



The Journal of Gemmology

Volume 25 No. 4

October 1996





President
E.M. Bruton

Vice-Presidents
A.E. Farn, D.G. Kent, R.K. Mitchell

Honorary Fellows
R.T. Liddicoat Jnr., E. Miles, K. Nassau

Honorary Life Members
D.J. Callaghan, E.A. Jobbins, H. Tillander

Council of Management
C.R. Cavey, T.J. Davidson, N.W. Deeks,
R.R. Harding, I. Thomson, V.P. Watson

Members' Council
A.J. Allnutt, P. Dwyer-Hickey, R. Fuller,
B. Jackson, J. Kessler, G. Monnickendam,
L. Music, J.B. Nelson, K. Penton, P.G. Read,
I. Roberts, R. Shepherd, C.H. Winter

Branch Chairmen
Midlands: J.W. Porter
North West: I. Knight
Scottish: J. Thomson

Examiners

A.J. Allnutt, M.Sc., Ph.D., FGS	S.M. Anderson, B.Sc(Hons), FGA
L. Bartlett, B.Sc., M.Phil., FGA, DGA	E.M. Bruton, FGA, DGA
C.R. Cavey, FGA	S. Coelho, B.Sc., FGA, DGA
A.T. Collins, B.Sc., Ph.D.	A.G. Good, FGA, DGA
C.J.E. Hall, B.Sc.(Hons), FGA	G.M. Howe, FGA, DGA
G.H. Jones, B.Sc., Ph.D., FGA	H.L. Plumb, B.Sc., FGA, DGA
R.D. Ross, B.Sc., FGA, DGA	P.A. Sadler, B.Sc., FGA, DGA
E. Stern, FGA, DGA	Prof. I. Sunagawa, D.Sc.
M. Tilley, GG, FGA	C.M. Woodward, B.Sc., FGA, DGA

The Gemmological Association and Gem Testing Laboratory of Great Britain
27 Greville Street, London EC1N 8SU
Telephone: 0171-404 3334 Fax: 0171-404 8843

The Journal of Gemmology

VOLUME 25

NUMBER 4 OCTOBER 1996

Editor

Dr R.R. Harding

Production Editor

M.A. Burland

Assistant Editors

M.J. O'Donoghue

P.G. Read

Associate Editors

S.M. Anderson	London	Dr C.E.S. Arps	Leiden
G. Bosshart	Lucerne	Prof. A.T. Collins	London
Dr J.W. Harris	Glasgow	Prof. R.A. Howie	Derbyshire
Dr J.M. Ogden	Cambridge	Dr J.E. Shigley	Santa Monica
Prof. D.C. Smith	Paris	E. Stern	London
Prof. I. Sunagawa	Tokyo	Dr M. Superchi	Milan
C.M. Woodward	London		

Any opinions expressed in *The Journal of Gemmology* are understood to be the views of the contributors and not necessarily of the publishers.



Cover Picture

Fine gem quality rubellite crystal, 75 mm long, from the Cruzeiro mine, Minas Gerais, Brazil. See 'The location, geology and mineralogy of gem tourmalines in Brazil' on pp. 263-98

ISSN: 1355-4565

New President



Professor Howie receiving his Badge of Office from Vivian Watson, Chairman at the AGM.

At the Annual General Meeting of the Gemmological Association and Gem Testing Laboratory held on 10 June,* Eric Bruton stepped down from his two-year term as President and handed over his badge of office to the incoming President, Professor R.A. Howie.

Bob Howie graduated in Natural Sciences at Cambridge university and followed this with a doctorate on Indian metamorphic rocks, graduating in 1952. After a period at Manchester University, he moved to King's College, London, and was appointed to a personal chair in mineralogy in 1972. He was President of the mineralogical Society in 1978–80 and since 1966 has edited *Mineralogical Abstracts*, being responsible for a prodigious output of information in a digestible and relevant form appreciated throughout the world.

Countless students and professional geologists have perhaps most appreciated his involvement with W.A. Deer and J. Zussman in producing *Rock-Forming Minerals* and a condensed version *An introduction to rock forming minerals*. This work was published in five volumes in 1962 and with the later edition has been an integral part of the tremendous growth of activity in the earth sciences in the last three decades.

A lifelong interest in gemstones has found expression in lectures to a wide range of audiences and his presidency will reinforce the strong links that the Gemmological Association and the Laboratory have always had with King's College.

* A report of the Annual General Meeting and the President's address are published on pp 312–14.

The location, geology and mineralogy of gem tourmalines in Brazil

Jacques P. Cassedanne, Dr. Sc., and Maurice Roditi, FGA***

* Institute of Geosciences UFRJ, Cidade Universitária, 21.910.240, Rio de Janeiro

** Roditi Jewellers, Rua Visconde de Pirajá, 482, 22.410.002, Rio de Janeiro

Abstract

A comprehensive survey of Brazilian gem tourmalines, mainly green, blue, pink and red elbaite, including their gemmological properties and significant inclusions is given. The tourmalines are recovered from granitic pegmatites and detrital deposits. Tourmaline-bearing pegmatites, which commonly are lens-shaped, are variable in their strike and dip, and show a range of patterns of zoning and albitization. Wallrocks are mica schists, quartzites or rarely granite or gneiss, all Precambrian in age. The pegmatites occur either singly or in fields or clusters and belong to the Brazilian tectonic cycle (650–450 m.y.). Five types of gem-bearing pegmatites are described:

- poorly differentiated, almost homogeneous, with small albitic replacement bodies;
- poorly differentiated with strong albitization;
- zoned with small albitic replacement bodies;
- zoned with strong albitization;
- lithium-rich, very well zoned, with strong albitization.

Gem tourmalines occur in the inner parts of the pegmatites, on each side of a quartz core or concentrated in pockets, which are variable in shape and size, as are the crystals that they

contain. The tourmaline-bearing pegmatites mainly consist of K-feldspar variably perthitized, albite, muscovite and milky quartz with some lepidolite, schorl and locally huge tabular crystals of spodumene. Accessory minerals are listed for different localities.

The main area producing tourmaline is the 'Eastern pegmatitic province' of Minas Gerais. One general and three detailed maps of specific areas show the location of the tourmaline deposits, and their regional zonation and age are briefly examined. Short descriptions are given for the most important pegmatites, and methods of prospecting and working, generally by hand, are discussed.

Weathering of tourmaline-bearing pegmatites produces detrital deposits, eluvial and alluvial. Only eluvial deposits sometimes yield deposits of economic worth and they also are worked by hand.

Non-pegmatitic deposits of tourmaline include the Brumado mine (Bahia) which produces fine red uvite crystals and the Serra Branca prospect (Paraíba) which produces large black dravite specimens.

Keywords: Tourmaline, pegmatite, eluvial deposits, gem mining, Brazil

Introduction

Tourmaline is one of the most remarkable coloured gemstones mined in Brazil where, erroneously, for a long time it was marketed as Brazilian emerald, peridot, sapphire and chrysolite. Hardness, relatively high specific gravity and chemical resistance explain the abundance of its occurrence: tourmaline is found mainly in metamorphic rocks, quartz veins and granite pegmatites which produce the bulk of the gems. Therefore the deposits are many and have been the subject of a range of publications from old compilations to recent travel records (e.g. Ferraz, 1929; Calmbach, 1938; Putzer, 1956; Proctor, 1985a, 1985b). However, geological reports on the deposits are rare and as a result, our purpose is to summarize the main geological and mineralogical features of the tourmaline deposits, both primary and secondary, and to examine the gems produced.

Tourmaline has no industrial application and is mined only to recover crystals suitable for cutting and use in jewellery, or for other ornamental purposes, or less commonly for collectors. Tourmaline is the name given to a group of borosilicates of general formula:

$WX_3Y_6(BO_3)_3Si_6O_{18}(O,OH,F)$ where
 $W = Ca, K, Na$; $X = Al, Fe^{2+}, Fe^{3+}, Li, Mg, Mn^{2+}$; $Y = Al, Cr^{3+}, Fe^{3+}, V^{3+}$ (Fleischer and Mandarino, 1995). The most sought after varieties, green and blue (indicolite) or pink and red (rubellite), are traditionally referred to as elbaite $Na(Al,Li)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$; and the brown varieties are referred to as dravite $NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ or uvite $(Ca,Na)(Mg,Fe^{2+})_3Al_5Mg(BO_3)_3Si_6O_{18}(OH,F)_4$.

Tourmaline is the gem with the widest array of colours. This is due to the many isomorphous substitutions that occur and explains why only the colour is taken into account during transactions by miners, lapidaries and jewellers. Chemical analysis of a tourmaline sample aiming at an accurate mineralogical identification requires complex equipment which is neither accessible nor economically justifiable for daily

trading. In this paper the mineralogical species will not be specified but, in common with daily use, the tourmaline will be described by means of its colour.

Tourmaline is trigonal hemimorphic and Brazilian elbaite (rubellite) was used by Ito and Sadanaga in order to determine its structure in 1951. Tourmaline commonly occurs as long, vertically striated prisms, with some crystals reaching up to one metre in length. Crystals show a rounded triangular cross-section with 3, 6 or 9 main faces, and flat or complex terminations with pyramids of 3, 6 or more faces, commonly irregularly developed or asymmetrical. Short crystals, thin tablets, needles, radiating parallel, stacked and irregular crystal groups are common as are compact or felty (asbestiform) masses (Coelho, 1948) (Figure 1) identical to those reported from California (Jahns and Wright, 1951). Tourmaline pebbles and gravels are common. Twins are rare, but some are reported by Madelung (1883) and Frondel (1948). Crystallographic reviews of tourmaline forms were published by Reimann (1907) and Goldschmidt (1923).

The streak is colourless and lustre is vitreous to waxy. Crystals are transparent, translucent or opaque. Elbaite is pink or green, also colourless, red, orange, yellow, blue, purple, white or black (which is smoky purple when strongly illuminated – Prescott and Nassau, 1978). Elbaite from Paraíba displays outstanding blue, purple, green and light purple colours. The colour is either homogeneous or shows variations within the crystal. Multicoloured tourmalines exhibit either one or more fairly regular patterns of colour zoning or irregular, patchy arrangements of their diverse hues. Regular patterns of zoning may be either perpendicular to the *c*-axis (roughly parallel to the pedion face) or parallel to *c* (roughly parallel to prism faces such as {1010} or {1120}). For example, along *c* green or blue may gradually pass to pink or dark blue, or a pink termination is separated from a green prism by a colourless zone.



Fig. 1. Fibrous tourmaline crystals upon quartz, from the São José da Safira region. Sample is 130 mm long.

Occasionally contrasting hues succeed one another as in the famous 'parrot' tourmalines from the Itatiaia deposit, near Conselheiro Pena (Minas Gerais), where up to five distinct colours occur along the main axis. Tourmaline exhibiting the zoning parallel to prism faces with pink centres and green rims are widely referred to as 'watermelon' tourmalines. The opposite arrangement also occurs. Zoning around the c axis may consist of repeated alternations of colour such as black-green-black-green or blue. Transitions between differently coloured zones have been reported to range from abrupt (Foord and Mills, 1978) to gradual over a few microns to a few millimetres, and these differences are possibly due to sudden changes in conditions of growth (Wagner *et al.*, 1971). Within individual pockets, all crystals, large and small, tend to exhibit zoning with essentially identical colour sequences.

Fracture is usually recorded as conchoidal to uneven, all specimens being brittle. The predominant fractures are roughly parallel, uneven, more or less per-

pendicular to the c -axis, but differ from the {0001} cleavage reported by Dunn *et al.* (1977) in liddicoatite. It is important for lapidaries to recognize the potential fracture locations because such fractures surround globular to subspherical zones called 'nodules'. They are essentially flawless and constitute especially valuable gemstone material. In some Brazilian deposits miners have found long crystals of tourmaline cracked in sections that can be broken apart with the fingers and then 'peeled' like an onion to obtain the small clear nodules present in the core of each section (Sinkankas cited by Dietrich, 1985). In the Barra da Salina area (Minas Gerais) where the nodules are common they have been called 'bolinhas' by the miners.

Cleavage is frequently reported as lacking in tourmaline. However, very poor (indistinct) cleavages may be present, one parallel to {1120} and another parallel to {1011} (Dietrich, 1985) in addition to that on {0001} mentioned above.

Hardness is 7 to 7.5. Specific gravity varies according to the colour, ranging

from 3.03 to 3.10 for elbaite. Values for particular colours are pink to reddish = 3.01–3.06, pale green = 3.05, dark green = 3.08–3.11 and blue = 3.05–3.11.

Tourmaline is uniaxial and optically negative. Refractive indices for elbaite are: $\alpha = 1.603$ to 1.634 and $\beta = 1.619$ to 1.655 , with a birefringence of 0.013 to 0.024 (Arem, 1987). Dispersion is 0.017 . Dichroism is most pronounced in green crystals. Refractive indices of crystals from one deposit show a range depending on colour and probably on their place in the sequence of deposition within the pegmatite. Thus this property cannot be used to determine the source of a gem tourmaline. Commonly colour saturation correlates with indices of refraction for both pink and green elbaites, i.e. the more intense the colour, the higher the indices of refraction as previously noted by Dunn (1975b).

Foord and Mills (1978) reported that biaxiality occurs in deformed crystals and in strained and cracked zones with birefringence visible when the tourmaline was viewed along the c -axis; $2V$ values up to 20° and an extinction pattern similar to that shown by twinned microcline may be present. Some cut and faceted stones may exhibit more than two shadow edges on a refractometer; this is due to overheating or to thermal shock during polishing (Mitchell, 1976).

The spectrum is generally weak. In green crystals the red part of the spectrum is almost completely absorbed up to 640 nm and the yellow and green are freely transmitted except for a faint absorption region near 560 nm. There is a fairly strong and narrow band centred at 497 – 498 nm (due to ferrous iron) which is accompanied by a weaker band at 468 nm. In blue and in some green crystals a strong band is observed at 415 nm. Pink and red tourmalines show a broad absorption in the green region centred about 525 nm accompanied by a narrow band at 537 nm and two lines at 458 and 450 nm due to manganese

(Webster, 1970). The turquoise-blue stones from São José da Batalha (Paraíba) exhibit two strong absorption bands at 698 and 524 nm, the first produced by Cu^{2+} and the second by Mn^{3+} . The green tourmaline from the same locality exhibits only two bands, both due to Cu^{2+} at 920 and 698 nm.

Some pink tourmalines fluoresce under short wave ultraviolet radiation. The fluorescence colour differs from specimen to specimen and has been recorded as ranging from inert to faint chalky blue (Beesley, 1975) but some pink and red crystals exhibit a lavender glow.

Some fibrous tourmalines exhibit chatoyancy. Those of a good quality and colour can be cut as cabochons to make fine cat's-eyes (Figure 2). The chatoyancy depends upon the presence of fibrous



Fig. 2. A set of cabochon tourmaline cat's-eyes. (Photo: F.A. Becker)

inclusions of other minerals or channels, hollow or filled with fluids, that are typically aligned parallel or subparallel to the c -axis. It is widely thought that the hollow tubes predominate. Bhaskara Rao and de Assis (1968) stated that the chatoyancy of some elbaites from north-eastern Brazil can be attributed to channel leaching.

Pseudomorphs after tourmaline are relatively common and consist of partial to total replacement by lepidolite and/or muscovite, with or without a clay mineral. They have been reported from north-eastern Brazil (Bhaskara Rao and de Assis,

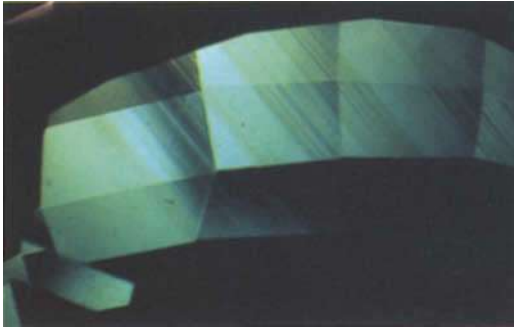


Fig. 3. Very fine channels in a transparent green cut tourmaline.

1968) and are plentiful in tourmaline deposits in Minas Gerais. In some occurrences the mica plates appear as if they were plastered on the tourmaline – they commonly have their basal planes parallel or nearly parallel to the faces of the underlying, typically partially replaced tourmaline.

As in beryl, the principal element of the crystal structure consists of rings of six SiO_4 tetrahedra which are connected by interstitial ions in a layered manner. The characteristic forms of the internal features arise from this structural architecture: as with beryl the tendency to develop growth tubes is based on the specific arrangement of the silica rings (Figure 3). The layered nature of the lattice on the other hand, leads to a tendency for the crystal to break and crack parallel to the basal plane (a poor cleavage), thus encouraging the formation of syngenetic, secondary liquid inclusions (Gübelin and Koivula, 1986). The syngenetic secondary fluid residues in the partially healed fractures form fibre-like capillaries plaited in nets, which have earned the name 'trichites' on account of their hair-fine appearance. These trichites are deemed as highly diagnostic characteristics of tourmaline and occur in all the varieties examined, but are particularly common in rubellite (Figures 4 and 5). Under strong magnification the tell-tale threadlike inclusions reveal themselves as two-phase inclusions consisting of a



Fig. 4. Trichites in a cut rubellite from the Laranjeira mine (Coronel Murta).



Fig. 5. Trichites in a cut rubellite from the Laranjeira mine (Coronel Murta).

watery phase with its vapour bubble. Otherwise trichites resemble undulating long and fine hairs, or inclusions consisting of very small triangular cavities with two predominant faces joined with a liquid network. The trichites occur either singly or in groups comprising interlaced net-



Fig. 6. Bicolour cut tourmaline with mica flakes in the green zone and fibres in the pink zone. Sample from the São José da Safira area.

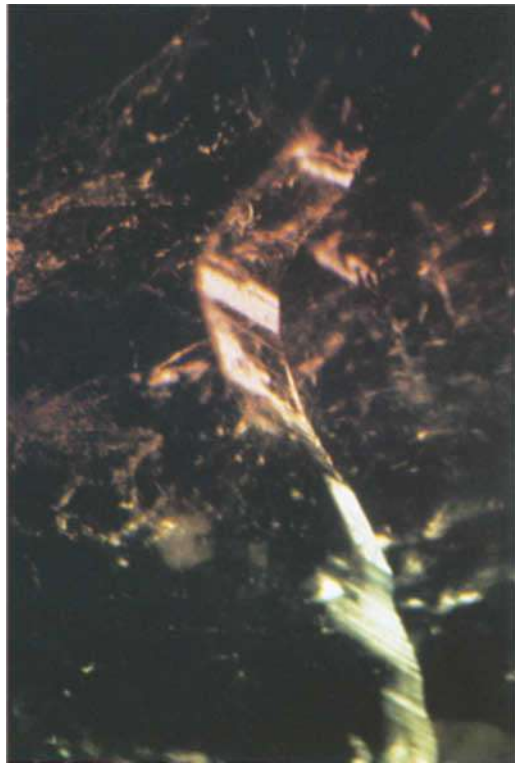


Fig. 7. Growth boundary intersecting colour zones in a cut tourmaline.

works; they commonly cross colour-zone boundaries with no interruption, as reported by Gübelin (1979). In watermelon specimens from the Minas Gerais deposits transitions between green zones with densely packed fibres and pink zones with irregular trichites are common (Figures 6, 7 and 8).

Remnants of the mother-fluid and/or secondary associated minerals (cookeite or actinolite for instance) commonly fill the growth channels running parallel to the *c*-axis, and can be considered as the cause of chatoyancy (Figure 9).

When present, fluorapatite occurs in euhedral transparent yellow or colourless crystals. It is a pegmatitic mineral and is a protogenetic or syngenetic inclusion in tourmaline.

Muscovite in pink tourmalines shows

flashes of bright interference colours from its cleavages when illuminated obliquely from above.

Other solid inclusions are albite, hematite, hornblende, pyrite and rutile; quartz is rare. Small dendritic plates of native copper and tenorite are distinctive of the São José da Batalha tourmalines (Paraíba – Brandstätter and Niedermayr, 1994) (Figure 10).

Three-phase inclusions do occur in complex healed fractures but are not common. Some films or fractures displaying iridescence may appear opaque in transmitted light. Cracks and fissures perpendicular to the *c*-axis are common in crystals from all deposits (Figure 11). Cracks filled with gas and carbonaceous flakes occur sporadically in rubellite crystals.

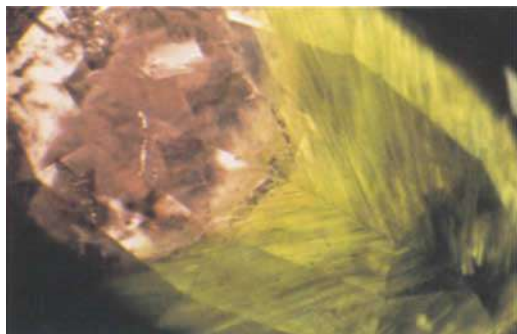


Fig. 8. Bicolour cut tourmaline with a channel-rich green section. Sample from Minas Gerais.

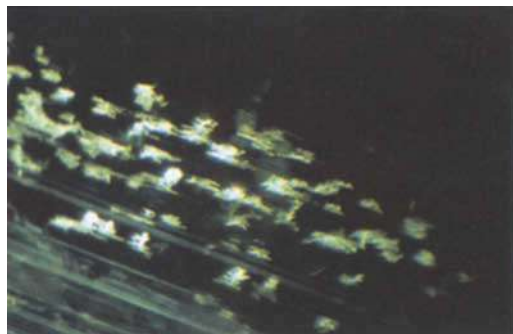


Fig. 10. Jagged plates of native copper in a green tourmaline crystal. These inclusions are characteristic of the tourmalines from the São José da Batalha mine (Paraíba).



Fig. 9. Cat's-eye green tourmaline cabochon showing the many channels responsible for its chatoyancy.

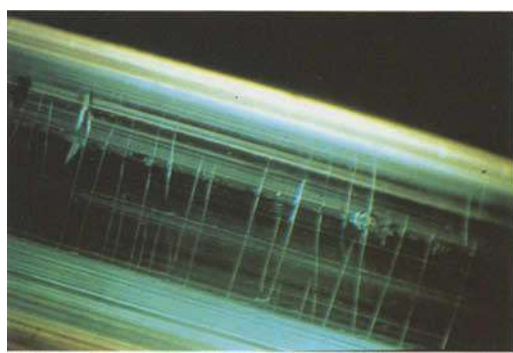


Fig. 11. Cracks perpendicular to the *c*-axis in a green gem quality tourmaline.

Tourmaline as an inclusion

Tourmaline is also a common inclusion in other minerals. In particular it has been reported in:

- quartz (called 'graphite' by miners). Milky or transparent, euhedral or anhedral, quartz occurs widely with clusters of needle-like tourmaline crystals or with tiny isolated tourmaline needles. This material is widely used for ornamental purposes and always originates from pegmatites. Both tourmalinated and rutilated quartz have been called 'Venus hairstone';
- quartz with helvite. Tourmalinated quartz from Governador Valadares contains helvite tetrahedrons which

terminate some of the schorl filaments and grunerite needles (Dunn, 1975a; Gübelin, 1976);

- hydroxylherderite, in the Virgem da Lapa pegmatitic area (Cassedanne and Lowel, 1982);
- beryl; in the fine morganite crystals from the Urucum pegmatite (Cassedanne, 1986);
- various micas, as needles (Araçuaí area) or very thin large plates (Boa Vista pegmatite near Galiléia, Minas Gerais);
- apatite (Linópolis area, Minas Gerais);
- fluorite (Pedra Redonda pegmatite near Mantena, Minas Gerais);
- loellingite, as dark green tourmaline needles (Urucum pegmatite).



Fig. 12. Collection of mixed cut tourmalines, the largest piece weighing 17 ct.



