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The Journal of Gemmology

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Table 1: *The chronology of synthetic gemstones*

Year	Synthetic material	Inventor/trade name/manufacturer/country	Growth method	Reference
Beryl, including emerald, aquamarine and red beryl				
Flux method:				
1848	Emerald (IS, NC)	JJ Ebelmen/France	FlS	N80, 128
1888	Emerald (IS, NC)	P Hautefeuille & H Perrey/France	FlS	N80, 129
1925	Emerald (IS, NC)	R Nacken/Germany	FlS	N80, 131
1934	Emerald (IS, NC)	H Espig/IG-Farben/Germany	FlS	N80, 129
1938	Emerald	CC Chatham/USA	FlS	N80, 141
1964	Emerald	Gilson/France	FlS	N80, 144
1964	Emerald (SP)	W Zerfass/Germany	FlS	N80, 130
Hydrothermal and other methods:				
1960	Emerald (IS, NC); emerald over-growth (SP)	J Lechleitner/Austria	HyS	N80, 149; G81, 98
1965	Emerald	EM Flanigen/Quintessa/Linde/USA	HyS	N80,150
1979	Watermelon beryl (SP)	Adachi Shin/Japan	?	G86, 55
1981	Aquamarine, pink and red beryl (SP)	Regency/Vacuum Ventures/USA	HyS	N90, 50; G81, 57
1988	Aquamarine, red and other colours (NC)	AS Lebedev/USSR	HyS	G88, 252; G90, 206
1994	Emerald, red beryl	Tairus/Russia and others	HyS	G96, 32
Corundum: ruby, blue sapphire and other colours				
Verneuil flame fusion, Czochralski pulling and other melt methods.				
1885	Ruby (SP) *(see Figure 3)*	'Geneva'/(Switzerland?)	FlF	N80, 42
1902	Ruby *(see Figure 4)*	AVL Verneuil/Société Hellerite/France	VeF	N80, 27
1903	Ruby (SP)	Hoquiam/USA	VeF	N80, 54
1907	Blue sapphire	Verneuil/Baikovsky/France	VeF	N80, 63, 66
1942	Ruby	L Merker/Linde/USA	VeF	N80, 69
1947	Star corundum	Linde/USA	VeF	N80, 69
1960	Ruby discs (SP)	Linde/USA	VeD	N80, 69
1965	Ruby	FR Charvat/Linde/USA	CzP	N80, 84
1971	Sapphire, colourless tubes, etc.	H LaBelle/Tyco/USA	CzE	N80, 87
1983	Ruby, etc. (NC)	Bijoreve/Seiko/Japan	FZo	G84, 60
1990	Pink Ti-sapphire	Union Carbide/USA and others	CzP	G95, 188, 214; G92, 66
Flux and vapour phase methods:				
1891	Ruby (IS, NC) *(see Figure 2)*	E Fremy and Verneuil/France	FlV	N80, 39
1958	Ruby	CC Chatham/USA	FlS	N80, 78; Pc
1958	Ruby (NC)	JP Remeika/AT&T Bell Labs/USA	FlS	N80, 78; Pc
1964	Ruby (IS,NC)	EAD White/England	VaR	N80, 91
1974	Blue sapphire	CC Chatham/USA	FlS	G82, 140; Pc
1980	Orange sapphire (padparadscha, SP)	CC Chatham/USA	FlS	G82, 140; Pc
1983	Ruby and sapphire; ruby overgrowth (NC)	J Lechleitner/Austria	FlS	N90, 53; J85, 557; G85, 35; J88, 95
Hydrothermal method:				
1958	Ruby (PQ, NC)	AT&T Bell Labs/USA	HyS	N80, 91; Pc
1965	Ruby (PQ, NC)	R Belt/Airtron/USA	HyS	N80, 91; G92, 278

Key

Growth methods:

CzE	CzP with edge-defined film-fed modification
CzP	Czochralski pulling from the melt
Exp	Explosion reaction
FlF	Flame fusion, pre-Verneuil variant
FlS	Flux solution
FlV	Flux-vapour complex system
FZo	Floating zone
HPI	HPS followed by irradiation
HPS	High pressure solution
HyI	HyS followed by irradiation
HyS	Hydrothermal solution
SkS	Skull Solidification and equivalnt methods
SkH	SkS with yttrium oxide content higher than usual
SkI	SkS followed by irradiation
SkL	SkS with yttrium oxide content lower than usual
VaR	Vapour phase reaction, atmospheric or low pressure
VeD	VeF with disc modification
VeF	Verneuil flame fusion
VeT	VeF with tricone burner modification

Fool's gold?... The use of marcasite and pyrite from ancient times

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London

ABSTRACT: This survey covers the early writings on the form, identification and occurrence of pyrite and marcasite. The origins of the confusion between the two species and their names are discussed. The material known today by the jewellery world as Marcasite and dismissed by many jewellery historians as merely a diamond imitation is, in fact, cut and polished iron pyrite. In order to differentiate clearly between the mineralogical marcasite and the cut and polished iron pyrite, a capital 'M' is used when referring to the latter. But, throughout its long history, pyrite was valued more for many other purposes. From antiquity and for many centuries iron pyrite was used by man as a convenient portable source of fire. This lead to the development of guns using the spark-producing properties of pyrite. Its value as a raw material for some chemical processes is shown.

Although little evidence remains of its early ornamental usage, there are examples from as far apart as S. America and Siberia. Since the early eighteenth century, Marcasite has been used in jewellery as an inexpensive alternative for the sparkle of diamonds. The cutting and polishing of the iron pyrite was initially done by hand but is now fully automated. The peak of the artistic use of Marcasite was in the 1930s where its soft steely sparkle compliments the beauty of other gems used in the design. This is best seen in the art deco styles of the company Theodore Fahrner. Subsequent decades did not produce such elegant pieces but Marcasite remains one of the options for the modern jeweller.

