, respectively, forming a continuous solid solution between the two end members (Deer *et al.*, 1966). Among the major components in these formulae, Ca and Mg are clearly derived from the original carbonate rocks, whereas Na, Al, B, Si, OH, F are considered to come from acidic magma. The observed changes in uvite–dravite components during the growth history of uvite crystals suggests that the crystals were formed at the beginning from a fluid enriched in the compositions derived from the original rocks. However, towards the later stages of crystallization, Mg and Ca diminished, whereas the dravite component derived from the acidic magma was enriched. In other words, the components

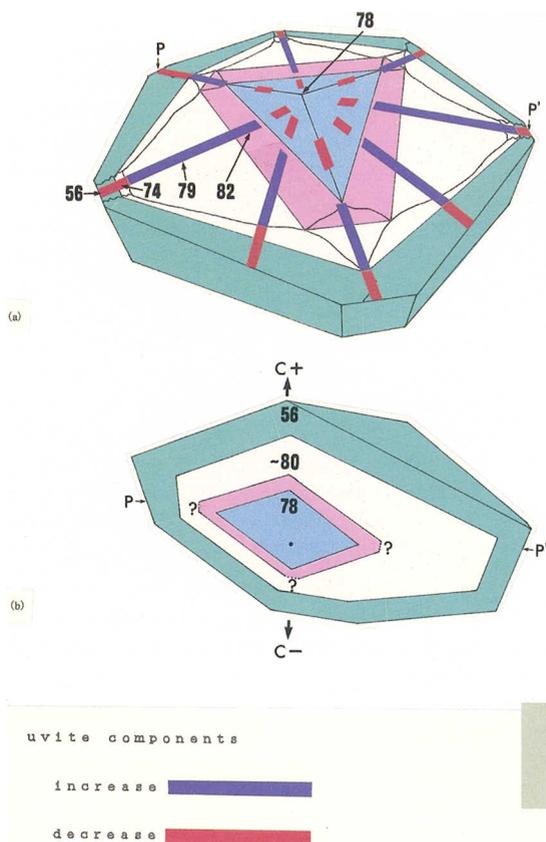


Figure 7: Schematic diagrams showing changes in uvite components in mole % and morphological evolution and growth stages in sections perpendicular (a) and parallel (b) to the c -axis. Numbers in (a) indicate uvite mole %. Trends of increase and decrease of uvite components are distinguished by different colour lines. The dot in (b) indicates the initial point of growth. Both (a) and (b) are perspective projections.

from the original rocks were consumed at the earlier stages, and those from the acidic magma became gradually enriched. This is reasonable, considering the reaction taking place between the original carbonate rocks and acidic magma.

The formation of uvite crystals from a fluid phase, not by solid-state reaction, is supported by their well-formed idiomorphic morphology, an indication of freely developed crystals. The fact that uvite crystals occur in isolation, not in a radiating

group, indicates that the nucleation rate was low. This implies that the nucleation took place under a relatively small driving force. Uvite growth proceeded throughout its history under such a condition, and neither partial dissolution during the growth process nor a rapid increase of the driving force at the latest stage took place. Nucleation and growth proceeded and finished in a gentle growth environment. Spiral growth is the most likely growth mechanism under such conditions (Sunagawa, 1984a). The undulating surface features of other faces imply that they appeared temporarily through the agencies of mechanisms other than spiral growth or two-dimensional nucleation growth. These features appear on faces by an adhesive-type growth mechanism on rough interfaces or by selective impurity absorption (see, for example, Sunagawa, 1988a).

During the morphological evolution from stages 1 to 4, the appearance and dominant development of second-order prism faces $a\{11\bar{2}0\}$ at the onset of stage 3 are clearly related to compositional change from a uvite-rich to a more dravite-rich composition. The change in morphology occurring at the onset of stage 3 was very distinct; up to that point, the major habit-controlling faces were $r\{10\bar{1}1\}$, $r'\{01\bar{1}\bar{1}\}$ and $c'\{000\bar{1}\}$, and possibly narrow m and $m'\{10\bar{1}0\}$ faces, with $a\{11\bar{2}0\}$ faces being entirely absent. The initial morphology probably represents the morphology of crystals of uvite composition, whereas the appearance of $a\{11\bar{2}0\}$ faces is attributed to an increase of dravite component.

It has been proven in the present study that the growth rate in the positive direction along the c -axis is twice as high as in the negative direction. Why there is a higher growth rate in the positive direction should be related to the structural characteristics of the tourmaline crystal and this is a subject of re-investigation and future study.

Summary

1. The uvite crystals were formed and grew freely in a fluid phase derived from the reaction between carbonate rocks and acidic or granitic magma. They nucleated

and grew under a small driving force condition. The uvite component in the fluid was relatively enriched in the early stages of growth, but decreased in favour of dravite in the later stages.

- Initially, uvite crystals were bounded principally by positive and negative trigonal pyramidal faces r and r' , but later when the uvite component diminished, second-order prism faces a started to develop.
- Uvite crystals grew by the spiral growth mechanism on positive and negative trigonal pyramidal r and r' , and second-order prism faces, a .
- Growth was twice as rapid in the positive c -axis direction as in the negative direction, a feature which is reflected in the differences of step separation and morphology of growth steps.
- The driving force changed rather monotonously during the whole process of growth. There was no abrupt change in the growth conditions, such as to cause partial dissolution during the growth process or rapid increase of the driving force at the final stage.

Acknowledgements

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Maxixe-type colour centre in natural colourless beryl from Orissa, India: an ESR and OA investigation

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ABSTRACT: A change in colour of colourless beryls to green to greenish-yellow on irradiation is reported for the first time from Indian samples. On heating to 300°C, the colour of the irradiated beryl changes from greenish-yellow to yellow and finally to colourless at 500°C. On the basis of Electron Spin Resonance (ESR) and Optical Absorption (OA) studies, the cause of colour is deciphered to be due to the formation of a defect centre similar to the Maxixe type, and radiation-induced oxidation of Fe²⁺ present at the octahedral Al³⁺ site with associated ultra-violet charge transfer (UVCT) tail. The former gives rise to blue and the latter to yellow colours in beryl. A combination of the above two results in a greenish-yellow colour. A new weak additional ESR line at 1500 gauss is reported for the first time after irradiation of a beryl crystal; the line gradually disappears on heating to 300°C.

Keywords: beryl, colour centre, electron spin resonance, gemstones, India, optical absorption

Introduction

Gem enhancement is a field of high potential wherein less attractive gemstones are transformed to more desirable stones by various methods such as chemical treatment, irradiation and heating; e.g. rendering an attractive blue hue to a colourless topaz crystal by irradiation, and removal of patches of silk in ruby by intense heating. An exhaustive review of such techniques is discussed by Nassau (1994). In the present paper the authors have documented colour enhancement

Technique Abbreviations

EPMA	Electron Probe Micro Analysis
EPR	Electron Paramagnetic Resonance
ESR	Electron Spin Resonance
IVCT	Intervalence Charge Transfer
NIR	Near InfraRed
OA	Optical Absorption
RT	Room Temperature
UVCT	Ultraviolet Charge Transfer

Experimental details

Colourless beryl samples from the Badmal mines of Orissa were irradiated using a Cavity Resonator type Linear Electron Beam Accelerator (model No. ILU6) at the Isotope Division, BARC, Mumbai, India. An energy of 1.7 MeV was used and the beam current was maintained at 2 mA with the samples kept on a water-cooled aluminium target. The samples were also subjected to gamma-ray radiation using a ^{60}Co source.

On the bases of external morphology and a conoscopic interference figure, the samples were cut parallel ($H\parallel c$) and perpendicular ($H\perp c$) to the c -axis and had dimensions of about $1.5 \times 1.5 \times 10$ mm for ESR measurements. ESR measurements were carried out on a Varian E-112 E-line century series X-band ESR spectrometer which utilizes 100 KHz field modulation. Tetra Cyno Nitro Ethylene (TCNE, $g = 2.00277$) was used as a standard for g -factor measurements. A Varian variable temperature accessory was used to carry out experiments at different temperatures.

Polarized OAs were measured at variable temperatures over 300–2500 nm ($25000\text{--}4000\text{ cm}^{-1}$) range with a Shimadzu UV 3101PC scanning spectrophotometer. Colourless beryl crystals cut along the ac plane were doubly polished to a crystal thickness of 1.0 mm. Polarized sheets (HN 22) were used to obtain polarized spectra. Heat treatments in air at temperatures up to 500°C were carried out using an electric furnace, with samples kept in a nickel crucible. Analyses of colourless beryl samples were carried out by WDS EPMA using an SX-50 Microprobe. Operating conditions were 15 kV accelerating voltage, 20 nA beam current and 10 s counting time; the results are given in Table I.

Table I: EPMA of colourless beryls

Wt. %	1	2
SiO_2	65.698	64.240
Al_2O_3	17.740	17.442
FeO	0.545	0.744
MnO	0.025	0.012
Cr_2O_3	0.027	0.031
V_2O_3	0.032	0.012
TiO_2	0.034	—
NiO	0.022	0.016
CoO	0.056	0.056
MgO	0.093	0.281
CaO	0.020	0.041
K_2O	0.019	0.031
Na_2O	0.206	0.275
F	0.216	0.057
Total	84.733	83.238

1. When irradiated, colour changed to greenish-yellow.

2. When irradiated, colour changed to yellow-orange.

NB: Total iron reported as FeO; BeO and H_2O not determined.

experiments conducted on colourless beryls from Badmal mines of Orissa state, India, using a radiation technique.

Beryl is a typical cyclosilicate mineral with the chemical formula $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. It has a honeycomb-like hexagonal crystal structure belonging to the space group $P6/mcc$. The Si_6O_{18} sixfold rings of SiO_4 tetrahedra lie one above the other along the C_6 axis and form intercommunicating channels (Figure 1a). The channels are joined laterally by Al^{3+} and Be^{2+} ions (Figure 1b). The aluminium and beryllium ions are located in distorted octahedral and tetrahedral sites respectively, whereas the SiO_4 tetrahedron is nearly undistorted. The diameter of the channels varies between 2.8 \AA in the plane of Si_6O_{18} rings and 5.1 \AA between neighbouring rings and they are capable of accommodating a number of elements (e.g. Na, K, Rb, Cs and Fe) and molecules (e.g. CO_2 and H_2O). Two types of water molecules have been recorded in beryl occupying two distinct positions in

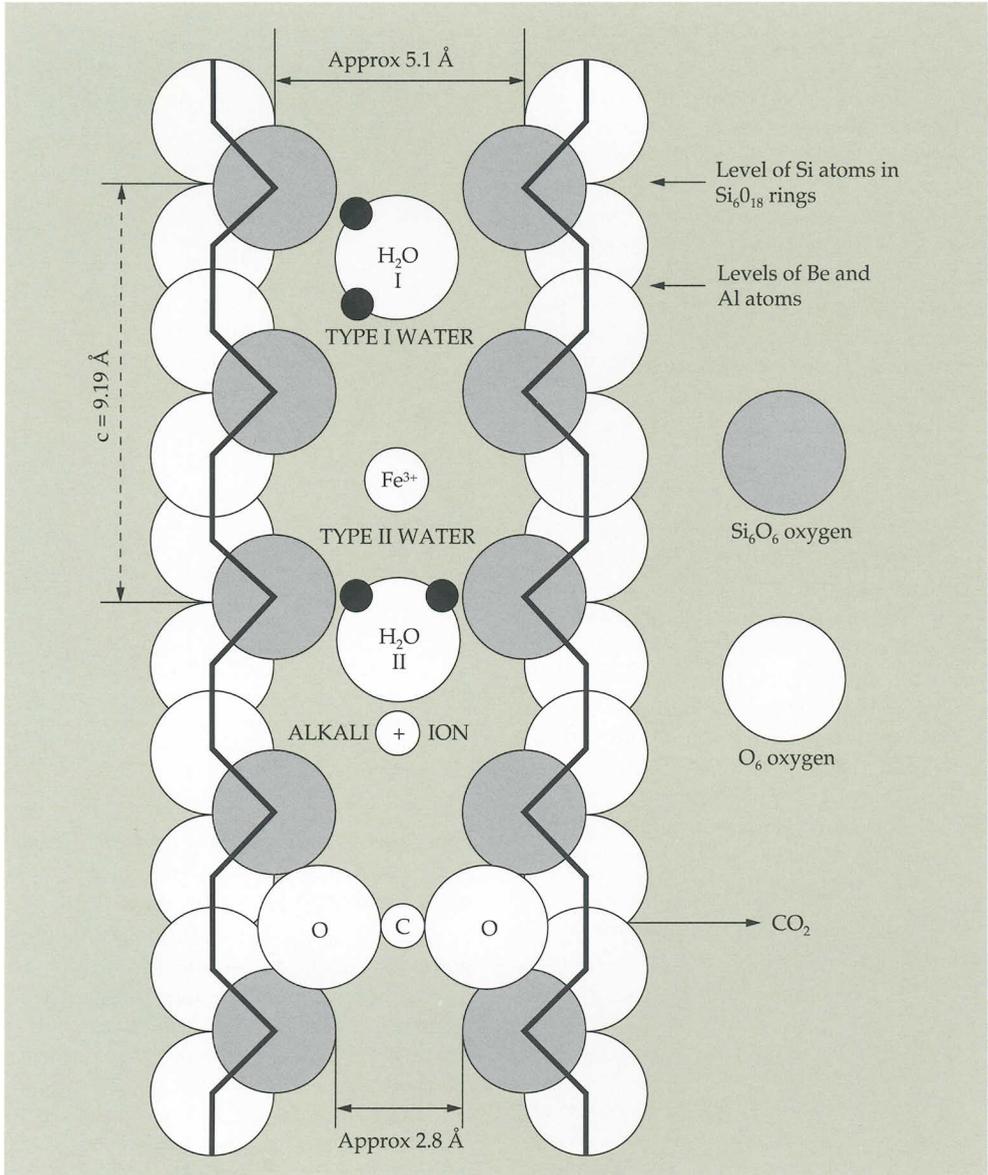


Figure 1a: Schematic drawing parallel to *c*-axis showing the Fe^{3+} ion in a channel site in the beryl structure (modified after Wood and Nassau, 1968).

the channel site (Wood and Nassau, 1967); the presence of such water molecules has also been noticed in the Orissan beryls (Mathew *et al.*, 1997).

High energy radiations are capable of changing the colour of several minerals and of inducing a variety of radiation damage

centres which include trapped electrons and oxidized and reduced cations and anions. It has been found that on irradiation, colourless beryl from various localities turns to (i) pale brown (Mukerjee, 1951); (ii) blue (NO_3^- and CO_3^{2-} impurity bearing variety: Nassau *et al.*, 1976); and (iii)

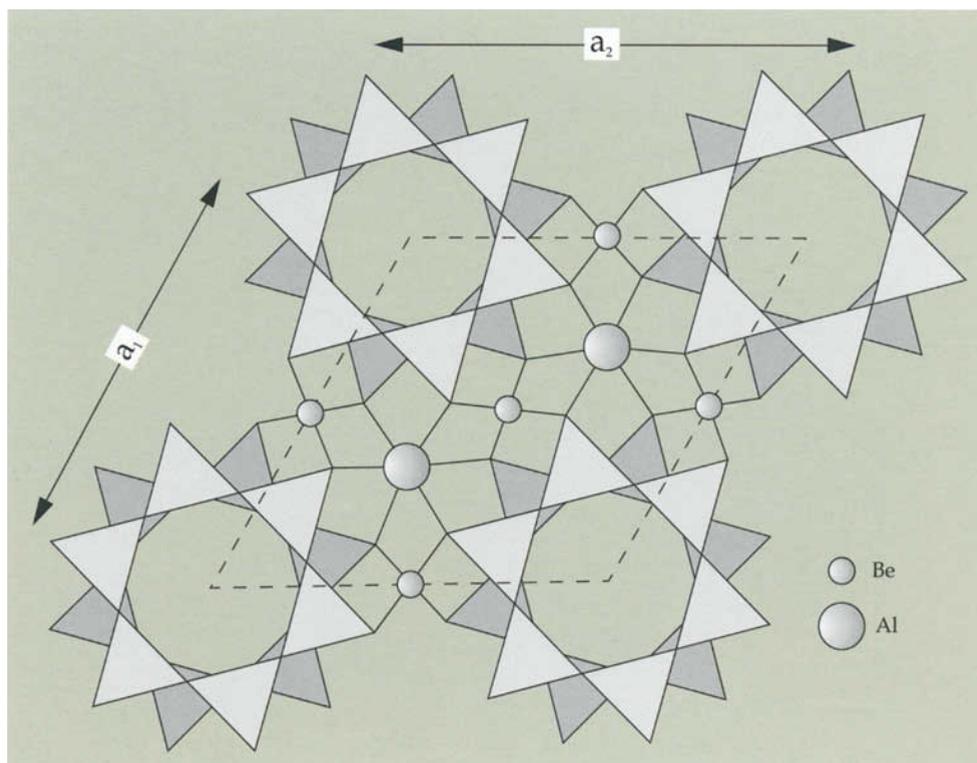


Figure 1b: Structure of beryl projected on plane perpendicular to c -axis.

yellow-orange (Nassau *et al.*, 1976; Sinkankas and Read, 1985). Nassau *et al.* (1976) observed that if the original beryl is yellow or green, then a green or blue-green colour results from generation of a Maxixe colour centre. According to a few authors (Wood and Nassau, 1968; Blak *et al.*, 1982) Fe^{2+} in a channel site is more powerful in causing a blue colour than in the substitutional Be and Al site, where it fails to induce any effect on colour. They attributed yellow in beryl to Fe^{3+} in a substitutional site, whereas its presence in the structural channel has no effect on colour. However, according to Goldman *et al.* (1978), the blue colour is due to IVCT and yellow is due to UVCT arising from Fe^{3+} in a channel site. When both Fe^{2+} and Fe^{3+} ions are present, the resultant colour depends on the proportion of each, thus explaining the 'gamut of hues' that may be observed from blue to various shades of blue-green,

yellow-green and yellow (Sinkankas and Read, 1985). Thus, the colour of iron-containing beryls depends on the distribution of iron in the channel, octahedral Al site, tetrahedral Be site and interstitial positions and upon the character of their interactions. From the above references it is evident that several researchers have proposed different views to explain the cause of colour in beryl. In the present study, it is shown that on irradiation some colourless beryl (goshenite) samples have turned to green to greenish-yellow and some to yellow-orange (Table I). The green colour fades on heating to 300°C , leaving yellow, and finally becomes colourless on further heating to 500°C . The yellow-orange beryl also turns colourless at 500°C . In this study, we report the results of the investigation on colourless beryl using the techniques of ESR and OA.

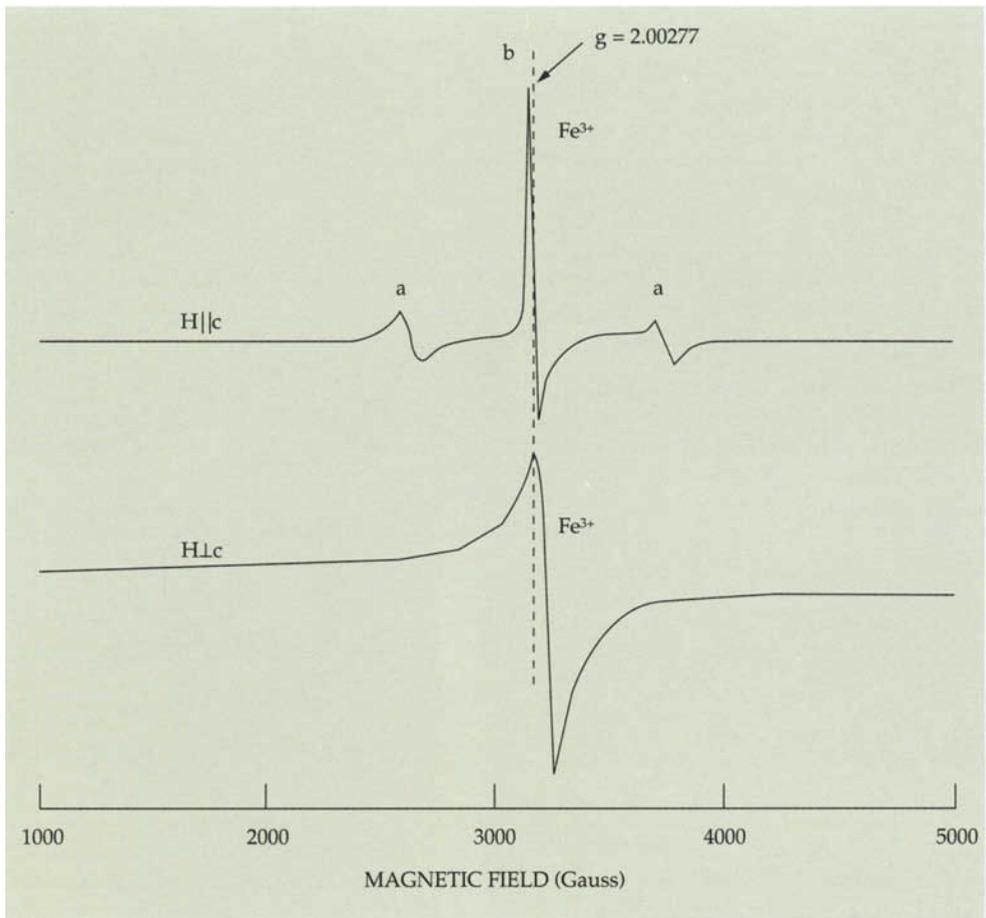


Figure 2: ESR spectra of colourless beryl (before irradiation) for two magnetic field directions ($H||c$ and $H\perp c$) in the 3200 G region. The $g = 2.00277$ line shown in the figure is the marker (TCNE).