Fig. 13. A lot of blue cut tourmalines from São José da Batalha (Paraíba). (Photo: F.A. Becker)

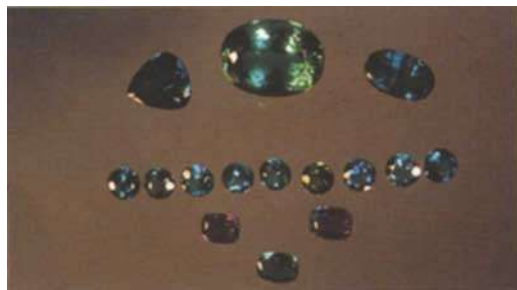


Fig. 14. A lot of mixed coloured tourmalines from São José da Batalha (Paraíba). (Photo: F.A. Becker)

As in aquamarine, the colour is commonly relatively even throughout a tourmaline crystal and may be heat treated to enhance the original shade. However, contrary to aquamarine, in the heat treatment process the maximum temperature is more important than the duration of the heating. The final colour becomes visible during cooling which may be controlled. For instance, tourmaline called 'batata roxa' (purple

potato), purplish-brown to purplish-blue turns into a faint pink by heating between 250 and 400°C (or for some crystals up to 600°C). Green and blue tourmalines are heated up to 600–700°C in order to 'abrir a cor', that is to say to clarify them or to make them more lustrous. Because of its many inclusions rubellite cannot be treated in this manner. From the Barra da Salina area (Minas Gerais) brown crystals which are a mixture of bluish-green and rose hues are likely to turn light blue after heat treatment. Some tourmalines withstand heating up to 725–750°C, but this operation is hazardous due to partial recrystallization at 780°C, and the stones may require repolishing.

Irradiation

Irradiation changes the colour of many tourmalines. As early as 1926 Stamm noted that, after exposure for 25 days to 125 mg of radium bromide (RaBr_2), blue and green Brazilian tourmalines remained unaltered whilst the green and brown varieties became darker. In the same way, Newcomet (1941) reported that green tourmaline turns darker after exposure to Ra. Vargas and Tupinambá (1962) pointed out that the saturated green colour induced in the laboratory may be lightened by heating, as can be done for natural dark colours. Today irradiation is a routine procedure in changing the colour of many tourmalines: pale pink crystals turn into a very fine red (particularly the specimens from the Formiga deposit, Minas Gerais), blue and dark green crystals turn yellow, pink (peach blossom – Barra da Salina, for instance) or purplish (Nassau, 1984).

Relatively abundant and practically without cleavage, tourmaline is a very popular mineral. Nevertheless rough crystals are commonly cracked and gem material is rare, which explains why faceted stones of 10 ct and over are relatively scarce on the market. However some museums and private collections possess cut specimens of more than 100 ct. The darker shade of

this strongly dichroic mineral is generally oriented in the direction of the optic axis. Thus stones with their tables cut parallel to the *c*-axis are lighter than those where the table is perpendicular to the same axis. In a range of cutting styles, the commonest is the baguette cut, but emerald, round, oval, barrel-shaped, navette (drop and briolette) styles are used for the transparent stones. Chatoyant material is fashioned as cabochons, and translucent stones are polished into pearls and beads (Figures 12–16). Large pieces of rough containing some gem material are used for carving as sculptures, ashtrays, amulets and animals (Figure 17).

The large tourmaline deposits (in northern Minas Gerais) and the bulk of the smaller ones, all originating from pegmatites, are located in a narrow ellipse running NNW-SSE and bounded by the towns of Salinas in the north and Conselheiro Pena in the south (compare the aquamarine bearing area described by Cassedanne and Alves, 1992–1994). This ellipse, sometimes referred to as the 'tourmaline bearing basin' (Gonsalves, 1949), is centred upon the 18°S parallel and the 42°W meridian and limited by the Rio Araçuaí in the north-west, the boundary between the states of Minas Gerais and Bahia, the highway BR 116 to the north of Teófilo Otoni, the boundary between the states of Minas Gerais and Espírito Santo in the south-east, the Rio Doce to the south and finally the Rio Suaçuí to the south-west (Figure 18). The whole region belongs to the 'Oriental pegmatitic province' of Paiva (1946). Elsewhere deposits are either smaller (including the famous Paraíba pegmatite), not presently mined or abandoned. See Figures 25, 27 and 33 for locations of the mines and occurrences; the former have all been visited and the latter have in part been derived from the literature.

Resistant to weathering, tourmaline is commonly preserved in eluvial deposits, the soils overlying the pegmatites, which form from their weathering. Some work-



Fig. 15. Set of cut rubellites from the Ouro Fino mine, the largest weighing 5 ct (Photo: ICA/Bart Curren)

ings exhausted the eluvium before entering the underlying pegmatite (Laranjeira and Poço d'Anta deposits near Taquaral, Santa Rosa, etc.), others are restricted to the eluvium (Ouro Fino deposit, Minas Gerais). The present output of this type of deposit is much lower than that from hard or weathered pegmatites. Some alluvial flats surrounding tourmaline-bearing pegmatites, are worked by garimpeiros



Fig. 16. Pendant of fine green tourmaline of 28 ct mounted with diamonds in 18 ct. gold.



Fig. 17. Two birds carved in multicoloured tourmaline. (Photo: F.A. Becker)

(prospectors), and they recover rounded fragments of tourmaline commonly associated with a little beryl, gahnite, topaz, amethyst and chrysoberyl (as in the Córrego do Fogo, near Malacacheta, Minas Gerais). But, compared to aquamarine (Cassedanne and Alves, 1991), tourmaline alluvial deposits are of little economic significance, probably because any large crystals that survive are always very cracked.

For a long time, the State of Minas Gerais has been famous both for the exceptional size of its gem quality tourmaline crystals (for example, in the Virgem da Lapa and Conselheiro Pena areas) and for the large number of tourmaline-bearing pegmatites and eluvium. Currently it is probably the foremost world producer of this gem. In contrast to aquamarine, large crystals are very rare, and prisms or pieces of prisms up to 0.3 metres long are commonest, albeit in large quantities. Named tourmaline crystals are rare and only the

giant rubellites from the Jonas deposit, near Itatiaia (Conselheiro Pena, Minas Gerais), have been given names such as Flor de Lírio, Rosa do Itatiaia, etc. The discovery of a gem accumulation that may weigh up to hundreds of kilograms, either in pockets or in eluvium, leads to a temporary rush of garimpeiros to the new deposit. Legends, fabulous or perhaps exaggerated journalistic stories may arise from a succession of outstanding finds that sometimes degenerate into armed conflicts, as in the Golconda area near Governador Valadares, before World War II.

Tourmaline-bearing pegmatites

Most pegmatites are chemically and mineralogically similar to granites, and consequently are commonly known as granite or acid pegmatites.

In order to clarify subsequent descriptions, the evolution of a pegmatite crystallizing from a magma richer in volatile and rare elements than the original magma will be

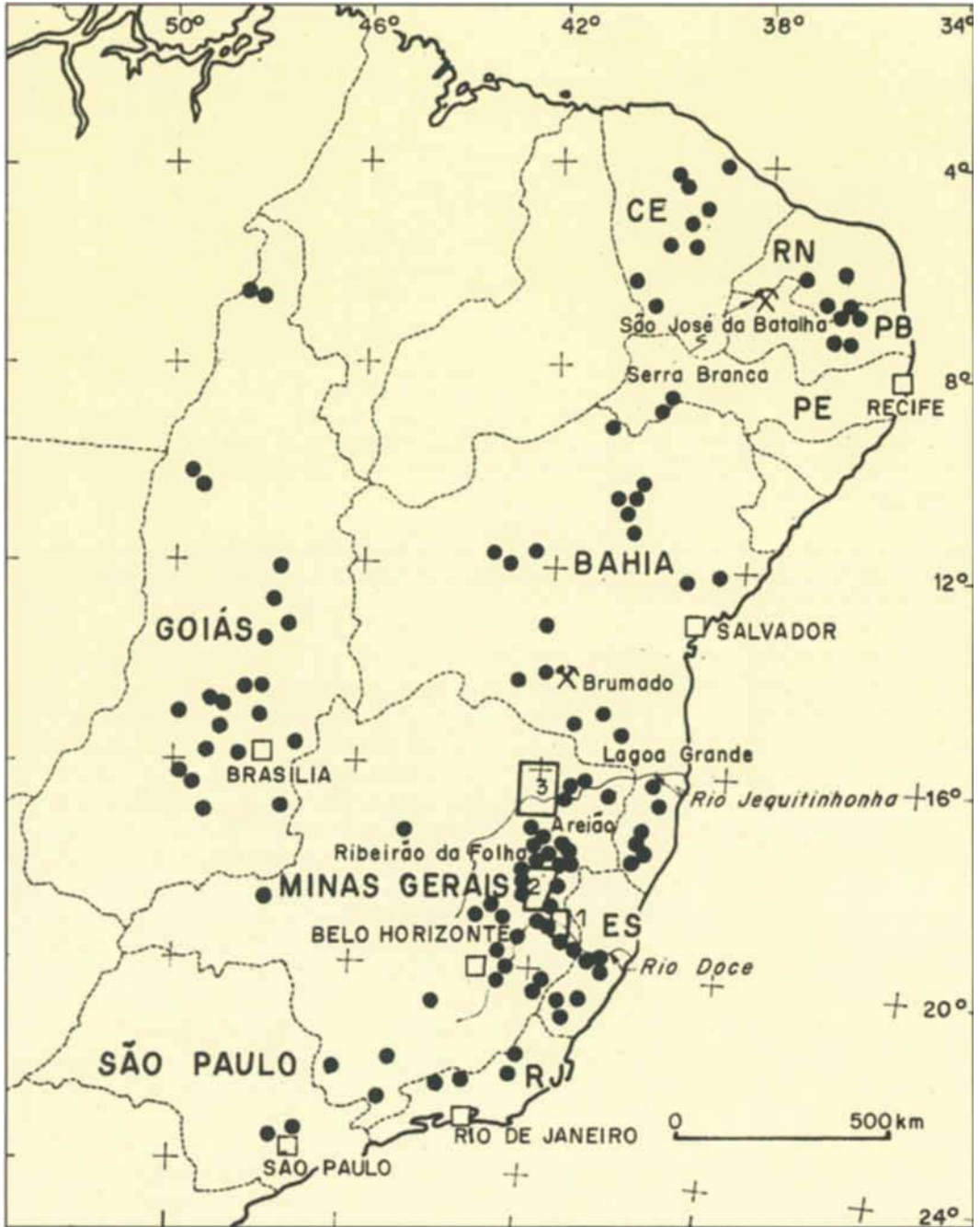


Fig. 18. Brazilian tourmaline occurrences and mines. Numbers refer to detailed area maps. Letter symbols for states are: CE = Ceará, ES = Espírito Santo, PE = Pernambuco, PB = Paraíba, RJ = Rio de Janeiro and RN = Rio Grande do Norte.

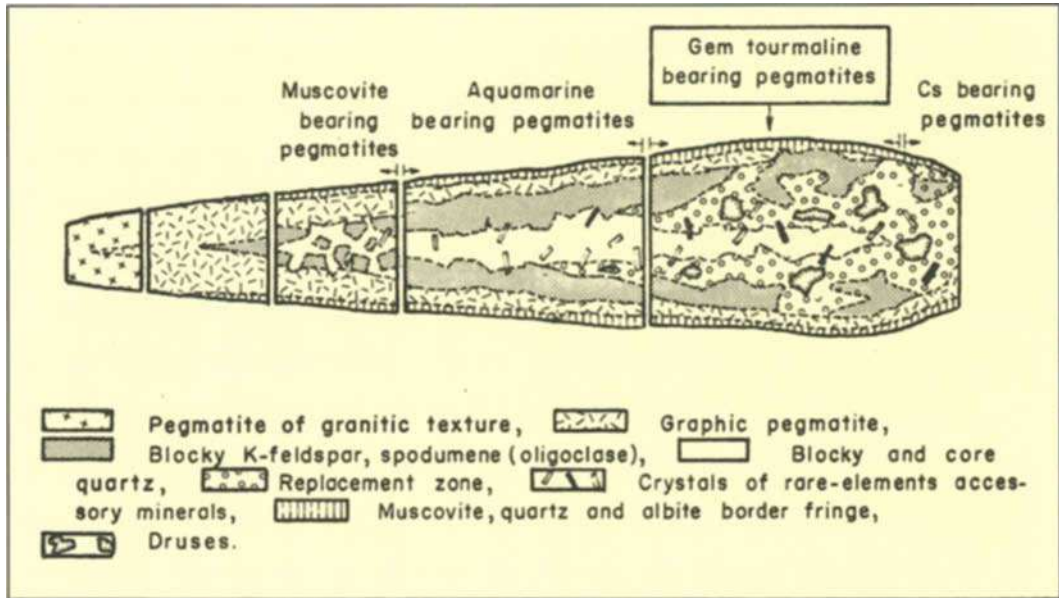


Fig. 19. Location of gem tourmaline bearing pegmatites in a schematic section of different textural-paragenetic types (modified from Vlasov, 1952).

briefly outlined (after Shigley and Kampf, 1984) and will be used as a basis for the proposed classification of the tourmaline deposits.

After the injection of pegmatite magma into fractured rocks and as the temperature falls, crystallization begins somewhat below 1000°C; first the minerals crystallize along the outer margin of the pegmatite chamber where plagioclase, quartz and muscovite form a fine grained border zone. Later these are joined in a coarser intermediate zone by microcline and sometimes by spodumene and beryl (Figure 19).

Because of their chemical and structural makeup, the early-formed minerals cannot, for the most part, incorporate the volatile or rare elements. As a result, these components are preferentially retained in the magma, where they become concentrated. As crystallization continues with further cooling, the water content of the magma eventually reaches saturation level. At this point an aqueous fluid, rich in volatiles and certain rare elements, separates from the remaining pegmatite magma between

750 and 650°C. The much lower viscosity of the aqueous fluid permits the rapid transport of chemical nutrients to the growing crystals, thereby promoting their growth in the innermost zones of the pegmatite. The greater concentration of volatiles and many of the rare elements contributes to the partitioning of elements between magma and fluid, and thereby to the segregation of minerals in separate zones. Aqueous fluids allow minerals to crystallize at lower temperatures and to reach greater sizes than do magmatic fluids. The aqueous fluid also may redissolve some earlier formed minerals and is responsible for much of the secondary mineral replacements occurring in the complex pegmatites. As crystallization proceeds, the aqueous fluid continues to exsolve from the silicic magmatic fluid which solidifies between 600 and 500°C. At this stage, the innermost portions of the pegmatite would be occupied by large crystals of feldspar and quartz (sometimes with spodumene and beryl) with a few isolated pockets of trapped fluid.

The formation of minerals in open pockets, the druses of Figure 19, is the final stage in the primary crystallization of the pegmatite. In this way, London (1986) showed that in pegmatites in Afghanistan and California, tourmaline pockets were formed between 475 and 425°C at pressures between 2800 and 2400 bars. With decreasing temperature to 400°C and rising internal pressure resulting from the release of volatilities, crystallization continues from the trapped fluid. Euhedral crystals of various minerals are able to form from the fluid within the open space of the pockets, and they may contain abundant liquid inclusions, attesting to their growth from an aqueous fluid. At this stage, the concentration of certain rare elements may reach sufficiently high levels of crystallization of unusual minerals. Some crystals projecting into the druses may start opaque and grow with addition of clearer zones of higher gem quality, ending in flawless terminations.

This continued mineral growth is accompanied by changes in the chemical composition of the fluid which, in turn, are reflected in corresponding changes in some minerals (e.g. colour zoning of tourmalines). The final temperature for mineral crystallization from this fluid may be as low as 250°C.

The changing fluid chemistry, coupled with decreasing temperature and increasing pressure, can eventually lead to the destruction of many pocket crystals. In addition, earlier formed minerals may become unstable in contact with this highly reactive fluid. As a result, some pockets are found to contain only the remnants of what may have been gem-quality crystals altered to secondary minerals such as lepidolite, cookeite or montmorillonite. If the leakage of volatiles is gradual, the pocket crystals will remain intact but, if the pocket fluid escapes rapidly, a very sudden drop in pressure has the same effect as a dramatic decrease in temperature. The

resultant thermal shock may be responsible for many of the internal fractures observed in gem crystals (particularly tourmalines) and for the shattered fragments found on the floor or embedded in the pocket clay of many gem pockets.

It is thought that the aqueous fluid required for pocket formation is only able to exsolve from the magma under the lower confining pressures experienced by pegmatites formed at shallow depths. This would explain the lack of gem crystal druses in deeper pegmatites in many parts of the world, e.g. in north-east Brazil in the Borborema pegmatitic province. According to Jahns (1955) only one per cent of pegmatites are drusy and furthermore, the elements required for gem growth are not always present. Size, shape and filling of the pockets are highly variable.

The last hydrothermal stage of evolution may be deeper in any one pegmatite than indicated in the general model described above. This stage causes strong alteration by hydrolysis of the feldspars, commonly the main components of a pegmatite, and results in a white or off-white clay mixture irregularly mottled with quartz and other unaltered mineral fragments. This assemblage resembles, and may be confused with, the weathering product of many pegmatites. In tropical conditions a number of pegmatite minerals are unstable, at least on the geological time scale. Such minerals as feldspars and spodumene change into clays, while others (e.g. biotite and magnetite) decompose in other ways and lead to the disintegration of the pegmatite body; the chemically stable or practically insoluble minerals such as tourmaline, topaz, beryl and quartz remain unaltered. Kaolin is commonly the predominant component of the mixture resulting from pegmatite alteration, either by hydrothermal means or from weathering, and may be associated with montmorillonite, gibbsite, chlorite and other layered silicates in lesser quantities. Being commercialized under the name of 'kaolin' for ceramics purposes

(frequently without strict standards), the deposits from which it comes are commonly referred to as 'kaolinized'. Since chemical or other mineralogical determination of the clay, and identification of its cause as hydrothermal alteration or weathering, are generally lacking, in most deposits it would be regarded as right and proper to describe the mineral assemblage as an 'alteration product'.

Location of the deposits

Virtually all the tourmaline-bearing pegmatites in Brazil are located in metamorphic rocks such as micaschists with or without specific metamorphic minerals (staurolite, garnet, kyanite, andalusite) or, more rarely, in gneiss or quartzites (Cruzeiro, São José da Batalha deposits). Pegmatites cutting granites are rare (Valdete deposit near Coronel Murta, Minas Gerais). This observation is of geomorphological importance in areas where recent erosion has occurred in a very active way following doming, tilting and repeated uplift: the tourmaline-bearing pegmatites are more

distant from the granite outcrops than are the beryl-bearing pegmatites. This observation is reflected by the regional morphology: the tourmaline bearing areas are commonly located in low hills overlooked by sporadic sugar loafs and inselbergs, topography that results from a high rate of chemical weathering accompanying the mechanical erosion (Figure 20). Although secondary deposits, mainly eluvial, were widely developed during the partial or almost complete destruction of the often kaolinized primary deposits, there are virtually no economic alluvial deposits of tourmaline. In contrast, 60 to 70 per cent of the Brazilian aquamarine output, comes from secondary deposits in which the alluvial type prevails (Cassedanne and Alves, 1991).

Tourmaline-bearing pegmatites occur singly or in groups (Cerny, 1982). Single pegmatite bodies are frequently large (Veadinho, Minas Gerais) to very large (Golconda, Cruzeiro, Pederneira deposits, Minas Gerais), up to many hundreds of metres in length and tens of metres in width. Individual pegmatites in the groups

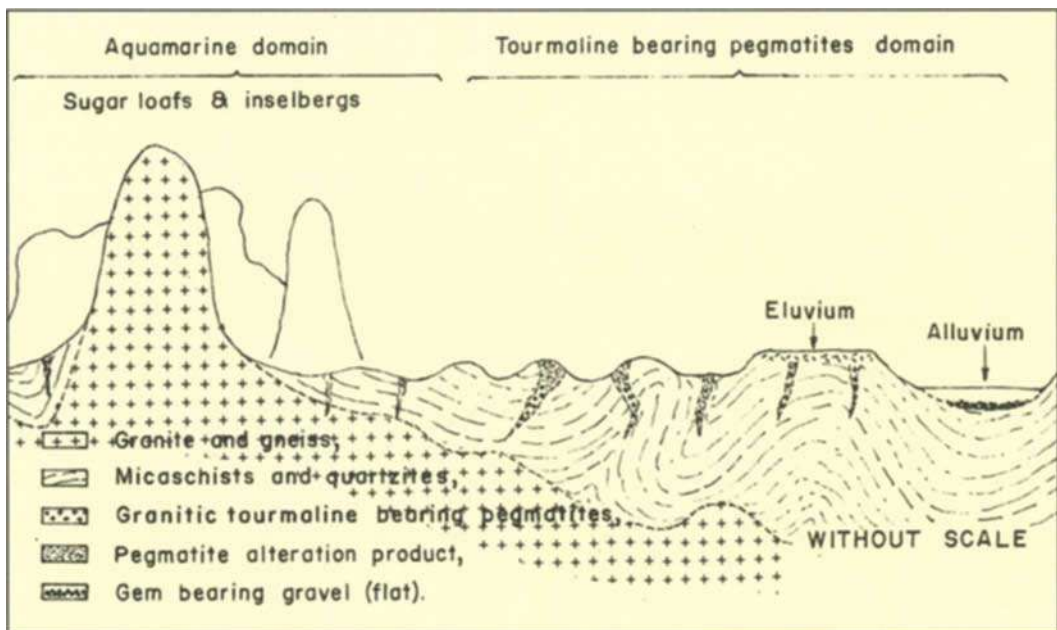


Fig. 20. Types of tourmaline deposits and their relationships with aquamarine deposits in an idealized section.

are always smaller, but the groups may comprise tens of pegmatite bodies with a range of sizes, strikes and dips (Taquaral, Barra da Salina near Araçuaí, Minas Gerais). Wall rocks, direction and dip may also change quickly in the same body, and such features are not of use as characteristic of any one deposit. The body of the pegmatite is commonly lens-shaped, sometimes tabular or dyke-like, and may be parallel to or cut across any banding or foliation of the wall rocks.

Typological classification of the deposits

Genetically, all tourmaline-bearing pegmatites show greater differentiation than aquamarine bearing pegmatites, which explains why the two gems do not occur together. Bearing in mind the above outline of pegmatite evolution, for practical purposes it is possible to distinguish two groups of pegmatites: homogeneous and heterogeneous.

Homogeneous pegmatites

Type 1 – single. These are K-feldspar pegmatites, commonly with well developed quartz-feldspar intergrowth textures (graphic granite), poorly evolved, with scattered albite and/or lepidolite-bearing substitution bodies where tourmalines are found. Pegmatite bodies of this type appear homogeneous on first examination, because zoning is not obvious, except in a few places where large K-feldspar crystals occur in the central zone.

The Humaitá deposit near Taquaral (Minas Gerais) may be used as an example: the vertical pegmatite, 6 to 8 metres in width, is irregularly worked along the 30 metres of its outcrop. Between the wallrock of staurolite schists and the pegmatite is a zone, 1 cm thick, of tourmaline. The texture of the pegmatite body is granitic to graphic and grain size ranges up to a few centimetres. The body consists of K-feldspar, some plagioclase, quartz and mica with much schorl, where albite replacement bodies containing small

druses or pockets are erratically scattered. The pockets are coated with cleavelandite, decimetre-sized K-feldspar crystals, scarce lepidolite, window (= quartz à fenêtres or cathedral) quartz crystals and gem-quality blue and green tourmaline crystals, associated with a little crystallized rose quartz and fine moraesite needles (Cassedanne and Cassedanne, 1987).

Type 2 – albitized. This type may be distinguished from the single type by replacement of the large K-feldspar crystals by Na-feldspar. Again, some large K-feldspar crystals can occur in the central zone of the pegmatite.

The Gordura (or Zé Antônio) deposit, also near Taquaral, is a typical example. Running EW, with a small northerly dip in country rocks of biotite schist, ten metres or so wide, the pegmatite is worked along approximately 300 metres of its outcrop. A granitic fringe some cm in width, fine grained and schorl rich, occurs between the wallrocks and the pegmatite. The highly kaolinized body consists essentially of Na-feldspar with milky quartz, schorl, muscovite and a little garnet. Blue and green tourmalines also occur as small crystals disseminated in quartz, or less commonly in feldspar, or grouped in small pockets coated by cleavelandite and quartz with some muscovite. These pockets are commonest in the central part of the body where a string of milky quartz lenses and large microcline crystals may be developed.