Introduction

My earliest recollection of Marcasite was as a young child in the early 1950s being fascinated by the glittering brooch and earrings worn by my mother when she dressed up to go out dancing with my father. It was only about ten years ago when I bought my first piece of thirties, silver-set, Marcasite jewellery from a market in Canterbury, that my interest was really kindled. By then I had become a gemmologist and amateur jeweller and I set out to discover more about the jewellery and the materials used. I was surprised and disappointed to find how little was written about the subject and resolved that I would try to find out more. The following account is the result of my researches so far and covers the uses of and thoughts about Marcasite/pyrites prior to the eighteenth century and the use of cut and polished stones for jewellery from the early part of the eighteenth century to the present.

What is Marcasite?

'Perhaps no other natural body has received so many names[1].' This is the

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Figure 1: *Group of pyrite crystals showing cube, pyritohedron and small octahedron (photograph by M. Hutchinson).*

challenge for anyone looking into the history of this widely spread mineral and has taken me along many diverse paths. Even the names by which the jewellery trade and the gemmologist know the material are confused. Marcasite is the jewellery trade name for iron pyrite when cut and polished. Pyrite is the cubic crystallization of iron disulphide (FeS_2). Mineralogical marcasite is the crystallization in the orthorhombic form of the same chemical compound. Orthorhombic marcasite will subsequently be spelled with a small 'm' and jewellers' Marcasite will have a capital 'M' to clarify meaning in the text. Although the cubic form is more stable, both decompose on prolonged subjection to heat, air and moisture. Both sulphides are found as opaque yellowish crystals with a metallic lustre but true marcasite has a more silvery appearance *(Figures 1 and 2).*

Figure 2: *Marcasite (photograph by M. Hutchinson).*

The confusion between the two species has existed for hundreds of years. The two names pyrite and marcasite were used interchangeably until the development of systematic crystallography in the early nineteenth century. It was only then that it became possible to distinguish between the minerals of similar appearance and identical chemical composition. Even after this the traditional names used in such old industries as mining continued to be used.

From the mid-sixteenth century, growing scientific interest resulted in an increasing number of books seeking to explain the natural world. Many took versions of ancient texts that had been passed down with a variable degree of accuracy but increasingly writers presented their own observations. The economic interest in mining and minerals ensured that all potential sources of metals were carefully examined.

Looking to the earliest writings on minerals, Boodt (1609)[2] refers to the writings of Galen on the subject of marcassites [*sic*]. Many types of metallic sulphides seem to have been covered by the term including both iron pyrites and chalcopyrite or copper sulphide[3]. The origin of the name is accepted by some writers as Persian, but there is also a view that the Persian word was probably adopted from a European language[4]. Chamber's Encyclopaedia of 1781 quotes Avicenna, who was writing in the early thirteenth century, as using the name 'marcasite nuhafi' but it is also stated that the Persians called it 'nagiar alruxenani' stone of light or brightness. The name pyrite is derived from the Greek, 'pyrites lithos' (stone which strikes fire)[5], which refers to its property of producing sparks when struck. Pliny mentions various stones which are interpreted as pyrites, the most likely being ...

'the kind of stone that contains a great quantity of fire. Stones known as 'live stones' are extremely heavy and are indispensable to reconnaissance parties preparing a camp-site.

When struck with a nail or other stone they give off a spark, and if this is caught on sulphur or else on dry fungi or leaves it produces a flame instantaneously.'[6]

Agricola[7] writing in 1546 notes that there are minerals which are intermediate between 'stones' and metals, a good example of which is pyrite 'which is called marchasite by the Moors'. Four kinds of mineral are described which are identified by colour; the true pyrite is 'silvery gold' and true marcasite, 'the colour of galena'. The others are probably chalcopyrite and arsenopyrite, being 'pure gold colour' and 'grey' respectively. He notes that only the hard pyrite can be struck to produce fire and also comments on the variable forms and location of the mineral.

Webster[8] gives a list of minerals said to be of affinity to metals; namely Cachimie, Marchasites, Pyritae and Firestones. All of these are said to be ... 'little known or regarded by miners as they can make no profit from them other than an indication of where metallic ores can be discovered.'

This opinion is confirmed by Woodward[9] in his description:

'A common Marcasite or Pyrite shall have the colour of gold most exactly and shine with all the Brightness of it and yet upon trial after all yield nothing of worth but vitriol and a little sulphur.'

He mentions the occurrence of pyrite nodules being washed out from chalky cliffs and found on beaches on the shores of Kent, Essex and Hampshire, among others.

Lovell[10] writing in 1661 in what is mainly a review of classical texts gives supposed healing properties for both pyrite and marcasite. As well as the fire-making properties of pyrite ('the best is that which is like brass') he notes that it 'purges away things hindering the eyesight', and 'it softens and discosseth hardnesses'. Marcasite is identified as being found in mines and used to produce salts with purgative properties.

The definitive text on pyrite, Pyritologia, was written in 1725 by Henckel[11], a former Chief Director of Mines at Freiberg in Saxony. He restricts the term to three types, namely yellowish or iron pyrite (also called sulphur pyrite), yellow or copper pyrite and white or arsenical pyrite. The latter is said to be unsuitable for smelting. Iron pyrite found in the mines at Freiberg and in the Harz Mountains was used for the production of vitriol and sulphur.

In spite of these clear distinctions and definitions, the name marcasite continued to be used widely by miners and mineralogists up to the end of the nineteenth century for all types of sulphides including those of bismuth and antimony. The development of systematic mineralogy led to more careful distinctions being made between the various species and in 1845 Haidinger gave the name of marcasite to the mineral previously known as white iron pyrite[12]. However by that stage the name of Marcasite for the cut and polished stones was so firmly established in the jewellery industry that it was maintained.

Form and occurrence

Iron pyrite crystallizes in the cubic system, the most symmetrical of the seven crystal systems into which all crystalline minerals are classified. It is often found as cubes or more rarely as octahedra *(Figure 1)*.

It does not exhibit the full symmetry of the system being typically found as pyritohedra, to which solid forms with twelve five-sided faces it gives its name.