Results and discussion

Electron Spin Resonance (ESR) studies on unirradiated beryl

ESR, also referred to as EPR, is a spectroscopic technique based upon resonant absorption of microwaves by paramagnetic substances tuned by an external magnetic field. It is a powerful technique in detecting colour centres which are responsible for colour in minerals. The first detailed ESR studies on beryls were carried out by Davir and Low (1960), in which they proposed that Fe^{3+} ions occupy octahedral Al^{3+} sites and also indicated their probability in tetrahedral sites.

The ESR spectrum of unirradiated colourless beryl presently under study is shown in Figure 2 for the two field directions ($H||c$ and $H\perp c$). Similar spectra were reported by Davir and Low (1960) and Blak *et al.* (1982). The spectrum consists of a large asymmetrical single line (labelled 'b') near the free electron resonance attributed to Fe^{3+} in the channel site ($g = 1.996$ for H parallel and $g = 1.998$ for H perpendicular to the crystallographic c -axis). The observed g -value for the Fe^{3+} ion (strong line) is close to the free electron value of 2.00233. The Fe^{3+} in the channel is surrounded by 24 oxygen atoms. The distance between Fe^{3+} and an oxygen atom is 3.4 Å in the SiO_6 plane and 4.1 Å in the plane

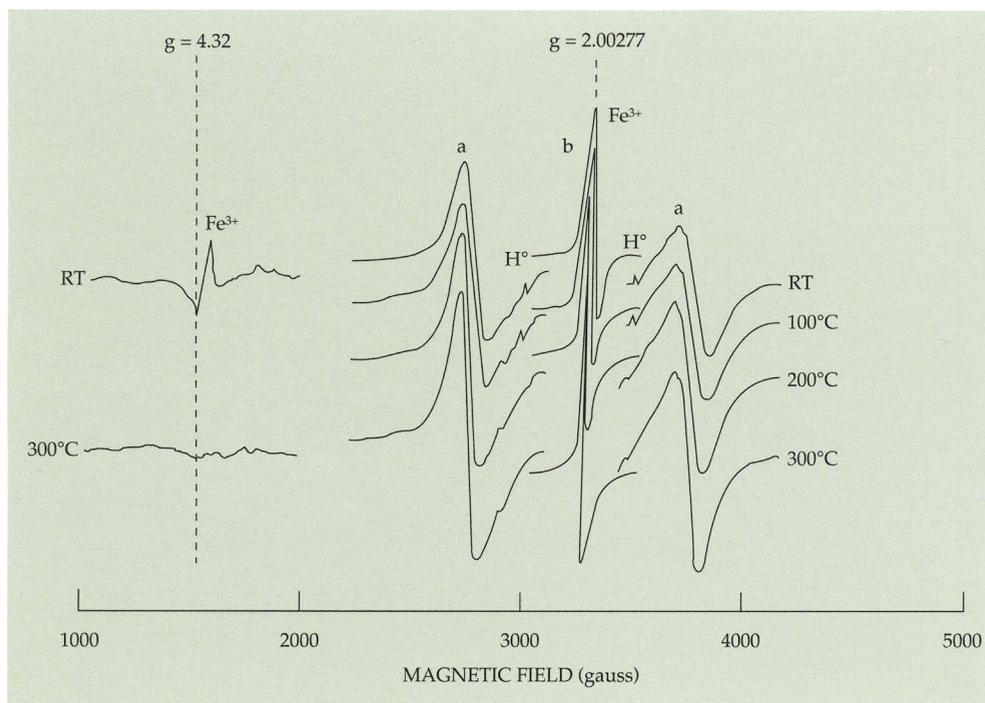


Figure 3a: Variable temperature ESR spectra of colourless beryl (after irradiation) for the magnetic field parallel ($H||c$) to the crystallographic c -axis depicting the presence of new line at 1500 G.

of O_6 (Blak *et al.*, 1983) and these distances are too large to allow the occurrence of any significant crystal field splitting in the ESR spectra and consequently in ESR absorption. Therefore, Fe^{3+} with a 'g' value close to 2.00233 behaves almost as a free ion; thus it probably occupies a site in the structural channel (Blak *et al.*, 1983). Additional weak lines (labelled 'a') are observed on either side of the strong line. These weak lines are possibly due to the small presence of Fe^{3+} substituting in the octahedral Al^{3+} site as suggested by Davir and Low (1960).

ESR studies on irradiated beryl

The colourless beryl samples from Orissa as explained above turned to greenish-yellow and some to yellow-orange after irradiation in the electron beam, whereas gamma radiation did not produce any colour change. Figures 3a and 3b show the ESR spectra of irradiated beryl for the magnetic

field along the c -axis and for a random orientation in the plane perpendicular to the c -axis respectively. In addition to the main Fe^{3+} peak at 3200 gauss, an additional line is observed in the low field region around 1500 G. Although such lines were reported by Blak *et al.* (1982) in natural green beryl, they are observed here for the first time in natural beryl crystals after irradiation. The g-factors in the vicinity of 4.3 in many minerals (e.g. feldspars and mica) have been attributed to high spin Fe^{3+} in a low symmetry environment of rhombic distorted site (Castner *et al.*, 1960; Abragam and Bleaney, 1970; Calas, 1988). Therefore it is likely that in the beryl sample under study, the Fe^{3+} ion occupies a distorted rhombic site. This indicates that the above Fe^{3+} ion was initially in the form of Fe^{2+} in the unirradiated sample and on subsequent irradiation it was oxidized/ionized to Fe^{3+} .

The low-intensity line observed around 1500 gauss in the ESR spectrum (Figures 3a

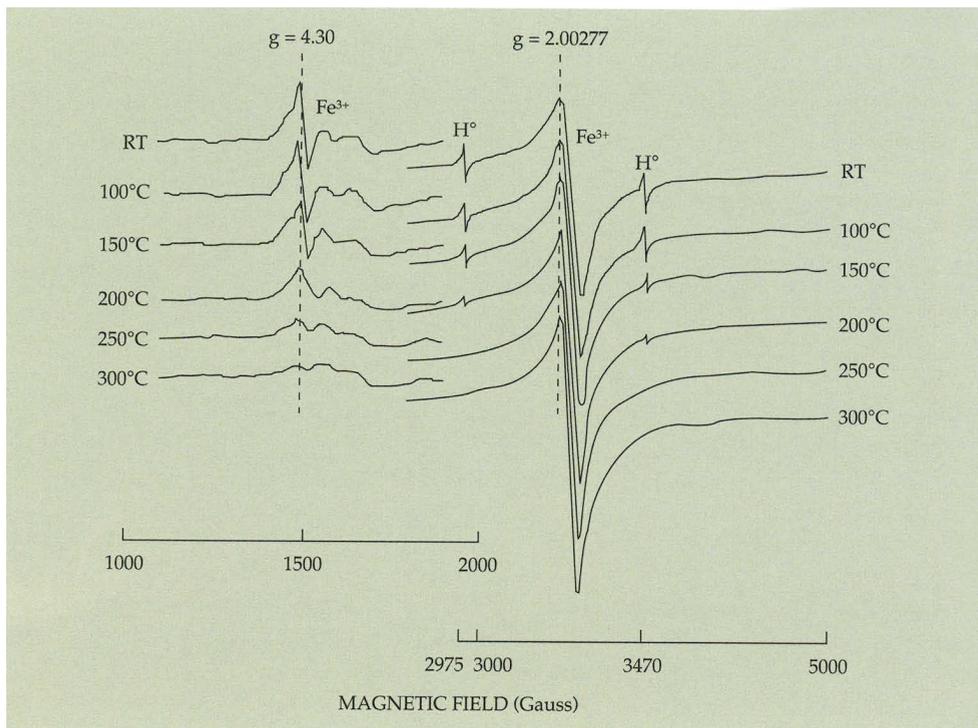


Figure 3b: Variable temperature ESR spectra of colourless beryl (after irradiation) for the magnetic field perpendicular ($H \perp c$) to the crystallographic c -axis.

and 3b) is tentatively assigned here to the Fe^{3+} ion formed by oxidation of Fe^{2+} at the Be^{2+} tetrahedral site. As the Fe^{2+} ion is characterized by a short spin relaxation time, it was not possible to observe the ESR lines attributable to Fe^{2+} in the present ESR investigation at room temperature.

The ESR lines around the g -factor of 4.3 (Figures 3a and 3b) due to the Fe^{3+} ion show a gradual decrease in intensity on heating, which points to a reduction of Fe^{3+} to Fe^{2+} . The Fe^{3+} line disappears around 300°C and is accompanied by a change in colour of irradiated beryl from greenish-yellow to yellow. This observation apparently indicates a possible correlation of Fe^{3+} at the tetrahedral site to the coloration in irradiated beryl. However, it is important to mention here that the disappearance of the above Fe^{3+} ESR signal around 300°C is also observed in irradiated yellow-orange beryl; but there is no significant change in the yellow-orange

hue. The yellow and yellow-orange colours are found to disappear around 500°C in both beryls irradiated to greenish-yellow and yellow-orange respectively.

A ' g ' value of 4.3 is not expected from an Fe^{3+} ion situated at the channel site, since here the ion behaves almost as a free electron ($g = 2.00233$). Its possible substitution at an octahedral site is also doubtful, as it is clearly seen in the ESR spectrum that the 4.3 signal of Fe^{3+} disappears at 300°C and yet the sample retains its yellow colour. It is well documented by many authors (e.g. Wood and Nassau, 1968) that yellow in beryl is due to the presence of Fe^{3+} at an octahedral site. Further it is known that the bond distances for Be–O and Si–O are 1.657 and 1.608 Å respectively and the typical Fe–O bond distance is 1.980 Å (Hazen *et al.*, 1986; Shannon and Prewitt, 1969). It is therefore likely that Fe^{2+} , although characterized by large ionic radius, substitutes in small

quantities at the fourfold coordinated beryllium site, while most Fe^{2+} ions prefer the octahedral Al^{3+} site and the channel site. According to Samoilovich *et al.* (1971), on thermal excitation (heating) of the electron, the capture cross-section is greater for the $[\text{Fe}^{3+}]_{\text{tet}}$ than for the $[\text{Fe}^{3+}]_{\text{oct}}$ ion. In the present study, step annealing experiments show that $[\text{Fe}^{3+}]_{\text{tet}}$ is first reduced to $[\text{Fe}^{2+}]_{\text{tet}}$ below 300°C (Figures 3a and 3b). On the other hand, $[\text{Fe}^{3+}]_{\text{oct}}$ is found to reduce to $[\text{Fe}^{2+}]_{\text{oct}}$ at higher temperatures. These findings are in accordance with the expectations of Samoilovich *et al.* (1971). It was found that the greenish-yellow colour as well as ESR signals could be restored after repeated irradiation.

ESR spectral studies also revealed that, on irradiation with an electron beam, beryl produces atomic hydrogen (H^0) represented by two weak satellites at 2970 and 3470 gauss (Figures 3a and 3b). The atomic hydrogen occupies the channel site and appears to be formed by irradiation-induced splitting of the hydroxyl group (Koryagin *et al.*, 1966). In the present study it was observed that H^0 becomes unstable above 200°C . Similar weak H^0 satellite peaks are also observed in samples irradiated by gamma rays, and these also disappeared above 200°C .

ESR experiments were also carried out on greenish beryl at low temperatures (77 K) to observe the presence of colour centres in the beryl lattice, but failed to reveal the possible presence of the ESR lines attributable to colour centres due to strong overlap from the Fe^{3+} signal around the free electron resonance region. Nevertheless, the presence of such colour centres has been deduced from OA spectroscopy as explained in the next section.

Optical Absorption (OA) studies

In general three types of processes generally contribute to OA spectra in minerals (Rossman, 1988):

1. crystal field;
2. charge transfer (UVCT and IVCT);
3. absorption edge.

OA studies of irradiated coloured beryl were carried out at various temperatures. The absorption spectra of irradiated greenish-yellow beryl taken at RT are shown in Figures 4a and 5. UVCT is due to electron transfer from anion to cation, i.e. transfer of electron from O^{2-} ligands to a central (Fe^{3+}) metal ion (Rossman, 1988) and the absorption this causes below 390 nm extends into the visible region. These transitions occur in the ultraviolet region and produce absorption 2 to 3 orders of magnitude higher than the ordinary crystal field transition (Marfunin, 1979). The tail of the absorption band extends into the visible region due to an increase in concentration of Fe^{3+} , which in turn resulted from ionization of Fe^{2+} as seen in Figures 4a and 5. The strongest absorption is in the violet and the tail extends into the green.

The visible region of the optical spectrum in the irradiated greenish-yellow beryl is characterized, in the ordinary ray only (o-ray or $\perp c$), by sharp absorptions at 644 and 688 nm (Figure 4b). Such a sharp absorption pattern is not seen in the beryl irradiated to yellow-orange. The sharp absorption feature observed above is similar to the optical spectrum of Maxixe-type beryl observed by Nassau *et al.* (1976) who attributed this absorbance to colour centre formation and concluded that this was the cause of blue colour in Maxixe-type blue beryls from Brazil. Later workers (Edgar and Vance, 1977; Andersson, 1979) with the help of ESR studies, inferred this centre to be the CO_3^- radical in Maxixe-type beryl and NO_3^- in Maxixe beryl. These radicals are derived from CO_3^{2-} and NO_3^- respectively residing in the structural channel sites of beryl crystals. On irradiation, these ions lose an electron and become CO_3^- and NO_3^- radicals. This results in generation of a hole centre in Maxixe-type beryls. Nassau *et al.* (1976) defined Maxixe beryls as those natural deep blue beryls formed by natural radiation in which the impurity precursor is NO_3^- , whereas Maxixe-type beryls are those deep blue-green beryls produced by artificial irradiation having the impurity precursor as CO_3^{2-} . Edgar and Vance (1977) considered also the presence of HCO_3^- precursors to be

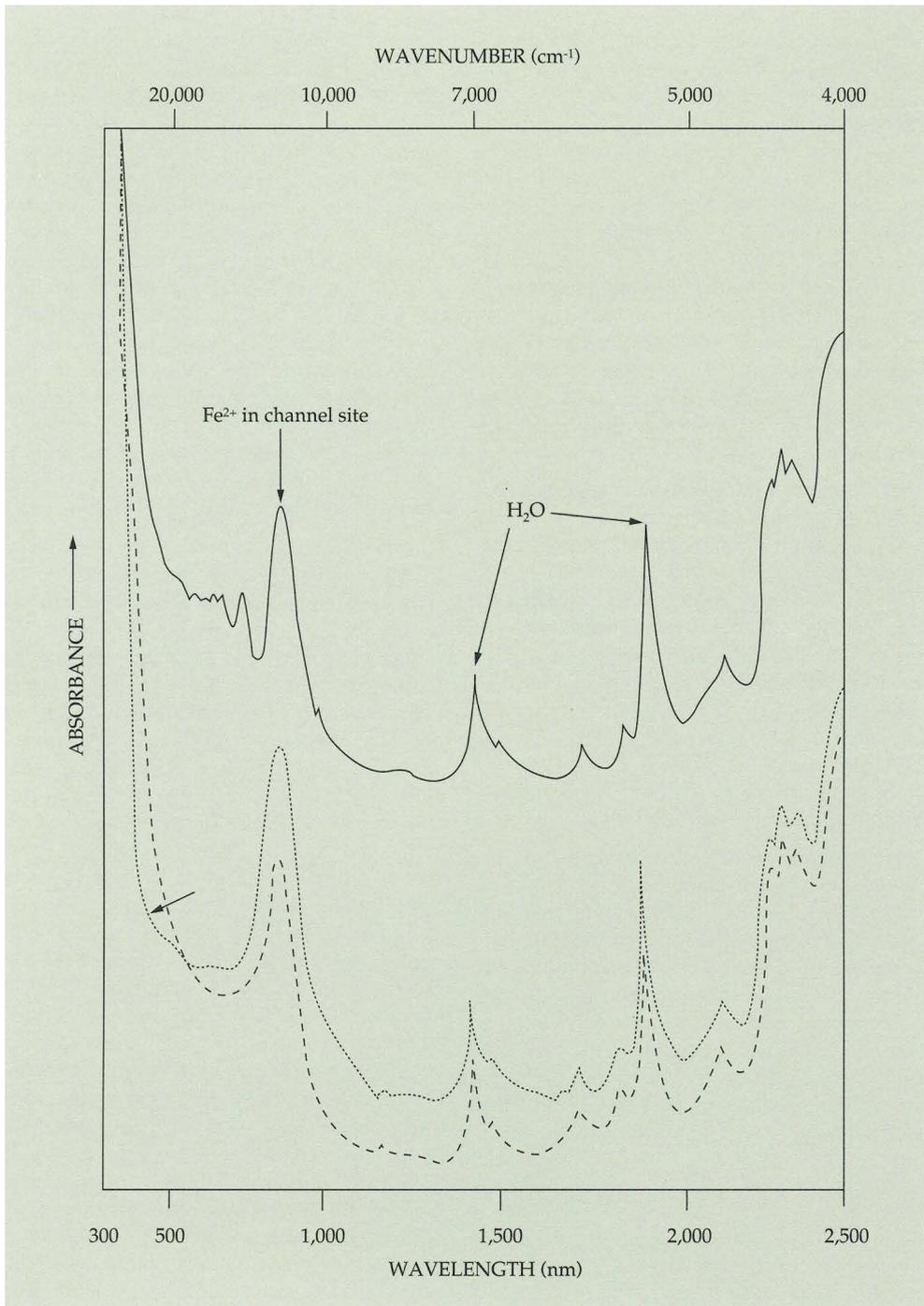


Figure 4a: Absorption spectra (UV-VIS-NIR) of irradiated greenish-yellow beryl showing the Fe^{2+} peak in channel site polarized along o-ray. Crystal thickness = 1.0 mm. Solid line RT, dashed line 300°C and dotted line 500°C.

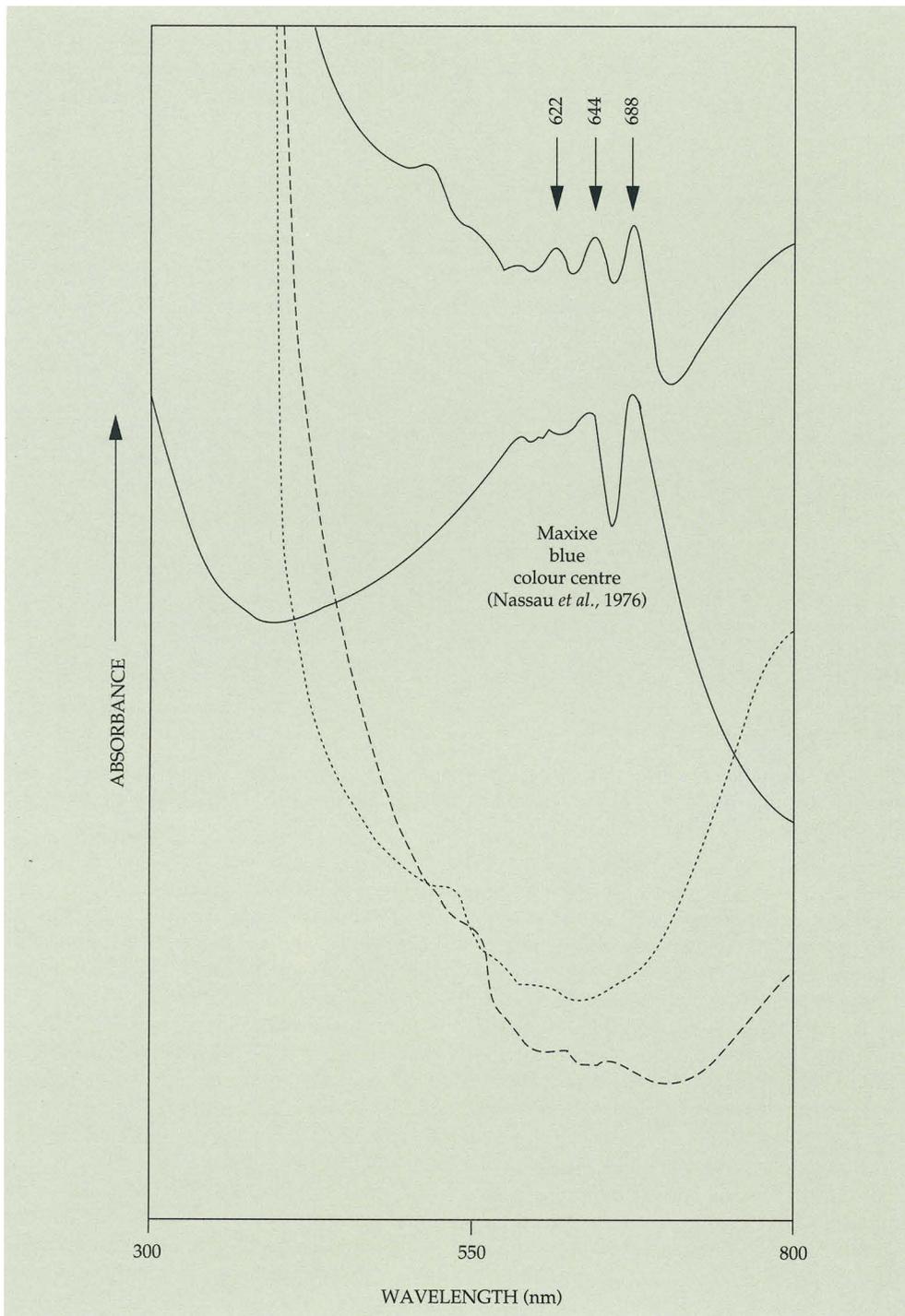


Figure 4b: Absorption spectra (UV-VIS) of irradiated greenish-yellow beryl polarized along o-ray showing the presence of Maxixe-type colour centre. Solid line RT, dashed line 300°C and dotted line 500°C.