Many pegmatites belong to this type in the neighbourhood of Taquaral and Barra da Salina, both hamlets in the state of Minas Gerais.

Heterogeneous pegmatites

The banding of the minerals is always conspicuous.

Type 3 – single. Part of the K-feldspar is substituted by small albite/lepidolite replacement bodies. With the exception

of banding, this type is similar to number one.

The Poço d'Anta pegmatite, in the vicinity of Taquaral, illustrates this type. The pegmatite body is horizontal, asymmetrical and has been worked along many hundreds of metres. From the roof to the floor, in a section of 2.5 metres, there may be seen:

- fine grained biotite schist;
- long flakes of muscovite perpendicular to the wallrock, embedded in granite (grain size about one centimetre);
- lens-shaped milky quartz core;
- microcline crystals up to 10 cm long with zones of albite substitution associated with lepidolite and pockets which are coated by cleavelandite, muscovite and window quartz with gem-quality green and blue, more rarely pink, tourmaline prisms up to 30 cm long;
- granite of medium grain size with a little muscovite;
- fine grained biotite schist.

The half-section of the symmetrical Xandá pegmatite, near Virgem da Lapa (Minas Gerais) will supplement the previous example. Dipping N20°E and 7 metres or so wide, the pegmatite was worked along its 150 metres outcrop. From the roof to the core may be seen:

- folded biotite schist;
- thin contact zone with perthite, plagioclase, quartz, muscovite and a little biotite;
- fine grained graphic granite with schorl, muscovite, biotite and pink garnet;
- a zone of very coarse to giant crystals of the above minerals associated also with some beryl. This zone is rich in substitution by albite and also contains pockets. The pockets are coated by cleavelandite, transparent and milky quartz crystals, lepidolite in a range of sizes, muscovite and/or zinnwaldite, blue transparent topaz (some crystals weigh 20 kilograms) and bluish and green tourmaline prisms which, exceptionally, may reach 80 cm in length. Less commonly present are bluish or greenish gem-quality

apatite, microlite and large, sometimes gem, hydroxylherderite crystals;

- lens-shaped core of milky quartz (Cassedanne and Lowell, 1982).

Type 4 – albitized. This may be distinguished on the basis of higher substitution of the large K-feldspars by Na-feldspar.

The half-section of a symmetrical pegmatite known as the Jonas deposit (Itatiaia) near Conselheiro Pena (Minas Gerais) will illustrate this type. The pegmatite body is vertical, ten metres or so in width and worked along the 70 metres of its outcrop. The zones from the biotite schist wallrocks to the core are:

- fine grained schorl-rich contact zone with granitic texture;
- medium grained graphic granite with schorl crystals perpendicular to the wallrock, biotite, some plagioclase and large muscovite flakes;
- coarse grained zone consisting mainly of albite with quartz, some muscovite, garnet and remnants of K-feldspar; pockets are scarce, but some are many cubic metres in size. These pockets are coated by transparent to pale yellow quartz crystals, commonly doubly terminated, lepidolite, cleavelandite, microcline and commonly pink (or green) gem tourmaline prisms, exceptionally more than one metre in length. Less common are microlite, arsenopyrite, monazite and gem quality apatite;
- milky quartz core and giant microcline crystals.

Type 5 – albitized with spodumene. The presence of spodumene crystals, commonly very altered and not of gem quality, some more than two metres in length, is the distinguishing feature of this type. Zoning is always conspicuous.

The half-section of a symmetrical vein from the Cruzeiro pegmatite field (Minas Gerais) will be outlined as an example. This pegmatite is vertical, approximately 12 metres wide, and has been partially

worked upon over a few hundred metres. The wallrock is a well banded, fine grained, white to grey quartzite, and from this to the core the zones are:

- coarse grained muscovite;
- granite consisting mainly of quartz and plagioclase with lenses of graphic texture;
- external intermediate zone, locally rich in large muscovite books (worked during World War II) with extensive graphic texture;
- internal intermediate zone, essentially of K-feldspar sporadically albitized;
- central zone: large quartz crystals which may or may not be idiomorphic (window), microcline, large tabular spodumenes and zones of albitic substitution bodies about 10 m wide, with cavities and pockets. The pockets are coated with cleavelandite and contain muscovite, lepidolite, quartz and commonly fine green or pink tourmaline prisms. Some iron and manganese phosphates may also be seen in the vicinity of the pockets;
- lens-shaped milky quartz core (Cassedanne *et al.*, 1980).

Identical sections may be observed in the Golconda and Barra da Salina (Cata Rica, Minas Gerais) deposits, where garnet is associated with the spodumene.

Minerals of the tourmaline deposits

From a mineralogical point of view, tourmaline-bearing pegmatites are simple: more or less albitized K-feldspar, albite, muscovite and milky quartz are always present. Lepidolite (Urubu, Limoeiro, Barra da Salina) and schorl (Sapo, Bananal, Caraíba) are commonly present and may be abundant. Niobotantalite and beryl (frequently as disc-shaped very pale blue, colourless or pink crystals) are also commonly present but always in small amounts. Finally, the following occur sporadically: apatite (gem quality fluorapatite at Jonas, Virgem da Lapa), amblygonite (Golconda, Palmeiras), cassiterite (Areião,

Sebastião Dutra, Morro Redondo), citrine (Benedito), cookeite, some of which contains boron (Benedito, Eraco Teixeira), garnet (commonly with a composition near 50 per cent almandine and 50 per cent spessartine – see Cassedanne and Cassedanne, 1980; occurs at Veadinho, Golconda), hydroxylherderite (Urubu, Golconda, Virgem da Lapa), microlite (Jonas, Pederneira), morion (dark brown quartz at Manoel Teixeira, Baixão, Ouro Fino), nontronite (Itatiaia, Santa Rosa), petalite (Urubu), iron and manganese phosphates: triphylite (Benedito), cyrilovite, eosphorite, ferrisicklerite (Manoel Teixeira), frondelite, graftonite, heterosite (Laranjeiras), hureaulite, mitridatite (Olho de Gato), phosphosiderite, strengite and vivianite; rarer phosphates: coeruleolactite (Cruzeiro), moraesite (Pirineú, Humaitá), wardite (Laranjeira), very fine rhodochrosite crystals (Pederneira), colourless or very pale pink gem spodumene (Benedito), thoreaulite (Urubu); secondary uranium minerals: autunite (Pederneira), phosphuranylite, saléeite (Olho de Gato) and torbernite (Cruzeiro), zinnwaldite and topaz. Topaz occurrences are restricted to the Laranjeira Velha deposit, Barra da Salina and Virgem da Lapa, and are almost always blue, yellow or green in contrast to the topaz in aquamarine-bearing pegmatites which is colourless. Manganese oxides, locally plentiful, stain the weathered pegmatites; commonly of superficial origin, they may be derived from the weathering of garnet.

The following minerals occur very rarely: large biotite crystals, massive rose quartz (Pederneira), crystallized rose quartz (Laranjeira, Valdete), rosette-shaped amethyst (Sapo), gahnite (Faria), monazite (Jonas, Baixão), bismuth minerals (Palmeiras), geochronite (Limoeiro), sulphides and arsenides (Antônio Magalhães, Laranjeira), xenotime (Urubu) and zircon (Baixão). Magnetite and hematite are absent. The above deposits are only quoted as examples.

Due to repeated pulsations during the final crystallization of some pegmatites, mainly in those which are most albitized, some minerals became unstable in the new conditions and disappeared, being variously reabsorbed or replaced by other minerals. One example of this is that lepidolite (at Urubu or Jonas) or cookeite has replaced to a greater or less extent the rubellite or green tourmaline. In the same way, large tabular spodumenes may be altered to vividly coloured montmorillonite (Cruzeiro, Palmeiras).

Prospecting and mining

Direction and dip of both the pegmatite bodies and their wallrocks broadly vary from one deposit to another and cannot serve as prospecting criteria.

The window quartz crystals ('jacaré' of the garimpeiros) vary from a few centimetres to more than one metre long, and appear to be the most typical mineral of the tourmaline-bearing pegmatites. They are commonly coated with smaller quartz crystals. Window quartz is transparent, translucent, or may be milky, or rarely smoky; frequently it contains very large liquid inclusions.

In early 1994 giant pockets containing tens of tons of astonishingly perfect quartz crystals were discovered in the tourmaline bearing pegmatite of Morro Redondo, near Virgem da Lapa (Minas Gerais). Individual crystals were more than 300 kilograms in weight and up to 2 metres in length, and totally window-featured or sceptre-shaped when grown upon an older crystal. In the tourmaline-bearing pegmatites, window quartz is found rather than the 3-pyramids quartz crystals that are typical of the aquamarine deposits (Cassedanne and Alves, 1992–1994). The association of window quartz crystals with abundant muscovite (or lepidolite) and manganese oxides is a very valuable guide to the proximity of gem pockets of tourmaline (Barra da Salina, Cruzeiro deposits for instance).

It seems that a significant albitization

stage is essential for the development and presence of gem tourmaline and a very pronounced zoning appears to be distinctive of the most important deposits (Cruzeiro, Barra da Salina, Jonas). This zoning is frequently asymmetrical, mostly in the horizontal pegmatite bodies where the gem quality tourmaline tends to occur below the quartz core. One explanation may be that a different distribution of the fluids results from differential upward migration due to different thermal gradients or gravity differentiation phenomena that is not obvious on a local scale in the vertical bodies. Uebel (1977) reported the same phenomenon in Norway. Frequently it may be noted that low dipping or horizontal pegmatite bodies have the greatest abundance of pockets (approximately one pocket per square metre in the Limoeiro pegmatite for example; Poço



Fig. 21. Pink and green tourmaline crystals close to the quartz core. Urubu pegmatite near Araçuaí.

d'Anta and Santa Rosa deposits are other good examples).

As a rule pockets are small (one to ten cubic decimetres in volume); those of one cubic metre or more are rare and found mainly in vertical pegmatites (Golconda, Jonas). The pocket shape is highly variable, commonly irregular, sometimes flat (Humaitá) or roughly ellipsoidal (Poço d'Anta). Locally there may be structural controls, mainly in subhorizontal or gently dipping pegmatites: e.g. in the famous Limoeiro pegmatite, pockets are concentrated in the vicinity of NS striking, steeply dipping fractures and below roof undulations due to small recumbent folds in the wallrock biotite schist. Elsewhere the very irregular distribution of pockets indicates that no geological hypothesis would be capable of predicting the sites of pockets and consequently where the tourmaline concentrations might be found. This fact, combined with a low economic (or industrial importance) explains why mining is

almost always carried out by hand and is very primitive. In order to reach a pegmatite body the garimpeiros sink cross cuts through the wallrocks or, where possible, start directly from the outcrops. Then the adits are cut in the vicinity of the core of the pegmatite to search for pockets ('caldeirões') (Figure 21). The adits are tortuous, rising and descending, by means of steps and stairways which are very narrow and timbered in the crumbling zones. The altered and weathered pegmatite is cut with picks and hard pegmatite rock is blasted with the help of small pneumatic drills and compressors. When not piled in the chambers abandoned after mining, the waste is cleared by wheelbarrow. In some places the weathered or powdery tourmaline-bearing vein material is roughly screened and/or washed near the adit entrance (as in the Barra da Salina and São José da Batalha deposits for instance, Figures 22–24). As each garimpeiro cuts his own adit, the number of distinct dumps is



Fig. 22. Hauling with a hand winch from a pit in the kaolinized pegmatite at São José da Batalha mine.



Fig. 23. Screening and washing the kaolinized pegmatite at São José da Batalha mine.

impressive, even in a small pegmatite body. Exceptionally the overburden is stripped out with the help of a bulldozer (Barra da Salina).

Prospecting for deposits is empirical by digging out every white superficial spot (ant hill, armadillo hole, erosion gulch, etc.). If gem material is found, there is a temporary rush of garimpeiros to the new deposit. Mining of the pegmatites is by

open pit or by means of adits. The weathered pegmatites where feldspars have been broken down by alteration are the easiest to work, and the gemstones are recovered simply by washing the hand-sorted ore. Fine gems also occur in the unweathered, hard pegmatites but there, outside the pockets, they are intergrown with quartz or feldspar. Extraction from this matrix commonly results in the breaking of the tourmaline crystals. The splendid specimens found in the gem pockets are sought after not only by lapidaries but also by mineral collectors.

The tourmaline crystals obtained from the workings vary greatly in colour, but generally green, blue or pink prevails. Achroite is rare (Urubu). Locally prisms showing chatoyancy are common (e.g. Olho de Gato, near Governador Valadares). One colour sometimes predominates in a deposit, e.g. blue (Pirineús), red (Ouro Fino) or green (Faria), but more frequently green/blue and red/pink are asso-



Fig. 24. Blue tourmaline pieces recovered after washing the ore at São José da Batalha (see Figure 23).

ciated (Cruzeiro, Santa Rosa, Barra da Salina). No prospecting guide exists to locate a particular colour, just as there is no simple explanation for colour genesis. However, from practical experience it appears that fine rubellite crystals are nearly always associated with Li-rich pegmatites (spodumene and/or lepidolite of type 5 above). According to Batista and Neto (1974) only 1 to 5 per cent of the extracted gem-quality tourmalines are of very good quality.

Spatial distribution and age of the pegmatites

In the geochemical evolution of the pegmatites, the transition from a dominant potassium phase to a more sodic one has been reported from many countries and it has been used as a basis for their classification (Fersman, 1931; Vlasov, 1952; Varlamoff, 1958; Smirnov, 1977, etc.). However, the establishment of a strict parallelism with the Brazilian deposits is not easy because criteria related to gems were not taken into account by the above authors. Nevertheless at a regional scale, the aforesaid geochemical evolution is shown in the eastern pegmatite province by a clear zonation: the tourmaline-bearing zone is surrounded in the east, north-east and south by the aquamarine-bearing zone. In turn, the aquamarine-bearing zone is bordered by a wide pegmatite belt, without gems and producing only muscovite, which extends south-west from the state boundary between Minas Gerais and Espírito Santo (Pecora *et al.*, 1949).

Beyond this zone and further to the south and south-west, pegmatites are only worked for feldspar (Menezes, 1982).

The intrusive granites with which gem bearing pegmatites are classically associated are either even grained (granodiorite, tonalite or other) or medium to coarse grained porphyritic varieties belonging to an active part of the Brazilian tectonic cycle between 650 and 450 m.y. (Correia Neves *et al.*, 1986). Pegmatites have been

dated at 450 m.y. in the Conselheiro Pena region (Moura *et al.*, 1978) and at 490 m.y. in the neighbourhood of Araçuaí (Afgouni and Sá, 1977). They are always regarded as contemporaneous with, or in some instances post dating, the last stage of the Brazilian tectonic cycle. There is one report that zircon from a certain pegmatite gave an age of 350 m.y. (Pecora *et al.*, 1949). The Brazilian tourmaline-bearing pegmatites are all located in the Precambrian basement and are contemporaneous with those of East Africa, Madagascar and northern Baikal Province (Černý, 1982).

Major tourmaline deposits

Minas Gerais State contains the major deposits responsible for the bulk of Brazilian gem tourmaline output today and the tourmaline occurrences known in the states of São Paulo, Rio de Janeiro (Lavra do Esmério) and Espírito Santo have no economic importance. Omitting the small and worked-out pegmatites (Abreu, 1963; Ferraz, 1929; Franco, 1967; Araujo *et al.*, 1982), the following large deposits should be recorded (N.B. 'lavra' means mine, deposit or prospect).

In the middle of the Rio Doce Valley (see detailed map of area 1, Figure 25) east of Governador Valadares, in the Conselheiro Pena-Divino das Laranjeiras area, the main deposits are Itatiaia, Jonas, Urucum, Formiga and Pamaró. When necessary, alternative names are also given.

The Lavra to Itatiaia (Lajão or Cascalho) was discovered about 1930 and in the 1940s produced astonishing tourmalines (nicknamed 'papagaios' = parrots), exhibiting four to five colours along the *c*-axis and reaching up to 15 centimetres in length. The deposit is composed of vertical pegmatite veins running NS to NNE-SSW, a few metres thick, with some wider parts. Huge altered spodumene crystals and flat blue or pale green beryl prisms may also be present. The adits have now caved in, but small alluvial diggings persisted until a few years ago.



Fig. 25. Detailed map of the Area 1 in Figure 18.

The Lavra do Jonas became world-famous around Easter 1978, after the discovery of a pocket 2 metres wide and 2.5 metres high, coated with quartz, lepidolite, cleavelandite and K-feldspar crystals, and containing outstanding large rubellite prisms of exceptional transparency, some of which were 40 centimetres in diameter and one metre in length (Lallemant, 1978; Sullivan, 1978, Keller, 1979). 1800 kilograms of gem quality were produced of which 200 kilograms were raspberry to magenta red of fine quality. The pegmatite body extends NS for 70 metres in outcrop and 70 metres in height, reaching 11 metres

in width; 23 pockets have been reported. The pockets contained green tourmaline, frequently producing cat's-eyes, rubellite, gem quality apatite, spessartine and microlite. The gems were extracted from irregular chambers, reached by cross cuts. Proctor (1985b) recorded the total tourmaline output as 2300 kilograms of gem material and 3600 kilograms of collectors' specimens.

The Lavra do Urucum (Lavrá do Tim) is famous mainly for its magnificent flat prisms of pink and salmon morganite (with many elbaite inclusions) and large kunzite crystals (Cassedanne, 1986). Almost black elbaite (Prescott and Nassau, 1978) and chatoyant tourmaline were also produced, and minor minerals include schorl, spessartine, stokesite and rare arsenates. The pegmatite body is lens-shaped, with an ESE-WNW strike and a high dip to the SW; it is locally 20 metres wide.

The Lavra da Formiga (Ferruginha, Fazenda Oswaldo Gonçalves) is a NS



Fig. 26. Highly transparent very pale green tourmaline from Pamaró mine. The sample is 28 mm long.

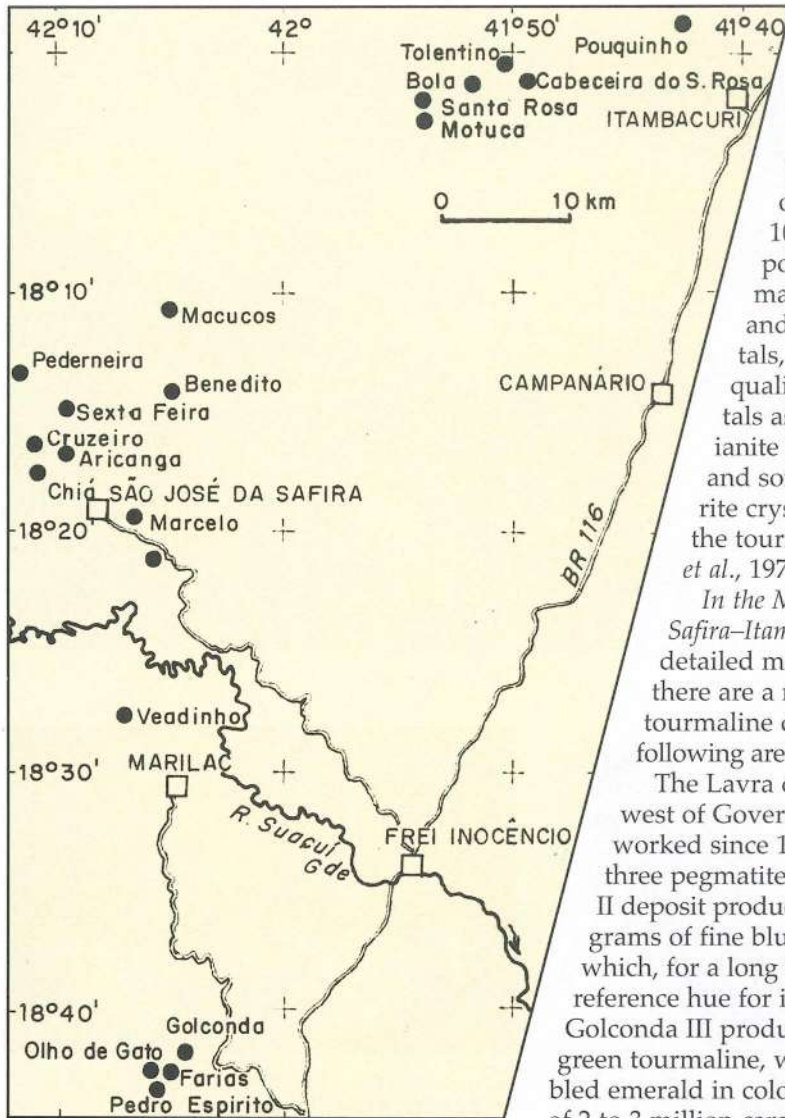


Fig. 27. Detailed map of the Area 2 in Figure 18.

pegmatite with a gentle westerly dip and many small undulations. About 1985 tons of blue, green, rose and bicoloured tourmaline crystals, some chatoyant, were produced. The finest crystal groups, up to one decimetre in length, were highly sought after by collectors and the remainder were cut and polished. After irradiation the pink specimens turned into a fine red hue.

The Lavra do Pamaró (Pamaroli, Morro do Cruzeiro) (Figure 26) is a pegmatite with an ESE-WNW strike and dip of 50–70° south. It is 10 metres wide and its pockets have yielded many gem quality green and rose tourmaline crystals, less commonly, gem quality amblygonite crystals associated with brazilianite (Cassedanne, 1983) and some very large eosphorite crystals associated with the tourmaline (Cassedanne *et al.*, 1971).

In the Marilac–São José da Safira–Itambacuri region (see detailed map of area 2, Figure 27) there are a number of famous tourmaline deposits of which the following are noteworthy (Figure 28).

The Lavra da Golconda, northwest of Governador Valadares was worked since 1908 and comprises three pegmatites. In 1968 the Golconda II deposit produced more than 500 kilograms of fine blue tourmaline crystals which, for a long time, were used as the reference hue for indicolite. About 1962, Golconda III produced 900 kilograms of green tourmaline, which closely resembled emerald in colour, and a total output of 2 to 3 million carats after cutting was reported by Proctor (1985b). Because of the value of the deposits Golconda III and the nearby Pedro Espirito and Faria pegmatites (Figure 29) suffered several armed disturbances provoked by disputed ownership and mining rights. Well zoned, with huge altered spodumene laths, the Golconda III pegmatite is 150 metres long, and 20 to 25 metres wide along a NNE-SSW strike. It has a westerly dip and is presently worked underground, producing green tourmaline, much quartz and some



Fig. 28. The large Chiá mine. Photograph taken from the Cruzeiro mine road.



Fig. 29. Dark green gem quality tourmaline from the Farias mine near Governador Valadares. The sample is 105 mm long.



Fig. 30. Dark green tourmaline crystals up to 15 cm in length, surrounding kaolinized feldspar lump, near the quartz core of the pegmatite. Golconda mine near Governador Valadares.

hydroxylherderite crystals (Dunn *et al.*, 1979) associated with gem quality apatite (Figure 30).

The Lavra do Veadinho produced some hundreds of kilograms of green and pink tourmaline but is now abandoned, as is the Macuco deposit where only colluvium with an indistinct stone line was worked.

The Lavra do Cruzeiro was the first and for a long time the main Brazilian deposit

producing rubellite (with green elbaite). Discovered in about 1674 (Serra das Esmeraldas of Paes Leme) by early Brazilian explorers ('Bandeirantes') it was then forgotten, before starting as a mica producer during World War I and becoming a major producer during World War II. Gem mining started in 1950 and continues today. Three vertical or steep south-west-dipping pegmatite veins are known, with a strike of N20°W and exposed over some hundreds of metres. Their thickness varies from a few metres to more than 50 m. A detailed description of the deposit has been reported by Cassedanne *et al.* (1980). The wallrock is a whitish, thin bedded quartzite. The tourmalines occur in the Na-rich replacement bodies which generally are located in the vein widenings, either in pockets or in whitish lenses of alteration products. Schorl, weathered spodumene laths and lepidolite (sometimes with Fe-Mn hydroxides) surround the pockets and are used as prospecting guides. The tourmaline crystals are pale green or pale blue, blue, greenish-blue, emerald-green ('cromolite'), pink or ruby-red and rarely, colourless (Figure 31 and Cover Picture). Watermelon specimens, inclusion rich and terminated by a blue pinacoid, and green cat's-eye tourmalines are common. The crystals are frequently thickset and flattened, and up to 30 cm in length. They occur singly or as small divergent groups. Fine sets of specimens were brought out particularly in the years 1966, 1968, 1971, 1983-84 and 1993 with a weekly output of up to 200 kilograms of tourmaline of which 1 to 2 kilograms were of superior gem quality.