Figure 3: *Pyrite inclusion in Colombian emerald (photograph courtesy of E.A. Jobbins).*

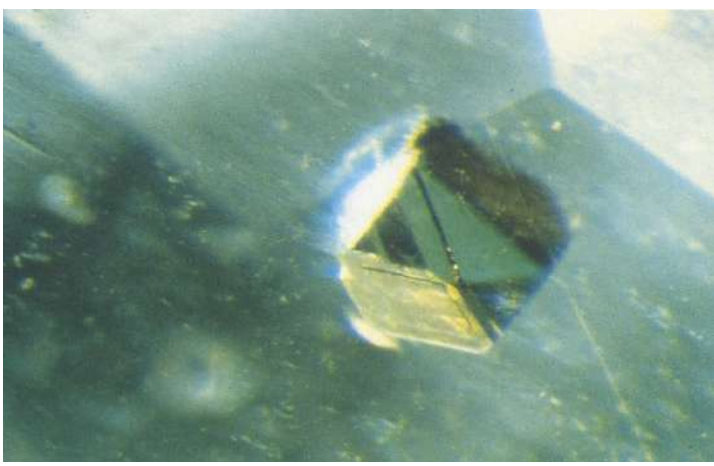

Figure 4: *Pyritized shells – some cut and polished on one side (photograph by M. Hutchinson).*

Figure 6: *Sand Dollar (photograph by M. Hutchinson).*

Figure 5: *Close-up of pyritized interior of shell (photograph by M. Hutchinson).*

Figure 7: *Pyrite nodules on slate (photograph courtesy of E.A. Jobbins).*

Even when found as well formed cubes, the faces of the cubes are often striated. Usually it is found as small cubes, pyritohedra or modified forms, often with the orthorhombic polymorph, marcasite, in irregular spherical nodules and veins in clay, slate and coal. It occurs abundantly in rocks of all ages from the oldest crystalline materials to the most recent alluvial deposits. Spangles and veins of pyrite are often found in lapis lazuli and sometimes very attractive microscopic crystals are found as inclusions in other gem materials such as emerald *(Figure 3)*.

Experiments[12] have established that when iron disulphide is crystallized from a neutral or an alkaline medium at high temperatures pyrite is produced, but from an acid medium at temperatures below 450°C marcasite crystallizes. In the Gault clays at Folkestone iron disulphide is in the form of pyrite nodules but in the limestone areas it is marcasite.

Both pyrite and marcasite are minerals that can replace the calcium carbonate in the shell of shellfish giving very attractive fossils[13]. Species, such as ammonites, buried in iron- and sulphur-rich mud can, over time, have part of the cell walls replaced by pyrite which is only evident when the fossil is broken *(Figures 4 and 5)*.

Other shapes such as 'sand dollars' which may resemble organic forms, are the product of the growing conditions of the pyrite crystals *(Figure 6)*.

Henckel[11] notes the occurrence of round pyrites washed down from the Swiss Alps and nodules the size of oranges and lemons from the island of Staritzo. These spectacular forms are illustrated in *Figure 7*.

Marcasite crystallizes in the less symmetrical orthorhombic system. Typical forms for marcasite are given more picturesque names such as 'cockscomb

pyrites' or 'spear pyrites' describing the typical twinned crystal shapes. Marcasite can be altered to iron pyrite.

The hardness of both species is 6 to 6.5 which means that pyrite can be carved using quartz sand as an abrasive but is hard enough to take a good polish. The specific gravity of iron pyrite is 4.95–5.10, slightly greater than that of marcasite, 4.85–4.90.

Iron pyrite is the most widespread sulphide in the world[12]. Nicholson[1] notes that 'pyritous minerals precede, accompany and follow veins of ores.' Pyrite is 'found in clays, chalk, marls, marbles, plasters, alabasters, slates, spars, quartz, granites, crystals' and 'also in pit-coals and other bituminous matters'. In view of such ubiquity, it is not worthwhile giving any location maps. Today where found in large deposits, such as in the copper mine at Rio Tinto in south-western Spain, it is still mined for the sulphur content. Pyrite crystals exposed to weathering can be altered to limonite, a hydrous iron oxide, and possibly further to hematite. Sometimes pyrite crystals are found with just a coating of limonite and other deposits are known where complete replacement has occurred, e.g. Hautes-Pyrenees in France. In a review of known ore deposits in 1896, Phillips[14] mentions that at Meggen in Germany operations commenced with surface mining of hematite but that these are underlain at depth by deposits of pyrite.

Exceptionally fine crystals of pyrite are found in Elba, Piedmont, various localities in Cornwall, St Gotthard in Switzerland, as well as in the former Czechoslovakia and many other locations in Europe. Well-formed crystals also occur in Peru, Bolivia, Chile, Brazil, Japan and Mexico. 'Sand dollars' are particularly known from Sparta in Illinois, USA, where they have formed in 'sedimentary rocks produced by compacted silt rich in carbonised plant material'[13]. Marcasite is much less common and, being relatively unstable, is easily altered. Good spear-shaped crystals can be found in the Pas de Calais and between Folkestone and Dover. The cockscomb form is found at Tavistock in Devon and Guanajuato in Mexico.

As well as iron and sulphur, iron pyrite can contain traces of other metals. Some localities contain sufficient gold or copper to make pyrite a worthwhile source of these metals. In his unpublished manuscript Halford-Watkins[15] conjectures that a large percentage of the world's free gold had its origin in pyrite that had subsequently decomposed releasing very fine particles of gold such as are found in alluvial deposits. Although it may be commercially feasible to process these 'auriferous' pyrites the amounts of gold they contain are very small. The bright brassy golden colour of pyrite has been known to cause confusion to the inexpert prospector and is also known as 'fool's gold'.

Early uses

Fire

Iron pyrite is arguably among the first minerals used by man. Caspall[16] estimates that the production of fire by striking pyrites with a flint edge was in use for around fourteen thousand years and was a method used in parallel with wood friction, depending on the local availability of materials. The sparks created were used to ignite a small pile of tinder such as dried fungus or grasses. Such fire-lighting kits comprising a nodule of pyrite, flint and tinder were found in a 'Beaker' burial site at Lambourn, Berkshire, and in three-thousand-year-old sites in Suffolk.