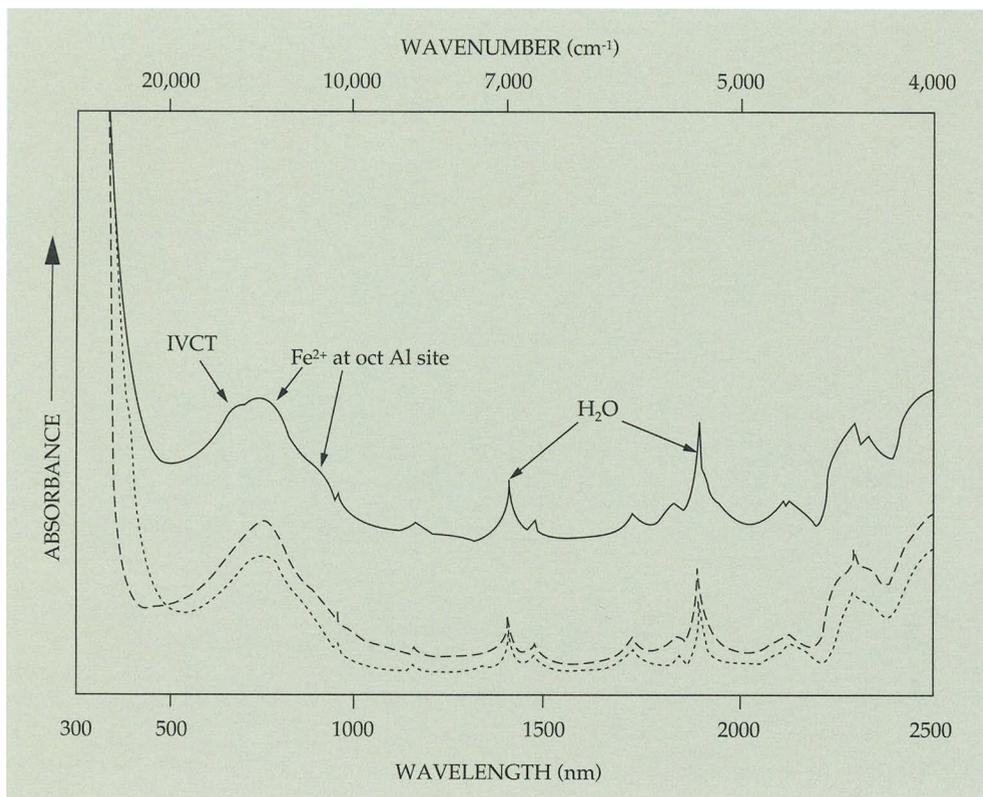


Figure 5: Absorption spectra (UV-VIS-NIR) of irradiated greenish-yellow beryl showing the Fe^{2+} peak in octahedral Al site along e -ray. Crystal thickness = 1.0 mm. Solid line RT, dotted line 300°C and dashed line 500°C.

more reasonable than CO_3^{2-} due to the formation of a neutral hydrogen atom (H^0) after irradiation. In the present study, as explained earlier, the formation of atomic hydrogen is seen both in the case of electron beam and gamma-ray irradiation. However, no colour is produced from gamma-ray irradiation and this indicates that atomic hydrogen produced from irradiation comes solely from H_2O .

The existence of two distinct types of Fe^{2+} in colourless Orissan beryl is indicated by the optical spectra (Figures 4a and 5). Wood and Nassau (1968) recognized three absorption bands in the NIR region and attributed them to Fe^{2+} . A band near 810 nm polarized $\perp c$ (perpendicular to the crystallographic c -axis) was assigned to Fe^{2+} in the Al^{3+} site. On the other hand, a set of bands near 810 nm and

1000 nm polarized $\parallel c$ (parallel to the crystallographic c -axis) was attributed to Fe^{2+} in the channel site and the band centred at 620 nm ($\parallel c$) was attributed to Fe^{2+} in a different site. Samoilovich *et al.* (1971) and Parkin *et al.* (1977) agreed with the assignments of Wood and Nassau (1968). However, according to Price *et al.* (1976), bands at 810 and 1000 nm ($\parallel c$) arose from Fe^{2+} in the Al^{3+} site and the 810 nm band ($\perp c$) possibly indicated Fe^{2+} at a tetrahedral site. Goldman *et al.* (1978) attributed 820 nm and 970 nm peaks in the spectrum polarized to Fe^{2+} in the Al^{3+} site and assigned 820 nm ($\perp c$) and 2100 nm ($\parallel c$) peaks to Fe^{2+} in a channel site. They ascribed a broad absorption feature seen from 1700 nm to 2500 nm also to iron in a channel site. Thus there is no universally agreed point of view regarding the interpretation of OA spectra of

beryl. Panjikar (1995) also carried out extensive work on Orissan beryls and indicated the possible presence of Fe^{2+} bands from octahedral as well as tetrahedral sites.

In the present study, strong absorption due to the crystal field transition of Fe^{2+} at 820 nm (Figure 4a) polarized along the ordinary ray ($\perp c$) is assigned to Fe^{2+} in the channel site. Since the octahedral Al site is distorted, the Fe^{2+} absorption band is expected to be in pairs rather than a single band due either to distortion of the polyhedron or to the dynamic Jahn-Teller effect (Goldman *et al.*, 1978; Burns, 1970). This absorption pair feature is seen at 760 and 920 nm polarized along the extraordinary ray ($\parallel c$) (Figure 5). It is attributed to the spin allowed crystal field transition of Fe^{2+} (${}^5\text{T}_2 \rightarrow {}^5\text{E}, {}^5\text{D}$), assigned to arise from Fe^{2+} in the octahedral site. This is further supported by the barycentre energy of $12,150 \text{ cm}^{-1}$, which indicates that the Fe^{2+} is situated in a site of 1.94 \AA average metal oxygen distance (Faye, 1972). This agrees favourably with the 1.90 \AA distance determined for the octahedral Al site in beryl by Gibbs *et al.* (1968). Although the presence of Fe^{3+} at the tetrahedral site cannot be deduced with any confidence from the OA spectrum, an absorption close to 684 nm (e-ray) is present as a shoulder after irradiation (Figure 5). This can be attributed to IVCT between Fe^{2+} and Fe^{3+} , the Fe^{2+} at an octahedral or channel site and the Fe^{3+} at a tetrahedral site.

Heating experiments (in air)

As described earlier, after heating the irradiated beryl to 300°C , the greenish-yellow beryl turned yellow and no significant change in hue of yellow-orange beryl was observed. On further heating to 500°C both greenish-yellow and yellow-orange beryl become colourless. The following changes in the optical spectrum were seen after heating the beryl crystals to 300°C (Figures 4a and 5):

1. sharp absorption peaks at 644 and 688 nm, which are polarized only along the ordinary ray, disappeared;

2. the intensity of the 820 nm band (o-ray) decreased;
3. the intensities of the 760 and 920 nm bands (e-ray) decreased; and
4. the absorption band at 684 nm (e-ray) disappeared.

On further heating to 500°C , it was observed that:

5. the intensity of the 820 nm band (o-ray) increased;
6. the intensities of the 760 and 920 nm bands (e-ray) increased; and
7. the UVCT tail receded to shorter wavelengths and became steeper.

The first observation indicates that the sharp absorption features at 644 and 688 nm have thermal decay characteristics, which are similar to the observation of Serway (1967) on irradiated calcite. In irradiated calcite, the 650 nm band shows thermal decay behaviour similar to that of the ESR signal attributed to the CO_3^- molecular ion. Identical decay characteristics of a narrow absorption band were also observed by Nassau *et al.* (1976) in Maxixe-type blue and green beryls as shown in Figure 4b. It appears that a defect centre, similar to Maxixe type, probably results in the blue coloration in irradiated Indian colourless beryl. On heating to 300°C , the defect centre decays and the crystal becomes yellow.

The second and third observations indicate that the amount of Fe^{2+} ions residing in the channel as well as in the octahedral site decrease. These changes are due to the fact that, on annealing, the Fe^{2+} ions in both channel and octahedral sites are converted into Fe^{3+} ions. This explains the decrease in the 820 nm (o-ray), 760 and 920 nm (e-ray) bands. The above observation indicates that on irradiation there is partial reduction of Fe^{3+} to Fe^{2+} . A similar feature was also observed by Goldman *et al.* (1978) in a natural yellow beryl which, on irradiation and subsequent heating to 500°C , showed recovery of the Fe^{2+} ion in the channel as well as in the octahedral sites. The complete disappearance of IVCT at 684 nm in the fourth observation is in accordance with the

disappearance of the Fe^{3+} ESR line at 1500 gauss at 300°C . Thus, in addition to the blue coloration due to a Maxixe centre, the IVCT band at 684 nm possibly also contributes to the blue colour after irradiation of colourless beryl. However, in the yellow-orange beryl the g -value of 4.3 in the ESR spectrum is seen only as a small hump, unlike sharp peaks in irradiated green beryl. This indicates that the Fe^{2+} is present only in very small concentration at the tetrahedral site in yellow-orange beryl, which does not favour appreciable charge transfer to be observed in the optical spectra. The fifth observation indicates that the amount of Fe^{2+} ions has increased. This suggests that the Fe^{3+} ions residing in the channel are reduced to Fe^{2+} by the thermal release of electrons. The sixth observation indicates that on heating above 300°C , the Fe^{2+} ion (760 and 920 nm, e-ray) increases in concentration at octahedral Al sites due to partial reduction of the Fe^{3+} ion to Fe^{2+} . The fifth and sixth observations are accompanied by the seventh observation. This is consistent with the decrease in Fe^{3+} concentration accompanied by a recession of the $\text{Fe}^{3+} - \text{O}^{2-}$ charge transfer band towards the ultraviolet region. These changes are accompanied by a change in colour of the sample from yellow to colourless. It is observed that the major portion of increase in intensity of the 820 nm band (o-ray) and the 760 and 920 nm bands (e-ray) manifests mainly above 300°C , and the UVCT tail recession also starts above 300°C . Therefore it would not be appropriate to correlate the yellow colour formed after irradiation to the UVCT tail arising from Fe^{3+} in the channel site.

Conclusion

From the present ESR and OA study of irradiated coloured beryls it appears that the coloration with electron-beam irradiation of colourless beryl to green to greenish-yellow and decoloration of the blue component and yellow with heating is due to the following:

1. formation of a defect centre and possible IVCT giving rise to the blue colour;
2. radiation-induced oxidation of Fe^{2+} and the associated UVCT tail, which results in a yellow colour.

The combination of these two colours results in a greenish-yellow hue in the beryl crystal. In the yellow-orange irradiated beryl, the above defect centre does not form due to the absence of suitable precursors except for the oxidation of Fe^{2+} at the Al site and the associated UVCT tail which results in a yellow colour.

On heating, the defect centre and IVCT decays at 300°C , resulting in disappearance of the blue colour. On subsequent heating to higher temperature, there is formation of some Fe^{2+} and an associated retreat of the UVCT tail to shorter wavelengths. This results in colourless beryl at 500°C . Although the Fe^{3+} line at 1500 gauss attributed to the tetrahedral site is tentative, its appearance after irradiation and disappearance after heating clearly demonstrates the oxidation and reduction phenomena. It is quite possible that various shades of green and yellowish-orange beryl may have formed in nature from colourless beryl due to natural irradiation during the course of geological time and subsequent heating of the host body might have resulted in the development of various shades of green. The differential behaviour of colourless beryl to irradiation from the same locality calls for further studies on the genesis of beryl crystals in relation to their crystal chemistry.

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The chemical signature of emeralds from the Campos Verdes-Santa Terezinha Mining District, Goiás, Brazil

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ABSTRACT: Emerald crystals from the Campos Verdes mining district have been analysed by inductively coupled plasma mass spectrometry (ICP-MS), Fourier transform infrared spectroscopy and Mössbauer spectroscopy. These gems contain measurable amounts of Fe²⁺, Fe³⁺, Cr, V, Sc, Ni and Zn; large-ion lithophile element (LILE, Ba, Sr, Rb, Pb) and high field strength element (HFSE, Zr, Y, Ti) contents are near or below the limit of detection. This chemical signature reflects the metasomatic reactions between the mineralizing fluids and the ultrabasic host-rocks of this gem deposit.

Keywords: Brazil, emerald, chemistry, infrared spectroscopy, Mössbauer spectroscopy

Introduction

The Santa Terezinha de Goiás–Campos Verdes region, herein termed the Campos Verdes mining district, located about 400 km northwest of the capital Brasília, Brazil, is one of the most important Brazilian emerald production areas (Giuliani *et al.*, 1990). Mining started on the surface and at shallow depths on a small scale in the early 1980s. Currently, as the underground mines reach depths of more than 100 m and have

required heavy investment, extraction is mostly performed by three large companies.

Emerald is a variety of beryl (Be₃Al₂Si₆O₁₈), characterized by different shades of green (Bosshart, 1991). Beryl is a cyclosilicate in which the arrangement of Si₆O₁₈ rings contains channels parallel to the *c*-axis, which can accommodate alkalis and molecules (such as H₂O and CO₂), retained in the structure during crystallization (Aines and Rossman, 1984; Wood and Nassau, 1968).

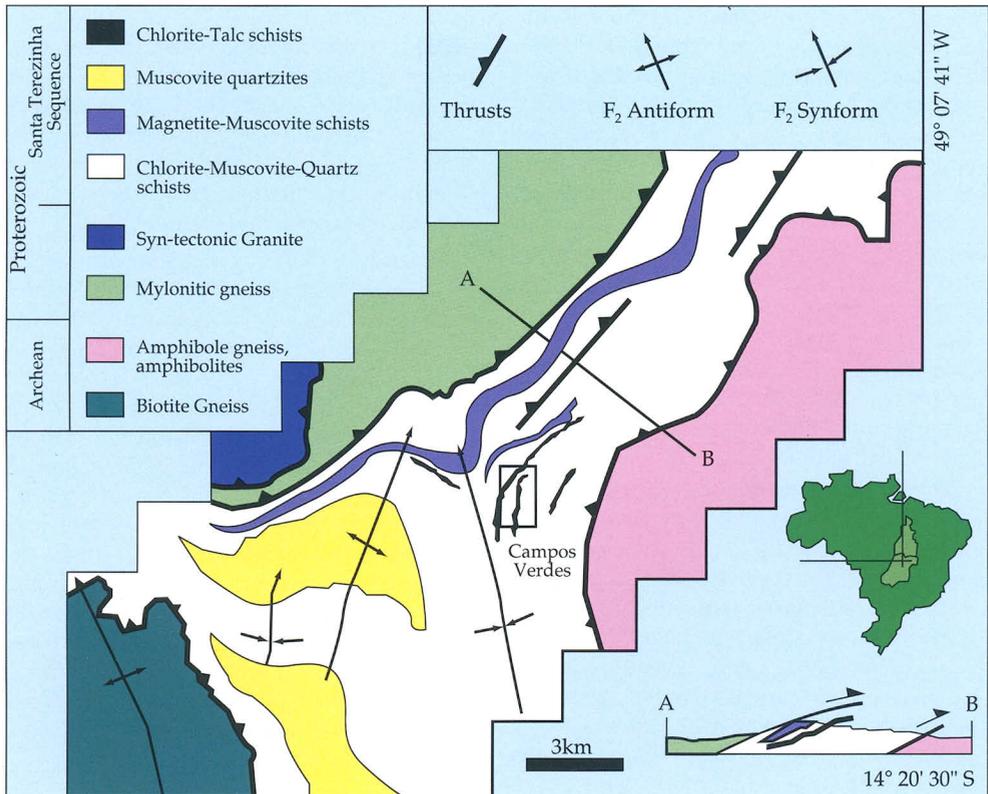


Figure 1: Simplified geological map of the Campos Verdes Mining District, Goiás. The rectangle represents the area occupied by the town of Campos Verdes, built right above the orebodies. AB is the line for the simplified geological cross-section.

More recent metallogenic studies have demonstrated the importance of these channels, as they provide clues for the geochemical composition of fluids entrapped therein (Fallick and Barros, 1987).

Since 1996, the Campos Verdes mining district has been the focus of intense geochemical research for gemmological objectives. This paper reports the results of the compositional determination of the emerald crystals by inductively coupled plasma mass spectrometry, Mössbauer spectroscopy and infrared spectroscopy, and the data provide diagnostic information.

Geological setting

The Campos Verdes mining district lies within a relatively narrow, NNE-SSW

Figure 2: Carbonate vein sample showing an emerald crystal from Campos Verdes. The length of the crystal is about 25 mm.



trending belt of the Santa Terezinha volcano-sedimentary sequence which has been deposited on biotite and amphibole gneisses of probable Archean age (Ribeiro Filho, 1981; Souza and Leão Neto, 1984). This volcano-sedimentary belt consists of talc schist, chlorite-muscovite-quartz schist, magnetite-muscovite schist, muscovite quartzite and emerald-bearing biotite schist and chlorite-carbonate-talc schist (Figure 1). The emerald crystals are recovered mainly from carbonate veins (Figure 2) in chlorite-carbonate-talc schist and biotite schist. All these rocks underwent ductile-brittle deformation and shearing in a number of episodes under greenschist facies metamorphism.

Most of the gem mineralizations coincide with the main phases of regional metamorphism and only small quantities of gems are found in the late-stage brittle fractures that crosscut all the ductile structures in the area (D'el-Rey Silva and Giuliani, 1988; Barros Neto and D'el-Rey Silva, 1995). Recently, Ribeiro-Althoff *et al.* (1996) argued that the ages of the mineralizations are close to 522 ± 1 Ma, based on K-Ar and ^{40}Ar - ^{39}Ar ages of phlogopites formed with the emerald crystals. These chronological data are consistent with the Brasiliano Orogeny, which involved reworking of older continental crust.

The polyphase structural evolution of the Campos Verdes mining district produced 1–10 m scale sheath folds with axes broadly parallel to the long axes of the deformed pyrite, feldspar and quartz, which plunge

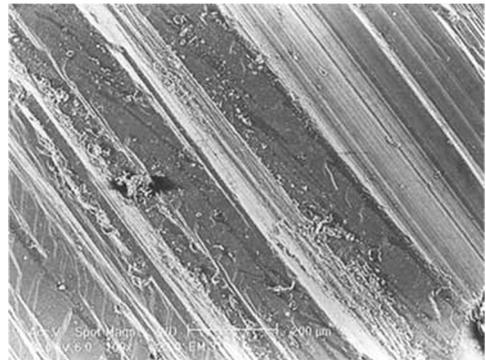
around 15° towards 350° . As a result, the orebodies consist largely of cigar-shaped bodies of carbonate-talc schists enclosed in the core of the sheath folds. On a regional scale it is part of a synformal structure. The strong structural control of the orebody demonstrates that the shear zones channelled the emerald-forming fluids.

According to Barros and Kinnaird (1987a) the emerald-forming fluids at Campos Verdes were aqueous solutions saturated with NaCl which also contained minor quantities of CO_2 and CH_4 . KCl, CaCl_2 and MgCl_2 salts were also identified in these fluid inclusions. The origin of the emerald-forming fluids was investigated by Fallick and Barros (1987) through stable isotope analyses. Their results indicated a clear distinction between the H_2O contained in the structural channels ($\delta\text{D} = -39 \pm 5\text{‰}$), the H_2O present in other parts of the emerald structure ($\delta\text{D} = -50 \pm 10\text{‰}$) and the H_2O in the fluid inclusions ($\delta\text{D} = -156 \pm 62\text{‰}$). These results suggest that the emerald-forming fluids were derived either from a magmatic source or from the metamorphism of ultra-basic rocks.

Gemmological properties

The emeralds of the Campos Verdes mining district appear mainly as euhedral crystals which combine a first-order hexagonal prism ($10\bar{1}0$) with a basal pinacoid (0001). The size of these crystals is extremely variable, reaching up to 27 mm in length.

Figure 3: Back-scattered electron images illustrating (a) parallel intergrowth and (b) growth striae on emerald crystal faces.