The Lavra da Pederneira, located NNW of the Cruzeiro mine, is worked underground, and has produced fine tourmaline crystals since 1985. The pegmatite is almost vertical with a SE-NW to ESE-WNW strike, is 20 metres thick and is well zoned. It has been almost completely albitized with a succession of quartz pods in the core (like a massive rosary) and many micaschist



Fig. 31. Fine gem quality rubellite crystal, 75 mm long, from the Cruzeiro mine.

xenoliths. Fine grained albite surrounds the tourmaline pockets and is a good prospecting guide. The tourmaline crystals, single or in groups, are green, grey blue, light pink with a dark termination or blue with a pale pink core and a red flat top. The most recently produced crystals were widely commented on (e.g. Koivula and Misiorowski, 1986). Also noteworthy was the abundance of milky-pink morganite and the occurrence of a few astonishing transparent dark red rhodochrosite crystals, probably formed in the final hydrothermal stages of the pegmatite crystallization.

The Lavra de Santa Rosa, discovered in about 1938 was worked first for mica and then abandoned. The first gem tourmalines appeared in 1967 when the mine was reopened. From 1968 to 1973 intense working produced several tons of gem quality tourmalines. Many multicoloured (zoned perpendicular or parallel to the c-axis)



Fig. 32. Bicolour tourmaline crystal, 82 mm long, from the Santa Rosa mine.

slightly divergent or bundle-shaped crystal groups from this deposit are at present proudly displayed in many world-famous museums. Some specimens are up to 45 cm long and weigh 20 kilograms. The crystals are blue, green (commonly with a pink flat top), pink or red (Figure 32). The watermelon crystals have a dark pink core surrounded by a turquoise blue or green rim (Pough, 1968; Behnke, 1986). The bulk of the output came from eluvium and the weathered upper part of the pegmatite. The pegmatite is 2 to 10 metres thick, hundreds of metres long with a gentle dip, and contains abundant pockets in common with other gently dipping pegmatites.

The Lavra do Ribeirão da Folha, far in the SSW of the Araçuaí region produced fine emerald green, a few blue tourmalines, and virtually no pink specimens. Hundreds of kilograms of gem quality tourmaline were produced from pockets in

about 1982. At present the mine is abandoned. The pegmatite strikes N60°E with a low NW dip and is exposed for approximately 250 metres. It is locally more than 15 metres in width. Abundant lepidolite and muscovite, some bluish to pink flat beryl, amblygonite and bluish topaz are associated with the tourmaline. The wall-rock is a biotite schist.

The Lavra do Areião worked the eluvium of a NS striking pegmatite, exposed for 400 metres. Most of the tourmaline appears black but displays a fine dark green after cutting and polishing. Some blue and pink crystals were also recovered. Having been abandoned for a long time the mine was recently reopened.

In the *Araçuaí-Virgem da Lapa-Salinas region* (see detailed map of area 3, Figure 33) numerous tourmaline bearing deposits occur in the Rio Jequitinhonha basin which includes the Rio Araçuaí and Salinas valleys. Fine green and blue, pink and red gem-quality tourmaline crystals are produced from a series of pegmatite bodies, almost all within mica schists. The pegmatites are mostly comparatively small in size, so their lucrative working is short. However, as the discoveries of new occurrences or of rich unworked parts of abandoned deposits keep occurring, a continuous but highly variable production is maintained (Cassedanne and Alves, 1994).

The Lavra de Poço d'Anta (Manoel Timóteo) belongs to a small pegmatite field in which the Taquaral hamlet is the centre. The mine worked various pegmatites with a NS strike and gentle dip to the west, in part superimposed, with many spurs or offshoots. More than 1000 kilograms of green and pink, with less common greenish-blue tourmalines were produced before 1982. The crystals, flat ended or with three-faced pyramidal terminations occur singly or in groups with parallel growth. There were virtually no collectors' specimens, the output essentially being destined for cutting. At present, the mine is abandoned.



Fig. 33. Detailed map of the Area 3 in Figure 18.

The Lavra do Pirineú (Velha and Nova), in the past produced famous greenish-blue and green tourmaline crystals, reminiscent

of those from the Golconda deposit. The pegmatite strikes NS with a dip of 60° and is one tenth of a metre thick. Eosphorite,

moraesite and amblygonite were associated with the tourmaline. A few years ago, on reopening the mine accompanied by stripping of the eluvium and part of the weathered outcrop, fine light blue indicolite was produced. Proctor (1985b) reported that the Pirineú's tourmalines are highly prized because they allow cutting perpendicular to the *c*-axis without appreciable change of hue; this enables production of larger cut stones than is possible from rough of equivalent size from other deposits.

The Lavra do Limoeiro, in the NNW of the Virgem da Lapa region belongs to another small pegmatite field, first mined for mica during World War II. It became famous worldwide during the 1970s with the production of outstanding green tourmalines up to one metre long and blue topaz crystals. After a rush in 1974–75, output declined until 1980, at which time the remaining eluvium and partly weathered pegmatite were stripped out. At present, the mine is abandoned and has caved in. The pegmatite strikes N30°E, with a gentle westward dip, is lens-shaped and was very rich in pockets. Its structure is identical to that previously reported for the Xandá deposit. Gem-quality fluorapatite, hydroxylherderite and fine transparent blue topaz crystals weighing up to 25 kilograms are associated with the tourmalines. Both at the rim and in the interior of the pockets, the tourmalines are commonly terminated by a pinacoid at one extremity and a trigonal pyramid at the other (Cassedanne and Lowell, 1982).

The mines Xandá, Toca da Onça (Souín, Lavra do Bruno) and Campinos (Manoel Mutuca) also produced fine blue and green gem tourmalines until they too were abandoned. The dark blue crystals turned sapphire-blue on heating.

The Lavra do Morro Redondo (Morro Redondo Novo or Laranjeira) reopened in 1990, and started production in 1991, which increased in 1993–94 to several tons of fine green, blue, pink, cat's-eye, bicoloured and

tricoloured tourmalines. This huge output led to government intervention to resolve conflict between miners and landowners. The pegmatite strikes N30°E, dips 30°W locally and is up to 20 metres thick along an exposure of more than 350 metres. It is weathered in its upper part and is well zoned with a core of quartz masses shaped like a rosary (beaded), and zones of Na-rich feldspar with pockets lined with cleavelandite, tourmaline, quartz and much lepidolite. Window and sceptre quartz crystals are very abundant, and one particularly large pocket yielded more than 50 tons of quartz with outstanding transparent crystals more than one metre long and weighing 500 kilograms. The latest tourmaline being produced is brownish-pink and light green, with a small white strip between the two colours and small coloured crystals with a rich green termination (ICA, 1995).

The Lavra da Barra da Salina (Salinas, Vieirinho, Vieirão and Cata Rica), near the confluence of the Rios Salinas and Jequitinhonha, known as long ago as 1910, was worked by underground methods and hydraulicking until 1945. From 1973 long trenches and small open pits have been excavated using rippers, scrapers and bulldozers. Some trenches extend for up to 400 metres and are 20 metres deep. At present a series of highly weathered veins with a NNW-SSE strike and dip of 60 to 70° are being worked. They are up to 150 metres long and 6 to 8 metres thick and contain pockets with huge altered spodumene tabular crystals, window quartz, and columnar lepidolite associated with green, pink, bicoloured, tricoloured, and cat's-eye tourmaline crystals (Figure 34). Each pocket has yielded 20 to 25 kilograms of gem material of which approximately 0.1 per cent is of very good gem quality (Proctor, 1985a). The deposit of Salinas is well known for supplying large numbers of flat beryl crystals ranging from pale blue to pink (morganite) or colourless; some are also chatoyant.



Fig. 34. Spray of fan-like grey-green needle-like crystals of tourmaline from the Virgem da Lapa area. Sample is 140 mm long.

The Lavra do Ouro Fino (Chiquinho Freire) eluvial deposit with quartz fragments and limonitic pisolites was worked from 2 to 8 metres depth from 1979. In Spring 1981 approximately one ton of splendid cherry and ruby-red tourmalines were unearthed of which 50 kilograms were of astonishing colour and of the highest quality. Some pink, blue and green broken crystals were also present and the small size of these tourmaline fragments is characteristic of the deposit. The eluvium was sorted by sieving and washing in a nearby pond. After producing the finest Brazilian rubellites the mine was abandoned in about 1982.

Tourmaline deposits in the other states. In the State of Bahia a series of small tourmaline occurrences were explored, but none is of economic importance. At present almost all have been abandoned (Galvão *et al.*,

1975; Pedreira, 1976; Sampaio *et al.*, 1983 and 1985). The small Lagoa Grande (Fazenda do Osmar) deposit on the edge of the Vitória da Conquista high plain yields a sporadic output of green and blue tourmalines from eluvium covering a partly weathered pegmatite.

In the State of Paraíba, small occurrences have been known since World War II (Rolff, 1946); in particular the Alto Feio pegmatite (Johnson Jr., 1945) contains beryl, tantalite and much rose quartz associated with emerald-green tourmaline that fluoresces topaz-yellow (Cassedanne and Cassedanne, 1978a).

The Lavra de São José da Batalha (Figures 35 and 36, see also Figures 10, 22, 23, 24), an old tantalite-bearing prospect was reopened in 1985. Since August 1987 an astonishing output of 'fluorescent', 'neon', 'sapphire', bright emerald-green,



Fig. 35. A pit in a pegmatite, 60 cm thick, at the São José da Batalha mine.

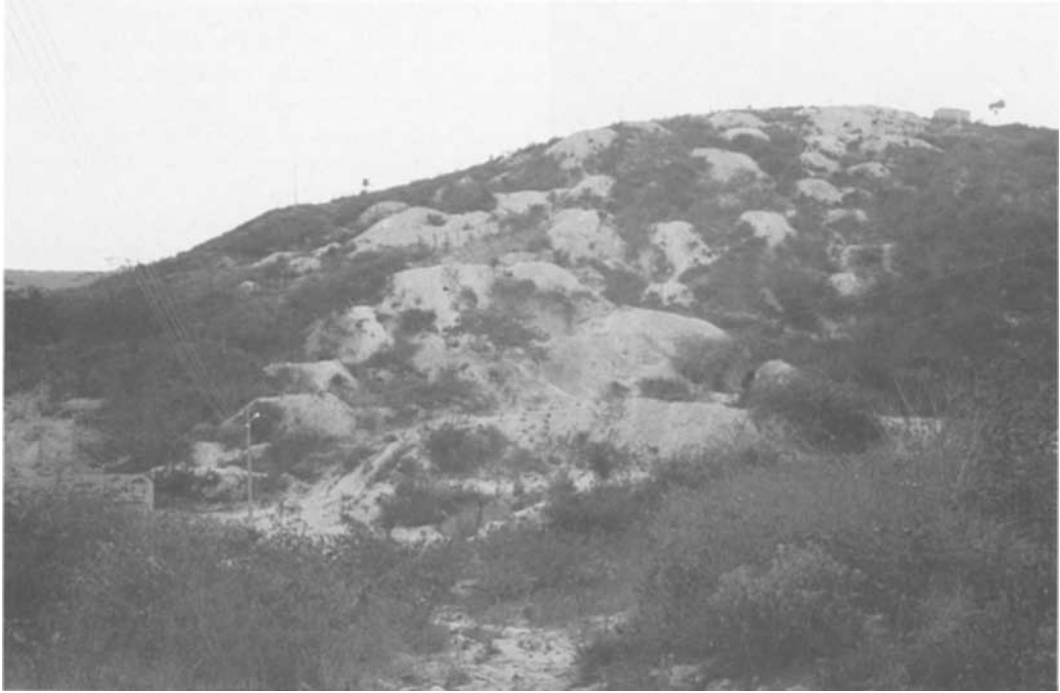


Fig. 36. Partial view of the São José da Batalha mine. Each white dump consists of discarded rock from an adit.

mauve and violet tourmaline (Koivula and Kammerling, 1989) made the deposit rapidly famous. It is composed of four pegmatites which strike WNW-ESE and dip 60–85°N, a few decimetres to 3 metres wide and up to 75 metres high. The wall-rock is a white thin-bedded quartzite. The pegmatite is highly weathered and since hydrothermal leaching affected many tourmaline crystals, the gems almost always occur as angular fragments. Quartz, altered feldspar, lepidolite, muscovite and, less commonly, garnet are the only associated minerals. Gemstone production has totalled some hundreds of kilograms of which a small percentage is of the highest gem quality (Sauer in Cassedanne, 1996). Invariably the tourmalines of this deposit are characterized by a copper content of up to 2 per cent, associated with some bismuth and gold.

Occurrence in the states of Pernambuco and Rio Grande do Norte (Farias, 1977) are devoid of economic importance as are those

in Ceará where the sporadic production is very small in comparison with that of Minas Gerais (Mendes, 1975; Limaverde, 1980).

In the central part of the state of Goiás, green, pink and bicoloured tourmalines are sporadically produced from some pegmatites, but always in small quantities (e.g. Lavra da Capivara Velha and Fazenda Cafezal-Cruzeiro). No large deposit is known at present (Lima Jr. *et al.*, 1984).

Detrital deposits of tourmaline

A series of physical and chemical surface phenomena under the general heading 'weathering' affect the primary deposits and lead to the formation of gem-bearing alluvium. Various types of deposits may be related to intermediate stages of this process, the formation of eluvium being the most important. For a detailed study of the Brazilian detrital deposits see Cassedanne and Roditi (1993). It is notable that, like chrysoberyl, tourmaline has been subjected to abnormal abrasion in the red

clay of the residual soil/regolith, resulting in more or less rounded fragments associated with lateritic pisolites. But only schorl survives the subsequent transportation and is deposited in alluvium (Cassedanne and Roditi, 1993). In contrast, the gem tourmaline which is almost always cracked, quickly disintegrates during transportation from the eluvium and only a very small portion of it reaches the alluvium. Schorl, however, commonly makes up an appreciable part of reworked alluvium.

Eluvium deposits

In the Oriental pegmatite province, the eluvium is commonly lateritic, and results from the more or less complete destruction of the underlying pegmatites. This medium preserves the gems, commonly as angular or subround fragments with fissures coated by ferriferous plastic reddish clay, or as the cores of small lateritic nodules. These eluvial deposits, which are also called 'Chapadas', and the high colluvial

deposits are located upon the outliers of old peneplains or upon later piedmont slopes, always at some distance from the knick point of an inselberg. Locally, where slopes are gentle, eluvium passes imperceptibly to more steeply dipping tourmaline-bearing colluvium (e.g. at Macuco, Ferruginha, Acode a Chuva, Barra da Salina). Commonly no well-defined mineralized horizon occurs, and the gems are erratically present in a brown to reddish, sandy argillaceous bed several metres thick (Figure 37). Locally a thinner layer has been developed in the eluvium, where the gems are associated with abundant milky quartz fragments. This layer is incorrectly called 'gravel' by the garimpeiros. A pit section in the Lavrinha workings, in the neighbourhood of Barra da Salina (Figure 38), will illustrate this type of deposit. From the top to the bottom the sequence is:

- reddish soil with large pebbles: 1 metre;
- red ochreous sandy clay: 2.5 metres;
- locally hardened lateritic level: 0.3 metre;



Fig. 37. Typical landscape of a once rich eluvial deposit, now abandoned; Laranjeira mine (Araçuaí).

- 'gravel': 0 to 1 metre;
- bedrock made of argillaceous weathered schist.

'Gravel' is a lateritic soil with clay nodules containing some detrital gem tourmalines ('bolinhas') associated with abundant limonitic pisolites, quartz and a few schorl fragments.

The areal extent of the eluvium deposits may be several hectares (Ouro Fino, Santa Rosa) and they are extensively worked by means of irregular pits, small shafts of variable section and large irregular excavations which exceptionally may be 10 metres in depth. Their waste is typically brown to red, contrasting with the white to pale grey waste from pegmatite workings. Seen from afar the workings are an undulating scene of pits and dumps and resemble a bombed landscape. Sorting of the gems is generally carried out during the quarrying. However, where tourmalines occur in lateritic soil, the ore is crushed and washed in order to separate the gems

(Lavrinha, Ouro Fino). Preliminary stripping of overburden with a bulldozer is rarely necessary. Prospecting for gems in eluvial deposits is hazardous because the gems are erratically distributed in unconsolidated sand and clay soils. No rich mineral-bearing horizon has ever been observed in eluvial deposits.

Alluvial deposits

Alluvial deposits typically consist of a mineralized gravel lying upon bedrock and overlain by fine-grained sediments; they are the same as those described for the chrysoberyl deposits by Cassedanne and Roditi (1993). No workings have been reported from lower areas of colluvium or terraces.

Alluvium specifically worked for tourmaline. At present the only small worked deposit is at Pouquinho, near Teófilo Otoni (Minas Gerais), in the vicinity of a large weathered pegmatite. A section through the alluvium comprises from top to bottom:



Fig. 38. The eluvial Lavrinha deposit near Barra da Salina.

- very sandy yellow clay with mud and organic matter-rich intercalations: 0.5 to 2 metres;
- gravel containing gem quality green tourmaline fragments: 0 to 50 cm;
- fine grained, slightly weathered granite bedrock, with pot holes.

Gem bearing alluvium with tourmaline as a by-product. In places tourmaline is a less important by-product of mining for other gems such as chrysoberyl or aquamarine (Cassedanne and Alves, 1991).

A pit section through old alluvium of the Córrego do Fogo chrysoberyl deposits near Malacacheta (Minas Gerais), will serve as a typical example. From top to bottom it consists of:

- yellow sandy colluvium overlying the alluvium: 1 metre;
- barren angular gravel: 60 cm;
- yellow argillaceous sand: 1.4 metre;
- black clay with grey lenses: 1.5 metre;
- mineral bearing gravel containing some green and pink tourmaline fragments associated with chrysoberyl: 40 cm;
- weathered schist bedrock.

The main areas of production are the chrysoberyl bearing gravels in northern Minas Gerais (Córrego do Fogo, Americana) and the adjacent aquamarine and/or chrysoberyl producing valleys of Rio Marambaia and Rio Santa Cruz (see location in Cassedanne and Roditi, 1993).

Alluvium working is commonly carried out by a small team of garimpeiros. Timbered square pits, a few metres in size are sunk down to bedrock, in a haphazard way. Water is evacuated by small pumps. In places part of the overburden is scraped off by bulldozer. Locally, working is done by using a 'dredge', a small horizontal gravel pump set upon a steel pontoon. The tourmaline is sorted by hand upon a coarse sieve, after washing to eliminate the clay, silt and sand which is then run to waste (Figure 39).

There are no reliable reports of possible reserves or future production of gem grade tourmaline from the detrital deposits. However, in alluvium, the tourmaline can be assessed very approximately as a few grams per cubic metre of gravel, but its quality and gemmological properties are variable and unpredictable.

Deposits not connected with pegmatites

There are only two important deposits in this category: the first is Brumado in the state of Bahia, West of Vitória da Conquista in the NNE of area 3 described above, and the second is Serra Branca in central Paraíba, WNW of the famous São José da Batalha deposit.

The Brumado or Serra das Éguas locality is one of the largest magnesite deposits in the world. It is famous particularly to mineralogists for its extraordinary specimens of



Fig. 39. Washing tourmaline-bearing alluvium at the Itatiaia mine (Conselheiro Pena).

twinned quartz, large magnesite crystals, dolomite, beryl, topaz, hematite, metazeunerite and novacekite along with others such as magnetite, tremolite and talc (Cassedanne and Cassedanne, 1978b). Although it has been known since 1884 it was only a few years ago that many very fine transparent tourmaline crystals belonging to the uvite species were found. There was a small production of emerald between 1913 and 1923, and extraction of the magnesite only began during the 1940s. Now there is a very large open pit more than 150 metres deep (the Pedra Preta deposit) and other minor excavations such as Pirajá and Gravatá.

In summary, the geology consists of Precambrian basement overlain by a metamorphosed sequence of dolomite in the lower part and quartzites in the upper part, both belonging to the Minas Series. The dolomite is more than 150 metres thick and was extensively converted to magnesite by replacement and fracture filling mechanisms. The sequence is tightly folded in a large synclinal structure striking about N20°E. This structure plunges south at a low angle and reverses at its southern extremity to dip north, so that the structure of the range, as a whole, is canoe-shaped. Thick talc veins are associated with large faults across the deposit. This talc is of excellent quality, being almost free of other minerals and in some places yielding a few large transparent crystals. Dark brown, reddish-brown, red, dark green and light green uvite crystals have been found both in the talc and in the surrounding magnesite (fresh and weathered) mainly in the Jatobá zone of the Pedra Preta open pit. Uvite occurs there as loose crystals scattered in a sandy and very ferruginous, buff to violet soil or in red or white magnesite, and in clear talc in the unaltered ore. The uvite crystals are flattened and stubby, rarely reaching 5 cm in length, commonly in clusters of parallel prisms; they are commonly translucent to transparent and perched upon magnesite

scalenohedrons or set in a matrix of thin platy white dolomite. The gem crystals are much sought after by mineral collectors (Moore, 1992 and 1994) and fine red gems of up to 10 ct have been cut. In the Pirajá zone, the uvite crystals are either small and flat or are partially enclosed by yellow topaz crystals.

Serra Branca deposit. Completely different in shape, colour and host rock from Brumado, tourmaline crystals from this locality have sporadically appeared on the specimens market, probably from collection at the site more than twenty years ago. Only during 1994 did proper mining begin. Serra Branca is in the Baixo dos Pereiras area NNW of Sousa town in Paraíba (Cassedanne, 1995). The deposit lies in a series of talc schist lenses which replace basic intrusions, roughly concordant in gneiss with a strike of N70°E and dip of 40–60°S. The lenses are some metres in width and a few hundreds of metres long, and are worked by open pit to a depth of 25 metres. The dark grey green, coarse or fine grained talc schists contain irregular flakes of quartz and feldspar, with molybdenite, apatite and rutile, and are stuffed, in no particular orientation, with tourmaline crystals. These are black and stubby, rarely elongated, and almost always doubly terminated. Generally they are 1 to 2 decimetres long and a few centimetres in diameter, but exceptionally may be up to 80 cm long and 20 cm in diameter. The faces are smooth, and the section is triangular, or more rarely flattened or hexagonal, with three predominant faces. The trigonal pyramid is the most common termination. Crystals occur singly or in groups, and are commonly brittle due to tectonic stress suffered by the host rock. Small orange rutile and transparent apatite crystals occur as inclusions in the tourmalines which belong to the dravite species. The deposit is worked only because the crystals belong to a rarer mineral species than elbaite (at least in Brazil) and have a very unusual habit; their opa-

city and unattractive colour rule them out for use as gems.

Conclusion

Although there is neither an official record nor a comprehensive account of past, recent or present total output of gem tourmaline, one can be confident that Brazil has abundant tourmaline reserves to be developed in the future.