Irregular nodules of iron pyrite have been found in Anglo-Saxon graves[17] in Cambridgeshire, Suffolk, Hampshire, Sussex and Wiltshire. As, in some of these areas, pyrite nodules occur naturally in the surrounding soil, it was established in the course of the excavations that these were items deliberately placed in the graves and not accidentally included. In Burwell, Cambridgeshire, pyrite balls were found at the hips of a male skeleton. Meaney[17] concludes that these finds indicate a possible religious significance rather than any magical or amuletic properties. 'If pyrite was used to make fire as seems possible, it might simply have been buried as a prized possession.' Almost all of the finds have been with male skeletons and can be seen either as a valued personal possession or as a means of making light and heat in the next world. A notable

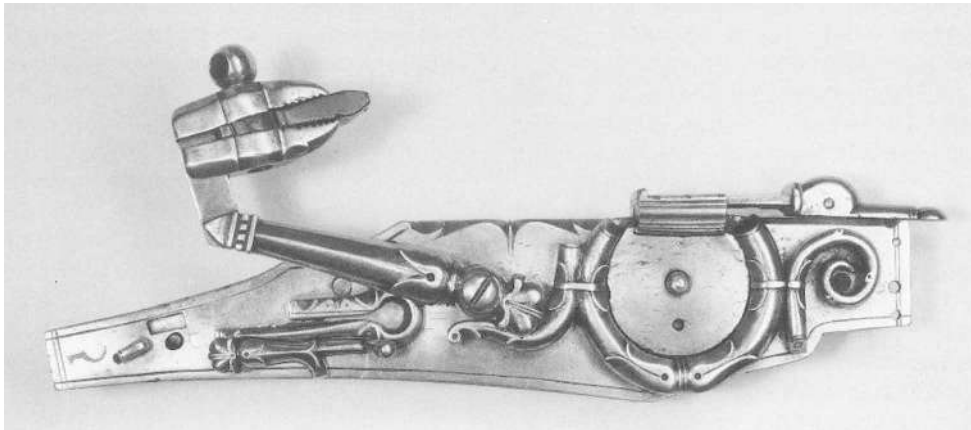

Figure 8: *Wheel-lock gun mechanism. Pyrite is held in a clamp, top left of the picture (photograph courtesy of Victoria and Albert Museum).*

exception to the predominantly male-related finds is a pyrite nodule found in Bronze Age Denmark, as part of a group of objects in a leather bag and thought to be the collection of a 'wise-woman'.

This combination of pyrite, flint and tinder continued in use throughout Europe as fire lighting apparatus until iron became readily available. Pyrite was then replaced by more conveniently-shaped iron strikers. The subsequent development of steel allowed the production of more durable strikers and resulted in a system, i.e. the tinder box, which was to last until the early years of the nineteenth century as the universal fire lighting system. Attempts to mechanize the earlier process resulted in the *Monk's gun system* in the late fifteenth century in which a piece of pyrite was held in steel jaws and forced against a roughened steel bar by the operation of a ring pull. A refinement of this system was the wheel-lock.

Firearms

The earliest records of wheel-lock mechanisms are those drawn by Leonardo da Vinci[18]. Several variations of the mechanism appear in drawings dated from the late fifteenth or early sixteenth century. A small piece of pyrite was forced by a spring against the serrated edge of a revolving steel wheel causing a shower of sparks which ignited the tinder.

Caspall[16] illustrates an elegant German sixteenth century example of such a tinder pistol which must have been owned by a wealthy man. Not only is the mechanism itself intricate and delicate but the decoration of the pistol is very elegant. Often the skills of gunsmiths, clockmakers and even blacksmiths were used to produce these luxuries for the very wealthy. Even much simpler examples would have been affordable only by the affluent middle classes.

The wheel-lock mechanism was more widely used for guns. Indeed another term for pyrite mentioned by Caire[19] is 'pierre de carabine' from its use by the Italians in early firearms. Apparently the material from Elba is particularly good for producing sparks (C. Cavey, personal communication).

The earliest dateable firearms using this mechanism are from the second quarter of the sixteenth century and it is now accepted that the Italians were the first to develop them[18]. The impact on society of these 'secret' weapons was on a par with the nuclear weapons of the twentieth century. These were the first guns that could be carried concealed and ready for immediate firing. Wheel-lock guns were produced in many countries in Europe for a further one hundred years *(Figure 8)*.

During this period older systems continued to be used and newer mechanisms were being

developed. The wheel-lock gun had superseded the match-lock system which relied on a slow-burning fuse and was in turn replaced by the simpler flint lock and other safer mechanisms. The delicate mechanism and the tendency of the pyrite to wear down quickly or break at inopportune moments made the wheel-lock a rather unreliable gun for warfare. A later gun development in Italy also used pyrite. This segment-lock, dating from the early seventeenth century, had some features in common with the wheel-lock, but operated with a steel striker instead of a wheel which scraped against the pyrite.

The rough cutting of the pyrite was probably not done by the gun-makers themselves. There would have therefore been a 'cottage' industry for the cutting of iron pyrite which would have needed to find alternative outlets when wheel-lock guns finally went out of production.

Chemicals

A major use for pyrite, described by Agricola[20], was to produce ferrous sulphate which was used, among other things, as a black dye. Its Roman name was *atramentum sutorium* (literally shoemakers blacking). In the thirteenth century this was given the name vitriol because of the glass-like transparency of the salts.

The production of vitriol from pyrite certainly dates back to pre-Christian times as a supplement to natural green vitriol called Melanteria[20] which was said to be mined in Cyprus. Vitriolus was the name given to the calcined pyrites and Agricola describes the process by which it was turned into vitriol. Vitriolus was left in heaps exposed to heat and rain for at least five months with regular turning before being covered and left for a further six to eight months. The weathered ore was stirred in a vat with water and the resultant pale green solution was run off. Solid salt was then obtained by evaporation. Writing in 1748 Hill[21] notes that vitriol is commonly called Copperas. In addition to its use as a black dye for hats and cloths, he mentions some varieties with other uses. A bluish-green vitriol (possibly a mixture of ferrous and copper sulphates) was used as a styptic and a white vitriol (lead or zinc sulphate) as a gentle and safe emetic.