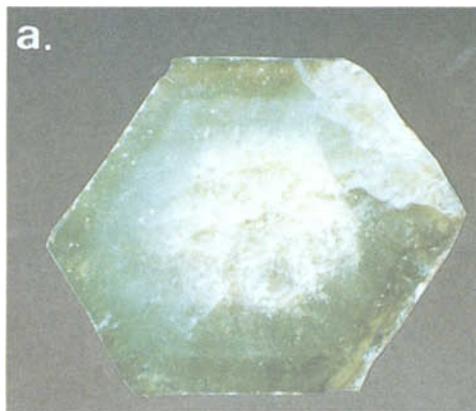
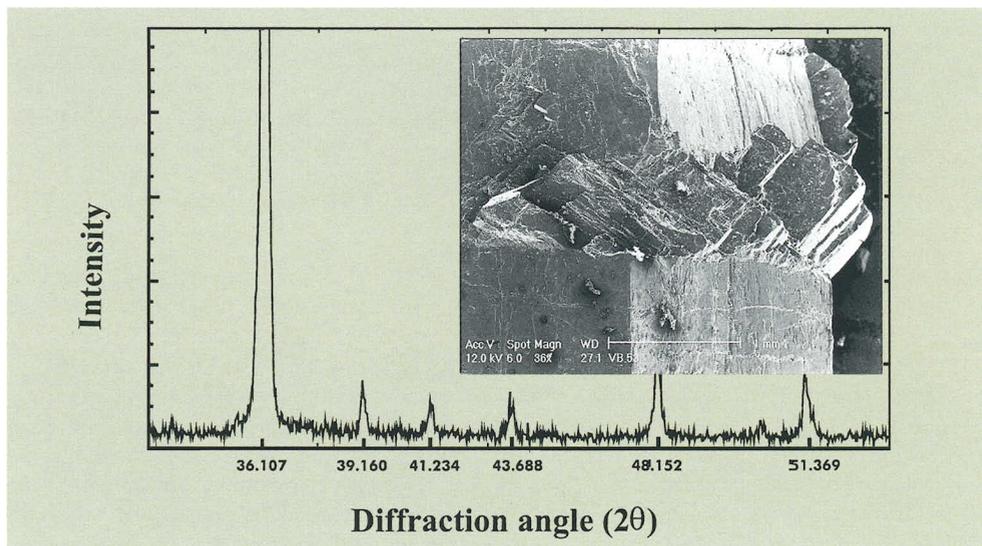


Figure 4: Photomicrographs of emerald crystals with sharply defined colour zones. (a) Colourless core surrounded by a green outer zone. (b) Green core enveloped by colourless outer zone.

Short prismatic crystals, parallel intergrown (Figure 3a), and radiating and irregular crystal groups are common. All crystals show a strong parting perpendicular to the *c*-axis and striae parallel to this crystallographic axis (Figure 3b). Rarely, the crystals contain gradational colour zoning parallel to the basal pinacoid (0001), passing from green to colourless. Concentric zoning is also observed, which comprises a colourless core enveloped by a green outer zone (Figure 4a) or the opposite – a green core and a colourless outer zone (Figure 4b).

The densities obtained from transparent emeralds varied between 2.713 and 2.793 g/cm³, whereas those crystals with abundant solid inclusions showed values up to 2.8 g/cm³. Under the gemmological microscope, the emerald crystals in this study were seen to contain one or more inclusions of the following: talc, phlogopite/biotite, carbonate, pyrite, beryl and quartz. Magnesite and dolomite (Figure 5) were identified by X-ray diffraction and not only occur as inclusions but also fill emerald fractures. Inclusions of

Figure 5: Scanning electron image of dolomite crystals filling a fracture in emerald, and an X-ray diffractogram of the dolomite shown.



Analytical procedures

Refractive indices of emerald crystals were measured with a Schneider refractometer on polished surfaces of emerald crystals, and the crystal density was determined in distilled water at room temperature using a hydrostatic balance.

Emerald crystals apparently free of inclusions were washed with a dilute solution of HCl at 130°C, for 90 minutes, in order to remove carbonate from the fractures. The minerals were analysed by X-ray diffraction, after that only samples free of solid inclusions were selected for analysis by inductively coupled plasma mass spectrometry (ICP-MS), Fourier transform infrared spectroscopy (FTIR) and Mössbauer spectroscopy (MS).

The X-ray diffraction analyses were carried out using a Siemens diffractometer equipped with CoKa tube, operating at 30 kV and 30 mA, in the 2–80° 2 θ range. The angles of diffraction spacings were measured with a precision of 0.026° 2 θ . Quartz powder was used as internal standard.

Emerald crystals without colour zoning were analysed by ICP-MS. The contents of SiO₂, TiO₂, Al₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅, Cr₂O₃, BeO, V₂O₅, Cs₂O, Sc₂O₃, Rb₂O and LOI were determined by fusion; FeO/Fe₂O₃ contents were measured by titration. The other elements (Ba, Sr, Y, Zr, Li, Cu, Pb, Zn, Ag, Ni, Cd and Bi) were analysed by total digestion.

The CO₂ content was determined on an automated LECO CS-344 carbon sulphur

analyser. A weighed sample was mixed with iron chips and a tungsten accelerator, and was then burned in an oxygen atmosphere at 1370°C. The moisture and dust were removed and the CO₂ gas and SO₂ gas were measured by a solid-state infrared detector. CO₂ was determined by taking a second sample in a ceramic crucible and adding 25% HCl dropwise until no reaction was observed. The sample was dried on a hotplate at low temperature and C was redetermined on the dried residue. The difference was calculated as CO₂.

The Mössbauer analyses were performed using absorbers prepared with appropriate amounts of ground (320 mesh) material in order to satisfy the ideal absorber thickness approximation (Long *et al.*, 1983). Each sample, ground in an agate mortar, was mildly compacted in a Plexiglas holder. The spectra were obtained at room temperature (RT) using a constant acceleration electromechanical drive system with a multichannel analyzer for collecting and storing the data.

The volatile substances in the powder of the emerald crystals were identified using a Galaxy series 3000 Fourier transform infrared spectrophotometer, operating at room temperature, with a precision of 4 cm⁻¹. These analyses were done on powder pellets consisting of emerald and KBr in the ratio 1:100, according to the technique described by Russell (1974).

feldspar, ankerite, garnet, baryte, apatite, chromite, picotite, actinolite/tremolite, glass, rutile, hematite, limonite, ilmenite and magnetite have already been reported by Bank and Petsch, 1982; Barros and Kinnaird, 1987b; Borelli, 1986; Cassedanne and Sauer, 1984; Fillmann, 1987; Giuliani and Weisbrod, 1988; Hänni and Kerez, 1983; Lind *et al.*, 1986; Mendes and Svisero, 1988.

The RI measurements supplied relatively constant averages with $n_o = 1.590$ to 1.593 and $n_e = 1.580$ to 1.587 , while the birefringence ranged from 0.005 to 0.012. The dichroism is distinct and the colours are green // *c* and yellowish-green $\perp c$. These emerald samples showed a reddish glow when viewed under the Göttinger colour filter, but they are inert under the Chelsea filter and to long- and short-wave ultraviolet light.

Table I: Compositions of emeralds from Campos Verdes obtained by inductively coupled plasma mass spectrometry (ICP-MS)

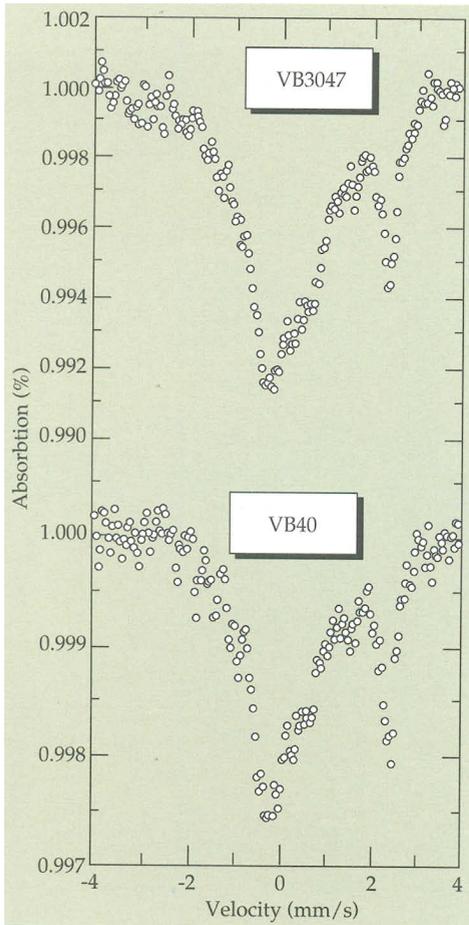
Sample	VB-1000	VB-3000	VB-4000	VB-5000	VB-6000
colour	medium-green	medium-green	medium-green	medium-green	medium-green
wt. %					
SiO ₂	59.22	63.42	63.82	60.44	63.50
Al ₂ O ₃	12.68	12.42	13.58	12.74	13.02
Fe ₂ O ₃	1.52	1.77	1.21	1.67	1.54
FeO	0.62	0.25	0.26	0.25	<0.1
MnO	0.01	<0.02	<0.02	<0.02	<0.02
MgO	6.26	4.52	3.56	5.06	4.10
CaO	1.10	0.24	<0.02	1.38	0.18
Na ₂ O	2.32	2.36	2.34	2.32	2.36
K ₂ O	0.06	0.10	0.06	0.04	0.08
TiO ₂	<0.01	<0.02	<0.02	<0.02	<0.02
P ₂ O ₅	<0.02	<0.02	<0.02	<0.02	0.06
Cr ₂ O ₃	0.36	0.44	0.46	0.44	0.36
BeO	10.95	10.66	11.14	10.78	10.78
V ₂ O ₅	0.07	0.08	0.06	0.06	0.06
Cs ₂ O	0.10	0.10	0.10	0.10	0.10
Sc ₂ O ₃	0.20	0.22	0.18	0.20	0.18
Rb ₂ O	<0.01	<0.02	<0.02	<0.02	<0.02
LOI	4.52	3.32	2.92	4.62	3.18
Total	99.99	99.90	99.69	100.10	99.50
wt. %					
CO ₂	2.27	0.54	0.08	2.24	0.34
ppm					
Ba	1	<2	<2	<2	<2
Sr	32	10	<2	38	6
Y	<1	<2	<2	<2	<2
Zr	<1	4	<2	4	<2
Li	30	24	38	28	28
Cu	2	2	5	3	2
Pb	<5	<5	<5	<5	<5
Zn	7	4	8	7	2
Ag	<0.4	<0.4	<0.4	<0.4	<0.4
Ni	97	44	40	44	37
Cd	<0.5	<0.5	<0.5	<0.5	<0.5
Bi	<5	<5	<5	<5	<5

Chemical signature

The composition of Campos Verdes emerald is summarized in Table I. The ICP-MS results of emerald samples indicate a relatively constant Be content of 10.6 to 11.2 wt.% BeO and variable quantities 11.96 to 13.58 wt.% of Al₂O₃. These results are consistent with previous works (Fillmann, 1987; Schwarz, 1990). In all samples there is fair correlation between Ca + Mg and the CO₂ contents (Table I), which suggests that the analyses were contaminated with carbonate inclusions. Therefore, the values for Ca and Mg are not considered in relation to the emerald structure.

In all emerald samples analysed (Table I), the elements Fe, Cr, Ni, Zn, Sc and V were all present in detectable quantities. The large-ion lithophile elements (LILE, Ba, Sr, Rb and Pb) and the high field strength elements (HFSE, Zr, Y and Ti) occur in amounts near or below the detection limits. The presence of the Cr–Ni–Zn association and the low contents of LILE and HFSE suggest the contribution of an ultrabasic component during the interaction between fluids and rocks.

However, we have not recognized any systematic correlation between the intensity of the green colour and Cr³⁺ or V³⁺ quantities.



The valence state of iron in the Campos Verdes emerald samples VB40 and VB3047 was investigated by Mössbauer spectroscopy. The spectra obtained are very complex (Figure 6) and resemble quite closely that obtained by Parkin *et al.* (1977) for a blue beryl sample. Although it was not possible to fit the Campos Verdes emerald spectra, they indicate proportions of $\text{Fe}^{3+} > \text{Fe}^{2+}$, consistent with results in Table I. Thus, according to ligand field theory it is reasonable to expect that the variety of hues observed in the Campos Verdes emerald samples is in part due to the presence of Fe^{3+} in these gems. In addition, the values of the birefringence (Δ up to 0.012) and the failure of the emeralds to respond to both short- and long-wavelength ultraviolet light probably can also be attributed to the Fe content of these gems, such as has already been suggested by Gübelin (1989) for Pakistan emerald crystals.

Alkali metals were detected in all Campos Verdes emerald crystals, which show $\text{Na}^+ > \text{Cs}^+ > \text{Li}^+$ (Table I). The average Li content is 29.6 ppm, which probably is

Figure 6: Mössbauer spectra for emerald samples at room temperature.

Figure 7: Diagram of Al^{3+} versus $(\text{Fe}^{3+} + \text{Cr}^{3+})$ values, expressed in atomic proportions, in emerald from Campos Verdes.

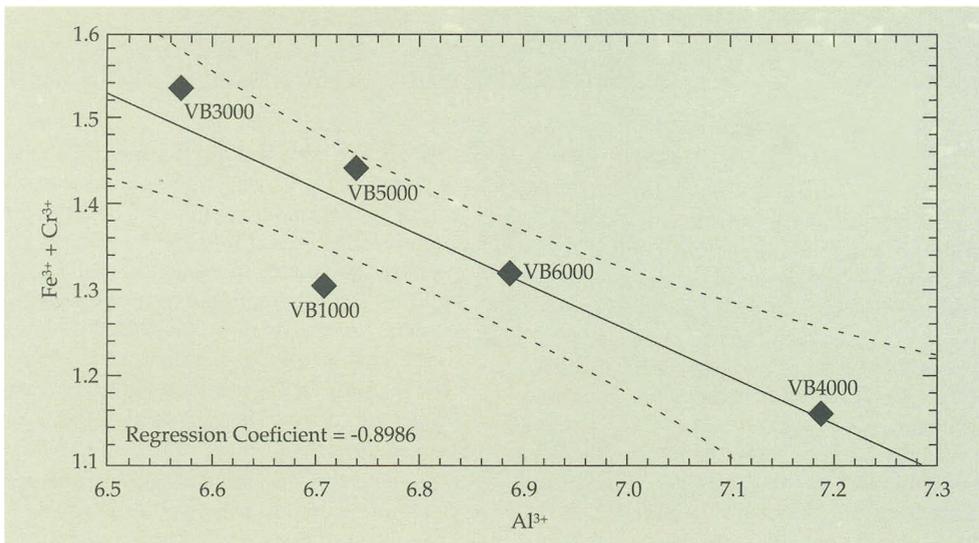


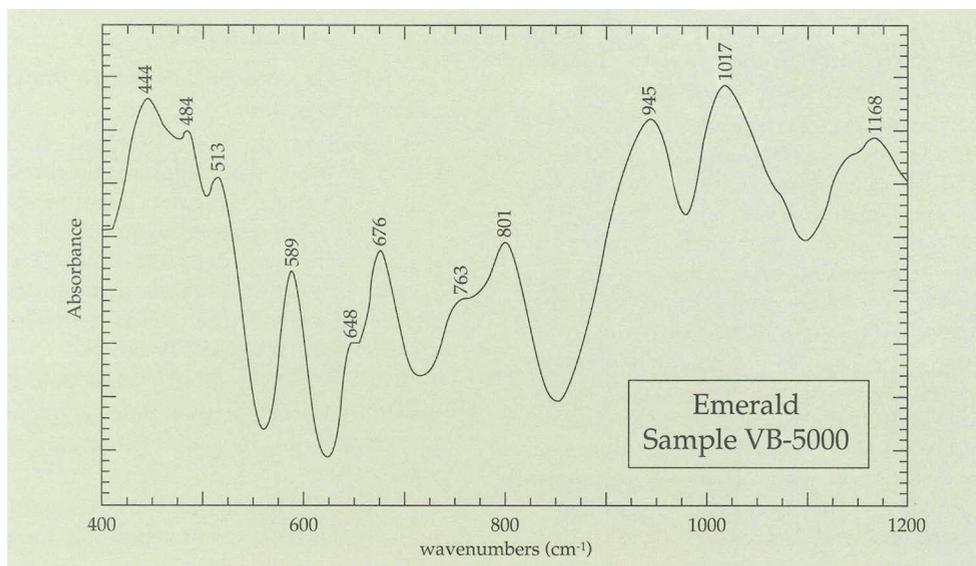
Table II: Comparison of H₂O contents in Campos Verdes emeralds with those reported by Aurisicchio et al. (1988) and Cheilietz (1993) in emeralds from other deposits..

Locality	Sample number	H ₂ O (wt.%)	Reference
Mingora, Pakistan	4	2.20	
Habachtal, Austria	23	2.60	
Carnaíba, Brazil	9	2.30	Aurisicchio et al., 1988
Muzo, Colombia	10	2.40	
Ural Mountains, USSR	26	2.30	
Carnaíba, Brazil	CATV	2.42	Cheilietz et al., 1993
	VB-1000	2.25	
	VB-3000	2.78	
Campos Verdes, Brazil	VB-4000	2.84	This study
	VB-5000	2.38	
	VB-6000	2.84	

related to the Be-deficiency according to the Be ↔ Li isomorphous replacement (Aurisicchio et al., 1988; Hawthorne and Cerny, 1977). The Al-deficiency is compensated by (Fe³⁺ + Cr³⁺) as indicated by the negative linear correlation between these elements (Figure 7). Any charge deficiency due to such substitutions is normally compensated by introduction of Na⁺ and Cs⁺ into channel sites (Aurisicchio et al., 1994; Hawthorne and Cerny, 1977).

The total volatile content of the Campos Verdes gems ranges from 2.92 to 4.62 wt.%, while the CO₂ content varies between 0.08 and 2.27 wt.% (Table I). The abundance of H₂O may be estimated by subtraction of the CO₂ from the LOI content. Thus, the total H₂O contents of Campos Verdes emerald crystals vary between 2.25 and 2.84 wt.%. These values are similar to H₂O contents of emerald crystals from other schist deposits (Table II). For example, Aurisicchio et al.

Figure 8: Fourier transform infrared (FTIR) spectrum from 400 to 1200 cm⁻¹ for emerald VB5000 from Campos Verdes.



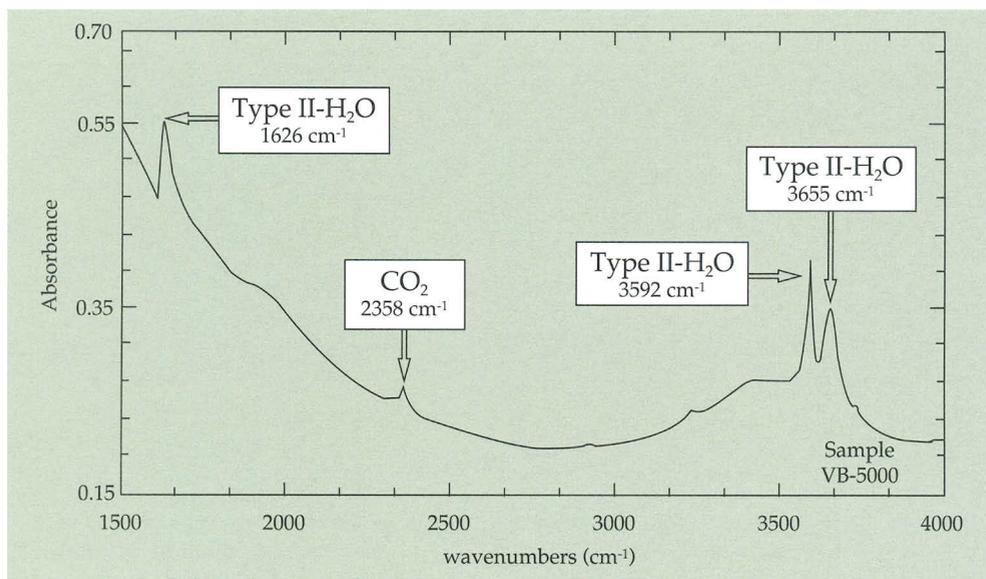


Figure 9: Infrared spectrum from 1500–4000 cm^{-1} showing CO_2 and type II H_2O peaks in emerald from Campos Verdes.

(1988) reported similar H_2O quantities in emeralds from Habachtal (Austria), Carnaíba (Brazil), and Mingora (Pakistan).

Infrared spectroscopy analyses were done on 18 emerald powder samples, in order to identify volatile substances in these gems. The various spectra obtained are very similar in the 400–1200 cm^{-1} interval (Figure 8), except for the vibration intensities. According to Plyusina (1964) the bands in this range are typical for the beryl structure.

The presence of molecular species, such as H_2O and CO_2 , can be easily recognized in the FTIR spectra (Figure 9) of the emeralds from Campos Verdes. Wood and Nassau (1968) classified water molecules as type-I or type-II, depending on whether the symmetry vector of H_2O molecule is oriented, respectively, perpendicular or parallel to the c -axis. The Campos Verdes emerald samples present bands at 1625–1627, 3591–3592 and 3655–3658 cm^{-1} , which indicate the presence of type-II H_2O (Figure 9). The predominance of this kind of water is related to the alkali content in the beryls as suggested by Hawthorne and Cerny (1977). The spectra of the Campos Verdes emerald samples also

show a peak at 2353 cm^{-1} , which is typically caused by CO_2 molecules either in the channel sites or in fluid inclusions (Wood and Nassau, 1968). The water peaks are of higher intensity than the CO_2 peak, which is consistent with the relative contents found by analysis (Table I).