References

- Abreu, S.F. de, 1963. Diamantes e pedras coradas. *Gemologia*, VIII, 31, 7–37
- Afgouni, K., and Sá, J.H. da, 1977. Minério de lítio no Brasil. *Miner. Metal.*, XLI, 392, 60–6
- Araujo, A.C. de, Mello, M.P. de, Litwinski, N., and Martins Jr, P.P., 1982. Principais recursos minerais do Alto e Médio Vale do Rio Jequitinhonha e Alto Rio Pardo, M.G.. *Anais XXXII Congr. Bras. Geologia, Salvador*, 4, 1284–95
- Arem, J.E., 1987. *Color encyclopedia of gemstones*. 2nd Ed. Van Nostrand Reinhold, New York
- Batista, H.F., and Neto, O.M.Q., 1974. Comercialização da tourmalina. Bol. No 1, *Resumo das comunicações. XXVIII Congr. Bras. Geologia, Porto Alegre*, 604–5
- Beesley, C.R., 1975. Dunton mine tourmaline: an analysis. *Gems and Gemology*, 15, 19–24
- Behnke, R., 1986. Brazilian discoveries. *Miner. Record*, 17, 2, 150–1
- Bhaskara Rao, A., and de Assis, A.D., 1968. Chatoyant and pseudomorphosed tourmalines in Northeastern Brazil. *Journ. Mineralogia*, 6, 31–6
- Brandstätter, F., and Niedermayr, G., 1994. Copper and tenorite inclusions in cuprian elbaite tourmaline from Paraíba, Brazil. *Gems and Gemology*, XXX, 3, 178–83
- Calmbach, W.F. von, 1938. *Handbuch brasilianischer Edelstein und ihrer Vorkommen*. Medawar Ed., Rio de Janeiro
- Cassedanne, J.P., 1983. The Córrego Frio mine and vicinity, Minas Gerais, Brazil. *Miner. Record*, 14, 4, 227–38
- Cassedanne, J.P., 1986. The Urucum pegmatite, Minas Gerais, Brazil. *Miner. Record*, 17, 5, 307–14
- Cassedanne, J.P., 1995. Le gîte de tourmaline noire (dravite) de Serra Branca. Etat de Paraíba, Brésil. *Minéraux et Fossiles*, 21, 226, 6–10
- Cassedanne, J.P., 1996. Le gîte de tourmaline de São José da Batalha (Paraíba, Brésil). *Revue de Gemmologie, AFG*, 127, 6–11
- Cassedanne, J.P., and Alves, J.N., 1991. L'aigue-marine au Brésil. 1 – Les gîtes détritiques. *Revue de Gemmologie, AFG*, 107, 13–16 and 108, 3–7
- Cassedanne, J.P., and Alves, J.N., 1992–1994. L'aigue marine au Brésil. 2 – Les gîtes primaires. *Revue de Gemmologie, AFG*, 111, 11–14; 112, 7–11; 118, 21–3
- Cassedanne, J.P., and Alves, J.N., 1994. Excursion au Nord de Minas Gerais (Brésil). Les tourmalines de la vallée du Rio Jequitinhonha. *Minéraux et Fossiles*, 20, 220, 6–21
- Cassedanne, J.P., and Cassedanne, J.O., 1978a. La pegmatite à quartz rose du Alto Feio. *Revue de Gemmologie, AFG*, 57, 11–14
- Cassedanne, J.P., and Cassedanne, J.O., 1978b. Famous mineral localities: the Brumado district, Bahia, Brazil. *Miner. Record*, 9, 3, 196–205
- Cassedanne, J.P., and Cassedanne, J.O., 1980. Les grenats de Poço dos Cavalos (Ceará, Brésil). *Revue de Gemmologie, AFG*, 62, 5–8
- Cassedanne, J.P., and Cassedanne, J.O., 1987. La moraesite de la mine de Humaitá, Minas Gerais, Brésil. *Can. Mineralogist*, 25, 419–24
- Cassedanne, J.P., Cassedanne, J.O., and Sauer, A.D., 1980. Famous mineral localities: the Cruzeiro mine, past and present. *Miner. Record*, 13, 1, 19–28
- Cassedanne, J.P., Guillemín, C., and Johan, Z., 1971. Nota sobre as jazidas brasileiras de esforita e 'childrenita'. Continuação. *Miner. Metal.*, 54, 321, 107–10
- Cassedanne, J.P., and Lowell, J., 1982. Famous mineral localities: the Virgem da Lapa pegmatites. *Miner. Record*, 13, 1, 19–28
- Cassedanne, J.P., and Roditi, M., 1993. The location, geology, mineralogy and gem deposits of alexandrite, cat's-eye and chrysoberyl in Brazil. *Journal of Gemmology*, 23, 6, 333–54
- Černý, P., 1982. Anatomy and classification of granitic pegmatites: 1–39 in: *Granitic pegmatites in Science and Industry*. P. Černý Ed., Short course handbook, MAC, Vol. 8
- Coelho, I.S., 1948. Turmalina fibrosa da 'Mina do Cruzeiro', Santa Maria do Suassuí, Minas Gerais. *Miner. Metal.*, 13, 49–53
- Correia Neves, J.M., Soares, A.C.P., and Marciano, V.R.P.R.O., 1986. A província pegmatítica oriental do Brasil à luz dos conhecimentos atuais. *Rev. bras. Geociências*, 16, 1, 106–18
- Dietrich, R.V., 1985. *The tourmaline group*. Van Nostrand Reinhold, New York
- Dunn, P.J., 1975a. Notes on inclusions in tanzanite and tourmalinated quartz. *Journal of Gemmology*, 14, 170–4
- Dunn, P.J., 1975b. Elbaite from Newry, Maine. *Miner. Record*, 6, 1, 22–5
- Dunn, P.J., Nelen, J.A., and Appleman, D.E., 1977. Liddicoatite, a new calcium end-member of the tourmaline group. *Amer. Mineralogist*, 62, 1121–4
- Dunn, P.J., Wolfe, C.W., Leavens, P.B., and Wilson, W.E., 1979. Hydroxylherderite from Brazil and a guide to species nomenclature for the herderite/hydroxylherderite series. *Miner. Record*, 10, 1, 5–11
- Farias, C.C., 1977. Sobre as turmalinas do 'Alto Boqueirão'. *Atas VIII Simp. Geologia do Nordeste*, Campina Grande, 467–77
- Ferraz, L.C., 1929. *Compêndio dos minerais do Brasil em forma de dicionário*. Imprensa Nacional, Rio de Janeiro
- Fersman, A.E., 1931. *Les pegmatites, leur importance scientifique et pratique*. Tome III: *Pegmatites granitiques*, 439–479. Akademyia Nauk SSSR Leningrad. Translation: R. du Trieu de Terdonk & J. Thoreau, Université de Louvain, Uijstpruist Ed.
- Fleischer, M., and Mandarino, J.A., 1995. *Glossary of mineral species*. Miner. Record Ed., Tucson.
- Foord, E.E., and Mills, B.A., 1978. Biaxiality in 'isometric' and 'dimetric' crystals. *Amer. Mineralogist*, 63, 316–25
- Franco, R.R., 1967. *Recursos brasileiros em pedras preciosas*. Circ. Soc. Bras. Geol., roneot. p.9
- Frondel, C., 1948. Tourmaline pressure gauges. *Amer. Mineralogist*, 33, 1–7
- Galvão, C.F., Conceição F., W.H., Lopes, G.A. de C., Costa, V.R., and Andrade, A.P., de, 1975. *Projeto cadastramento de ocorrências minerais do Estado da Bahia*. Volume 1: *Área de Vitória da Conquista*. SME-CPM, convênio SME/CBPM, Salvador

- Goldschmidt, V., 1923. *Atlas der Krystallformen*. Band IX, Tafeln 7 to 29, Text, 16–36. Carl Winters, Heidelberg
- Gonsalves, A.D., 1949. *As pedras preciosas na Economia Nacional*. Gráfica Olímpica, Rio de Janeiro
- Gübelin, E.J., 1976. Helvite and tourmaline accompanied by grunerite in quartz. *Journal of Gemmology*, **15**, 111–13
- Gübelin, E.J., 1979. Einschlüsse im Turmalin. *Lapis*, **4**, 38–9
- Gübelin, E.J., and Koivula, J.I., 1986. *Photoatlas of inclusions in gemstones*. ABC Ed., Zurich
- ICA gazette, 1995. Tourmaline from Morro Redondo, Brazil, April, 9
- Ito, T., and Sadanaga, R., 1951. A Fourier analysis of the structure of tourmaline. *Acta Crystall.*, **4**, 385–90
- Jahns, R.H., 1955. *The study of pegmatites*. Ec. Geol. Fiftieth Anniversary Vol. II, 1025–30
- Jahns, R.H., and Wright, L.A., 1951. *Gem and lithium-bearing pegmatites of the Pala district, San Diego County, California*. Calif. Dept. of Natural Resources, Special Report 7A
- Johnson Jr., W.D., 1945. *Os pegmatitos berilo-tantalíferos de Paraíba e Rio Grande do Norte*. DNP/DFPM, Bol. 72
- Keller, P.C., 1979. More on rubellite of the Itatiaia mine. *Miner. Record*, **10**, 1, 33–4
- Koivula, J.I., and Kammerling, R.C., 1989. Gem news. Unusual tourmalines from Brazil. *Gems and Gemology*, **XXV**, 3, 181–2
- Koivula, J.I., and Misiorowski, E., 1986. Gem news. New find of elbaite tourmaline. *Gems and Gemology*, **XXII**, 4, 248
- Lallemant, A., 1978. New discovery in Brazil. *Miner. Record*, **9**, 5, 298–9
- Lima Jr., E.R., Teixeira de Deus, W., and Priori, R.S., 1984. Gemas no Estado de Goiás: ocorrências e estudos geológicos preliminares. *Anais XXXIII Congr. Bras. Geologia*, Rio de Janeiro, 10: 5027–39
- Limaverde, J.A., 1980. *Produção, industrialização e comercio de gemas no Nordeste*. Banco do Nordeste do Brasil. Dept. Est. Econ. Nordeste
- London, D., 1986. Formation of tourmaline-rich pockets in mirolitic pegmatites. *Amer. Mineralogist*, **71**, 396–405
- Madelung, A., 1883. Beobachtungen mit Breithaupt's Polarizationsmikroskop. *Zeitschr. Für Krist.*, **7**, 73–6
- Mendes, M.H.P.T., 1975. Posição do Departamento Nacional da Produção Mineral, com relação às pedras preciosas brasileiras. *Geologia*, **21**, 41/2, 13–51
- Menezes, S. de O., 1982. *Catálogo dos principais pegmatitos do Estado do Rio de Janeiro*. Bol. Técnico no. 2, DRM, Secr. Est. Industria, Comércio e Turismo
- Mitchell, R.K., 1976. R.I. anomalies in tourmaline and a strange zircon. *Journal of Gemmology*, **15**, 17–18
- Moore, T., 1992. What's new in minerals? Tucson show 1992. *Miner. Record*, **23**, 3, 273–81
- Moore, T., 1994. What's new in minerals? Tucson show 1994. *Miner. Record*, **25**, 211–19
- Moura, O.J.M. de, Fanton, J.J., and Arioli, E.A., 1978. Geologia da região de Galiléia-Mendes Pimentel, Minas Gerais. *Anais XXX Congr. Bras. Geologia*, Recife, **1**, 26–37
- Nassau, K., 1984. *Gemstone enhancement*. Butterworths, London
- Newcomet, W., 1941. Some radium reactions on minerals. *Rocks and Minerals*, **16**, 126
- Paiva, G., 1946. *Provincias pegmatíticas do Brasil*. DNP/DFPM, Bol. 78, 13–21
- Pecora, W.T., Klepper, M.R., Larrabee, D.M., Barbosa, A.L. de M., and Frayha, R., 1949. *Mica deposits in Minas Gerais, Brazil. Geological investigations in the American Republics*. USGS Bull. **964C**, 205–305
- Pedreira, A.J. de C., 1976. *Carta geológica do Brasil ao milionésimo. Folha Brasília SD-23*. MME-DNPM, p. 162
- Pough, F.H., 1968. The Santa Rosa, Brazil, tourmaline mine. *Lap. Journal*, **22**, 7, 890–5
- Prescott, B.E., and Nassau, K., 1978. Black elbaite from Corrego do Urucum, Minas Gerais, Brazil. *Miner. Magazine*, **42**, 357–9
- Proctor, K., 1985a. Gem pegmatites of Minas Gerais, Brazil: the tourmalines of Araçuaí district. *Gems and Gemology*, **XXI**, 1, 3–19
- Proctor, K., 1985b. Gem pegmatites of Minas Gerais, Brazil: the tourmalines of Governador Valadares district. *Gems and Gemology*, **XXI**, 2, 86–104
- Putzer, H., 1956. *Mineralmacht Brasilien*. Deutsch. Brasilianische Handelskammer im São Paulo Ed., São Paulo
- Reimann, G., 1907. Beiträge zur Kenntniss des Turmalins aus Brasilien. *Neues Jahrb. Für Min.*, **23**, 91–162
- Rolff, P.M. de A., 1946. *Recursos minerais do município de Picuí*. DNP/DFPM Bol. 80
- Sampaio, D.R., Batista, J.J., Motta, A.A. de B., Guimaraes, J.M., and Carmo, U.F., de, 1983. *Bahia. Anuário da mineração 1983*. Ano VII, SME-CPM, Salvador
- Sampaio, D.R., Batista, J.J., Motta, A.A. de B., Guimaraes, J.M., and Carmo, U.F., de, 1985. *Bahia. Anuário da mineração 1985*. Ano IX, SME-CPM, Salvador
- Shigley, E., and Kampf, A.R., 1984. Gem bearing pegmatites: a review. *Gems and Gemology*, **XX**, 1, 64–7
- Smirnov, V.I. Ed., 1977. *Ore deposits of the USSR III*. Pitman, London
- Stamm, P., 1926. Die absorption des sichtbaren und ultravioletten Lichtes und die Interferenz der Röntgenstrahlen beim Turmalin. *Neues Jahrb. Für Min.*, **54**, 293–319
- Sullivan, B., 1978. Letter from Europe. *Miner. Record*, **9**, 5, 316–318 and 6, 367–9
- Uebel, P.J., 1977. Internal structure of pegmatites, its origin and nomenclature. *Neues Jahrb. Miner. Abh.*, **13**, 83–113
- Vargas, J.I., and Tupinambá, G.A.C., 1962. Tourmaline as a new thermal neutron dosimeter. *Intern. American Symp. On the peaceful application of Nuclear Energy*, 4th, Mexico City, 67–70
- Varlamoff, N., 1958. Zonographie de quelques champs pegmatitiques de l'Afrique Centrale et les classifications de K.A. Vlasov et J.A. Ginzbourg. *Ann. Soc. Géol. Belgique*, **LXXXII**, 55–87
- Vlasov, K.A., 1952. Classification des pegmatites granitiques d'après leur texture et leur paragenèse. *Bull. Acad. Sc. URSS, Série Géol.*, **2**, 30–55. Translation 698, BRGM, Paris
- Wagner, C.E., Pollard Jr., O., Young, R.A., and Donnay, G., 1971. Texture variants in color-zoned tourmaline crystals. *Amer. Mineralogist*, **56**, 114–32
- Webster, R., 1970. *Gems, their sources, descriptions and identification*. 2nd edn, Butterworths, London

A spectral-luminescent technique for gemmology

Vladimir I. Solomonov*, Sergei G. Mikhailov*, Vladimir V. Osipov*, Alexander I. Lipchak*,
Vladimir N. Avdonin** and Maria F. Vasilevskaya**

*The Electrophysics Institute of the Ural Division of the Russian Academy of Sciences,
Ekaterinburg, Russia

**The Ural State Academy of Mining Geology Ekaterinburg, Russia

Abstract

The experimental results of investigation of the pulsed cathodoluminescence (PCL) of rubies, sapphires and topazes in the red range of the spectrum are presented. The results are useful for a variety of gemmological applications. The colour density dependence of a mineral upon the band width of its PCL spectrum is shown. Common minerals from different occurrences have been shown to have distinctive PCL spectra. It has also been shown that identical colours of topaz may result from different dopants or trace elements. It is concluded that the phenomenon of PCL can be used as a basis for a fast non-destructive identification in various gemmological applications.

Key words: pulsed cathodoluminescence, spectrum, ruby, sapphire, topaz

Introduction

Spectral luminescent techniques of material analysis are fast, versatile and informative. They are widely applied in various fields of human activity. However, their role is comparatively small in gemmology due to the peculiarities of the problems presented. Knowledge of the exact chemical composition of a gem is rather desirable but not so necessary that one must use the most advanced methods (such as atom-emission analysis). Such a method

also requires partial destruction of the specimen which is undesirable for gems. Conventional non-destructive luminescent techniques used to obtain structural information of a material (luminescence of minerals) are far from being perfect and are applicable only to a limited number of 'luminescent' gems.

Some reports describing pulsed cathodoluminescence (PCL) excited by irradiation of minerals by high-current short-pulse beams of energetic electrons have appeared recently (Mesyats *et al.*, 1992; Mikhailov *et al.*, 1993; Solomonov *et al.*, 1993; Mesyats *et al.*, 1994). The PCL intensity is ten thousand times greater than the intensity of X-ray-luminescence or continuous cathodoluminescence and it can be excited in every mineral showing dielectric behaviour. Such gems may be considered as dielectrics containing dopant ions, i.e. all common gems should exhibit the property of pulsed cathodoluminescence. Besides, the PCL spectrum is characterized by high stability of its parameters: namely the wavelength, half-width, intensity and number of spectral bands and lines for each mineral species, and by their reasonable reproducibility. As a rule, the high PCL intensity generates a higher number of spectral bands and lines in a gem than continuous cathodoluminescence. That is why one can perform a more precise gem analysis by PCL. The general running time of PCL gem analysis takes only a few minutes because there is no need to perform preliminary treatment such as cooling or evacuation of specimens.

This work presents the results of experiments on the PCL of rubies, sapphires and topazes, and demonstrates an application of the techniques in characterization of gems.

Apparatus

A detailed description of the experimental methods used in PCL investigations has been presented by Mesyats *et al.*, 1993. To excite pulsed cathodoluminescence a portable (600x300x200 mm, about 15 kg weight) electron accelerator of 'RADAN-220' type (Zagulov *et al.*, 1989) was used. An electron beam of $\approx 2 \cdot 10^{-9}$ s duration, ≈ 180 keV energy, and ≈ 100 –200 A/cm² current density was input into a metal chamber, which protected the operator from X-rays. Within this chamber a test specimen was placed in the electron beam.

The emitted light was directed from the specimen to the inlet slit of the portable (150x75x75 mm) polychromator with a special diffraction grid (Skokov *et al.*, 1991). An optical spectral analyser, based on a 512-element CCD-array detector connected with a computer, was used to carry out the experiments. The detector can record simultaneously the spectral range of 300 nm in a time of ≥ 20 ms. The gems under test need neither chemical nor mechanical pre-treatment, nor extraction from their settings. All investigations were performed at room temperature in the air.

Results

Some tested gems in natural illumination are shown in Figure 1a and their pulsed cathodoluminescence is shown in Figure 1b. The spectral range 600–800 nm is the most informative for PCL of rubies and sapphires. This range displays both common and individual spectral characteristics of gems. The common feature of rubies and sapphires, as representatives of the same mineral species corundum, is a broad structured red band with a narrow double R-line due to Cr³⁺ ($\lambda_{R1} = 694.3$ nm, $\lambda_{R2} = 692.9$ nm, Figures 2 and 3). A general

spectral feature of artificial rubies and sapphires is that they display about ten times greater intensity of luminescence than that shown by natural gems of the same colour.

Rubies

Eleven artificial and 36 natural specimens were investigated. Among the natural specimens 21 were from the occurrence Makar-Ruz' in the Rai-Iz mountain range (Urals, 66°52'N, 65°15'E), and six were from the Polozhikha occurrence (Urals, 57°22'N, 61°01'E). The rest of them were individual specimens from different occurrences. All the ruby specimens (Figure 2) are characterized by the dominant role of Cr R-lines located near the centre of a broad and comparatively weak red band. The structure and width of these broad red bands are distinctly different for different occurrences and production technologies, but are consistent for the specimens from the same locality or manufacture.

A considerable increase of R-lines intensity (6–10 times greater than intensity of any local maximum of the underlying red band) is a distinguishing feature of the spectra of the artificial specimens (Figure 2, curve 1). These rubies are characterized by a minimum of the broad red band width of $\Delta\lambda \approx 55$ nm. The structure of the local maxima is amplified in the short wave range.

The PCL spectra of the natural ruby specimens from the Polozhikha occurrence have much in common with the spectra of the artificial specimens investigated (Figure 2, curve 2). However, the R-lines intensities are only two to three times greater than the local maxima of the red band. Also, there are fewer distinctive maxima and the band width is up to 65 nm.

The rubies from Makar-Ruz' show additional structure in their spectra (Figure 2, curve 3). Apart from the R-lines and the red band there is a pronounced infrared band at $\lambda_{\max} \approx 770$ nm.



Fig. 1. Ruby (1), sapphire (2) and topaz (3) in (a) natural illumination and (b) displaying a pulsed cathodoluminescence

Sapphires

Specimens of different blue tints were investigated. The total number of specimens was 22, seven of which were artifi-

cial, five were from the Polozhikha occurrence (Urals), four were from Semiz-Bugu (Kazakhstan, 50°14'N, 75°00'E) and the rest were from other locations. The PCL inten-

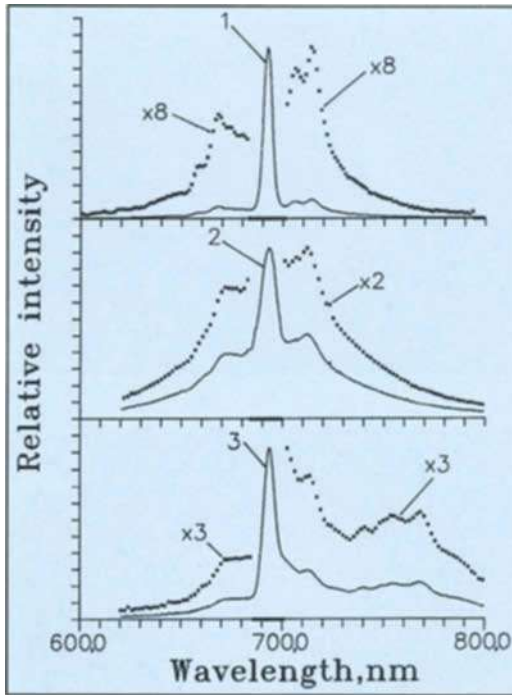


Fig. 2. Normalized PCL spectra of rubies: 1. artificial; 2. ruby from Polozhikha (Urals); 3. ruby from Makar-Ruz' (Urals)

sity of most of the sapphires is lower than that for rubies. The main difference in the spectra of the two varieties is that the red band for sapphires is wider and less structured than in rubies. The dominant role of the R-lines of chromium (Figure 2) in rubies is not nearly so great in sapphires (Figure 3).

Most artificial specimens displayed spectra of the type shown in Figure 3, curve 1. For two specimens the spectra appeared to be of the type shown in Figure 3, curve 2 with a wide red-orange band at $\lambda \approx 625$ nm. Among natural sapphires this kind of spectrum was observed only in specimens from the Kyshtym occurrence (Urals, $55^{\circ}52'N$, $60^{\circ}33'E$). For the remaining specimens the first type of spectrum is the one most commonly met. The curves 3 and 4 (Figure 3) for the specimens from the Polozhikha occurrence demonstrate this fact. While the blue colour density of tested

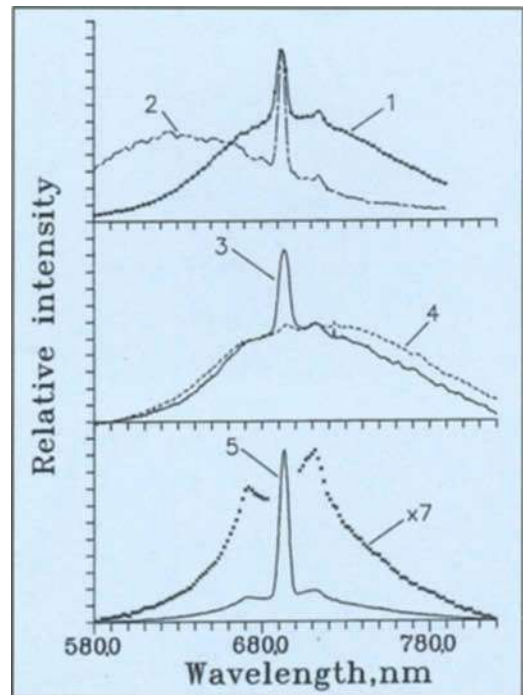


Fig. 3. Normalized PCL spectra of sapphires: curves 1 and 2, artificial; 3 and 4, sapphires from Polozhikha (Urals) (4 specimen with denser colour); 5, sapphires from Semiz-Bugu (Kazakhstan).

sapphires increases, the relative intensity of the R-lines decreases and the red band becomes wider (Figure 3, curves 3, 4). For the sapphires of Semiz-Bugu the PCL spectrum (Figure 3, curve 5) is similar to that for rubies; it differs in having fewer local maxima and a wider red band ($\Delta\lambda \approx 75$ nm).