The Copperas industry was a noted feature of Kent in the seventeenth century[22]. Pyrite nodules were collected by the local poor people on the beaches under the cliffs at Queenborough in Sheppey, Swalecliffe and Whitstable. At the end of the sixteenth century the stones were processed locally, but by the end of the seventeenth century the factories moved to places such as Deptford to be near the major market in London.

As well as vitriol, pyrite was also processed further to obtain sulphuric acid or 'oil of vitriol' and sulphur, and the latter use continues today.

Ornament

Undoubtedly such a bright, attractive and ubiquitous material has been known and used by man for ornament since prehistoric times. References have been made to pyrite found in various archaeological locations both in the old and new worlds. Pyrite beads[23] have been found in ancient Egypt, in Iron Age Iranian sites and in graves of the second and third centuries AD in Taxila in the Indus valley. The relative paucity of finds of such a widely occurring material must be because the conditions in some sites would cause chemical or physical break down and it would be unusual to find pyrite *in situ*. It is interesting to note that Sumerian Lapis jewellery has pyrite-shaped holes where the typical inclusions have decomposed (M. Hutchinson, personal communication).

Preserved in the frozen ground in a woman's grave at Pasyrak[24] in the eastern Altai was a pair of boots whose leather soles were decorated with colourful woollen embroidery and 42 pyrite crystals. The grave is dated to the six to fourth centuries BC. The pyrites are thought to have been obtained as a by-product from mining. A unique decorative use comes from the 'New World'. Pouget, the Parisian court jeweller, writing in 1762[25], calls Marcasite the 'pierre des Incas' because of its use as mirrors and from examples found in Inca tombs. So far it has not been possible to

Figure 9: *Aztec mirror depicting the God Quetzalcoatl (photograph collection musée de L'Homme, Paris).*

identify the source of his information, although one mirror survives[26] from the Mochica culture 100 BC–AD 600, in the National Anthropology and Archaeology Museum in Lima. This mirror consists of a carved wooden face with inlay of bone and shell on one side and an inlaid plaque of pyrite on the reverse. Other examples from Peru have not been traced and it is possible that Pouget was misled by some incorrect

Figure 10: *Mexican mask with pyrite eyeballs (photograph courtesy of the British Museum).*

labelling when the Le Cabinet Royal d'Histoire Naturelle was opened to the public in Paris in 1745[27]. A splendid Mexican obsidian mirror, thought to be part of the treasure from Mexico sent by Cortes in 1522 to Charles V of Spain, captured by the pirate Jean Fleury of Honfleur and given to Francis I in return for safe anchorage in French ports, was labelled 'Miroir des Incas du Perou'. All sources so far discovered referring to Marcasite in later periods tend to quote Pouget but no mention is made of the Incas prior to his description. Indeed, in one of the most informative books about the Incas, Garcilaso de la Vega[28] notes, 'The mirrors used by the women of the blood royal were of highly polished silver, the ordinary ones of brass.'

Undoubtedly pyrite was known in South America. Barba[29] mentions 'margatita or perytis' mined by the Incas at Acoraymes and in the Potosi mines which are now in Bolivia.

There are several examples from Mexico of polished nodules of pyrite used either as mirrors or as eyeballs in decorated skulls. In the Musee de L'Homme in Paris there are three mirrors. The oldest is a simple cylindrical shape about 3 cm in diameter with one polished face and is dated AD 150–750 from Teotihuacan. The two other examples are approximately twice the diameter and date from the Aztec period (1325–1521) from Vallee de Mexico. One is a simple shape but the other is finely carved on one side *(Figure 9)*.

All have lateral drill holes so that they could have been worn suspended from the body in some way. Drawings of the carving were published by Kunz[30], who also refers to a carved head of iron pyrites with chalcedony eyes in the United States National Museum, Washington. In the collection at the British Museum[31] is a mask from the Mixtec-Aztec period 1400–1521: 'A human skull forms the base for this mask of Tezcatlipoca, 'Smoking Mirror', one of four powerful creator gods in the Aztec pantheon. His distinguishing emblem, an obsidian mirror, symbolizes his control over the hidden forces of creation and destruction. The mask is decorated with a mosaic of turquoise, lignite and shell; polished iron pyrites have been used to fashion the eyes.' *(Figure 10)*.

An example of pyrite carving seen in a middle eastern context is a Byzantine intaglio ring mentioned by Ogden[23]. This ring dates from the sixth to seventh century AD and has a monogram carved in the pyrite which was set in gold. The pyrite was partially decomposed. The ring was sold at auction in 1981–2 and its current whereabouts are not known. Lack of further evidence or examples may mean that suitable material for carving was not available, was not considered suitable or, more probably, smaller items were completely degraded after burial. Exactly when, where and why iron pyrite was first cut and faceted for use in jewellery is not recorded.

Marcasite jewellery in the eighteenth century

Until the early part of the eighteenth century there is relatively little evidence of the widespread decorative use of Marcasite. The earliest reference to Marcasite-set jewellery is by Pouget in 1762[25] but it had already been in production for some years. Its main attraction was as a simulant for diamond and it would not therefore have been introduced until the fashion for diamond-set jewels had become well established.

During the seventeenth century France had emerged as the centre of elegance and fashion, especially at the sumptuous court of Louis XIV. This pre-eminence was particularly true for jewellery[32] and French jewellery designs were disseminated throughout Europe. By the end of the century most of the diamond cuts now known had been established and diamond-set naturalistic styles predominated. The most widespread cut used for diamonds was the rose cut.

The discovery of diamonds in Brazil in the early decades of the eighteenth century ensured that, with an expanded supply, diamonds became the major stone used. They were generally set in silver and mounted in gold.