Conclusions

The following conclusions can be drawn from the investigation:

1. The emerald samples analysed from Campos Verdes show significant contents of Fe, Cr, V, Ni, Zn, Sc and alkali metals ($\text{Na} \gg \text{Cs} > \text{Li}$), while LILE and HFSE are near or below the detection limits. This chemical signature suggests metasomatic exchanges between the emerald-forming fluids and the ultrabasic host rocks.
2. The emeralds contain Fe^{3+} and Fe^{2+} in quantities sufficient to influence colour, refractive index and other gemmological properties.
3. The infrared spectra of these emeralds indicate the presence of type-II H_2O and CO_2 .

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An interdisciplinary approach to identifying solid inclusions in corundum: thorite in a 'Sri Lanka' sapphire

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ABSTRACT: A blue sapphire of commercial provenance examined using a transmitted-light microscope revealed at least two different types of inclusions. One was considered to be an idiomorphic spinel with an appreciable content of Cr³⁺, and the second, a metamict zircon. A more complete characterization by EDS microanalysis and gamma-spectrometry led to identification of the latter inclusion as thorite (ThSiO₄). This report emphasizes the desirability of using completely independent techniques when dealing with complex identification problems.

Keywords: gamma-spectrometry, sapphire, Sri Lanka, solid inclusions, spinel, thorite

Introduction

Reports have been published recently (Ajò *et al.*, 1996a; Carbonin *et al.*, 1998) on the application of photoluminescence (PL) spectroscopy to gemmological problems. The PL technique was successfully employed by some of us, in addition to the more usual methods, in the investigation of minerals and of their synthetic analogues. These studies are of interest in different fields, among which are gemmology, laser material production (Barba *et al.*, 1997) and works of art (Ajò *et al.*, 1996b).

A comprehensive discussion concerning our studies of corundum and related

materials is presently in preparation. However, we think it is useful at this stage to briefly demonstrate the value of a multi-disciplinary approach to chemical, structural and morphological features of corundum.

Results and discussion

A 'classic' blue sapphire was one in a series of samples kindly provided by Mr Silvano Bettella (Settore Orafo, Confederazione Nazionale Artigianato (C.N.A.), Padova), whose experience (in the absence of reliable information about its provenance) induced us to ascribe it to the 'Sri Lanka' type.



Observation by means of transmitted-light microscopy revealed at least two different types of inclusions.

The first kind of solid inclusion (*Figure 1*) is associated with 'fingerprints' and its red colour and habit led us to think it was an idiomorphic spinel octahedron, reported as a typical feature of Sri Lanka sapphires by Gübelin and Koivula (1992) and Webster (1994).

Since a red spinel should have an appreciable concentration of Cr^{3+} , we recorded a photoluminescence (PL) spectrum of this material using a He-Ne ($\lambda = 632.8 \text{ nm}$, 25 mW) laser. Most sapphires, blue or even colourless (Ajò *et al.*, 1996a; Carbonin *et al.*, 1998), and spinels investigated so far contain enough chromium to give rise to a PL spectrum.

The He-Ne excited PL spectrum exhibited the well-known Cr^{3+} (Ajò *et al.*, 1996a) emission from the host sapphire but it was much weaker and noisier than those of materials previously studied by He-Ne (Ajò *et al.*, 1996a; Carbonin *et al.*, 1998). Therefore,



Figure 1: Idiomorphic octahedral inclusion in transmitted light (50x).

in order to confirm the assignment we resorted to a much more intense Ar ($\lambda = 488.0 \text{ nm}$, 1.5 W) source (*Figure 2*).

On examination through a microscope, the second solid inclusion (*Figure 3*) showed the typical habit and tension-halos and

Figure 2: Ar-excited PL spectrum of the sapphire.

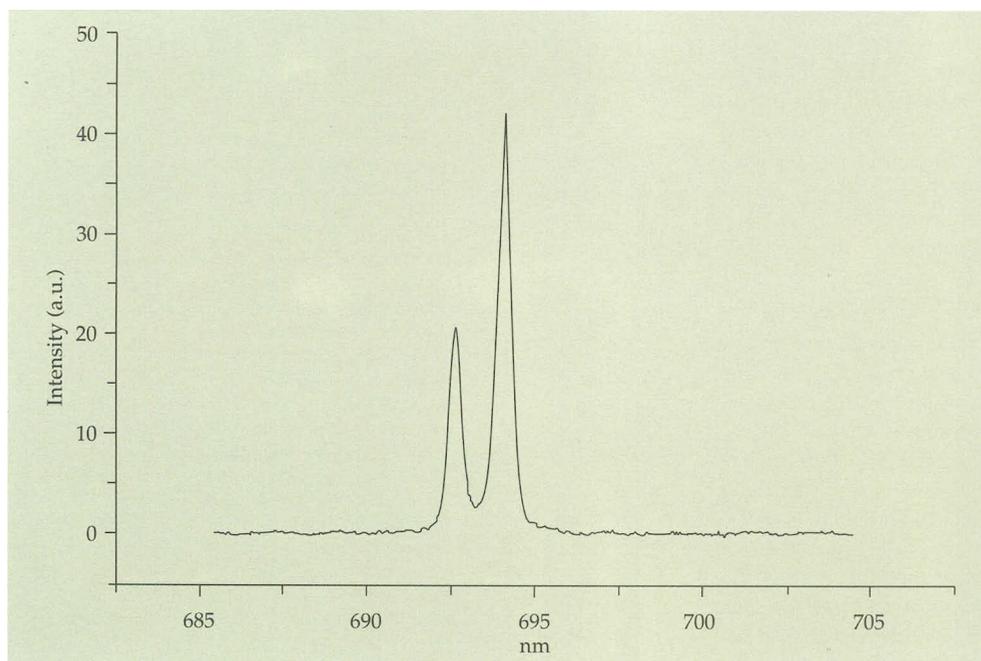




Figure 3: Thorite inclusion about 45 μm long, resembling zircon, transmitted light (100x).

fissures of a metamict zircon grain (Gübelin and Koivula, 1992; Webster, 1994). This inclusion appeared close to the surface of the host crystal, and during preparation of the sapphire for electron probe microanalysis, it was thought worthwhile to determine the nature of this inclusion by polishing the sapphire until the level of the inclusion was reached and then analysing it.

Surprisingly, once the electron beam was focused on the extremely small polished area, no characteristic Zr radiation was detected by means of the energy dispersive system (EDS). Instead, together with the already expected silicon $K\alpha$, various wavelengths were present that could be ascribed to thorium: among these the most intense were $M_{\alpha 1}$, $M_{\alpha 2}$ (2.996, 2.986 keV) and M_{β} (3.145 keV). No other major peaks were present and the possibility that the mineral was thorite (ThSiO_4) is supported by the habit which is very similar to that of zircon.

Due to the extremely small size of the crystal under investigation, we thought further support for our identification using a different technique was necessary. So, using gamma-spectrometry with a low-background configuration n-type intrinsic germanium detector equipped with an epoxy window, the presence of natural ^{232}Th in the sample was definitively confirmed. The identification was possible through the gamma emission of daughters ^{212}Pb and ^{208}Tl at 238.6 keV (44.7% probability) and 583.1 keV (84.2%), respectively.

Conclusions

The above results indicate the value of using completely independent techniques – in the present case related to electronic (valence and core) and nuclear energy levels – when dealing with complex identification problems. In particular, we have shown that some caution is needed when an inclusion is attributed to zircon on the basis only of optical and morphological properties.

Finally, our findings concerning solid inclusions indicate the possibility of considering another mineral species in determining the provenance of a sapphire.

Acknowledgements

The authors gratefully thank Dr A. Speghini (Ist. Policattedra Facoltà di Scienze, University, Verona) for recording the Ar-excited PL spectrum, and Dr C. Brogiato and Mr L. Tauro (Dipart. Mineralogia e Petrologia, University, Padova) for pictures and for carefully polishing the sapphire, respectively.

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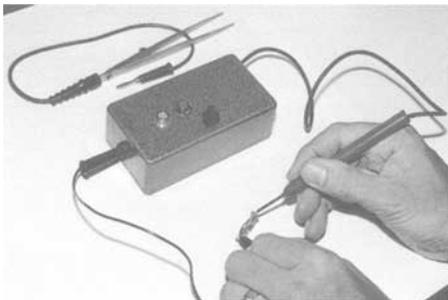
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Diamonds

Gem news – the 26th International Gemmological Conference.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(4), 1997, 298–310, 15 illus. in colour.

Cathodoluminescence could be used to help determine the diamond type with a possible classification of mixed types given. Diamond and graphite inclusions have been found in sapphires from Ban Huai Sai, Laos. Major mineral inclusions in large Yakutian diamonds were found to be sulphides, olivine and chromite, with the proportions varying from mine to mine. Three growth morphologies are found in natural diamonds; octahedral being the most common and forming the majority of gem material, cuboid of which only a portion forms gem material and fibrous which never yields gem-quality diamonds. J.J.

Mineral inclusions in diamonds from the River Ranch kimberlite, Zimbabwe.

M.G. KOPYLOVA, J.J. GURNEY AND L.R.M. DANIELS. *Contributions to mineralogy and petrology*, 129, 1997, 366–84.

Mineral inclusions in diamonds from the River Ranch kimberlite pipe in Zimbabwe are almost entirely composed of phases of harzburgitic paragenesis (olivine (Fo92), orthopyroxene (En93)), G10 garnets and chromites. The pipe is situated in the Late Archean Limpopo Mobile Belt (LMB). Inclusion studies are used to assist the assignment of the tectonothermal age of the LMB and strengthen the theory that an ancient thick mantle root existed beneath the Belt about 530–540 million years ago. M.O'D.

[Diamonds in suevites of the Sudbury impact structure, Canada.] (Russian with English abstract)

V.L. MASAITIS, G.I. SHAFRANOVSKY, R.A.F. GRIEVE, W.V. PEREDERY, E.L. BALMASOV AND I.G. FEDOROVA. *Proceedings of the Russian Mineralogical Society*, 26(4), 1997, 1–6.

The treatment of samples of suevite from Black Onaping, Sudbury, Ontario, has revealed the presence of diamonds. Their morphology, optical properties, X-ray data and e.p.r. spectra show the surface and polycrystalline state of the cubic phase and prove the impact origin of the diamonds. Three forms of carbonaceous material, including shocked and single-crystal graphite, were found together with diamonds, having probably originated by the transformation of graphite in the target rocks. R.A.H.

A contribution to understanding the effect of blue fluorescence on the appearance of diamonds.

T.H. MOSES, I.M. REINITZ, M.L. JOHNSON, J.M. KING AND J.E. SHIGLEY. *Gems & Gemology*, 33(4), 1997, 244–59, 9 illus. in colour, 3 tables.

Over the last few decades diamond dealers thought that fluorescence in diamonds had a negative effect on the overall appearance of the stone. Under concentrated LW ultraviolet radiation some diamonds fluoresce blue and this should be used as an identifying feature rather than a grading factor by gem testing laboratories. The GIA GTL investigated the effect of blue fluorescence on colourless to faint yellow diamonds when viewed from various positions under different lighting conditions. Four sets of six stones were chosen, which were similar in all respects (clarity, size, etc.) except fluorescence. The observers ranged from diamond dealers to people outside the trade. Only the experienced observers found any difference and their responses varied, but a correlation was found between viewing position and fluorescence. Strong blue fluorescing diamonds were thought to have a better colour appearance when viewed from the table down. Otherwise no relationship between fluorescence and transparency was found. These results show that it is best to judge each diamond on its own visual merits. J.J.

Gem Trade Lab notes.

T.H. MOSES, I.M. REINITZ AND S.F. McCLURE. *Gems & Gemology*, 33(4), 1997, 292–6, 7 illus. in colour.

Diamonds can crack spontaneously without any apparent cause, but this could be linked to high amounts

Abstractors

R.K. Harrison R.K.H.
R.A. Howie R.A.H.

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G. Raade G.R.

P.G. Read P.G.R.
E. Stern E.S.
P.J. Treloar P.J.T.

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

of strain within the stone. A square cut diamond of saturated pink colour with abundant fractures was examined and after fracture filling procedure the colour appearance was much enhanced, although the clarity was not significantly improved. J.J.

Radiation-induced diamond crystallization: origin of carbonados and its implications on meteorite nano-diamonds.

M. OZIMA AND M. TATSUMOTO. *Geochimica et Cosmochimica Acta*, 61(2), 1997, 369–76.

Analyses are presented of 10 carbonados from Central Africa, for U–Th–Pb elements and isotopes, and of Y, Th-derived noble gases. On the basis of the U–Th–Pb systematics a model is proposed for the origin of carbonados in which radiation-induced diamond crystallization is involved. This mechanism may be relevant to the origin of nanodiamonds in primitive meteorites. A minimum age of 2600 m.y. and a maximum age of 3800 m.y. are assigned to the radiogenic Pb by assuming instant production or integrated production from radioactive decay of U. The radiogenic Pb in the carbonados was implanted from its surroundings due to the a-recoil of radiogenic Pb. Excess radiogenic Pb and fission Xe, Kr and ⁴He in carbonados suggests that energetic particles emitted by U and Th changed carbonaceous precursor material to diamond, the crystallization age of microdiamonds in carbonados being 2600–3800 m.y. R.K.H.

The Premier mine, Pretoria, South Africa.

R. SANCROFT-BAKER. *Christie's Jewellery Review* 1997, 1998, 14–15, illus. in colour.

Short account of a visit paid to the Premier diamond mine, Pretoria, South Africa. Details of the local geology and of the recovery of diamonds are given. M.O'D.

Mineral inclusions in diamonds from the Sputnik kimberlite pipe, Yakutia.

N.V. SOBOLEV, F.V. KAMINSKY, W.L. GRIFFIN, E.S. YEFIMOVA, T.T. WIN, C.G. RYAN AND A.I. BOTKUNOV. *Lithos*, 39(3–4), 1997, 135–57.

The Sputnik kimberlite pipe is a small satellite of the larger Mir pipe in central Yakutia (Sakha), Russia. Study of 38 large diamonds (0.7–4.9 ct) showed that nine contain inclusions of the eclogitic paragenesis, while the remainder contain inclusions of the peridotitic paragenesis, or of uncertain paragenesis. The peridotitic inclusion suite comprises olivine, enstatite, Cr-diopside, chromite, Cr-pyrope (both lherzolitic and harzburgitic), ilmenite, Ni-rich sulphide and a Ti–Cr–Fe–Mg–Sr–K phase of the lindsleyite-mathiasite series. The eclogitic inclusion suite comprises omphacite, garnet, Ni-poor sulphide, high-Ti phlogopite and rutile. G.R.

Syngenetic inclusions in diamond from the Birim field (Ghana) – a deep peridotitic profile with a history of depletion and re-enrichment.

T. STACHEL AND J.W. HARRIS. *Contributions to Mineralogy and Petrology*, 127(4), 1997, 336–52.

The physical properties (size, shape, colour, deformation, inclusion assemblage, N content, % B, type, $\delta^{13}\text{C}$, $\delta^{15}\text{N}$) of diamonds from placer deposits of the Akwatia mine, southern Ghana, are tabulated and the inclusion abundance is reported for 693 inclusion-bearing diamonds. In comparison with a worldwide database for 1100 diamond inclusions, the Akwatia inclusions have olivines with lower Mg/Fe ratios and extremely high Ni contents. Geothermometry shows the Akwataian inclusions to be 140–190°C hotter than the peridotitic average (1050°C), and since garnet-orthopyroxene equilibria (1100°C/50 kbar to 1370°C/67 kbar) indicate a typical shield geotherm (40–42 mW/m²), these elevated temperatures imply an origin for the Akwatia diamonds unusually deep for a peridotitic suite. It is considered that the inclusions in these diamonds represent the most complete cross-section through peridotitic subcontinental lithospheric upper mantle so far observed, down to a maximum depth of 200–240 km. R.A.H.

Diamanten aus China.

G. STEINER. *Lapis*, 22(11), 1997, 13–17, 1 map in colour.

The presence of diamond in the territory composing present-day China has been known as long ago as the fourth century. Several Chinese authorities are cited in support of this view. Today at least 14 major sites have been identified and three major platforms accommodate both peridotite and lamproite-housed diamond deposits. Today about one million carats of diamond are recovered annually and details of the occurrence and working of the Chang-ma kimberlite pipe are given. This area is already responsible for notable crystals. M.O'D.

Metamorphic evolution of diamond-bearing and associated rocks from the Kokchetav Massif, northern Kazakhstan.

R. ZHANG, J.G. LIOU, R.G. COLEMAN, N.V. SOBOLEV AND V.S. SHATSKY. *Journal of Metamorphic Geology*, 15(4), 1997, 479–96.

Representative diamond-bearing gneisses and dolomitic marble, eclogite and Ti-clinohumite-bearing garnet peridotite from Kumdu Kol and whiteschist from Kulet were studied. Diamond-bearing gneisses contain variable assemblages including Grt + Bt + Qtz ± Pl ± Kfs ± Zo ± Chl ± Tur ± Cal and minor Ap, Rt and Zrn; abundant inclusions of diamond, graphite + chlorite (or calcite), phengite, clinopyroxene, K-feldspar, biotite, rutile, titanite, calcite and zircon occur in garnet. Diamond-bearing dolomitic marbles consist of Dol + Di ± Grt + Phl; inclusions of diamond, dolomite ± graphite, biotite and clinopyroxene were identified in garnet. Other ultrahigh-pressure (UHP) indicators include Na-bearing garnet (≤ 0.14 wt.% Na₂O) with omphacite Cpx in eclogite, occurrence of high-K diopside (≤ 1.56 wt.% K₂O) and phlogopite in diamond-bearing dolomitic marble, and Cr-bearing kyanite in whiteschist. P.J.T.

Neue Smaragdfunde aus Chile, Südamerika.

A.G. BANKO, F. BRANDSTÄTTER, G. NIEDERMAYR AND J. KARFUNKEL. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 213–24. 16 photographs, 3 graphs, 4 tables, bibl.

One new occurrence of emeralds is high in the Andes, east of a town called Ovalle in Chile, near the Argentinian border; and another report indicates that emeralds have been found in the Atacama desert between the coast and the Andes. Up to now there have been very few Chilean emeralds on the market. The emeralds have proto- and syngenetic one-, two- and multi-phase mineral inclusions. There is strong zonal coloration, emphasized under crossed nicols. The inclusions consist largely of actinolite, dolomite, pyrrhotite, rutile, with also some bismuth, sulphides, silicates, oxides and phosphates (determined by spectroscopy, electron microprobe and an analytical scanning microscope). The Chilean emeralds are mineralogically and gemmologically very similar to the metamorphic emeralds from the Habachtal. E.S.

Radiation damage in zircons.

R. BIAGINI, I. MEMMI AND F. OLMI. *Neues Jahrbuch für Mineralogie Abhandlungen*, **6**, 1997, 257–70.

The uranium and thorium content of zircon affects the degree of metamictization observed. U and Th contents of samples tested ranged from 57–2890 ppm and 27–420 ppm respectively. Density decreased in parallel with U and Th content and a range $4.80 > 4.10 \text{ g/cm}^3$ was measured. Changes in X-ray powder diffraction were also noticed. During annealing these patterns gave different results as did IR spectra. After heating at 950°C, X-ray diffraction patterns became sharp and showed a nearly complete structural recovery which was, however, seen to be incomplete when compared to fully crystalline examples. M.O'D.

Dossier central [on pearls].

J. CASEIRO, J.-P. GAUTHIER, J. TABURIAUX, G. GROSPIRON, C. LEVI-PLÉ AND P. VERHOEVEN. *Revue de gemmologie*, **133**, 1998, 10–22, illus. in colour.

A collection of short papers dealing with: pearls from Tahiti; *pinctada margaritifera*; trends and developments in the world of the pearl; the possibility of grading pearls; pearl restoration; freshwater pearls. M.O'D.

Rubies, sapphires and emeralds – quality and origin.

A.I. CASTRO. *Christie's Jewellery Review* 1997, 1998, 26–8, illus. in colour.

Properties, values and outstanding features of the major gemstones are briefly described, the piece accompanied by illustrations selected from items recently sold by Christie's. M.O'D.

Aussergewöhnlicher Quarzfund im Valle Bedretto, Tessin.

D. DONATI, R. GUERRA, N. OPPIZZI AND P. OPPIZZI. *Lapis*, **23**(2), 1998, 31–5, illus. in colour.

Extraordinarily large crystals of smoky quartz have been found near the Valleggia glacier in the Valle Bedretto, Ticino, Switzerland. The largest crystal so far found measures 92 cm in length, 45 cm in thickness, weighing 150 kg. Fluid inclusions are visible in some specimens. Temperature of formation is believed to be 300° to 450°C with a pressure of between 2 and 3.5 kbar. M.O'D.

XRD and IR spectroscopic investigations of some chrysoprases.