Topaz

Our investigations were performed on about one hundred specimens. Their PCL is characterized by intense wide bands with weak structure in the blue range. For yellow, pink, red and red-violet specimens the red range of the spectrum is most informative, while topaz of other colours generated no distinctive luminescence in these wavelengths.

The yellow topazes from the Emerald Mines of the Urals have a near-symmetrical band with $\lambda_{\max} = 691$ nm, and width 60–70 nm. This symmetry is disturbed by

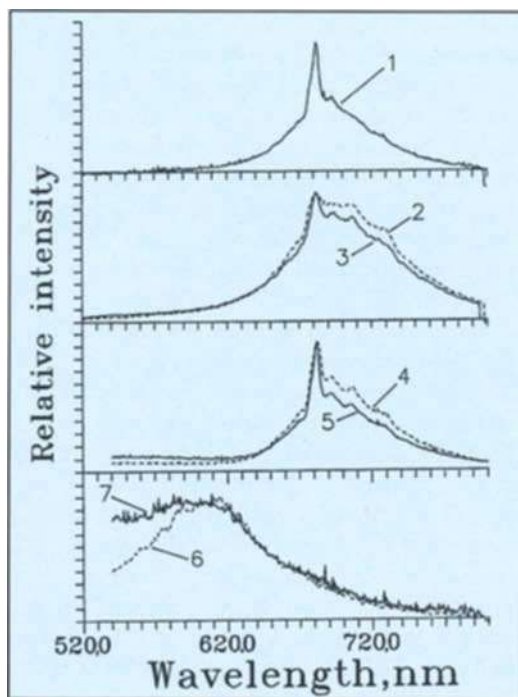


Fig. 4. Normalized PCL spectra of topaz : 1 yellow topaz from Emerald Mines (Urals); 2 and 3, pink-violet topaz from Kachkar' (Urals) (2 specimen is a denser violet); 4 and 5, from Chuksa (4 pink topaz, 5 yellow topaz); 6, pink-yellow topaz from Pakistan; 7, pink topaz from Volyn' (Ukraine)

the presence of a strong doublet R-line of Cr^{3+} ($\lambda_{R1} = 682.0$ nm—the stronger, and $\lambda_{R2} = 677.1$ nm—the weaker). In addition, there are three slight maxima in the band structure with $\lambda = 691, 722$ and 729 nm (Figure 4, curve 1).

The red band of luminescence is wider (95 nm) in the pink topazes with a violet tinge from Kachkanar (Urals, $58^{\circ}45'N$, $59^{\circ}44'E$) than it is for yellow topaz. The violet tint density increase is related to the expansion of that luminescence band (Figure 4, curves 2 and 3). The local maxima become more pronounced and more numerous due to the appearance of new maxima at $\lambda = 663, 707, 740$ nm. The relative intensities of R-lines decrease in this case.

For the Chuksa (Urals, $54^{\circ}23'N, 60^{\circ}49'E$) yellow-pink topazes (Figure 4, curves 4 and 5) the red band of luminescence is

similar to the band shown in Figure 4, curve 1. The local maxima presented here at the same wavelength are more pronounced. Also, there is a considerable decrease of the R-lines intensity for the pink topazes as compared with that in the yellow ones and the red band width remains virtually constant.

In a number of pink, yellow and yellow-pink specimens from other localities the red band with the characteristic R-lines of chromium does not occur. However, a new red-orange band absent in the spectra of other specimens ($\lambda_{\text{max}} = 605$ nm, width = 90 nm) is present (Figure 4, curves 6 and 7). This band appears as single for Pakistan yellow-pink topazes (Figure 4, curve 6), while for the pink topazes of Volyn' (Ukraine, $50^{\circ}53'N, 28^{\circ}43'E$) it is overlapped by another band on the short-wave side (Figure 4, curve 7).

After the analysis there were no mechanical defects and colour changes in any of the investigated specimens.

Discussion of the results

If the crystal lattice of these minerals were perfect and if there were no trace elements, one would be dealing with colourless and transparent crystals. Luminescence of such crystals could be studied in the context of optical transitions between the conduction band and the valence band in the UV and vacuum ultraviolet (VUV) ranges. In real crystals, lattice defects are always present as dopant ions and their complexes. These defects are, in essence, the centres of luminescence (LC) in the visible spectral range. Every LC has its characteristic bands and lines of luminescence whose wave length and width are dependent on the type of centre and its position in the crystal lattice. The intensity of a specific spectral band or line is determined both by the number of corresponding LCs contained in the mineral (the greater the number the higher the intensity) and by the concentration of centres of luminescence absorption (LCA). Some dopant ions such as iron may absorb

luminescence and in some situations luminescent centres may self-absorb; these are known as luminescence absorption centres (LCAs).

The most important dopant ion in ruby is Cr^{3+} which isomorphously replaces Al^{3+} (Taraschan, 1978; Marshall, 1988). In the absence of other dopant ions in the immediate vicinity of the individual Cr^{3+} ions the Cr narrow doublet R-line may be observed in the spectrum. It is important that the wavelength of this line is defined strictly. It is constant for each mineral species and it can be treated as an absolute indicator of minerals. For example, for corundum the wavelengths of R-lines are: $\lambda = 694.3$ and 692.9 nm; for topaz, $\lambda = 682.0$ and 677.1 nm; for spinel $\lambda = 685.9$ and 686.3 nm, and so on. The presence of these lines in the luminescence spectrum is uniquely indicative of the mineral species of a gem. Thus, the data obtained do not require further refining by any analytical methods. The presence of two ions of Cr^{3+} close together in the structure results in Cr-Cr pair formation, and gives rise to a luminescence band in the red spectral range with well-defined wavelengths of the local maxima (N-line of Cr (Taraschan, 1978)). If there are more ions of Cr^{3+} or ions of other elements in the vicinity, then complicated LCs are formed. They lead to luminescence as a widened red band that, generally, has different numbers and wavelengths of the local maxima. In addition, the dopant ions of other elements can produce their LCs emitting luminescence in other spectral ranges.

In most artificial rubies Cr^{3+} ions are the predominant dopant ions. The corresponding LCAs formed by other defects appear in a very minor way. This composition causes a very high PCL intensity of R-lines of Cr^{3+} and a comparatively low intensity of the red band due to Cr-Cr pairs. As the density of the red colour increases, i.e. the concentration of Cr^{3+} ions increases, the ratio of the intensity of R-lines and the red band changes, the latter becomes higher

and the ratio falls. Such a phenomenon can be used to estimate the quality of specimens by their colour density.

Along with the Cr^{3+} ions other dopants should be present in natural rubies. The chemical nature and concentration of the dopants depends on the different geological and geochemical conditions in which the mineral formed. Such differences in composition will manifest themselves either through the distinctiveness of the red band structure (Figure 2, curve 2) or through other luminescence bands that may be typical for certain occurrences (Figure 2, curve 3). This seems to occur not only in rubies but also in other gems, at least as far as sapphires and topazes are concerned. If a spectral PCL data bank were available for gems from all occurrences, then it would be an easy matter to identify the occurrence for a specific specimen if its PCL spectrum characteristics were obtained.

There are two kinds of spectral PCL lines for artificial sapphires and this indicates that the blue colour of a sapphire can be due to at least two types of dopant ions. Specimens having the spectra of the type shown in Figure 3, curve 2 are very rare and such spectra have so far been found only in specimens from Kyshtym (Urals). It should be pointed out that the density of the colour blue in sapphires is reflected in the PCL spectrum by a width change of the red band and by the intensity of R-lines of Cr (Figure 3, curves 3 and 4). It makes the identification of the specimens more objective.

The investigation of the PCL spectra of topaz specimens shows that different dopants may cause similar colours (cf. sapphire described above). The violet-tinted pink colour can more or less unequivocally be assigned to the effect of the Cr^{3+} ions, while the yellow-pink colour seems to be a response either to Cr^{3+} ions and unidentified dopants or to such dopants emitting luminescence within the band at wavelength $\lambda = 605$ nm in the absence of

Cr^{3+} ions (Figure 4). The PCL spectra of topazes contain distinctive features related to their occurrences. As with the sapphires, this provides another technique for sorting specimens and perhaps for estimating the financial value of gems in a more objective way.

Conclusion

The investigation of the cathodoluminescence spectra of rubies, sapphires and topazes through the PCL-based technique (the PCL method) opens up considerable possibilities for obtaining fast and correct solutions to a wide range of gemmological problems.

These are:

1. the possibility of fast identification of a gem without invoking an additional investigative technique;
2. the possibility of fast determination of the origin of a gem (geographical or laboratory). With advanced computer and data-processing technology and with a quick-response PCL technique, the creation of a data bank of spectra becomes practically feasible;

3. the possibility of objective evaluation of the colour quality of a gem with identification of the dopants responsible for the colour;
4. the possibility of exact identification of artificial analogues of natural gems.

Further application of the PCL-method to various gemmological problems would undoubtedly lead to useful developments.

References

- Marshall D.J., 1988. *Cathodoluminescence of geological minerals*. Unwin Hyman Boston, p. 146
- Mesyats G.A., Mikhailov S.G., Osipov V.V., and Solomonov V.I., 1992. Pulsed cathodoluminescence of minerals. *Pisma v Journal Tehnitcheskoi Fiziki*, 18, 87-90
- Mesyats G.A., Solomonov V.I., Mikhailov S.G., and Osipov V.V., 1994. On possibility of improving energy levels structure in solids. *Doklady Akademi Nauk.*, 339, 6, 757-60
- Mikhailov S.G., Osipov V.V., and Solomonov V.I., 1993. Pulsed-periodic cathodoluminescence of minerals. *Russia, Journal Tehnitcheskoi Fiziki*, 63, 52-64
- Skokov I.V., Juravlev D.A., Juravleva V.P., 1991. *Projection of diffraction spectrographs*. Mashinostroenie, Moscow, p.128
- Solomonov V.I., Osipov V.V., and Mikhailov S.G., 1993. Pulsed-periodic cathodoluminescence of apatites. *Journal of Applied Spectroscopy*, 1-2, 107-13
- Taraschan A.M., 1978. *Luminescence of minerals*. Naukova dumka, Kiev, p. 296
- Zagulov P.Y., Kotov A.S., Shpak V.G., and Yurike Y.Y., 1989. RADAN-compact high-current accelerator of electrons. *Pribori i Tehnika Experimenta*, 2, 146-9

YOUR FGA IN ONLY SIXTEEN MONTHS

A programme of fast-track evening classes providing the efficient way to gain your Diploma in Gemmology

The Accelerated Evening Programme provides full theory and practical tuition preparing students for the Preliminary and Diploma Examinations in gemmology.

Take the classes and examinations at the GAGTL's London Gem Tutorial Centre.

Next start date: 27 January 1997

Examinations: Preliminary 23 June 1997; Diploma 23 and 24 June 1998

The price of £995 includes:

Two evening tutorials per week – Course notes – Preliminary and Diploma Exam fees

For further details and an application form contact:

Education Department, GAGTL, 27 Greville Street, London EC1N 8SU

Telephone: 0171-404 3334

Fax: 0171-404 8843

Abstracts

Diamonds

Gems and Minerals

Instruments and Techniques

Synthetics and Simulants

Diamonds

Diamonds and their host rocks in the United States.

W.D. HAUSEL. *Mining Engineering*, 47(8), 1995, pp 723-32.

More than 220 000 diamonds have been found in the US ranging in weight from microdiamonds to the largest authenticated diamond of 40.42 carats. Diamonds have been reported from several states in the US with the greatest concentrations coming from Colorado, Arkansas, California, Oregon, Georgia, Wyoming and Michigan. Many diamonds were mined from either kimberlite or lamproite, but in the case of the Appalachian and Pacific Coast diamonds, the source is unknown. W.D.H.

History of diamond sources in Africa: Part II.

A.J.A. JANSE. *Gems and Gemology*, 32(1), 1996, pp 2-30, 14 illus. in colour, 5 tables.

In this second article the history of diamond exploration and mining in East and West Africa with detailed production figures are discussed. Theories on the geology and origin of the diamond are discussed and E.J. Dunn was the first to introduce the term *pipes* in print; later H.C. Lewis proposed the name kimberlite for the 'new' ultrabasic rock found in the pipes at Kimberley and recognized the volcanic nature of these pipes.

The central theme of modern theories is that dia-

monds were formed at depths of 150-200 km in the upper mantle as much as 3300 My ago. The presence of garnet and ilmenite in alluvial samples was a useful indication that diamonds might occur and from trace elements such as nickel in garnet it was possible to estimate the temperature of formation; when these corresponded to the temperature of the formation of diamond, the potential for diamond was correspondingly high.

The history of diamond production is given in detail and in the first thirty years (1871-1900) showed the emergence of De Beers as the dominant factor. The opening of the Premier mine in 1903 challenged the De Beers Syndicate but progressive buying of shares by the Barnato Brothers resulted in their control of the Premier Mine which then joined the quota system. World War I reduced demand for diamonds and production was curtailed. A glut of cut diamonds from Russia and a general recession in 1921/22 again resulted in a reduced output.

The emergence of the Oppenheimer Syndicate helped to stabilize the situation with Ernest Oppenheimer becoming the chairman of De Beers in 1929. A year later the Diamond Producers' Association was formed and prices were controlled through the depression of the 1930s. By 1932 De Beers had closed all their operating kimberlite mines. To cope with increased production from sources outside South and South West Africa the Syndicate was restructured in 1934. Buying was covered by the

ABSTRACTORS

R.K. Harrison

R.K.H.

R.A. Howie

R.A.H.

R.J. Peace

R.J.P.

W.D. Hausel

W.D.H.

M.O'Donoghue

M.O'D.

E. Stern

E.S.

For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

Diamond Corporation whilst sorting and selling became the concern of the new Central Selling Organisation (CSO); the first 'sight' was held in 1939. Diamond production today indicates that Botswana and South Africa are the largest producers by value on the African continent with Botswana the highest value producer in the world. R.J.P.

Gem News.

J.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, 32(1), 1996, pp 52–62, 17 illus. in colour.

At the 1996 Tucson Show there were diamonds in matrix from both China and named localities in Russia. Synthetic diamonds from Russia were on sale by the Morion Company. Synthetic moissanite (silicon carbide SiC) is marketed as a diamond simulant with suitable orientation to minimize doubling of facets. R.J.P.

Gem Trade Lab.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, 31(4), 1995, pp 266–73, 17 illus. in colour.

Energy dispersive X-ray fluorescence spectroscopy used to detect synthetic diamonds will detect iron and nickel which are used as catalysts in synthetic diamond formation even when flux inclusions cannot be identified. Even so the presence of iron and/or nickel is not proof of a synthetic origin. A heavily included black diamond with black inclusions in bands showed brown staining. The black inclusions were probably graphite and EDXRF revealed iron. Despite the detectable iron content the stone was not attracted to a powerful magnet (the iron and nickel found in synthetic diamonds is strongly magnetic).

A fracture-filled yellowish-orange cut-cornered rectangular modified brilliant showed feathers and blue and orange flash colours. EDXRF spectroscopy of the fill revealed lead and bromine and some thallium. R.J.P.

Orange spessartine garnets have been found in gneisses in Namibia; RI 1.800–1.801, SG 4.08–4.12. Distinct growth zoning and hollow tubes were observed with an immersion microscope. They are spessartine-rich garnets of the binary solid solution series pyrope-spessartine. Bright blue-green copper-bearing tourmalines have been found in Rio Grande do Norte in Brazil; they are similar to those from Paraíba and are sold as Paraíba-tourmalines. Porcelanite is a rock mined in the Czech Republic which can be manufactured into jewellery objects; it is a metamorphosed marly clay showing attractive sedimentary textures. Some lapis lazuli has come on the market showing attractive golden veins; these, however, proved to be cement with pyrite dust! Some synthetic hydrothermally grown blue sapphires from Novosibirsk are on the market, RI 1.760–1.762, 1.768–1.770; DR 0.008; SG 3.98–4.06. There are swirl-like growth marks and black bread-crumbs like residues. Also from Russia are some synthetic chrysoberyls grown by the float-zone method and coloured by vanadium, RI 1.743–1.751; DR 0.008; SG 3.68. E.S.

Der Korallenachat von Halsbach bei Freiberg/Sachsen.

W. BECK. *Lapis*, 21(6), 1996, pp 44–6, illus. in colour, 1 map.

Pink to brown banded agate is reported from the area of Halsbach, Freiberg, Saxony, Germany. The coral-like banded material has been fashioned. M.O'D.

Australian sun opal.

G. BROWN, S. STREET AND S. FAIRLEY. *South African Gemmologist*, 10(1), 1996, pp 20–2, illus. in colour.

A golden-yellow oval brilliant weighing 1.94 ct was found to be opal. The material was reported to have occurred as a cavity filling in decomposing rhyolitic thunder-eggs from a basalt flow in the Mullenbimby area of north-eastern New South Wales. Minor flow features were detected inside the stone. M.O'D.

Gems and Minerals

Gemologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 45(2), 1996, pp 43–6, 6 photographs in colour.

Le gîte de tourmaline de São José de Batalha (Paraíba-Brésil).

J. CASSEDANNE. *Revue de Gemmologie*, 127, 1996, pp 6–11, 1 map.

Green and blue tourmaline of exceptional colour is reported from São José de Batalha, Paraíba, Brazil. Details of the occurrence in pegmatite and a history of its working for gem

material are given: the material is elbaite with the appropriate properties apart from the presence of Cu as a colouring agent. Notes on attempted simulants are given and there is a bibliography. M.O'D.

Shape, structure and colours of Polynesian pearls.

J.P. CUIF, Y. DAUPHIN, C. STOPPA AND S. BEECK. *The Australian Gemmologist*, 19(5), 1996, pp 205-9, 9 illus. in black-and-white.

The shell structure of the *Pinctada margaritifera* and its development is discussed with some excellent microphotography. The cultured pearl is made by inserting a mother-of-pearl bead together with a piece of mantle tissue into a surgical incision made in the gonad of the oyster. After initial deposition of organic material, layers of prismatic calcite are deposited by epithelial cells of the 'outer layer' type whilst the more numerous 'inner layer' type deposits layers of aragonite nacre.

The black pigment in the outer layer of the oyster shell consists of a mixture of several organic compounds of relatively low molecular mass. Spectrophotometric examination suggested that three kinds of pigment molecules gave rise to the colour variations seen in Polynesian pearls. The hypothesis had some support from reflectance measurements which revealed variable mixtures of two molecular types. Reflectance spectroscopy was used to determine the statistical distribution of colour in pearl populations and hopefully would enable improved cultivation programmes to be devised. R.J.P.

Worldwide mineralogy: a sketch of an exposition.

A.A. EVSEEV. *World of Stones*, 9, 1996, pp 28-36.

The misleading title conceals an important list of specimens held at the newly established (1991) Moscow State Geological Exploration Academy. Entries are listed by continent, country and mine where known and many gem minerals are included. M.O'D.

Gem Trade Lab notes.

C.W. FRYER. *Gems & Gemology*, 32(1), 1996, pp 44-51, 20 illus. in colour.

A grossular garnet-bearing rock resembled impregnated jadeite. Magnification showed the grossular standing out against the softer under-

cut white areas. The latter did not react to a hot point and X-ray diffraction analysis showed it to be a chlorite mineral. Bright brownish-orange metallic flakes present in mottled green and white beads of jadeite were shown to be elemental copper.

Several abalone pearls have been encountered shaped like shark's teeth. An X-radiograph revealed a large hollow centre; several new abalone pearl culturing farms are reported. A string of pearls had been partially coated to fill drill holes which did not pass near the centre (presumably for attachment to fabric). The pearls had then been re-drilled through the centre.

A transparent near-colourless emerald-cut stone had properties not significantly different from grossular garnet. EDXRF spectrometry and X-ray diffraction showed it to be periclase MgO. An imitation ruby necklace was shown to be dyed, quench-crackled quartz whilst a ruby doublet was shown to have two natural parts. A natural pink sapphire had unusual rounded facet junctions. A green synthetic sapphire revealed curved colour zones and EDXRF analysis indicated the presence of Co which was possibly the cause of the colour. R.J.P.

Spessartine aus Pakistan.

U. HENN. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 45(2), 1996, pp 93-4, 2 photographs, bibl.

A new occurrence of orange- to cherry-red spessartine garnets was found in 1993 in Azad Kashmir in Pakistan; known under the trade name of 'Kashmirine', it is composed mainly of spessartine with some almandine and grossular. RI 1.798-1.802, SG 4.05-4.18. The clear crystals show only a few healing cracks with fluids; some crystals had inclusions which were analysed and shown to be potassium feldspar. E.S.

Durchsichtiger Obsidian (Marekanit) im Perlit von Superior, Arizona, U.S.A.

G. HOLZHEY. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 45(2), 1996, pp 83-9, 5 photographs, 2 diagrams, 1 table, bibl.

Obsidian is a nearly water-free glass which seldom occurs in a transparent form as those found in Superior, Arizona. The transparent, smoky coloured marekanite is rhyolitic in composition and has an RI of 1.480, SG 2.33. Anomalous birefringence is characteristic for rough stones only. The commonest microlites

within the marekanite consist of pyroxenes which mark the flow structure. E.S.

Sterndisthen und Disthen-Katzenaugen aus Indien.

J. HYRSL AND C.C. MILISENDA. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 45(2), 1996, pp 91–2, bibl.

Dark blue kyanite cabochons weighing up to 10 ct from India came on the market recently. R.I. 1.71–1.72, SG 3.62–3.64. Some samples were chatoyant, some showed a four-rayed star, caused by parallel oriented hollow tubes. Chromium was the colouring agent. Included black crystals seemed to be ilmenite, some yellow-brown inclusions were thought to be biotite. E.S.

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, 31(4), 1995, pp 266–73, 17 illus. in colour.

Impregnated black opal rough showing a play of colour gave two separate RI readings of 1.44 and 1.50, this latter high value being attributed to the impregnating substance. The SG of 1.82 was slightly lower than the lowest values obtained from Kyocera treated synthetic opal, and a faint orange fluorescence to short wave UV was consistent with Kyocera test samples. Magnification revealed a 'lizard skin' effect and a pronounced columnar structure. FTIR analysis showed several absorptions between 6000 and 4000 cm^{-1} which are not seen in natural opal and it was concluded that the specimen was impregnated synthetic opal.

A green and yellow bicoloured quartz, three rubies and a sapphire with chromium were described. A natural dark blue spinel showed a colour change from violetish-blue in fluorescent light to purple in incandescent light. R.J.P.

Instruments and Techniques

New methods for photography through the microscope: application to gem materials.

K.A. KINNUNEN. *Geological Survey of Finland. Special Paper*, 20 (Current Research 1993–1994), 1995, pp 185–7.

New techniques are described for the photomicrography of macroscopic specimens in the natural state, including crystal faces and gold nuggets. An acetate peel is obtained from the cleaned surface of the specimen, and the peel is mounted and studied in transmitted light and photographed. Colour-filter shadowing is used

to enhance the 3D aspects of the specimen. Examples are presented of the rhombohedral faces of amethyst crystals. The method has been applied to the identification of faked specimens and in criminological studies. R.A.H.

Application of Fourier transform infrared spectroscopy to silica diagenesis: the opal-A to opal-CT transformation.

S.B. RICE, H. FREUND, W.L. HUANG, J.A. CLOUSE AND C.M. ISAACS, *Journal of Sedimentary Research*, A65(4), 1995, pp 639–47.