Around this time it became the fashion for social occasions to take place at night where diamond-set jewels sparkled beguilingly under the flickering candlelight[33]. Also at this period the growth in a more prosperous 'middle-class' created a demand for jewellery which imitated the precious jewels of the rich and the aristocracy. A flourishing business in such items developed and, such was the artistry and workmanship of the jewels produced, it became fashionable in its own right. The fineness of the settings and the elegance of the designs employed for the Marcasite pieces were equal to the best used for diamond-set jewels and show that it was not treated by the craftsmen of the time as an inferior material. Diamonds were also imitated by paste, i.e. glass, but the dark sparkle of the small rose-cut diamonds was best simulated by Marcasite. Being a reasonably hard stone iron pyrite takes a good polish as well as having a naturally high lustre. Both diamonds and glass, being transparent, were foiled to enhance the reflective properties of the stones. This involves the application of a fine reflective material to the back of the stones and is a skilled and expensive process. This extra cost was avoided by using Marcasite which is opaque.

The use of Marcasite as a diamond simulant was said to have first come into fashion during the reign of Louis XIV[34]. Little of the jewellery from the eighteenth century survives but there are more examples of that set with Marcasite than of the diamond-set pieces of the same period. The latter were liable to be refashioned as styles changed or sold in times of difficulty because of the intrinsic value of the stones.

The identification of makers of Marcasite set pieces from this period is not possible as there are usually no marks on the jewels. There are a few examples from the second half of the century in the Jewellery Gallery at the Victoria and Albert Museum[35] and from the Hull Grundy bequest to the British Museum *(Figure 11)*.

As with diamonds, Marcasites were mounted in silver and, as well as necklaces, brooches and earrings, were used for buttons, buckles and chatelaines. Marcasite is well suited to the rococo scrolls, bows and straps of the period. Pouget[25] tells us that this jewellery became fashionable in Switzerland when sumptuary laws forbade the wearing of diamonds. In fact it was only in Geneva in 1668 that such laws were enacted and at the

Figure 11: *Marcasite brooch-pendant 1790–1800 (photograph courtesy of the British Museum).*

time Geneva had not yet become a Canton of Switzerland. He also stresses the inexpensive nature of Marcasite set jewellery in comparison to that set with diamonds and implies that the period of economic retrenchment proposed in 1759 by M. de Silhouette, one of the finance ministers to Louis XV, encouraged the aristocracy to wear it. The fashion was also said to have been supported by the Comtesse Du Barry, the King's mistress[36]. Whether for patriotic, stylish or more practical reasons in times when 'highway robbery' was common, the fashion for Marcasite jewellery continued until the end of the century when the revolution in France changed the focus of the fashionable world. The lightness and elegance of the French pieces[37] are in contrast to the more showy nature of the Swiss jewels of the period[38].

Another diamond simulant produced at around the same period which may occasionally be confused with Marcasite is cut steel. Tiny studs of steel, originally from old nails, were cut and polished and set into jewellery and other trinkets. In England cut-steel became more fashionable than Marcasite and could be very costly. It was particularly favoured by men in the form of decorative sword hilts, buttons and shoe buckles. The two simulants can be identified by the settings. Marcasite was set in pavé settings with the metal mounting being used to hold the stones into place whereas cut-steel rosettes were riveted onto the mounts.

Marcasite jewellery in the nineteenth century

The exquisite workmanship of the eighteenth century could not be sustained as the demand for greater volume and less expensive pieces grew. Although it was still seen as a diamond substitute, the brilliant cut (now predominant for diamonds) gave an effect that could not be reproduced with marcasite and limited its use. Marcasite-set jewellery continued to be produced, but attempts to revive the original eighteenth century styles in the middle of the nineteenth century failed[39]. The settings were generally less well made and the jewellery was no longer seen as a fashionable alternative to gem-set pieces but cheap copies for those who could not afford the real thing. Some fine work was still done where Marcasites were used as surrounds for small enamels and miniature mosaics of the Tonbridge-ware type[32]. Nonetheless, Marcasite, having been established as one of the many stones available to the jeweller, continued to be used in a limited way, in a sense waiting for a change in fashion to improve its fortune.

One particular occurrence that was exploited by the local jewellery trade in this era was a thin encrustation of iron pyrite on shale found near Dublin[39]. Pieces of this material were cut and shaped and set in brooches that were sold by Cornelius Goggin in Dublin[40].

Cutting through the centuries

Caire[19] states that the cutting of Marcasite was carried out in the region of Geneva and that the stones were exported to many areas.

Only Portugal prohibited the import of Marcasite, which may have been due to a protectionist attempt to safeguard the diamond-cutting industry based on rough being imported from Brazil. Bauer[39] also quotes Geneva as the source of cut material but in addition mentions the Jura Alps in France. The relationship between these two areas, particularly in the field of lapidary work, goes back to the late fifteenth century[41].

The adoption of Calvinism in 1536 by Geneva resulted in refugees, who wished to retain their religious freedom, fleeing to the catholic areas of St. Claude in the Jura region of eastern France. Among the refugees were goldsmiths and jewellers skilled in the arts of gem-set work. In about the middle of the sixteenth century the new trade of watchmaking spread to Geneva and numerous lapidaries were employed in the manufacture of glasses, stones for the ornamentation of the cases and, after about 1700, in the cutting of rubies for the mechanisms. In 1673 strict religious laws forbidding the wearing of jewellery had a severe impact on the trade and further emigration occurred resulting in the emergence of Septmoncel in the Jura as a watchmaking area. The Jura was a poor farming region and there was a ready supply of outworkers who cut stones by hand in the long winter months to supplement their meagre income from the land.

Having thus been established, the lapidary business continued with fluctuating fortunes cutting whatever materials were required by the jewellers of Paris. This included Marcasites although, as the details of the various operations were considered to be trade secrets, it is not possible to identify particular cutters.

Iron pyrite is mostly cut into circular shapes with a flat back and six triangular facets on the front. This cut is similar to the standard rose cut for diamonds. Stones are produced with various diameters but most are quite small. Initially, as for all stones, this was done by hand but over time parts of the process were automated and production was moved into factories. In the early years of the twentieth century, the town of Turnov in Bohemia is mentioned[42] as an important centre for the cutting and polishing of both glass and Marcasite. The work was done by semi-automatic machines and the raw material came from South Tuscany in Italy. The complete history of one cutting factory in Turnov was related to me as follows. In 1899 a young man, having served in the Austro-Hungarian army, finished his engineering studies and established a cutting business in Turnov. The business must have flourished because by 1938 it employed approximately a thousand people. However, during the Second World War stone cutting ceased and although attempts were made to revive it in 1945 they were unsuccessful. In fact the 'young man', by then aged 70, escaped to Germany and followed his family to South America.