A. GAWEL, S. OLKIEWICZ AND W. ZABINSKI. *Mineralogia Polonica*, **28**, 1997, 43–50.

Chalcedony content of some chrysoprase from different localities was examined by XRD and IR spectroscopy. Samples showed a wide range of silica crystallinity. Specimens with a low degree of silica crystallinity generally have higher Ni content and an intense green colour. Some of these samples also gave XRD reflections of the microcrystalline silica phase moganite as well as a broad reflection $d_{\text{hkl}} \sim 10 \text{ \AA}$ whose origin is still unestablished. In none of the specimens examined were reflections of NiO (bunsenite) present. M.O'D.

Les gisements d'émeraude du Brésil: genèse et typologie.

G. GIULIANI, A. CHEILLETZ, J.-L. ZIMMERMANN, A.M. RIBEIRO-ALTHOFF, C. FRANCE-LANORD AND G. FERAUD. *Chronique de la recherche minière*, **526**, 1997, 17–61, illus. in colour, 9 maps.

The pre-Cambrian mineralization of the Brazilian emerald deposits is discussed. Main locations are in the states of Bahia (Carnaíba and Socotó), Minas Gerais (Mina Belmont, Capoeirana) and Goiás (Santa Terezinha). The deposits are always located in Lower Proterozoic volcano-sedimentary sequences with intercalations of mafic to ultramafic rocks. Mineralization is associated either with pegmatites intruding mafic to ultramafic rocks (Socotó, Carnaíba, Belmont, Capoeirana) or are linked to ductile shear zones affecting formation of mafic or ultramafic rocks. The origins of both types of deposit are described and considerable detail on the quality of the emeralds and their inclusions is provided. M.O'D.

La foitite delle pegmatiti di S. Piero in Campo, Isola d'Elba.

A. GUASTONI AND F. PEZZOTTA. *Rivista mineralogica italiana*, **21**, 1997, 251–5, illus. in colour.

Foitite, a newly-reported end-member of the tourmaline group, is found in the S. Piero di Campo pegmatites on the Isle of Elba, Italy. It occurs as fibrous crystals, and details of some of the gem-quality elbaite crystals are also given. M.O'D.

Über die Bildung von Perlmutter und Perlen.

H.A. HÄNNI. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 46, 1997, 183–96, 7 photographs, 3 diagrams, bibl.

The author reviews various papers dealing with nacre and pearls and compares these notes to his own observations. Nacre and pearls are formed in the same way, the outer mantle epithelium first producing the periostracum, then columnar and finally tabular calcium carbonate (nacre). The same sequence produces natural pearls from the centre to the rim of the pearl. The transplantation of an epithelium graft to an organ in the shell means that a 'microchip' brings the knowledge of nacre forming to a part of the animal with no tradition of pearl forming and the graft grows into an entire pearl sac. The article ends with a short survey of the properties of natural, cultured and imitation pearls. E.S.

Quartz-Mineralisationen in Rhyolithkugeln nahe des Seebachsfelsens südwestlich Friedrichroda, Thüringer Wald.

G. HOLZHEY. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 46, 1997, 197–212, 16 photographs, 2 maps, 1 table, bibl.

Globular rhyolites (spherulites) contain in central star-shaped cavities epigenetic jasper-like minerals, agates and macrocrystalline quartzes such as rock crystal and amethyst as well as calcite and fluorite. The agates, including the dominant horizontal granular type agate are characterized by differences in genetic attributes. Layers of granular type are followed by layers of increasingly crystalline grained structure, followed by layers showing macrocrystalline quartz. E.S.

Some new unusual cat's-eyes.

J. HYRSL. *Canadian Gemmologist*, 18, 1997, 105–6, illus. in black-and-white.

Some rare chatoyant gem materials recently reported include yellow baryte from the Czech Republic, brazilianite, dark blue translucent kyanite from India, red to dark red Tasmanian crocoite, bluish danburite from Alto Chapare area of Bolivia and from Madagascar, light brown enstatite from Tanzania, rhodochrosite from a new locality in Kazakhstan and opaque, brownish-black rutile from Sri Lanka. M.O'D.

Darwin-Glas: ein schleifwürdiger, grüner Tektit.

SR.-A. JACOBS. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 46(1), 1997, 7–12.

Tektites of gem quality have been recovered from the area of Mount Darwin, Tasmania, and have been found to be compositionally similar to moldavites from Bohemia. They arise from an impact event and are mostly pale to dark green with a few greenish-brown and black specimens. The RI range is 1.470–1.482 and SG is 2.26. Swirl marks and gas bubbles are found as inclusions. M.O'D.

Gem news – the 26th International Gemmological Conference.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(4), 1997, 298–310, 15 illus. in colour.

The Renishaw Micro-Raman spectroscopy system with a near infrared system has helped to separate amber from its various imitations. Kauri gem from New Zealand may be labelled amber if older than Middle Tertiary otherwise younger material should be called copal. Fluorescence zoning in amber is associated with fauna inclusions and is diagnostic for natural amber. Three new chrysoberyl deposits were discovered in 1996 near the east coast of India, although separated by hundreds of kilometres they were probably formed at the same geological time. Bactrian emeralds are now thought to have come from Bactria (Northern Afghanistan) on the basis of new deposits of emeralds found in the Panjshir valley. The country of origin of emeralds, especially Colombian emeralds, may be determined by the isotopic composition of oxygen of the various rock types and the emeralds found in association with these rocks. Emeralds used by the ancient Romans were probably mined in Upper Egypt.

Blue quartz from Madagascar was found to contain many species of inclusion; lazulite inclusions were significant and imparted the overall blue colour to the quartz. Ornamental and gem stones from Bolivia are discussed with regard to their location, size and economics. Good quality cultured pearls from Indonesia are produced from blister pearls grown in the mollusc *Pinctada maxima*; recently resin has been used as the bead nuclei in some pearls so that they resemble artificial pearls with a low SG and a deceptive sheen caused by a thin nacreous layer. Several new sapphire deposits have been found in Madagascar especially in the north. The Tunduru-Songea gem field in southern Tanzania produces many different varieties of gemstone such as corundum, spinel, garnet, quartz, beryl, tourmaline, kyanite, diamond, etc. J.J.

Pearl identification.

S.J. KENNEDY. *Australian Gemmologist*, 20(1), 1998, 2–19, 48 black-and-white illustrations and 1 in colour, 1 graph.

Commencing with the description of a new X-ray unit, designed as a replacement for the original unit in the Gem Testing Laboratory's London premises, this review of pearl identification covers their mode of formation and the various techniques employed to test both individual pearls and pearl necklaces. The use of X-ray techniques to test pearls is discussed as well as the visual features which allow pearls to be categorized. 'Keshi cultured pearls', natural blister pearls, imitation pearls and the treatment of pearls are also covered. The differentiation of natural pearls from non-nucleated cultured pearls is considered to be the biggest challenge facing the pearl tester. P.G.R.

Pearls and pearl oysters in the Gulf of California, Mexico.

D. MCLAURIN, E. ARIZMENDI, S. FARELL AND M. NAVA. *Australian Gemmologist*, 19(12), 1997, 497–501, 6 illus. in colour, 1 map.

For more than four centuries until overfishing caused their demise, pearl fisheries in the Gulf of California were the main source of natural coloured pearls. Now a pilot-scale commercial venture has been set up by I.T.E.S.M.-Perlas de Guaymas for culturing the native pearl oysters *Pteria sterna* and *Pinctada mazatlanica*, and their pearls. The pearl farm is located at Bacochibampo Bay, Guaymas, Sonora, Mexico, and uses the suspended culture system and the Mexican grafting technology developed by I.T.E.S.M. Around 150,000 pearl oysters were cultured from both the above species, and in 1997 produced 30,000 mabe pearls and some round pearls. P.G.R.

What's new in minerals.

T. MOORE. *Mineralogical Record*, 28, 1997, 505-8 illus. in colour.

Gem-quality yellow prisms of the rare mineral sturmanite are reported from the Springfield, Massachusetts Mineral Show, 1997. Other species of interest and of gem quality include sea-green fluorite octahedra from the Wise mine, Westmoreland, New Hampshire (once more being worked for specimens), orange transparent baryte from the Rosh Pinah mine in southern Namibia and crystals of pale brown transparent axinite from Khapalu, Ghanche District, Baltistan, Pakistan. M.O'D.

Gem Trade Lab notes.

T.H. MOSES, I.M. REINIZ, AND S.F. MCCLURE. *Gems & Gemology*, 33(4), 1997, 292-6, 7 illus. in colour.

A green aquamarine showed an unusual absorption band at 537 nm in addition to the bands at 427 and 456 nm, this line is typical of untreated aquamarines and is found in yellow and colourless beryls. A violetish-blue cushion-shaped stone thought to be tanzanite was found to be beryl and it was strongly pleochroic with six sharp closely spaced lines between 575 and 690 nm. The colour in these stones is not stable and liable to fade. Using a Raman spectrometer and EDXRF a large dark red cabochon was found to be a pyrope-almandine garnet and not highly refractive glass. J.J.

Chrysoptase from Warrawanda, Western Australia.

T. NAGASE, M. AKIZUKI, M. ONODA AND M. SATO. *Neues Jahrbuch für Mineralogie, Monatshefte*, 1997(7), 289-300.

A study of chrysoptase from the boundary between granite and serpentinite in the Warrawanda district, 80 km SW of Newman, Western Australia, is reported using EM, TEM, FTIR and EPMA techniques. Inclusions of a cotton-like aggregate of kerolite were found as extremely fine-grained crystals; the kerolite contains ~10 wt.% NiO, the NiO content increasing with the degree of silicification of the surrounding serpentinite. It is inferred that this Ni-bearing kerolite is the cause of the apple-green colour of the chrysoptase. R.A.H.

Gems from the collection of Princess Dashkov.

O. YA NEVEROV. *World of Stones*, 12, 1997, 39-41, illus. in colour.

Engraved gems form part of the collection of Princess Catherine Dashkov, whose *Memoirs* were published in

1859. Some outstanding specimens are illustrated with a brief biography. The Princess played a conspicuous part in the Revolution of 1762. M.O'D.

Titanite und seine Einschlüsse.

G. NIEDERMAYR. *Mineralien Welt*, 9(1), 1998, 15-16, illus. in colour.

Titanite (sphene) has been found to contain a number of fluid inclusion patterns which are described and illustrated from specimens originating from Austria and Brazil. M.O'D.

Business review: gemstones.

M. O'DONOGHUE. *Britannica Book of the Year 98*, 1998, 164.

Reviews new gem species and varieties, stones returning to the market after long periods of absence, developments in gemstone commerce and the saleroom with details of particularly important prices paid. Reports on the use of child labour in the Indian diamond trade are noted and the economic financial situation in some Asian countries is reviewed as it affects gemstone prices. (Author's abstract) M.O'D.

Le contrôle des perles à partir de 1929 au Laboratoire Gemmologique Français (du laboratoire syndical au laboratoire CCIP).

J.-P. POIROT AND E. GONTHIER. *Revue de gemmologie*, 133, 1998, 26-7, illus. in colour.

History of the part played by the Laboratoire Gemmologique Français in pearl testing since 1929 with details of some of the instruments and tests used. M.O'D.

Turkis aus Thüringen und Sachsen.

H. RIEDEL, G. HOLZHEY, S. PESTEL AND S. WEISS. *Lapis*, 23(2), 1998, 42-4, illus. in colour, 1 map.

Turquoise of ornamental quality is reported from Weckersdorf, Thuringia, Germany, where it occurs in a siliceous schist with iron hydroxides and translucent crystals of yellow baryte. Turquoise is also described from Chrieschwitz near Plauen in the Vogtland area of Saxony. Some of this material may also be of fashioning quality. M.O'D.

Green vanadium-bearing titanite from Chibougamau, Quebec, Canada.

G. ROBINSON AND W. WIGHT. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 46, 1997, 225-8, 1 photograph, 2 tables, bibl.

Gem-quality emerald-green titanite (sphene) has been found at the Lemoine vanadium mine near Chibougama, Quebec, where it occurs in alpine-type hydro thermal veins in magnetite and gabbro. RI 1.90-1.99, SG 3.519. Because chromium is present only in trace amounts, vanadium seems to be the principal chromophore; vanadium causing emerald-green colour in titanite has not previously been reported. E.S.

Historie, Geologie und Mineralogie der Quarz-Kristalle von Herkimer, New York.

R.H. RUSS. *Mineralien Welt*, 8(6), 1997, 61–71, illus. in colour, 2 maps.

Rock crystal quartz from the Herkimer 'diamond' mine in the Upper Cambrian at Middleville, north-west of Albany, New York, is famous for its perfection of form. Crystals took their varietal name from Nicholas Herkimer (1728–1777), from a family of German origin. They occur at different levels in the mine and may show phantom effects or sceptre forms. Some specimens of particular clarity have traditionally been called Herkimer diamonds. M.O'D.

Bitterfelder Bernstein: der Schatz aus der 'Goitsche'.

S. SCHELLHORN. *Lapis*, 23(3), 1998, 35–7, Illus. in colour.

Short history of the amber finds, estimated at approximately 22 million years old, in the Bitterfeld region of central Germany. The actual amber-producing area, known locally as Goitsche, contains brown-coal recovery sites, some flooded, which have been illegally raided for amber specimens. Some insect inclusions have been reported. M.O'D.

Die Tucson Show 1998.

J. SCOVIL AND B. LEES. *Lapis*, 23(4), 1998, 35–8, illus. in colour.

Among gem-quality minerals appearing at the 1998 Tucson Show were fine crystals of amazonite from Tree Root Pocket, Pike's Peak, Colorado, USA, where it occurs in a pegmatite with smoky quartz. Fine blue aquamarine crystals from the Thuong Xian district, Hoa Province, Vietnam, were also on display. M.O'D.

A new era for opal nomenclature.

A. SMALLWOOD. *Australian Gemmologist*, 19(12), 1997, 486–96, 26 illus. in colour.

A new opal nomenclature, formulated by the GAA Opal Nomenclature Sub-committee, is designed for use throughout the gemstone and jewellery industry, not only in Australia but internationally.

Under the category 'Types of natural opal', three forms of natural opal are listed which apart from being cut and polished are otherwise untreated. These types include opal having a substantially homogeneous chemical composition, boulder opal and matrix opal.

The next category, 'Varieties of natural opal', describes the gem's body tone (i.e. its face-up relative darkness or lightness, ignoring play-of-colour) and its transparency. Body tones N1 to N4 are used for black opal, N5 and N6 for dark opal, and N7 to N9 for light opal. An opal with a distinctly coloured body has a hue notation appended to its body tone classification. Transparency codes A, B and C are used to cover all forms of diaphaneity ranging from transparent to opaque.

Although not associated with the descriptive classifications for natural opals, the nomenclature also discusses opal treatments, composite natural opal, synthetic opal and imitation opal. P.G.R.

What's new in minerals.

[VARIOUS AUTHORS.] *Mineralogical Record*, 28(5), 1997, 409–17, illus. in colour.

Among gem minerals displayed at recent shows were large green Chinese fluorites from the Zianghualin mine, Hunan, and large rutile crystals from the classic site at Graves Mountain, Georgia, USA. The Chinese fluorites are reported from more than one show in the United States. Tanzanite crystals are still on the market; one fine specimen was nearly 3 cm long. The area of Xu Bao Diang, Piugwu, Sichuan, China, is known for fine specimens of cassiterite. It is associated with crystals of colourless beryl to make attractive groups. Crystals of ruby on calcite matrix, some with a fine raspberry-red colour, and measuring up to 5 cm, have been found at the Luc Yen ruby mine in Vietnam and featured in the Paris show. Fine reddish crystals of grossular from Sierra de las Cruces, Coahuila, Mexico, measured up to 2.8 cm and beautiful crystals of amethyst and smoky quartz up to 12.7 cm were shown from the Phillis Ann claim, Lake George, Colorado. The same locality produces twins of purple fluorite. M.O'D.

What's new in minerals.

[VARIOUS AUTHORS.] *Mineralogical Record*, 29, 1998, 125–41, illus. in colour.

Different correspondents describe mineral specimens seen at a number of gem and mineral shows during 1997 all in the United States except for the München Mineralientage. Among the specimens of gem quality are amazonite and smoky quartz from the classic locality at Pike's Peak, Colorado, pink fluorite octahedra from the Chamonix area of the French Alps, yellow-brown sphene crystals from Alchuri, Baltistan, Pakistan, emerald crystals from the Brumado mine, Bahia, Brazil, and from the Medina mine, Minas Gerais, Brazil.

The feature also describes the newly-opened mineral hall at the National Museum of Natural History, Smithsonian Institution, Washington DC, USA. M.O'D.

Synthetics and Simulants

Gem news – the 26th International Gemmological Conference.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 33(4), 1997, 298–310, 15 illus. in colour.

(Further summaries of papers given at the 26th IGC cover a range of topics.) 80% of imitation pearls manufactured in Japan use plastic bead centres, while other imitation pearls have shell or white alabaster glass for the central bead. Growth induced imperfections and inhomogeneities in crystals are important especially in the identification of synthetic material. Recent research into synthetic quartz grown in sodium hydroxide solutions shows variations in morphology with an increase in temperature. Three pieces of a transparent purplish-pink material were found to be neodymium penta-phosphate ($\text{NdP}_5\text{O}_{14}$).

Titanium and chromium diffusion-induced star sapphires can be identified by characteristic colour zoning, absorption spectra together with a red halo on the surface and a high relief red outline when immersed in methylene iodide. J.J.

Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE. *Gems & Gemology*, 33(4), 1997, 292–6, 7 illus. in colour.

A pair of sunglasses made for Elton John had lenses made from synthetic sapphire. J.J.

Synthetic moissanite: a new diamond substitute.

K. NASSAU, S.F. MCCLURE, S. ELEN AND J.E. SHIGLEY. *Gems & Gemology*, 33(4), 1997, 260–75, 19 illus. in colour and 2 tables.

A new diamond substitute is synthetic moissanite, a silicon carbide (SiC), and has only recently been manufactured as a near colourless material. The GIA examined 23 samples of near colourless to light yellow, green and grey stones, but all appeared colourless when viewed face up. Although there is no simple test to identify moissanite conclusively, there are many tests that will prove it is not diamond. Moissanite is slightly less brilliant than diamond, shows more dispersion and is doubly refractive with a birefringence of 0.043, which is most readily seen when viewed through the girdle as all the stones examined were cut with their *c*-axis perpendicular to the table facet. Moissanite shows none of the strain fractures and inclusions associated with diamonds, but instead there are white line inclusions parallel to the *c*-axis. Moissanite has an SG of 3.20–3.24 (diamond 3.52) and a hardness of 9¼. Problems do occur when a thermal probe is used as diamond and moissanite have overlapping thermal inertial ranges and further tests must be used to separate these stones. J.J.

Characterization of Chinese hydrothermal synthetic emerald.

K. SCHMETZER, L. KIEFERT, H.-J. BERNHARDT AND Z. BEILL. *Gems & Gemology*, 33(4), 1997, 276–91, 20 illus. in colour and 3 tables.

In 1993 hydrothermal synthetic emeralds made by Professor Zeng Jiliang, China, became commercially available. These emeralds were grown in an alkali-free chlorine-bearing solution at much higher pressures than normally associated with synthetic emeralds. The authors examined 11 stones and tested them by standard

gemmological methods. Diagnostic microscopic features were observed in the stone which included natural or synthetic beryl seeds together with characteristic growth zoning, usually associated with colour zoning, parallel to the seed. The zoning formed at an angle of between 20° and 40° to the *c*-axis of the synthetic emerald and as no crystal faces in natural emerald are found within this range it is an important diagnostic feature. Spicules orientated parallel to the *c*-axis were commonly associated with tiny crystals of chrysoberyl or occasionally beryl. Also typical were needle-like inclusions which were found orientated almost perpendicular to the seed on dominant growth faces. EDXRF analysis and infrared spectroscopy showed chlorine to be a diagnostic element giving rise to a series of absorption bands in the 2500–3100 cm⁻¹ region, which are not seen in natural emeralds. The stones examined did not show any detectable iron, but this is similar to certain natural emeralds. Also it was found that the RI and SG values of the synthetic stones overlapped those of low alkali natural emeralds. J.J.

Techniques and Instruments

The Hodgkinson method, a.k.a. the eye and prism method: some further adaptations.

D.B. HOOVER. *Australian Gemmologist*, 20(1), 1998, 20–33, 5 diagrams, 4 graphs, 3 tables.

The Hodgkinson method, which uses only the human eye and a distant light source, permits the identification of many gemstones by enabling their refractive indices, absorption spectra, dispersion and birefringence-to-dispersion ratio to be estimated. The fundamentals of this method are reviewed, an alternative technique for estimating refractive index explained, and the method of quantifying the birefringence-to-dispersion ratio for identification purposes described. P.G.R.

Kristalle und Licht.

O. MEDENBACH, P.W. MIRWALD AND P. KUBATH. *Mineralien Welt*, 9(2), 1998, 17–32, Illus. in colour.

Despite the title, the article illustrates and describes a number of optical instruments used for mineral identification. Microscopes, producers of polarized light, goniometers, universal stages and instruments for obtaining refractive index are presented with brief biographical notes of pioneers in mineralogical instrumentation. M.O'D.