Fourier transform IR spectroscopy is combined with XRD and TEM to experimental run products and natural opals from the Monterey formation and siliceous deposits in the W. Pacific. Using a ratio of two IR absorption intensities, the relative proportions of opal-A: opal-CT can be determined. Three stages in the opal-A to opal-CT reaction are: opal-A dissolution, opal-CT precipitation (with the end product marked by completion of opal-A dissolution), and opal-CT ordering during which tridymite stacking is eliminated in favour of cristobalite stacking. R.K.H.

Synthetics

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, 31(4), 1995, pp 266–73, 17 illus. in colour.

A corundum in for test was near colourless and examination under short wave UV radiation revealed curved striae. However, on removing the stone after about three minutes it had changed to a brownish-yellow. Six hours exposure in a solar simulator removed most of the induced colour and a few minutes gentle heating over an alcohol lamp returned the stone to its original near-colourless condition. R.J.P.

Fabrication of hollow porous shells of calcium carbonate from self-organizing media.

D. WALSH AND S. MANN. *Nature*, 377(6547), 1995, pp 320–3.

A method for synthesizing hollow porous shells of aragonite resembling the coccospheres of marine algae, is described. Thin cellular frameworks of mesoporous or macroporous aragonite can be formed from oil-water-surfactant microemulsions supersaturated with calcium bicarbonate. R.K.H.

BOOK REVIEWS

Roman jet in the Yorkshire museum.

L. ALLASON-JONES, 1996. The Yorkshire Museum, York. pp 55, illus. in colour, softcover. £4.50. ISBN 0 905807 17 0.

The Yorkshire Museum holds a collection of Roman jet artefacts retrieved since the nineteenth century and consisting largely of ornamental and some domestic specimens. This short and well-produced catalogue is arranged by specimen type beginning with pendants and concluding with unfinished items. Many of the pieces can be classed as jewellery: items are well-drawn or photographed, with entries giving specimen type, description, dimensions, details of the find and museum accession number.

Introductory chapters describe the Roman use of jet and its nature, how jet is worked and remarks on the particular uses of the specimens in the collection. A single page gives a chemical analysis of jet and there is a useful bibliography, from which Muller's *Jet* (*Butterworths Gem Books series*) is unaccountably absent. This is an excellent addition to the literature of jet and at the price should be available to a wide readership.

M.O'D.

Rock-forming minerals. Second edition. Vol. 5B. Non-silicates: sulphates, carbonates, phosphates, halides.

I.L.Y. CHANG, R.A. HOWIE, AND J. ZUSSMAN, 1996. Longman Group Ltd., Harlow. pp 383, hardcover. £115.00. ISBN 0 582 30093 2.

The stately progress of 'Deer, Howie and Zussman' continues after a lengthy pit stop of nearly ten years and with the addition of Professor Chang as senior author. We now await the volume dealing with oxides, hydroxides and sulphides.

All the good points of previous volumes are incorporated in this one: comprehensive lists of references, clear crystal drawings and phase diagrams and tables giving properties (for comparison purposes) of representatives of the minerals covered. The gap in publication means that references in the previous volumes are out of chronological balance with those in this one but it would be nearly impossible to keep up a

steady rate of production and we should be satisfied with the data provided.

Readers of the *Journal* will find this volume worth consulting for the carbonates rhodochrosite, calcite, aragonite, malachite, azurite and smithsonite and for several less common species which are sometimes fashioned. Of the four rock-forming sulphates, baryte, celestine and gypsum have some ornamental significance: the apatite group needs no introduction and fluorite is a major member of the rock-forming halides.

To give an example of the type of information provided, the section describing fluorite gives a summary of the major optical and physical properties, a general overview of the mineral, details of crystal structure, chemistry, details of recent experimental work, a discussion of optical and physical properties which includes the cause of colour, distinguishing features in hand specimens and paragenesis. The list of references covers three closely-printed pages and concludes the section.

This type of reference work should not be considered 'above' the competence of gemmologists to understand but rather as a back-up to those more accessible sources of information which sometimes have to be consulted. The price rather limits accessibility to readers who are members of universities but we have left behind the days when reference books could be purchased by individuals and the smaller reference libraries.

M.O'D.

Opal, das edelste Feuer des Mineralreichs.

1996. CHRISTIAN WEISE VERLAG, MÜNCHEN. [*extraLapis* no 10]. pp 96, illus. in colour, softcover. DM 45.00. ISBN 3 921656 37 0.

The text contains pieces on many different aspects of opal while being arranged geographically, with sections covering Australia, Mexico, Brazil and Kirschweiler [the 'opal village' bordering Idar-Oberstein and celebrated for a concentration of opal dealers and cutters]. Before the text splits up into countries, introductory material includes notes on the nature and colouring of opal and an update on world localities. This is essential reading for all gemmologists.

M.O'D.

The centre of
Excellence...

... for diamonds

The London Gem Testing Laboratory was founded in 1925 and from the start established a reputation for integrity and excellence.

Diamond grading services were established in 1980 and the Laboratory has built up an enviable international reputation for consistency and quality.

The London Diamond Report is based on the principles of harmonized grading for colour and clarity of diamonds and gives the most essential and up-to-date information required by the trade.

The Laboratory is also proficient in the grading of fancy-cut diamonds and in colour origin determination.



With a London Diamond Report your diamond's prestige is assured



The Gem Testing Laboratory

GAGTL, 27 GREVILLE STREET,
LONDON EC1N 8SU, UK

Tel: +44 (0) 171-405 3351

Fax: +44 (0) 171-831 9479

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

THE 1997 GAGTL PHOTO COMPETITION Collector's Gems

In the competition this year members are asked to submit pictures of exceptional or unusual gems which justify their place in a collection.

A gem's value in a collection may be in its rarity, its exceptional colour compared with most gems of its species, in its demonstration of particular features or perhaps in its historical associations. Send us your pictures of gems exceptional in some way for the 1997 Photographic Competition.

All entries will be judged for originality, beauty and gemmological interest.

The following prizes will be awarded:

First Prize: £100

Second Prize: £75

Third Prize: £50

Entry forms and details of the rules of entry will be circulated to all members.

OBITUARY

Mr John Francis Hodges, FGA (D.1953), Bradley, Wrexham, died on 11 June 1996.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes: Jamie Anderson-Slight, Horsham, Sussex, for an aquamarine fragment from the border of Zambia and Mozambique.

John Fyfield, Pinner, for a collection of specimens including dyed rubies, bone carvings, jade, an ivory bead necklet and an imitation shell cameo.

Dr A. Peretti and C.P. Smith, Switzerland, for cut sapphires from Vietnam.

Mr M. Sevdermish of Herzliya, Israel, for *The dealer's book of gems and diamonds* by M. Sevdermish and A. Mashiah, 1996, in two volumes. Gemology (A.M.) Publishers Ltd., Israel.

Mr Manfred Szykora, Munich, Germany, for a copy of *extraLapis No. 10: das edelste Feuer des Mineralreichs*.

MEMBERS' MEETINGS

London

On 5 June at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, David Minster of Pretoria, South Africa, gave a 3-D slide presentation of gemstones and minerals.

On 4 September at the Gem Tutorial Centre John Kessler gave an illustrated lecture entitled 'The importance of gems in Brazil's development'.

North West Branch

On 19 June at Church House, Hanover Street, Liverpool 1, David J. Lancaster from Christie's, South Kensington, gave a talk entitled 'Jewellery in the auction world and period jewellery'.

On 18 September at Church House, Deanna Brady gave a talk entitled 'Brush up your gemmology'.

Scottish Branch

On 23 June a field trip was organized to the Campsies to collect jasper.

On 6 September at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Rosamond Clayton gave an illustrated talk on jade.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 10 June 1996 at 27 Greville Street, London EC1N 8SU. Vivian Watson chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

The Chairman announced that Eric Bruton had completed his two-year term as President and expressed the Association's gratitude for his

FORTHCOMING MEETINGS

London

Unless otherwise stated, meetings will be held at the GAGTL Gem Tutorial Centre, 27 Greville Street (Saffron Hill entrance), London EC1N 8SU. Entry will be by ticket only at £3.50 for members (£5.00 for non-members) available from the GAGTL.

20 November	The mystery of opal	David Callaghan
4 December	Burmese gems at the Natural History Museum	Cally Hall
15 January	Growth and identification of synthetic diamonds	Chris Welbourn
12 February	Sleepers—rediscovery and reattribution in the antique jewellery trade	Geoffrey Munn

Midlands Branch

Monthly meetings will be held at the Discovery Centre, 77 Vyse Street, Birmingham 18. Further details available from Gwyn Green on 0121-445 5359.

29 November	Jewellery for the world and his wife	Shena Mason
7 December	Annual Dinner	
31 January 1997	Bring and Buy and Quiz	

North West Branch

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

20 November	Annual General Meeting
-------------	-------------------------------

Scottish Branch

13 November	Lab Night. Telford College, Crewe Toll, Edinburgh
12 February	Lab Night. Barmulloch College, Barmulloch Road, Glasgow

For further details of Scottish Branch meetings contact Ruth Cunningham on 0131-225 4105.

positive contribution during that period. To commemorate his Presidency, a new prize to be named the Bruton Medal would be awarded for the best set of answers submitted in the Gem Diamond Examinations.

The Council had recommended that Professor R.A. Howie be elected President for the 1996–1998 term (see p. 260) and the nomination was unanimously carried. Professor Howie's address is given below.

Terry Davidson and Noel Deeks were re-elected to the Council of Management.

It was announced that Patrick Daly and Gary Monnickendam had expressed the wish to retire from the Members' Council. John Greatwood and Jeffrey Monnickendam were elected and Peter Dwyer-Hickey, John Kessler, Laurence Music and Jamie Nelson re-elected to the Members' Council.

Following the Annual General Meeting, members enjoyed a Reunion and Bring and Buy sale. The winners of the 1996 Photographic Competition were announced and entries were displayed.

ADDRESS BY PROFESSOR R.A. HOWIE

I am very conscious of the honour that the Association is bestowing on me today, and I shall hope to fill the post of President as best I can.

On taking up such a position, one looks at the names of one's distinguished predecessors with awe. When I was invalided out of the Air Force in 1946 and went up to Cambridge, one of my lecturers in Physics was Sir Lawrence Bragg, an avuncular figure of great renown who later became your President. Through no fault of his, I soon switched to Mineralogy as my main subject, and soon afterwards joined the Mineralogical Society which has been my main Learned Society for over 45 years (indeed I've been on its Council for most of the last 38 years). There I came across Frank Claringbull, Sir Lawrence's successor, first as General Secretary and later as President and Managing Trustee. Eric Bruton I have not met, but his name is familiar and he and I share one vice: we both write books, though his have much more elegant titles, such as *Diamonds*. Who could resist dipping in to a book with that title. Many years ago I presented myself one freezing December morning at the door of one of the main diamond cutters in Amsterdam, asking to be shown around. I was both intrigued and appalled by the process of brufing whereby chunks of one diamond are

knocked off by rotating it against another diamond. Yes, I know that this technique was developed more than 200 years ago and that the name had nothing to do with Eric, but I am sure nevertheless that he can knock spots of anyone!

Thank you for placing your confidence in me. I will try to repay your trust.

ISLAND OF GEMS

An exhibition on the gems and gem industry in Sri Lanka is to be held at the Commonwealth Institute, Kensington High Street, London W8 6NQ on 16 and 17 November 1996 from 9.30 a.m. to 4.30 p.m. Further details from Sri Lanka Gems, P.O. Box 1837, London N17 9BW (telephone/fax 0181 808 4746).

GEM DIAMOND EXAMINATION

In June 1996, 70 candidates sat the Gem Diamond Examination, 47 of whom qualified, including two with Distinction.

The names of the successful candidates are as follows:

Qualified with Distinction

Birrell, Andrew Tierney, Edinburgh.
Lake, Richard John, Gorey Village, Jersey, C.I.

Qualified

Abramian, Levon, London.
Baker, Kimberly Helen, Leicester.
Bowis, Mark Lister, London.
Burch, Clive R., Sunderland.
Buxani, Naina Mahesh, London.
Cadby, Sarah, London.
Carvalho, Roberta Melo de, Rio de Janeiro, Brazil.
Clarke, Norman V., Dunfermline.
Coker, Olive Admira, Freetown, Sierre Leone.
Daniel, Eliena, London.
Daniels, Razia, Chester.
Dinnis, Simon John, Swadlincote.
Dokken, Aarrynne Dennise Celeste, London.
Ezzedine, Marwan, London.
Guo, Lei, Wuhan, P.R. China.
Higgins, Sally Ann, Birmingham.
Hird, Shelly Rose, London.
Jackson, Lam, London.
Jones, Maureen, Coventry.
Jurvakainen, Risto, Helsinki, Finland.
Kathoon, Junaida, Singapore.
Lao Weng Hong, Scholastica Loretta, Macau, Hong Kong.
Liang-Chin, Wu, Birmingham.

GAGTL GEM TUTORIAL CENTRE

27 Greville Street (Saffron Hill entrance), London EC1N 8SU

- 5 and 6 November **Synthetics and Enhancements Today**
 Are you aware of the various treated and synthetic materials that are likely to be masquerading amongst the stones you are buying and selling? Whether you are valuing, repairing or dealing, these two days of insights, tips and practical investigation will increase your knowledge of the market.
Price £223.25 (including sandwich lunches)
- 20 November **Review of Diploma Theory**
 A day for Gemmology Diploma students to review their theory work and to prepare for the Diploma theory examinations. Find out about our tips on the consolidation and revision of facts, figures, principles, practical techniques and instruments.
 Let us help you to review your examination technique with the help of past questions. This review would help students who intend to enter the Diploma examination in 1997.
Price £33.49 (including sandwich lunches)
- 27 November **Enquire Within : Ruby and Sapphire**
 A day looking at all aspects of these gems – natural, treated, synthetic and imitation.
Price £111.63 (including sandwich lunch)
- 7 and 8 December **Weekend Diamond Grading Revision**
 This intensive weekend course has been designed for all students about to take the Gem Diamond Diploma. This workshop will include a mock examination to help students gain familiarity and confidence with examination conditions.
Price £129.25
- 4 and 5 January 1997 **Two-Day Diploma Practical Workshop**
 The long-established intensive practical course to help students prepare for the Diploma practical examination; also highly effective for those in the trade and elsewhere to brush up on technique. This is the course to help you practise the methods required to coax the best results from gem instruments. The course includes a half-length mock exam for you to mark yourself.
Price £160.39 (£111.04 for GAGTL registered students) – includes sandwich lunches

NOTE: All prices include VAT at 17.5%

Please ring the Education Office (0171-404 3334) for further information

Li, Zheng, Wuhan, P.R. China.
 Lin, Songshan, Wuhan, P.R. China.
 Lodge, Sara Anne-Marie, Nottingham.
 Lord, Karen, Lutterworth.
 McIntosh, Robert P., Edinburgh.
 Metaxa, Ioulia, London.
 Mistry, Janak Arvindbhai, Surat, India.
 Mitchell, Beverly J., London.
 Mitteregger, Unni, London.
 Pepprell, Eija-Liisa, London.
 Quinn, Samantha, Maidenhead.
 Sotolongo, Sachiko Kashiba, London.
 Sveen, Per Olav, Trondheim, Norway.
 Turner, Caroline, London.
 Vaja, Pravin, London.
 White, Michele, Moseley, Birmingham.
 Withington, Terry, London.
 Xu, Feng, Wuhan, P.R. China.
 Yang, Hui Hsien, Hong Kong.
 Zhang, Weibo, Wuhan, P.R. China.
 Zhang, Yindi, Wuhan, P.R. China.
 Zhou, Li, Wuhan, P.R. China.

EXAMINATIONS IN GEMMOLOGY

In the June 1996 Examinations in Gemmology, 241 candidates sat the Preliminary Examination, 175 of whom qualified; 306 sat the Diploma Examination and 103 qualified, including three with Distinction.

The Tully Medal for the candidate who submits the best set of answers in the Diploma examination which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Miss Ding Qian, Shanghai, P.R. China.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was awarded to Mr Liu Xu, Wuhan, P.R. China.

The Diploma Trade Prize for the best candidate of the year who derives his/her main income from activities essentially connected with the jewellery trade was awarded to Miss Ding Qian, Shanghai, P.R. China.

The Anderson Medal for the best candidate of the year in the Preliminary examination was awarded to Miss Unni Mitteregger, London.

The Preliminary Trade Prize for the best candidate of the year who derives his/her main income from activities essentially connected with the jewellery trade was awarded to Miss Victoria Forbes, Portadown, Co. Armagh.

The names of the successful candidates are as follows:

Diploma

Qualified with distinction

Haria, Aarti Vipul, Nairobi, Kenya.
 Mitteregger, Unni, London.
 Sulan, Dai, Wuhan, P.R. China.
Qualified
 Aarden-Kilger, Flavia, L.M., Haalderen, The Netherlands.
 Achten, Louisa Wendelina Wilhelmina, Horst, The Netherlands.
 Adams, Victoria, London.
 Backstrom, Ingrid, Stockholm, Sweden.
 Barnes, Patricia Ellen, Dunkirk, Md., USA.
 Bonjer, Chantelle, M., Abbotsford, B.C., Canada.
 Cameron, Iain, A., London.
 Cao, Shumin, Wuhan, P.R. China.
 Chan, Wai Keung, Hong Kong.
 Cheung, Sau Ping Pamela, Hong Kong.
 Cho Du-Ri, Taegu, Korea.
 Choi, Kyeong Hye, Seoul, Korea.
 Clark, Antony, Bolton.
 Clarke, Sandra Davina, Wapping, London.
 Clevers, Irene Laurina Rita, Utrecht, The Netherlands.
 Curtis, Simon James, Torquay.
 Damianidou, Tereza, Pireus, Greece.
 Duguid, Angus Keith, Harare, Zimbabwe.
 Effendy, Jusak, Hong Kong.
 Forbes, Victoria E., Portadown, Co. Armagh.
 Fujii, Noboru, Nara City, Nara Pref, Japan.
 Fong Ka Chun, John, Hong Kong.
 Getgood, Fiona Josephine, Hastings.
 Harris, Annette Mia, Birmingham.
 Hegi, Matthieu Manuel Marie, London.
 Ho, Yan Yee Winne, Hong Kong.
 Hopley, Katharine Bridget, Coventry.
 Janssen, Maurice Janwillem, Schoonhoven, The Netherlands.
 Kabiatis, George, Athens, Greece.
 Karatzas, George, Athens, Greece.
 Kasliwal, Ritika, Jaipur, India.
 Kawczynski, Eva, Vancouver, B.C., Canada.
 Kei, Oo Oo Tracy, Hong Kong.
 Khairallah, Theresa, London.
 Kitamon, Hideaki, Yamatokouriyam City, Nara Pref, Japan.
 Kritikou, Eleni, Rhodes, Greece.
 Kwok, Esther W.S., Vancouver, B.C., Canada.
 Lai, Li, Wuhan, P.R. China.
 Lam, Chiu Hung, Hong Kong.
 Lee Ae Sook, Kyung Buk-Do, Korea.
 Li, Anan, Wuhan, P.R. China.
 Li, Li, Wuhan, P.R. China.
 Li, Lung Hsing, Taipei, Taiwan, R.O. China.

- Li, Qingnian, Wuhan, P.R. China.
 Lindblom, Joachim, P.L., Turku, Finland.
 Lindwall, Torbjorn, Lannavaara, Sweden.
 Lixin, Yang, Wuhan, P.R. China.
 Ly, Huong Dinh, Toronto, Ont., Canada.
 Mackay, Colin Alexander, Edinburgh.
 McKenzie, Wilma, South Surrey, B.C., Canada.
 Modi, Shivani, New Delhi, India.
 Mourtzanos, Stefanos M., London.
 Ng, Emerald, Toronto, Ont., Canada.
 Ng, Shuk Hing Jonas, Kowloon, Hong Kong.
 Pan, Jianqiang, Wuhan, P.R. China.
 Pani, Tonu, Tartu, Estonia.
 Pankaj, Nirmal Sethia, Mumbai, Bombay, India.
 Parsons, Michael John, Bath.
 Pepprell, Eija-Liisa, London.
 Pham, Christina Tuyet Lieu Thi, Markham, Ont., Canada.
 Pontynen, Raija, Helsinki, Finland.
 Raghuwanshi, Prachi, Bombay, India.
 Raphael, Menachem, Leeds.
 Ren, Jiakai, Wuhan, P.R. China.
 Rogers, Mark, Tauranga, New Zealand.
 Ronkko, Veera Viktoria, London.
 Sallinen, Virpi, Helsinki, Finland.
 Schutt, Alan W., Bristol.
 Seligman, Dominic, London.
 Sequeira, Silvia W., Bombay, India.
 Sharpe, Erica Jane, Wells, Somerset.
 Shende, Vivekanand V., Mumbai, Bombay, India.
 Snyman, Johanna E.W., Pretoria, Republic of South Africa.
 Susan, V.E., Naarden, The Netherlands.
 Tao, Hongwei, Wuhan, P.R. China.
 Tao, Jinbo, Wuhan, P.R. China.
 Thidar Htoo, Li Jin Hua, Yangon, Myanmar.
 Tsang Wai Yi, Rita, London.
 Van Dijk, Ennie, Schoonhoven, The Netherlands.
 Vummidi, Sreeramakrishna, Madras, India.
 Wang, Congyou, Wuhan, P.R. China.
 Wang, Dequan, Wuhan, P.R. China.
 Wang, Fenglan, Wuhan, P.R. China.
 Wang, Liqun, Guangzhou, P.R. China.
 Whiting, Sarah, Crouch End, London.
 Willis, Kathryn, Muswell Hill, London.
 Wisawayodhin, Kitiya, London.
 Wong, Mei Wai, May, Kowloon, Hong Kong.
 Wu, Ming Hsun, Taipei, Taiwan, R.O. China.
 Wu, Xiaobing, Wuhan, P.R. China.
 Xie, Liming, Wuhan, P.R. China.
 Xu, Xiaoxia, Wuhan, P.R. China.
 Yoshikawa, Yoichi, Osaka, Japan.
 Yoshimura, Shinya, Osaka, Japan.
 Zhengyun, Bi, Wuhan, P.R. China.
- Zhang, Xueli, Wuhan, P.R. China.
 Zhang, Xueyun, Wuhan, P.R. China.
 Zhang, Yanjun, Wuhan, P.R. China.
 Zhu, Xionghua, Wuhan, P.R. China.
 Zou, Tao, Wuhan, P.R. China.
- Preliminary Examination**
Qualified
 Akashi, Kazuko, Kakogawa-city, Hyogo Pref, Japan.
 Apergis, George, Athens, Greece.
 Aukee, Sari, Vaasa, Finland.
 Autar, Michael Suradj, Spijlienne, The Netherlands.
 Avery, Hilary Elizabeth, Bangor, N. Ireland.
 Barsk, Christer, Lannavaara, Sweden.
 Branch, Henry Christopher, Hampton.
 Brittain, Roger Anthony, Norwich.
 Brooks, Ian Edward Charles, Carshalton.
 Budel, Annabelle N., London.
 Cai, Bing, Guilin, P.R. China.
 Cao, Huasong, Beijing, P.R. China.
 Cao, Lianmin, Guilin, P.R. China.
 Catlin, Elaine, Austin, Tex., USA.
 Cauchi Savona, Louis, Brentwood.
 Chan, Chi-Kian, Hong Kong.
 Chang, Wai Chu, Josephine, Hong Kong.
 Chang Yeun Hwa, Taegu, Korea.
 Chen, Liang-Hsuan, Toronto, Ont., Canada.
 Cheng, Jennifer, Hong Kong.
 Cheng Kwai Tim, Hong Kong.
 Cheung, Ping Kwan (Shadow), Hong Kong.
 Chiang, Sheau-Yiun, Schoonhoven, The Netherlands.
 Chih-Liang Lai, Taipei, Taiwan, R.O. China.
 Choi Yun Hwa, Taegu, Korea.
 Chu, Li-ji, Taipei, Taiwan, R.O. China.
 Clarke, Sandra Davina, Wapping, London.
 Coope, Simon David, Carlisle.
 Cox, Michael Brian, Great Yarmouth.
 Crabtree, Peter Flaherty, Harrogate.
 Crutcher, Christie Barrett, Atlanta, Georgia, USA.
 Deligianni, Christina, Athens, Greece.
 Demner, Natascher, London.
 Dongsheng, Li, Guilin, P.R. China.
 Draper, Zoe Shaw, London.
 Edwards, Heidi Louise, Burntwood.
 Engstrom, Lena Elisabeth, Jarfalla, Sweden.
 Fairhurst, James, Godalming.
 Fan, Tai-ti, Taipei, Taiwan, R.O. China.
 Goddard, Andrea Margaret, Weston, Sidmouth.
 Griffin, Anthony Edgar, Godalming.
 Guastoni, Alessandro, Milan, Italy.
 Gao, Ms Honwei, Wuhan, P.R. China.