The company of Golay-Buchel based in Lausanne established the first fully automated cutting and polishing machine for Marcasite over fifty years ago and continues in the business today[43].

Not all pyrite is suitable for cutting; in particular the well-formed cubes are too brittle. Italy continued to be a major source of suitable material for cutting until it became uneconomic in the mid 1980s. Today the raw material comes from South America and most of the cutting of high quality stones is done in the Philippines using fully automated machinery. There is also some hand cutting in Thailand.

Marcasite jewellery in the twentieth century

To understand the success of the use of Marcasite in the manufacture of affordable and stylish jewellery in Europe in the 1920s and 1930s, it is necessary to discuss briefly the ideas and methods of one of the German jewellery industry's more innovative manufacturers, Theodor Fahrner, and the development of his company.

The firm of Theodor Fahrner of Pforzheim[44] was noted for the production and marketing of a range of stylish, artistic and relatively inexpensive jewellery at the turn of the century. In particular, Fahrner worked to improve the artistic quality of wholly or partly machine-made jewellery. He collaborated

with the artists of the Darmstadt Art Colony, such as Joseph M. Olbrich, to obtain designs for unusual jewellery that had a distinctive German character and individuality which broke free from the influence of France.

The Darmstadt Experiment was promoted by the Grand Duke Ludwig of Hesse to encourage collaboration between artists and manufacturers and promote the growth of local industry. The intention had been that there would be collaboration with the jewellery industry in Hesse but, whereas the jewellers of Hanau showed little interest in the project, Fahrner from Pforzheim was able to see the possibilities for modern jewellery and build on the contacts.

As an artist-manufacturer, Fahrner recognized the limitations of art nouveau designs for factory production but was determined to produce well designed, affordable jewellery. The modern styles worked well with the newer fashions which tended to simpler and more geometric lines. He recognized early the value of advertising and registered the TF monogram as a trade mark in 1901. In order to reach a wider, artistically aware, readership, he placed advertisements for the jewellery in a periodical about art and decoration *Deutsche Kunst und Dekoration* rather than in jewellery trade journals.

Fahrner died in 1919 after a long illness. The strong tradition of the marriage of artistic design with industrial manufacture that he had established provided a good base for Gustav Braendle who bought the business from Fahrner's widow. After war service, Gustav Braendle had returned to the family business in Esslingen but rather than just taking over the existing jewellery business, he saw greater potential for success in Pforzheim. He showed a flair for publicity comparable to that of Theodor Fahrner by advertising his ownership of Theodor Fahrner Nachfolge with a spoof telegram in the *Deutsche Goldschmiedezeitung* in 1920.

In the years after the First World War precious material such as gold and silver were in short supply. Companies that could use a minimum of these metals with other materials, including wood, to produce low- and medium-priced jewellery of artistic merit stood a better chance of survival than their more traditional competitors, many of whom were forced by the 1923 economic crisis to cease production. It is in this period that we first hear of the use by Braendle of Marcasite which had already been in use in the German jewellery industry since 1910.

Figure 12: *Maracasite, onyx and coral pendant with enamel ca. 1929 (photograph courtesy of Arnoldsche Verlagsanstalt GmbH, Stuttgart, Germany).*

From then onwards, through the 1920s and into the early 1930s, Marcasite became a regular design component for much of the company's production. The company designers, including Braendle himself, obviously appreciated the artistic properties of the material. They made full use of the particular steely glitter of the stone in combination with quartz, black onyx, red coral and other opaque decorative stones to

Figure 13: *Typical art deco silver, Marcasite and cornelian brooch, maker unknown (photograph by M. Hutchinson).*

Figure 14: *1950s Marcasite set brooch and earrings (photograph by M. Hutchinson).*

produce the art deco styles popular in this period *(Figures 12 and 13).*

Other manufacturers, even some of the top French jewellery houses, also used Marcasite to produce art deco styles. Black and white combinations were particularly popular. In 1923 Vogue[45] reported, 'the mode has a passion for black and white jewelry, particularly when the black is onyx and the white is marcasite.'

The 'patriotic' styles of the late 'thirties, encouraged under the aegis of the Nazi regime, virtually eliminated the production of innovative and stylish jewellery in Germany, and Marcasite was once again out of fashion.

The styles of the 'forties and early 'fifties were characterized by exuberant and colourful jewels, which featured lavish amounts of gold (solid or plated) and multi-coloured stones. It was only during the mid- to late-'fifties when 'white' diamond jewellery returned to popularity that Marcasite was again used to imitate the sparkle of the more expensive stone *(Figure 14).*

At this period there was a marked change in the materials used for manufacture in comparison with earlier years. Until this decade Marcasite had been set in silver mounts with grain or rub-over settings; pre-war apprentices were often given the job of setting Marcasites while training for the setting of diamonds. In the 'fifties the majority of mounts were made of base metals, often chromium or rhodium plated, and the stones were glued into place. One of the most popular themes was that of a bird or animal fashioned as a lapel brooch and sold at a very modest price. Although the artistic merit of these pieces was very variable, there was probably no woman or girl of the time who did not possess at least one Marcasite brooch. Unfortunately it is this unexceptional jewellery that many people think of when Marcasite is mentioned today.

The wider use of colourful plastics and the fashion revolutions of the 'sixties once again pushed Marcasite out of the mainstream.