BOOK REVIEWS

Famous diamonds. [Third edition]

I. BALFOUR, 1997. Christie's, London. pp 320, 150 colour and 70 black-and-white illustrations. Hardback and DW £65.00. ISBN 0 903432 56 X.

Although this is the third edition of *Famous diamonds*, it is on an altogether more lavish scale than its predecessors. It has a slightly larger format, is on better quality paper, and much new information has been added on important stones, including stones auctioned up to 1997.

The book starts with a most informative general introduction to diamonds, detailing their history, sources, mining, trade cutting and use. The mention of their properties of brilliance and fire is unfortunately so brief as to be, perhaps, unhelpful to those not already familiar with these properties.

There are then 76 separate chapters dealing alphabetically with individual major stones, most in impressive detail including descriptions of the stones themselves, their history and often details of associated and similar material. Some of these chapters, particularly that on the Hope, have been significantly expanded from the previous edition. These are followed by a chapter devoted, again alphabetically, to describing more briefly a further 40 'notable' stones.

In many cases, due to their value, the ownership of such stones is extremely closely guarded, and it is very difficult to acquire accurate knowledge about them. Ian Balfour, who spent many years in the diamond business, has been granted unprecedented access to many of these stones and their associated archival material. He has gathered together in this book a vast amount of information on major diamonds that is simply not available elsewhere. A table is included towards the end of the book listing the 89 diamonds of over 100 carats known up to 1997. Diamonds are not easy to photograph well, and the producers of this book are to be congratulated on the generally fine illustrations throughout.

There is a section of three pages on fancy coloured diamonds and the causes of their colour. This has been written by Eric Emms, FGA, DGA, who has handled a difficult subject very well in such a small space.

A column is included on the carat weight and the confusion that can occur from the difference between various old carats and the modern metric carat (0.2 gram). It is unfortunate that, as an example of such confusion, the Koh-i-Noor is used. The previously much quoted weight of the Koh-i-Noor (after re-cutting in 1852) as 108.93 ct, rather than the recently authenticated weight of 105.60 metric ct, seems, in fact, to have arisen from faulty research by authors rather than from any confusion over the unit of weight (108.93 metric carats converts to 106 $\frac{1}{16}$ old English carats). This incorrect weight is reported in several nineteenth-century books including Davenport's

English regalia of 1897. It seems then to have been copied by many later authorities. However, both Dieulaufait in 1871 and Professor Church in 1882 give a weight of 102 $\frac{3}{4}$ ct. This converts to 105.53 metric carats, extremely close to the actual weight.

An absolutely fascinating appendix is included which reproduces, over five pages, Asscher's step-by-step diary of their cutting of the Cullinan between February and October 1908.

There is a useful bibliography of two pages with some interesting items, although it should really be headed 'A selected bibliography' because the literature on diamonds is now immense. It is satisfying to find that the book ends with a good index, the lack of which has ruined many an otherwise good publication. This is, perhaps, the place to plead with publishers to revert to the old custom of binding in a bookmark (or even two). This greatly facilitates looking up items that have more than one reference in indexes.

This is a most desirable book, full of useful and fascinating information, beautifully produced at a price which, by current standards, is quite reasonable. It should have wide appeal to both jewellery and other historians, as well as to a large spread of general readers. N.B.I.

Identifying gems and precious stones

C. HALL, 1997. Apple Press, London. pp 80, illustrated in colour, hardcover. £5.99. ISBN 0 85076 426 3.

Reprint of an excellent short guide first published in 1993 by Quintet Publishing Ltd. The major gem species are described with notes on properties neatly set out diagrammatically and in colour. M.O'D.

Collecting and classifying coloured diamonds: an illustrated history of the Aurora collection.

S.C. HOFER, 1998. Ashland Press Inc., New York, USA (distributed in the UK by CRU Publishing Ltd., London). pp xxi, 742, illus. in colour. Hardcover ISBN 0 9659410 1 9. £197.00.

This very large and heavy book is a celebration of the 260 polished coloured diamond specimens at present on display at the American Museum of Natural History, New York. The collection is catalogued, described and illustrated at the beginning of the book, which continues with an account of the world of coloured diamonds, including a lengthy examination of the cause and perception of colour. Chapters deal with the collecting of coloured diamonds, natural supply and human demand and the conception of rarity, buying and selling, colour perception and colour grading, how face-up colour can be defined, coloured diamond classification and the terminologies used. Appendices include a cut and colour compendium, a glossary and a bibliography.

The book is beautifully produced and there is no doubt that serious collectors will want to buy it, whether or not they also collect coloured diamonds. The standard of photography is state-of-the-art and the hundreds of illustrations gain a great deal by being kept small. Mounted stones are so often chosen to illustrate books on gemstones that the reader cannot see very much of individual diamonds and when coloured diamonds are featured it is much better to group loose polished examples together, sometimes with several everyday coloured objects for comparison and this is what has been done here. Opening the pages, with the text embraced by very wide margins, the carefully-placed photographs, many by Nick Hale and Tino Hammid, lead the eye naturally through the print. In many pages the text is also broken up by quotations, printed in light red, taken from a variety of sources, which amplify or give a fresh imaginative dimension to the topic under discussion.

So as a production the book scores very highly. As a treatise on coloured diamonds it first provides a *catalogue raisonné* to the Aurora collection which, maintained for a long time without addition, was greatly enhanced in recent years by additional specimens provided by Alan Bronstein, who, with the author, visualized a major book on coloured diamonds. Each of the stones in the collection is fully described and each one illustrated to show one of the widest colour ranges of diamond kept as a single collection. The formation of a collection of coloured diamonds is described with particular reference to the Aurora collection and how some of the stones were acquired. Chapters on rarity, buying and selling and colour perception lead very easily to the second major theme of the book, the singular importance of colour and how to describe it. During examination of these topics, the current colour theories are discussed with well-drawn diagrams and applied, with explanations of colour grading, to diamonds. All through the text the specimens illustrated are given their provenance where it has been ascertained and one feature of the book is the noting of important coloured diamonds that have passed through the major salerooms. I have long advocated the collection of saleroom catalogues which are not usually indexed in the ways gemmologists would want!

The glossary and bibliography are well up to present-day standard with many citations of significant papers. Interesting sidelights on diamond, colour, buying and selling abound through the book which is a delight in every way: expensive but well worth it. M.O'D.

The Jewellery of Roman Britain: celtic and classical traditions.

C. JOHNS, 1996. UCL Press, London. pp xvii, 246, illus in black-and-white and in colour. Hardback £36.00. ISBN 1 85728 566 2.

The author states in her introduction that this is the first general survey devoted to the jewellery worn in Roman Britain and that this country, distant from the centres of empire on the Continent, had received less consideration than others when ornament was discussed. The book takes 'jewellery' as any item of personal adornment, whatever it was made of and equates the English noun *jewellery* to the German *Schmuck*.

After a survey of what jewellery means in the context of Roman Britain, the book considers some of the evidence with an examination of hoards and of the general archaeological context. The two cultures, Celtic and Graeco-Roman (i.e. native and imported) brought together distinct types of ornament and the designs, metals and workmanship of the two areas make up most of the following text.

Material is considered under the headings finger-rings, gemstones and other settings, necklaces and bracelets, earrings and hair-ornaments and brooches. The last chapter describes how Roman jewellery was manufactured and there is an afterword in which the author asks for jewellery and other ancient artefacts to be considered in context rather than in isolation and for more care to be exercised by the metal digger. The archaeology of jewellery (and mineral collecting) is not the only area in which a certain type of tedious amateur wastes the time of scholars and many fail to see that persistence with the private possession of particular artefacts may cause the progress of identification to be slowed down.

An appendix gives details of the Backworth treasure (Tyne and Wear), the Snettisham hoard, the Thetford treasure and the Hoxne treasure. Notes relating to the chapters follow this section and there is an excellent bibliography. M.O'D.

Gem identification made easy. Second edition.

A. L. MATLINS AND A. C. BONNANO, 1997. Gemstone Press, Woodstock, VT. pp xxii, 322, illustrated in colour, hardcover. US \$34.95. ISBN 0 943763 16 9.

Well-conceived and constructed gem testing manual in which the reader can quite easily find clues to the nature of most gem specimens. Written from the standpoint of the retail jeweller, the text begins with describing the equipment needed by the beginner, without going too deeply into the principles behind their operation. Instead the authors concentrate upon evaluating the results obtained: a central colour section illustrates synthetic and treated gemstones with excellent clear photographs. Since the publication of the first edition in 1989 developments in these areas have been so extensive that the text has been re-written. The bulk of the text is written around the major gem testing instruments and there are useful chapters on less common instruments and on the handling by the retail jeweller of antique and estate jewellery. Appendices include lists of useful addresses and a short bibliography. Used in conjunction with other texts this would make a good addition to a gemmological library and for the beginner it is a worthwhile first book. M.O'D.

Synthetic, imitation and treated gemstones.

M. O'DONOGHUE, 1997. Butterworth Heinemann, Oxford. pp x, 203. Illus. in black-and-white with 10 pages of colour plates. Softcover £35.00. ISBN 07506 3173 2.

Filling an important gap in gemstone literature, this book by the well-known author, lecturer and gemmologist encompasses three related subjects of synthetic, imitation and treated gems in a manner suitable for both the student gemmologist with perhaps little knowledge of gem testing techniques, and the professional.

Following a brief preface and introduction, the plan of the book is outlined (a glossary is mentioned here but appears to have been omitted in production!) and suggestions for further reading are listed. The book proper then gets underway with a chapter giving an account of the basic ground rules and methods for the commercial growth of synthetic gemstone crystals. This is followed by a chapter on gem testing which describes the basic identification techniques and equipment. The next chapter, 'The major natural gemstones', describes the most important identifying features of diamond, corundum, spinel, beryl, quartz, opal, alexandrite and topaz in order that these can be compared with their synthetic, imitation and treated versions in the body of the book.

Each subsequent chapter takes one of these gem species and describes the tell-tale features which will enable the reader to distinguish the real from the man-made or imitation, or the untreated from the treated. One chapter deals with the organic gems, and the penultimate chapter includes other materials such as lapis lazuli, turquoise, the synthetic garnets and cubic zirconia. The final chapter covers glass, ceramics, plastics, composites and experimental materials. Many of the features described are illustrated by black-and-white sketches and in the book's 40 colour plates (although the latter would have benefited from being printed larger at three-to-the-page).

Perhaps the most valuable section in each of the gem chapters is the 'Reports of interesting and unusual examples from the literature'. Here, the author has gathered together a valuable hoard of information from articles, laboratory reports, gem shows and his own gem observations to give the reader faced with a puzzling specimen the chance to find matching features among the more unusual gems described.

As a practical guide to ways of avoiding the pitfalls of misidentification, the book is a must for the jeweller, the valuer and the gemmologist. P.G.R.

Topaz: das prachtvolle Mineral, der lebhafteste Edelstein.

1997, *extraLapis* no. 13 (not covered by Lapis subscription).

Christian Weise Verlag, Munich. pp 95, illus. in colour. Softcover DM 34.80. ISBN 3 921656 42 7 (series ISSN 0945-8492).

Numbers 1 to 6 of *extraLapis* are already out of print and readers who are unfamiliar with this out-of-series set of thematic monographs should try hard to obtain as complete a set as possible before second-hand prices become unreasonably high. Since the series deals in the main with gem-quality minerals and precious metals (totalling nine out of the thirteen) it is clear that this forms a major information resource for the study of gemstones.

Each issue that I have received seems even more excitingly produced than its predecessors: topaz is not the easiest gemstone for frequent reproduction since there is less colour variation than in some of the other species. None the less the publishers have faithfully shown the colour from yellow through to brown with amazing accuracy and as I particularly admire these colours I found the whole production the best illustrated guide to topaz that I have yet seen.

As in previous issues of *extraLapis* the work of the different authors does not fall easily into separate papers: rather, they combine their work in a long undifferentiated survey of the species. Thus we begin with topaz in antiquity, its chemical, physical and optical properties and its distribution. The main topaz-producing areas are then described, this task taking up most of the remainder of the text. Considerable attention is given to topaz from Schneckenstein, Saxony, and from the Russian Urals, with crystal drawing reproductions from Goldschmidt's *Atlas der Krystallformen* and from other authorities. Topaz mining in Brazil and Pakistan as well as at other sites is also described, with a continuous series of very fine photographs. There is no general bibliography but this is not too serious a loss. This is altogether a beautiful production and German printing has lost none of its skill.

M.O'D.

Gemmologists' compendium. [Seventh edition.]

R. WEBSTER, revised by E.A. JOBBINS, 1998. NAG Press, London. pp 240, illus. in colour. Hardcover £16.99. ISBN 0 7198 0291 1.

First published as a now rare and collectable small-format edition in 1938, this old friend has undergone further revision necessitating a new edition rather than a reprint. In general appearance alone this is welcome since the typeface is much more pleasant to read. The colour photographs are chiefly the work of the reviser and are first-class. As always there is ever more material to choose from and the reviser has unerringly selected a number of topics for consideration outwith the glossary which comprises most of the text. These topics include methods of gemstone manufacture and treatment, colour grading scale for diamond and an update on the hazards likely to be encountered in gem testing outside a laboratory. The short bibliography, too, has been updated and contains no dross (in fact it serves very well as an introduction to the subject).

Naturally everyone will find some favourite topic omitted (several mentioned in the photograph captions are not in the glossary) and brush aside some strays from the past (not very many and not worth worrying about). For general lucidity the descriptive sections would be hard to beat and the junction between original author and reviser, apart from obvious chronological differences, is imperceptible. My only criticism is that moissanite is out of sequence (but easily spotted) in the glossary and that there are a few unimportant typos. In my copy at least, the cover picture is quite noticeably out of focus, one large specimen showing as a glaring white and upsetting the otherwise fine balance. The caption to the cover might be misread by a beginner not realizing that all specimens depicted are opals. The price is unbelievably low for today! The reviser (and the author, from some unimaginable shore) should be proud.

M.O'D.

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

OBITUARY

Professor Harold Schnieden, FGA (D.1967), Bramhall, Stockport, Greater Manchester, died in January 1998.

On 25 September at the Royal British Hotel, Princes Street, Edinburgh, Alan Hodgkinson gave a talk entitled *What's new in gemmology, gems, simulants and synthetics*.

MEMBERS' MEETINGS

London

On 8 July 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, John Benjamin gave a talk entitled *The evolution of Georgian and Victorian jewellery*.

On 26 August at the Gem Tutorial Centre Shyamala Fernandes of the Gem Testing Laboratory, Jaipur, India, gave a lecture entitled *Gemstones of India: variety, quality, availability*. The talk was illustrated by slides and a collection of gemstones from India was displayed.

Midlands Branch

On 25 September 1998 an introductory social evening was held to explore the new Branch meeting venue in the Earth Sciences Building of Birmingham University. A guided tour of the Lapworth Museum was also held during the evening.

North West Branch

On 16 September 1998 at Church House, Hanover Street, Liverpool 1, John Pyke Snr gave a talk entitled *Gem collection with anecdotes*.

Scottish Branch

A field trip to Glenbuchat, Pitscurrie Quarry and the Pass of Ballater in Aberdeenshire was held from 25 to 27 July 1998.

NEWS OF FELLOWS

Congratulations to Martin Donoghue, Newlands, Glasgow, who gained top marks in the annual competition of the UK Facet Cutters' Guild. This is the first time that the competition has been won by a gemmologist.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 29 June 1998 at 27 Greville Street, London EC1N 8TN. Noel Deeks chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

Professor R.A. Howie was re-elected President for the period 1998-2000. Christopher R. Cavey and Ian Thomson were re-elected to the Council of Management.

Tony Allnutt, Robert G. Fuller and Brian Jackson were re-elected and Sally A. Everitt, Amanda G. Good and Peter J. Wates elected to the Members' Council. Messrs. Hazlems Fenton were re-appointed Auditors.

In response to comments from members, further details of the figures in the accounts were provided, the desirability of improving access to the library was discussed, and the possibility aired of the laboratory extending certification of fancy coloured diamonds. In answer to an opinion from the floor that membership of the Council of Management and the Members' Council could do with some new faces, the Chairman said nominations would be welcome.

Following the Annual General Meeting, a Reunion of Members and Bring and Buy Sale were

GIFTS TO THE ASSOCIATION

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

The American Institute of Diamond Cutting, Deerfield Beach, Florida, USA, for *Rough diamonds: internal and external features* by Nizam Peters.

Mr Ismail Hussein Duale, London, for a blue beryl crystal.

Mrs Shyamala Fernandes, Gem Testing Laboratory, Jaipur, India, for the Silver Jubilee book of the Jaipur Gem Testing Laboratory, a geological map of India, a picture made from various powdered gem materials, and cut gems and gem crystals from India including ruby, fluorite, feldspar, chrysoberyl, beryl, apatite, garnet and sillimanite.

Mrs Sonja Glaser NVK, Galle, Sri Lanka, for 12 stones including sapphire, aquamarine, tourmaline and kornerupine.

Mrs Gwyn Green, Barnt Green, Birmingham, for a collection comprising ruby, sapphire, emerald, shell cameos, pastes, garnet-topped doublets, quartz, opal, cultured pearls and pearl simulants, and many other materials, amounting to well over a thousand specimens.

Professor Robert A. Howie, President of the GAGTL, for *Exploring Minerals and Crystals* by R.I. Gait and *Rocks, Minerals and Gemstones* by I.O. Evans.

Mrs Brenda Hunt, London, for two pieces of opal.

Mrs Ameena Kaleel, Mount Lavinia, Sri Lanka, for eight pyrite crystals

Mrs Janice Kalischer, Finchley, London, for many interesting pieces including imitation coral and ivory bangles, star rubies, citrines and dress jewellery.

Mr Peter H.A. Nancarrow, West Horsley, Surrey, for two pieces of turquoise from Gunheath Pit, St Austell, Cornwall.

Mr Daniel Piat, Paris, France, for *L'émeraude*, D. Giard (Editor), Assoc. Francaise de Gemmologie, Paris, 1998.

Mr Samuel F. Redknap, Twickenham, Middlesex, for a microscope, a refractometer, books and journals.

Miss Elisabeth Strack, Gemmologisches Institut Hamburg, Germany, for a copy of *Antiker Schmuck*.

E.A. Thomson Gems, London, for two specimens of coated topaz.

277

held, at which the winners of the 1998 Photographic Competition were announced and entries displayed.

GEM DIAMOND EXAMINATIONS

In June 1998, 97 candidates sat the Gem Diamond Examination, 71 of whom qualified, including seven with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction

Bell-Burrow, Briony, London
Goddard, Valerie J., Alford, Surrey
Kearton, Michael J., Eastbourne, East Sussex
Makri, Hariklia, Thessaloniki, Greece

Sharpe, Erica J., Wells, Somerset
Vernon, Penny, High Wycombe, Buckinghamshire
Zhaoyang Wu, Wuhan, Hubei, P.R. China

Qualified

Ali, Shaukat, Karachi, Pakistan
Anastassiou, Evangelia, Athens, Greece
Anderson-Slight, Jamie, Horsham, West Sussex
Arnold, Jane E., London
Ashton, David, London
Au, Leslie Pak Hong, Kowloon, Hong Kong
Begley-Gray, Margaret, Little Carlton, Nottinghamshire
Bo Zhong, Wuhan, Hubei, P.R. China
Britton, Andrea L., Woking, Surrey
Brohi, Nosheen, Wanstead, London
Carter, Kevin J., Dagenham, Essex

Chan Yuk Yee, May, Kowloon, Hong Kong
 Clancy, Jo, London
 Cowley, Jacalyn G., Wimbledon, London
 Damiao, Lourenco, Streattham, London
 Dan Long, Wuhan, Hubei, P.R. China
 De Souza, Suzanne P., Walton on Thames, Surrey
 de Vries, Marius, London
 Deer, Georgina, Manchester
 Deligianni, Christina, Athens, Greece
 Edwards, Heidi L., Burntwood, Staffordshire
 Flynn, Matthew, Amersham, Buckinghamshire
 Forward, Stephen, London
 Franks, Ivor S., London
 Garrett, Frances S.J., West Worthing, West Sussex
 Gillary, Adam J., Woodley, Reading, Berkshire
 Hill, Emma, Maida Vale, London
 Howard, Christine, Sevenoaks, Kent
 Hussain, Arshid, Birmingham, Warwickshire
 Irwin, Edward, Limerick, Ireland
 Kimber, Sarah J., Weybridge, Surrey
 Kleiser, Alwen M., Anglesey, North Wales
 Kong Jie, Beijing, P.R. China
 Leung Andy Wing-Lok, Kowloon, Hong Kong
 Ling Yu, Wuhan, Hubei, P.R. China
 Liu Decai, Beijing, P.R. China
 Liu Feng, Beijing, P.R. China
 Ma Si Ji, Beijing, P.R. China
 Michael, Marios, Limassol, Cyprus
 Moore, Rowan D., Stoke, Coventry, Warwickshire
 Okutu, Yula, London
 Ouxiang Zhang, Beijing, P.R. China
 Owen, Charryn P., Rudheath, Cheshire
 Papadopoulos, Desiree, Wimbledon, London
 Paphitis, Constantinos, Limassol, Cyprus
 Pasmoooy, Pauline B., London
 Patel, Purnima, Kintbury, Berkshire
 Perks, Helen E., Kinver, Staffordshire
 Pinter, Max, London
 Raphael, Menachem, Alwoodley, Leeds, West
 Yorkshire
 Reilly, Clare, Sutton Coldfield
 Reineke, Antony M., Chelsea, London
 Rennes, Michael, London
 Shi Yan, Beijing, P.R. China
 Shun Yam Yau, Kowloon, Hong Kong
 Smith, Colin, Teddington
 Tete, Nair C., Waltham Cross, Hertfordshire
 Uhlin, Christophe, Leytonstone, London
 Vassiliou, Marianna, London
 Wealthall-Morrison, Maxine, Cold Ash, Berkshire
 White, Joanne C., Sheffield, South Yorkshire
 Willis, Keith T.J., Romford, Essex
 Wong King Suen, Kowloon, Hong Kong
 Yoshitake, Yumi, Golders Green, London

INTERNATIONAL GEMMOLOGICAL CONFERENCE – '99

The 27th IGC will be hosted in India by the Forum of Indian Gemmologists for Scientific Studies, a non-profit organization established by qualified gemmologists in India.