- Haitsma, Maaïke Cornelia, Schoonhoven, The Netherlands.
- He, Xinpíng, Guilín, P.R. China.
- Hill, John, St. Petersburg, Fla., USA.
- Ho Shuk Fun, Mercedes, Hong Kong.
- Hollander, B.M., Lopik, The Netherlands.
- Hsu, Tien Mei, Yangon, Myanmar.
- Hudson, Sally, Putney, London.
- Hui, Mei Sum Virginia Ann, Hong Kong.
- Iannicelli, Marco, London.
- Inoue, Hideko, Maida Vale, London.
- Ishijima, Juri, Nishinomiya City, Hyogo Pref, Japan.
- Jiang, Chun Qing, Beijing, P.R. China.
- Jiang, Ren-Yi, Shanghai, P.R. China.
- John, Victoria Alexei, London.
- Jones, Jesse Morgan, Auckland, New Zealand.
- Jurvakainen, Risto, Helsinki, Finland.
- Kadota, Yuka, Osaka, Japan.
- Kaskara, Tatiana, Pimlico, London.
- Kasliwal, Ritika, Jaipur, India.
- Katagiri, Kumiko, Osaka, Japan.
- Kim, Myung-Suk, London.
- Kjendlie, Ole Richard, Larvik, Norway.
- Konstantara, Aikaterini, Thessaloniki, Greece.
- Kortelainen, Kimmo, Helsinki, Finland.
- Ktistaki, Despina, Thessaloniki, Greece.
- Kuang, Yonghong, Guilín, P.R. China.
- Kuroda, Chikako, Hyogo, Japan.
- Kyi, Aung, Yangon, Myanmar.
- Lam, Ming Tak, Hong Kong.
- Leadbitter, Elizabeth Victoria, Ruislip.
- Lee, Ae Sook, Kyung Buk-Do, Korea.
- Leung, Lai Tze Cheri, Kowloon, Hong Kong.
- Leung, Wai Ming, Kowloon, Hong Kong.
- Li, Kwai Ching, N.T., Hong Kong.
- Liang-Chin, Wu, Tainan, Taiwan, R.O. China.
- Liao, Yang, Guilín, P.R. China.
- Lim, Seong Jim, Taegu, Korea.
- Lin, Shwun-Jiun, Taipei, Taiwan, R.O. China.
- Lin, Yauzhou, Guilín, P.R. China.
- Lin, Yi Hwa, Yangon, Myanmar.
- Liu, Ay Hwa, Taipei, Taiwan, R.O. China.
- Liu, Ming, Guilín, P.R. China.
- Liu, Olivia, Taipei, Taiwan, R.O. China.
- Lodjak, Toivo, Keila, Estonia.
- Ma, Qin, Beijing, P.R. China.
- Makarainen, Paivi, Helsinki, Finland.
- Makila, Kirsi Kaarina, Espoo, Finland.
- Manolakos, Dimitrios, Athens, Greece.
- Mao, Lingyun, Beijing, P.R. China.
- McCarthy, Kieran, Crouch End, London.
- Michelakou, Grigoria, Pireus, Greece.
- Mitchell, Brenda Hilary, Cosham.
- Miyamoto, Takuya, Himeji City, Hyogo Pref, Japan.
- Miyamura, Kayoko, Otsu City, Shiga Pref, Japan.
- Mol, Elisabeth Iefje, Bergambacht, The Netherlands.
- Moore, Rown Duggan, Birmingham.
- Muller, Hellen Ank Dorien, Wierden, The Netherlands.
- Murata, Sanae, Yamatokouriyama City, Nara Pref, Japan.
- Myint, Win, Yangon, Myanmar.
- Nakazawa, Haruyo, London.
- Nang Mo Kham, Yangon, Myanmar.
- Nazos, Konstantinos, Athens, Greece.
- Ng, Wai Ching, Hong Kong.
- Ng, Yiu Hong, Hong Kong.
- Nishiyama, Fumie, Suita City, Osaka, Japan.
- Nuoraho, Piia Johanna, Espoo, Finland.
- Nyan, Hlaing, Yangon, Myanmar.
- Panagiotou, Panagiotis, Ellassona, Greece.
- Plitsi, Catherine, Larissa, Greece.
- Ratcliffe, Matthew Patrick, Reading.
- Riga, Olybia, Athens, Greece.
- Rommens, Catharina Maria Christiana, Eindhoven, The Netherlands.
- Sandar, Hlaing, Yangon, Myanmar.
- Schweitzer, Wendy J., Guildford.
- Scott, Trudi Yvonne, Skegness.
- Seok, Jeong-Won, Taegu, Korea.
- Sham, Raymond, Vancouver, BC, Canada.
- Shao, Bing, Shanghai, P.R. China.
- Shao, Zhen-Yu, Shanghai, P.R. China.
- Shen, Yiming, Shanghai, P.R. China.
- Shepherd, Guy B., London.
- Shikazawa, Chiaki, Kofu City, Yamanahi Pref, Japan.
- Sietsma, Talke, Amsterdam, The Netherlands.
- Skliros, Athanasia, Athens, Greece.
- Skogstrom, Helena, Jarvenpaa, Finland.
- Speake, Malcolm Frank, Birmingham.
- Sun, Yin Nei, Hong Kong.
- Suzuki, Noriko, Ikoma City, Nara Pref, Japan.
- Tang, Kin Fan, N.T., Hong Kong.
- Tentakali, Nafsika, Thessalonika, Greece.
- Thant, Myo, Yangon, Myanmar.
- Thant, Tun min, Yangon, Myanmar.
- Tin Lei Lei Aung, Yangon, Myanmar.
- Tong, Wai Wan Vivian, Shatin, Hong Kong.
- Tun (a) Gentle Yang, Tun, Yangon, Myanmar.
- Tupper, Michael Ian, South Holmwood.
- Umeda, Evelyn Y., Sacramento, Ca., USA.
- Van Der Eng, Amber Valeska, Uitgeest, The Netherlands.
- Van Der Graaff, M.A.L., H.I. Ambacht, The Netherlands.

Van Hoften, Johannes Hubertus Fransiscus, Gouda, The Netherlands.
 van Kints, Matthias Cornelis Theodorus, Schiedam, The Netherlands.
 van Zanten, Sander, Arnhem, The Netherlands.
 Vernon, Penny Ann, High Wycombe.
 Vincelj, Peter, Lannavaara, Sweden.
 Wang, Chun Li, Beijing, P.R. China.
 Wang, Chunsheng, Beijing, P.R. China.
 Wang, Shu-Ying, Taipei, Taiwan, R.O. China.
 Wang, Yilong, Guilin, P.R. China.
 Wang, Zhong Hui, Beijing, P.R. China.
 Wang, Shu-Hui, Taipei, R.O. China.
 Wataya, Atsuto, Osaka, Japan.
 White, Joanne Clare, Sheffield.
 Williams, Lisa Jocelynn, Worcester.
 Wong Eng Wai Eagle, N.T., Hong Kong.
 Wong Poon, Wai Chun, Olivia, North Point, Hong Kong.
 Woo Pui Wa, Hong Kong.
 Wu, Sze Yin, Kowloon, Hong Kong.
 Wuruna, Yangon, Myanmar.
 Xia, Songyao, Beijing, P.R. China.
 Xie, Yujun, Guilin, P.R. China.
 Xiong, Ying, Beijing, P.R. China.
 Yan Yee Mei, Kowloon, Hong Kong.
 Yang, Gang, Beijing, P.R. China.
 Yang, Yuk-Ngor Sally, Hong Kong.
 Yap Hui Ling, Penang, Malaysia.
 Yau, Hau Yeung, Hong Kong.
 Yumi Akieda, Tagarazuka City, Hyogo Pref, Japan.
 Zhang, Sumei, Guilin, P.R. China.

Zhang, Wansong, Guilin, P.R. China.
 Zhang, Xiao Dong, Beijing, P.R. China.
 Zhu, Yong, Guilin, P.R. China.
 Zini, Grazia, Ferrara, Italy.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 12 June 1996 the business transacted included the election of the following:

Diamond Membership (DGA)

Li Zihui, Guangxi, China, 1996.
 Yip Yick Hing, Brenda, Central, Hong Kong, 1996.

Fellowship (FGA)

Kennedy, Karen Fiona, Bracknell, 1995.
 Sorrill, Rachel, Hammersmith, 1994.

Ordinary Membership

Andaluz Sanchez, Maria, London.
 Armero, Julia, London.
 Bambrick, Davina Jane, Graceville, Qld., Australia.
 Coker, Olive Admira, London.
 Cuschieri, Isaac, London.
 Edwards, James, St. Albans.
 Fujimura, Mika, Aichi, Japan.
 Harvey, Kirsty Louise, Witney.
 Scott, Anita, London.
 Sharpe, Erica Jane, Wells.
 Shiue, Ling-yu, Burnaby, BC, Canada.
 Westlund, Dennis, Los, Sweden.

MEMBERSHIP '97

Members, Fellows and Diamond Members receive *The Journal of Gemmology* and the *Gem and Jewellery News* quarterly. Fellows (members who hold our Diploma in Gemmology) may use FGA after their name and Diamond Members (members who hold the Gem Diamond Diploma) the title DGA, and both may also apply for the use of the Coat of Arms on their stationery.

Laboratory Members receive an annual membership certificate for display, *The Journal of Gemmology* and *Gem and Jewellery News* quarterly, discounted testing and grading fees, and may apply for use of the Laboratory logo on their business stationery. Overseas members are assisted with the temporary importation of gemstones for grading or testing.

All members are eligible for a 10 per cent discount on the retail price of most instruments and specimens and a 5 per cent discount on books, purchased from Gemmological Instruments Limited. Overseas members benefit from arrangements to pay membership fees by credit card and their journals will be sent by airmail.

Subscription Rates 1997

	UK	Overseas
Ordinary Member	£52.00	£70.00
Fellow		
Diamond Member		
Laboratory Member	£235.00 + VAT	£235.00

At a meeting of the Council of Management held on 17 July 1996 the business transacted included the election of the following:

Fellowship (FGA)

Ayyar, Rajeshwari, Bombay, India, 1996.
 Ding, Qian, Shanghai, China, 1996.
 Jayasendil, Janarthanan, Salem, India, 1996.
 Johnson, Jane, Biddenden, 1976.
 Liao, Zongting, Shanghai, China, 1996.
 Wall, Stephanie, Stratford-upon-Avon, 1980.
 Wu, Yaoxing, Jianguo, China, 1996.

Ordinary Membership

Colombo, Fabrizio, Torino, Italy.
 Hofer, Françoise, La Chaux-de-Fonds, Switzerland.
 Kerrigan, Mark William, Mortlake.
 Lee, Eung Min, Headingly.
 Perera, Stephen, Paris, France.
 Peretti, Adolf, Adligenswil, Switzerland.
 Roach, Dennis, Ooltewah, TN, USA.

Roach, Rose Mary, Ooltewah, TN, USA.
 Rogers, Geoffrey Alan Jackson, Saintfield, Co. Down, Northern Ireland.
 Sgroi, Tina, St Moritz, Switzerland.

BACK ISSUES

A member is seeking the following issues of *The Journal of Gemmology* which are no longer in print:

Volume 1, Nos 1,2,3,4,5,6 and 8

Volume 2, Nos 1,2,3,4,5,7 and 8

Volume 3, Nos 1,2,3,4,5,6 and 7

Volume 4, Nos 1,2 and 4

Volume 16, Nos. 1,2,3 and 4

If you are able to supply any of the above issues, please contact Mary Burland at the GAGTL, 27 Greville Street, London EC1N 8SU. Telephone 0171 404 3334, Fax 0171 404 8843.

CORRIGENDA

On p. 226 above, second column, line 1, for '10 ml' read '150 ml'

Мир Камня World of Stones

- *The only Russian popular science mineralogical journal*
- *Mines, minerals, museums and much more!*
- *Printed in English with supplementary sheet of text in Russian, volume 80pp*
- *One year subscription (4 issues) \$52, including postage*

You may subscribe at any time. Back issues are available.

Send your subscription details and cheque to:

UK: Don Edwards, Tideswell Dale Rock Shop, Commercial Road, Tideswell, Derbys SK17 88NU, UK
 Please make cheque payable in £ Sterling to Don Edwards

Germany: L. Schneider, Hemmersweiher 5, 66386 St-Ingbert BRD.
 Please make cheque payable in DM to L. Schneider.

USA: H. Obodda, Box 51, Short Hills, NJ 07078, USA
 Please make cheque payable in US \$ to H. Obodda

Editorial: Box 162 Moscow 103050 Russia. Telephone/Fax: (7-095) 203 3574

- GEMMOLOGY
- INSTRUMENTS
- CRYSTALS
- CUT SPECIMENS
- STUDY TOURS



● **WORLD LEADERS IN PRIVATE GEMMOLOGICAL EDUCATION**

We specialize in small group intensive tuition, from scratch to F.G.A. Diploma in 9 months. we are able to claim a very high level of passes including Distinctions & prize winners amongst our students.

● **GEMMOLOGICAL STUDY TOURS**

We organise a comprehensive programme of study tours for the student & the practising gemmologist to areas of specific interest, including :-
ANTWERP, IDAR- OBERSTEIN, SRI LANKA, THAILAND & CHINA.

● **DEALERS IN GEMSTONES/DIAMONDS & CRYSTALS**

We buy & sell cut and rough gemstones and diamonds, particularly for the F.G.A. syllabus, and have many rare or unusual specimens. Gemstones & Diamonds also available for commercial purposes.

● **SUPPLIERS OF GEMMOLOGICAL INSTRUMENTS**

We offer a comprehensive range of gem testing instruments, including inexpensive Petrological & Stereo-zoom Microscopes, Refractometers, Hand Lenses, Pocket U/V Lights, S.G. Liquids, the world famous OPL Spectroscope, and many other items including Books & Study Aids.



Illustrated:

Petrological Microscope. Mag. 20x - 650x, with full range of oculars & objectives, wavelength filters, quartz wedge, Bertrand lens, iris diaphragms, graticules etc.

From ONLY £650 + VAT & Delivery/Carriage

For further details of these and our other activities, please contact- Colin Winter, F.G.A. or Hilary Taylor, B.A., F.G.A. at GENESIS, 21, West Street, Epsom, Surrey. KT18 7RL England Tel. 01372 742974 or Fax 01372 742426

ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the Journal invite advertisements from gemstone and mineral dealers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

Rates per insertion, excluding VAT, are as follows:

Whole page	Half page	Quarter page
£180	£100	£60

Enquiries to Mary Burland
Advertising Manager
Gemmological Association and
Gem Testing Laboratory of Great Britain
27 Greville Street, London EC1N 8SU

HD Promotions Presents Rock 'N' Gem Shows

Specialist Exhibitions open to both
the Trade and the Public

*EXHIBITORS DISPLAYING AND SELLING A FINE
ARRAY OF ROCKS, GEMS, MINERALS,
FOSSILS AND JEWELLERY*

NOVEMBER 9/10 1996
KEMPTON PARK RACE-COURSE

Staines Road East, Sunbury on Thames
Open 10am - 5pm. Admission: Adults £2.00, OAP's
£1.50, Children (8-16) £1.00

FORTHCOMING EVENTS IN 1997

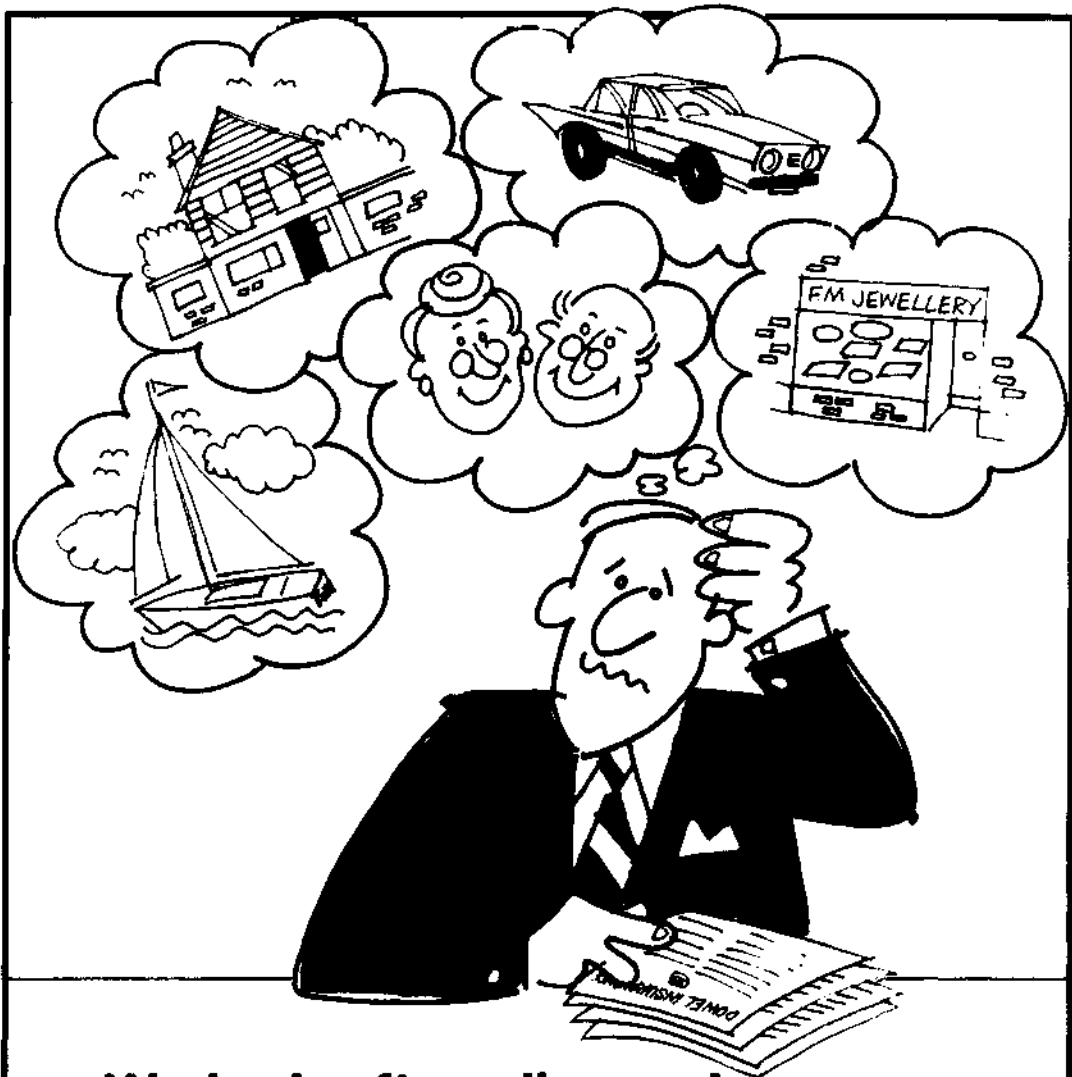
MARCH 8/9

YORK RACE-COURSE

APRIL 19/20

KEMPTON PARK RACE-COURSE

For more information on exhibiting or
visiting these shows telephone:
01628 21697 or 01494 450504



We look after all your insurance **PROBLEMS**

For nearly a century T. H. March has built an outstanding reputation by helping people in business. As Lloyds brokers we can offer specially tailored policies for the retail, wholesale, manufacturing and allied jewellery trades. Not only can we help you with all aspects of your business insurance but we can also take care of all your other insurance problems,

whether it be home, car, boat or pension plan.

We would be pleased to give advice and quotations for all your needs and delighted to visit your premises if required for this purpose, without obligation.

Contact us at our head office shown below.



T. H. March and Co. Ltd.
Saint Dunstan's House, Carey Lane,
London EC2V 8AD. Telephone 0171-606 1282
Also at Birmingham, Manchester, Glasgow and Plymouth.
Lloyd's Insurance Brokers

*You can't beat
Experience*

A new title from the Gemmological Instruments bookshop

The Dealer's Book of Gems and Diamonds

by M. Sevdermish and A. Mashiah

A two-volume treasure house of information on gemstones and diamonds - a necessary companion to every gem dealer, jeweller and gemmologist.

A major part of this work discusses the commercial aspects of gems, such as the analysis of rough gems and the process of modern fashioning of gems.

Price £70.00

plus postage and packing

Gemmological Instruments Limited

27 Greville Street, London EC1N 8SU

Telephone: 0171 404 3334

Fax: 0171 404 8843

PROMPT LAPIDARY SERVICE!

Gemstones and diamonds cut to your specification and repaired on our premises.

Large selection of gemstones including rare items and mineral specimens in stock.

Valuations and gem testing carried out.
Mail order service available.

R. HOLT & CO. LTD

98 Hatton Garden, London EC1N 8NX
Telephone 0171-405 0197/5286
Fax 0171-430 1279




MAGGIE CAMPBELL PEDERSEN
ABIPP, FGA

JEWELLERY & GEMSTONE
PHOTOGRAPHY

Tel: 0181-994 8341
Fax: 0181-723 4266

• AMETHYST • AMBER • BERYL • CHRYSOBERYL • CITRINE • TOPAZ • RUBY •
 • SAPPHIRE • IOLITE • AQUAMARINE • CAMEOS • PERIDOT •
 • CORAL • OPAL • GARNET • EMERALD • PEARLS •



E. A. Thomson (Gems) Ltd.
 Precious stone merchants
 also representing:
 Morris Goldman Gems Ltd
 Chapel House, Hatton Place,
 Hatton Garden
 London EC1N 8RX, England.
 Tel: 0171-242 3181
 Telex: 27726 THOMCO-G
 Fax: 0171-831 1776

GEMSTONES OF THE WORLD

- **HAMAG** faceting machines
with basic free formation
in our workshop.
- **Diamond polishing syringes**
(grains 0.25, 1 micron...)
- Minerals, Gemstones, Pearls

LUC GENOT

Chaussée de Wavre, 856
 B-1040 Brussels
 Belgium

TEL : 32-2-647.38.16
FAX : 32-2-648.20.26

Museums, Educational Establishments, Collectors & Students

I have what is probably the largest range of genuinely rare stones in the UK, from Analcime to Wulfenite. Also rare and modern synthetics, and inexpensive crystals and stones for students. New computerised lists available with even more detail. Please send £2 in 1st class stamps refundable on first order (overseas free).

Two special offers for students:
 New Teach/Buy service and free stones on an order.

A.J. French, FGA
 82 Brookley Road, Brockenhurst,
 Hants SO42 7RA
 Telephone: 01590 623214

Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

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

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50–100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B This is a second level heading

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in *dense* black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.³) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, 27, 2, 110–11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.



The Journal of
Gemmology

Contents

New President	262
The location, geology and mineralogy of gem tourmalines in Brazil <i>J.P. Cassedanne and M. Roditi</i>	263
A spectral-luminescent technique for gemmology <i>V.I. Solomonov, S.G. Mikhailov, V.V. Osipov, A.I. Lipchak, V.N. Avdonin and M.F. Vasovskaya</i>	299
Abstracts	306
Book Reviews	310
Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices	312

Copyright © 1996

The Gemmological Association and Gem Testing Laboratory of Great Britain

Registered Office: Palladium House, 1-4 Argyll Street, London W1V 2LD

ISSN: 1355-4565