IGC – '99 will be held in Goa from 27 September to 2 October 1999 and will be accompanied by pre- and post-conference excursions.

The Forum of Indian Gemmologists has set up an organizing committee to make the necessary arrangements chaired by Mr K.T. Ramchandran, with Dr (Mrs) Jayshree Panjekar as the Executive Secretary. Attendance at IGC is strictly by invitation and enquiries should be directed to the Forum at 29 Gurukul Chambers, 187-189 Mumbadevi Road, Bombay 400 002, India. Tel: +91 342 0039.

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in June 1998, 190 candidates sat the Preliminary Examination of whom 113 qualified. In the Diploma Examination 234 candidates sat of whom 96 qualified, including two with Distinction. The Tully Medal for the candidate who submits the best set of answers in the Diploma Examinations in 1998 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Mr Laurent Kellerson of London. Mr Kellerson was also awarded the Anderson Bank Prize for the best non-trade candidate of the year in the Diploma Examination.

The Diploma Prize for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Tina Notaro of Madison, Wisconsin, USA.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Miss Long Chu of Guilin, P.R. China.

The Preliminary Trade Prize for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Linda Rythen of Stockholm, Sweden.

FORTHCOMING EVENTS

- 1 November Annual Conference. Gems in Jewellery. To be held at the Barbican Centre, London. Current issues concerning gems and jewellery presented by a distinguished gathering of experts.
- 2 November Tours of jewellery and gemstone galleries at two London museums.
- 4 November London. F.F.H. Moissan, polytypes and synthetic moissanite. Kurt Nassau.
- 12 November Scottish Branch. Moissanite, a new diamond simulant. Kurt Nassau.
- 18 November North West Branch. Annual General Meeting.
- 27 November Midlands Branch. Gemmological journeys in Brazil. E. Alan Jobbins.
- 5 December Midlands Branch 46th Annual Dinner.
- 1999
- 13 January London. Insects in amber. Andrew Ross.
- 29 January Midlands Branch. Bring and Buy followed by Quiz.
- 26 February Midlands Branch. Cameo and gemstones carvings. David Callaghan
- 11 March London. Some current problems in diamond research. Dr H. Judith Milledge.
- 26 March Midlands Branch. Jewels in the hand. James Gosling

For further information on the above events contact:

- London: Mary Burland on 0171 404 3334
Midlands Branch: Gwyn Green on 0121 445 5359
North West Branch: Deanna Brady on 0151 648 4266
Scottish Branch: Catriona McInnes on 0131 667 2199

GAGTL WEB SITE

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

The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Kellerson, Laurent P., London
Notaro, Tina M., Madison, Wisconsin, USA

Qualified

Amor, Miranda, Taunton, Somerset
Astor, Flora, London
Avery, Hilary E., Bangor, Co. Down, N. Ireland

Bin Gao, Wuhan, Hubei, P.R. China
Boels, Vigdis, Ieper, Belgium
Burgoyne, Sheila, Totteridge, London
Castoro, Loretta C., New York, USA
Cho Ka Wah, Hong Kong
Combee, Mireille M., Capelle aan den Yssel, The Netherlands
Cooksey, Brian, Bures St. Mary, Suffolk
Dalsplass, Line M., Oslo, Norway
French, Thomas, Woking, Surrey
Fujii, Noriyuki, Higashi, Osaka, Japan
Fujiwara, Motoko, London
Gudmundson, Inger, Lit, Lannavaara, Sweden

Haitsma, Maaiké C., Schoonhoven, The Netherlands
 Han Xiao, Guilin, Guangxi, P.R. China
 Harding, Rachel A., Twickenham, Middlesex
 Haris, Mohamed Thowfeek Mohamed, Maggona,
 Sri Lanka
 Hodgson, Jane E., Watford, Herfordshire
 Hong, Angela, London
 Hsiao Chin-Kang, Taipei, Taiwan, R.O. China
 Ikebe Emi, London
 Ikeda, Yumi, Osaka City, Osaka, Japan
 Inoue, Kazuko, Tokyo, Japan
 Jacky Lee Chun Man, Hong Kong
 Jain, Reena, Jaipur, India
 Jing Zhang, Wuhan, Hubei, P.R. China
 Jones, Jesse, Auckland, New Zealand
 Jung-In Yang, Taegu, R.O. Korea
 Kim Mi Young, Taegu, R.O. Korea
 Konstandopoulou, Garoufalia, Athens, Greece
 Kuroda, Chikako, Kawanishi City, Hyogo Pref, Japan
 Lam Lai Chun, Kowloon, Hong Kong
 Lanz, Ernst, Veytaux, Switzerland
 Lee Yin Wa, Kowloon, Hong Kong
 Lempinen, Marita, Lahti, Finland
 Liying Fan, Shanghai, P.R. China
 Long Chu, Guilin, Guangxi, P.R. China
 Lule, Cigdem, Ankara, Turkey
 Maddison, Steven, Benfleet, Essex
 Makri, Hariklia, Thessaloniki, Greece
 Marshall, Andrew P., Gravesend, Kent
 Miwa, Yosuke, Tokyo, Japan
 Miyamoto, Takuya, Himeji City, Hyogo Pref, Japan
 Miyamura, Kayoko, Otsu city, Shiga Pref, Japan
 Morgan, Jacqueline, London
 Murakoshi, Mitsuko, Nagareyama City, Chiba
 Pref, Japan
 Muratsu, Hiroto, Neyagawa, Osaka, Japan
 Nakazawa, Haruyo, London
 Ning Zhang, Wuhan, Hubei, P.R. China
 Nishimura, Yoko, Nabari City, Mie Pref, Japan
 Nunn-Weinberg, Danielle, Toronto, Ontario, Canada
 O'Byrne, Rose-Marie, Bicester, Oxon
 Okamoto, Chizuko, Kochi, Japan
 Ono, Shiho, Kaidori Tama City, Tokyo, Japan
 Patel, Nita, Newbury, Berkshire
 Peng Gao, Guangzhou, P.R. China
 Plitsi, Catherine, Larissa, Greece
 Qiong Wei, Wuhan, Hubei, P.R. China
 Ramirez-Achinelli, Soledad, London
 Richardson, Julia H., London
 Said, Mohammad Ali, G'etborg, Sweden
 Segelken, Christine, Vancouver, Canada
 Shah, Varsheet, Kingston, Surrey
 Sheng Chun-Wei, Taipei, Taiwan, R.O. China
 Shyng Jin Chyr, Taipei, Taiwan, R.O. China
 Smits, Cynthia, Alphen a/d Rijn, The Netherlands
 Stern, Sara, Arlington, Virginia, USA
 Stratton, Claire A., London

Taylor, Christopher, Selsdon, Surrey
 Thomas, Caan, Chesham, Buckinghamshire
 Usami, Yumi, Suita City, Osaka, Japan
 Wang Shu-Ying, Taipei, Taiwan, R.O. China
 Waring, Paul, Highbury, London
 Watson, Mendis A., Toronto, Ontario, Canada
 Weisheng Wen, Wuhan, Hubei, P.R. China
 Wu Tsai-Yi, Taipei, Taiwan, R.O. China
 Xianshu Li, Wuhan, Hubei, P.R. China
 Xu Lizhen, Guangzhou, P.R. China
 Yahampath, Hirosha, Maharagama, Colombo, Sri
 Lanka
 Yamashita, Yuko, Osaka, Japan
 Yang Sibao, Guilin, Guangxi, P.R. China
 Ye Li, Wuhan, Hubei, P.R. China
 Yeung, Michelle, Thornhill, Ontario, Canada
 Yin Xiong, Wuhan, Hubei, P.R. China
 Ying Zhang, Wuhan, Hubei, P.R. China
 Ying Liana Ching, North York, Ontario, Canada
 Yixiang Zhang, Wuhan, Hubei, P.R. China
 Yizhi Huang, Wuhan, Hubei, P.R. China
 Yoneda, Chie, Nishinomiya City, Hyogo, Japan
 Young, Geoffrey W., Surbiton, Surrey
 Zhimei Wei, Shanghai, P.R. China
 Zou Hon Wah, Hong Kong

Preliminary

Adcock, Graham D., Lutterworth, Leicester
 Asanuma, Yukiko, Kyoto, Japan
 Atarashi, Yoshie, Osaka, Japan
 Bai Chen Guang, Guilin, P.R. China
 Bartels, Daphne K., Schoonhoven, The Netherlands
 Birrer, Julia M., Ruttinen, Switzerland
 Borg, David, Paola, Malta
 Boyle, Joyce, Clonakilty, R. Ireland
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EVERYDAY LIFE – TREATMENTS AND SYNTHETICS

28 October

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STUDENT WORKSHOPS

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

For further details contact the GAGTL Education Department

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Fax: +44 (0)171 404 8843

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Grostate, Stephen E., London
Guzman, Carolina C., London
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Hu Yi Qing, Guangzhou, P.R. China
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Ji Yan, Shanghai, P.R. China
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	<i>Fellows, Diamond Members and Ordinary Members</i>	<i>Laboratory Members</i>
UK	£57.00	£250.00 plus VAT
Europe	£64.00	£250.00
Overseas	£72.00	£250.00

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8TN on 24 June 1998 the business transacted included the election of the following:

Fellowship (FGA)

Arbeid, Martin Jolis, Dulwich, London. 1967
 Chan, Sau King, Hong Kong. 1998
 Dirlam, Dona Mary, Carlsbad, California, USA. 1982
 Ho, Chuan-Hsiang Taipei, Taiwan, R.O. China. 1998
 Htun, Han, Yankin, Yangon, Myanmar. 1998

Ordinary Membership

Garbis, Nikolaos, Argostoli, Kefalonia, Greece
 Hicter, Marie-Irene, Grenoble, France
 Knifeld, Stephanie Ann, Bournemouth, Dorset
 Leaver, Shirley, Edgeley, Stockport, Cheshire
 Lima Da Costa, Marcondes, Belem, PA, Brazil

Oparaeché, Charles, Brixton, London
Porter, Alan Redvers, Capel, Dorking, Surrey
Rajkumar, Rajendran, Cardiff, Glamorgan
Said, Mohammad Ali, Gothenburg, Sweden
Speer, Teresa Ann, Mountsorrel, Leicestershire

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8TN on 29 July 1998 the business transacted included the election of the following:

Diamond Membership (DGA)

Karim, Zapherali, Leicester. 1998

Fellowship (FGA)

Jankowiak, Anna H., Toronto, Ontario Canada. 1997
Mutton, Valerie Jean, Langley, Berkshire. 1998
van Keulen, Simone J. C., Amsterdam, The Netherlands. 1992

Ordinary Membership

Cunningham, Janice, Worcester Park, Surrey
Gandy, Peter John, Ashburton, Devon
Houser, Elizabeth P.Q., Burbank, Calif., USA
Koudou, Dally, East Ham, London
McKittick, Christopher D., Belfast, N. Ireland
Rythen, L.A. Carolina, Stockholm, Sweden
Smith, Katrina, Dartmouth, Devon
Whitehead, James Devereux, Eastcote, Ruislip, Middlesex

Laboratory Membership

R.D. Finnie Ltd, Aberdeen, Scotland
Hallam, Antique and Diamond Jewellery, Nottingham

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8TN on 23 September 1998 M.J. O'Donoghue FGA was appointed to the Council. The business transacted also included the election of the following:

Diamond Membership (DGA)

Ali, Shaukat, Karachi, Pakistan. 1998
Au, Pak Hong, Kowloon, Hong Kong. 1998
Carter, Kevin J., Dagenham, Essex. 1998
Damiao, Lourenco G., Streatham, London. 1998
Hussain, Arshid, Birmingham, Warwickshire. 1998
Irwin, Edward, Limerick, Ireland. 1998
Leung, Wing Lok, Kowloon, Hong Kong. 1998
Pasmoo, Pauline B., London. 1998
Reineke, Antony M., Chelsea, London. 1998
Willis, Keith, Romford, Essex. 1998

Diamond Membership and Fellowship (FGA/DGA)

Herold, Richard A.J., Bordon, Hampshire. 1985/86

Fellowship (FGA)

Avery, Hilary E., Bangor, Co. Down, N. Ireland. 1998
Beevers, Jacintha Mary, Henley-on-Thames, Oxfordshire. 1981
Boels, Vigdis L.N., Ypres, Belgium. 1998
Chung, Stephen, Leeds, Yorkshire. 1986
Combee, Mireille M., Capelle a/d Yssel, The Netherlands. 1998
Fujiwara, Motoko, Nagoya City, Aichi, Japan. 1998
Haitsma, Maaiké C., Gouda, The Netherlands. 1998
Haris, Mohamed Thowfeek Mohamed, Colombo, Sri Lanka. 1998
Hong, Angela S.L., London. 1998
Jones, Jesse, Auckland, New Zealand. 1998
Lanz, Ernst, Veytaux, Switzerland. 1998
Lempinen, Marita, Lahti, Finland. 1998
Notaro, Tina M., Madison, Wisconsin, USA. 1998
Taylor, Christopher, Selsdon, Surrey. 1998
Waring, Paul M., Highbury, London. 1998
Wu, Tsai-Yi, Taipei, Taiwan, R.O. China. 1998

Ordinary Membership

Ancemot, Alexandre, London
Andries, Stephanie U.S., London
Arrowsmith, Jodie, Oxhey, Hertfordshire
Bailey, Leigh-Ann, Hornchurch, Essex
Bashore, Kerri A., Hayes End, Middlesex
Dennis, Roger A., Elstree, Hertfordshire
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Domercq, Saurine, London
Duncan, Neil A., Twickenham, Middlesex
Dunning, Roy W. J., Watford, Hertfordshire
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Jeffrey, Robert Thomson, Elgin, Moray, Scotland
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Kukadia, Dave, Feltham, Middlesex
Kukadia, Dharmesh, Feltham, Middlesex
Kulukundis, John, London
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Maslik, Magdalena, Fulham, London
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Murase, Yuka, Croydon, Surrey
Nunn, Eva K., London
Pace, Michael, Elk Grove, Calif., USA
Panos, Masis R., Leyton, London
Perez-Dorao, Karlos, Golders Green, London
Perry, Michael, Dublin, Ireland
Pert, John, Windsor, Berkshire
Petkov, Nikolay, Bayswater, London
Prince, Ronald Fisher, Richmond, Surrey
Rose, Christine, Muscat, Sultanate of Oman
Schonberg, Eva A., London
Sinclair, Gary, London
Vallejo-Nagera, Maria, London
Waterfall, Mary C., Ely, Cambridgeshire
Wheeler, Nick, Sudbury, Suffolk

Laboratory Membership

Richard Herold Jewellers Ltd, Bordon, Hants.

Transfers

Transfer from DGA to FGA DGA

Lule, Cigdem, Ankara, Turkey

Transfer from Ordinary Membership to FGA DGA

Makri, Hariklia, Thessaloniki, Greece

Transfer from FGA to FGA DGA

Anastassiou, Evangelia, Athens, Greece
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Cowley, Jacalyn G., Wimbledon, London
Deligianni, Christina, Athens, Greece
Edwards, Heidi L., Burntwood, Staffordshire
Forward, Stephen, London
Franks, Ivor S., London
Goddard, Valerie J., Alford, Surrey
Hill, Emma, Maida Vale, London
Kearton, Michael J., Eastbourne, East Sussex
Kimber, Sarah J., Weybridge, Surrey
Kleiser, Alwen M., Llanfachaeth, Anglesey, North Wales
Moore, Rowan D., Stoke, Coventry, Warwickshire
Raphael, Menachem, Alwoodley, Leeds, West Yorkshire
Sharpe, Erica J., Wells, Somerset
Vernon, Penny A., High Wycombe, Buckinghamshire
White, Joanne C., Sheffield, South Yorkshire
Wong King Suen, Kowloon, Hong Kong
Yoshitake, Yumi, Golders Green, London

Transfer from Ordinary Membership to FGA

Astor, Flora, London
Burgoyne, Sheila, Totteridge, London
Castoro, Loretta C., New York, NY, USA
Cooksey, Brian D., Bures St Mary, Suffolk
Fujii, Noriyuki, Higashi-Osaka City, Osaka, Japan
Hodgson, Jane E., Watford, Hertfordshire
Ikeda, Yumi, Osaka City, Osaka, Japan
Konstandopoulou, Garoufallia, Athens, Greece
Kuroda, Chikako, Kawanishi City, Japan
Marshall, Andrew P., Gravesend, Kent
Miwa, Yosuke, Tokyo, Japan
Miyamoto, Takuya, Hyogo Pref., Japan
Miyamura, Kayoko, Otsu City, Shiga Pref., Japan
Murakoshi, Mitsuko, Nagareyama City, Chiba Pref., Japan
Muratsu, Hirotooshi, Neyagawa City, Osaka, Japan
Nakazawa, Haruyo, London
Nishimura, Yoko, Nabari City, Mie Pref., Japan
O'Byrne, Rose-Marie, Bicester, Oxfordshire
Patel, Nita, Newbury, Berkshire
Ramirez-Achinelli, Soledad, Skogas, Sweden
Said, Mohammad Ali, G*teborg, Sweden
Shah, Varsheet, Kingston, Surrey
Stern, Sara, Arlington, Virginia, U.S.A.
Thomas, Caan M., Chesham, Buckinghamshire
Usami, Yumi, Suita City, Osaka, Japan
Yamashita, Yuko, Sakai City, Osaka, Japan
Yoneda, Chie, Nishinomiya City, Hyogo, Japan
Young, Geoffrey W., Surbiton, Surrey

Transfer from Ordinary Membership to DGA

Anderson-Slight, Jamie G., Horsham, West Sussex
Arnold, Jane E., London
Ashton, David, London
Begley-Gray, M. M., Newark, Nottinghamshire
Bell-Burrow, Briony, London
de Vries, Marius L., London
Flynn, Matthew, Amersham, Buckinghamshire
Garrett, Fran S.J., West Worthing, West Sussex
Gillary, Adam J., Reading, Berkshire
Michael, Marios, Limassol, Cyprus
Okutu, Yula, London
Paphitis, Constantinos, Limassol, Cyprus
Patel, Purnima, Kintbury, Berkshire
Perks, Helen E., Kinver, Staffordshire
Pinter, Max, London
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Tete, Nair C., Antwerp, Belgium
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Wealthall-Morrison, Maxine, Cold Ash, Berkshire

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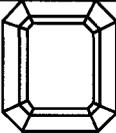
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285

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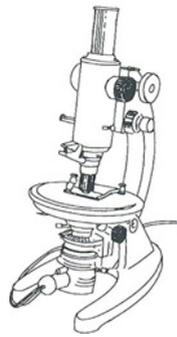
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The Journal of Gemmology

Contents

Blue euclase from Zimbabwe – a review	209
<i>S. Stocklmayer</i>	
Further aspects of the history of rose-cut diamonds	219
<i>H. Tillander</i>	
Kyanite in diamond identified by Raman analysis	222
<i>J.I. Koivula and S. Elen</i>	
Tourmaline: morphological and compositional variations during the growth history of uvite single crystals	226
<i>Y. Takahashi and I. Sunagawa</i>	
Maxixe-type colour centre in natural colourless beryl from Orissa, India: an ESR and OA investigation	238
<i>G. Mathew, R.V. Karanth, T.K. Gundu Rao and R.S. Deshpande</i>	
The chemical signature of emeralds from the Campos Verdes-Santa Terezinha Mining District, Goiás, Brazil	252
<i>G.M. Pulz, L.J.H. D'el-Rey Silva, L.S. Barros Neto, T.M.M. Brum, P.L. Juchem, C.A. Santos, V.P. Pereira and J.J. Silva</i>	
An interdisciplinary approach to identifying solid inclusions in corundum: thorite in a 'Sri Lanka' sapphire	262
<i>S. Carbonin, G. Sbrignadello and D. Ajò</i>	
Abstracts	266
Book Reviews	273
Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices	276

Cover Picture

Tourmaline crystal showing prominent basal and pyramidal faces resting on sketches of the growth step patterns of a pyramidal face. (see the paper on tourmaline by Takahashi and Sunagawa, pp 226–37)

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