The company of Butler and Wilson is credited[45] with the revival of silver, Marcasite-set jewellery in the 1980s. Sadly, there has been a tendency to produce pastiches of the styles of the 1930s rather than innovative designs. With the comparatively low labour costs, items of this kind are now mostly produced in Thailand *(Figure 15).*

A more recent manifestation of the ornamental use of iron pyrite has been the appearance on the market of a range of beads mostly cut in China. These are most effectively used either as large beads, which show some of the crystal structure, or as 'spacers' to compliment other materials, enabling the designer to produce a wide range of attractive necklaces *(Figure 16).*

It is also from China that an unusual combination of minerals has been exploited. Fine banded fluorite in various shades of green and violet with an encrustation of well crystallized iron pyrite has been discovered. This was cut by craftsmen in Germany into splendid bowls and demonstrates that such apparently unpromising material can, in the hands of skilled designers, be fashioned into exciting artefacts *(Figure 17).*

Figure 15: *1980's ring set with Marcasite and lapis lazuli with pyrite inclusion (photograph by M. Hutchinson).*

Figure 16: *Pyrite beads (photograph by M. Hutchinson).*

Figure 17: *Bowl carved by Becker in Idar-Oberstein (photograph courtesy of M. Pout).*

Figure 18: *Winner of the 1995 Prix Golay Buchel – a competition for young Swiss jewellery designers to design a stopper for a perfume bottle with marcasites – by Manuela Bär (photography courtesy of Golay Buchel).*

A really modern use of Marcasite is seen in the winning entry for the competition held in Switzerland in 1995 for students to design a perfume flask incorporating Marcasites in the design *(Figure 18)*.

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A combined spectroscopic method for non-destructive gem identification

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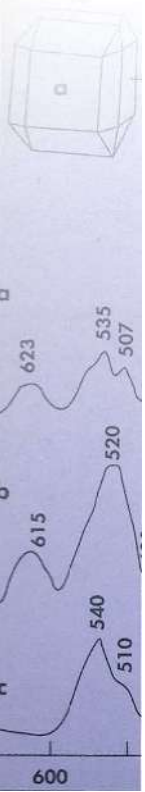
ABSTRACT: The combined use of spectroscopic methods including Raman laser spectroscopy, mirror infrared reflection spectroscopy and diffuse reflection spectroscopy in ultraviolet, visible, and near infrared wavelengths can supply non-destructive and diagnostic information to identify gems. The items can be natural or synthetic gemstones, loose or mounted in jewellery, or in a rock matrix in various forms and dimensions.

Keywords: infrared, visible, ultraviolet reflection spectroscopy, Raman laser spectroscopy, non-destructive gem identification



I. Introduction

Generally, identification of a gem can easily be made on the basis of optical and physical properties (Anderson, 1980; Bank, 1973; Smith, 1972). However, sometimes it is difficult or impossible to determine some physical properties of a gem mounted in jewellery with the use of standard gemmological equipment and in this case gem identification is made visually. Traditionally distinguishing synthetics from natural gems has been largely visual. The majority of well-known mineralogical techniques cannot be applied in gemmology because they are destructive (Gramaccioli, 1991). Also the full safety of some gems is not assured if their identification is attempted by single-crystal X-ray diffractometer (Bank, 1980; Pilati and Gramaccioli, 1988); there is a danger that a gem's colour may change under X-radiation. It is fundamental that gemmologists do not damage gems and jewellery in any way. That is why the requirement is to apply only non-destructive methods for gem identification. In the past, methods of infrared reflection spectroscopy have been described by Pfund (1945), Shimon (1951), Vierne and Brunel (1969, 1970, 1973), Brunel and Vierne (1970), Brunel *et al.* (1971), Tretyakova *et al.* (1987), Martin *et al.* (1989) and Gao Yan *et al.* (1995), and Raman laser spectroscopy by Griffith (1969), Nassau (1982) and Reshetnyak (1991).

Infrared reflection spectroscopy and Raman laser spectroscopy have been called methods of gem 'fingerprinting', and there are many optimistic declarations that each method may be used on its own to identify the majority of gems. In practice there can be problems with collection of spectra. Each method has serious technical limitations (usually not described in detail by authors). These limitations are connected with the chemical composition and crystal structure of a mineral, the dimension, form and surface characteristics of an item, and the mounting in jewellery or in matrix. Below, we propose that

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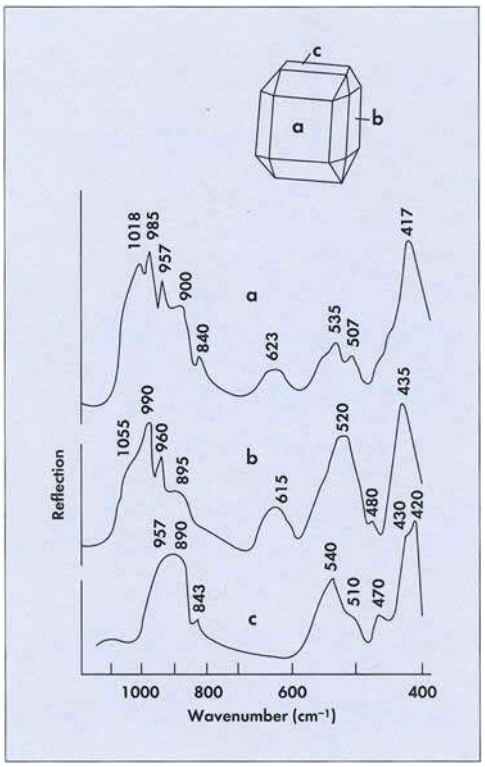

Figure 1: *The mirror reflection spectra in the medium infrared obtained from different orientation planes of an olivine crystal.*

the combined use of spectroscopic methods, including Raman laser spectroscopy, mirror reflection infrared spectroscopy and diffuse reflection spectroscopy in the ultraviolet/visible/near infrared (UV/VIS/NIR) range can provide non-destructive and diagnostic information for most gemmological objectives (Tretyakova and Reshetnyak, 1990; Tretyakova *et al.*, 1995; Tretyakova and Tretyakova, 1996).

II. The methods and their practical application

The methods are based on vibrational and electronic spectral analysis of a gem. The vibrational spectra obtained by IR mirror reflection spectroscopy and Raman laser spectroscopy are fundamental properties and can be used to identify a gem or mineral species. The number of spectrum lines, their frequencies, intensities and bandwidths in both the Raman spectrum and the spectrum of the medium infrared, are connected with the chemical composition and crystal structure of a mineral. Their patterns make them a reliable means of identification, in either the crystalline or the glassy state. The spectrum measurements using reflective spectroscopy and Raman scattering are simpler than in any other spectroscopic method. The gems do not require special preparation, or alteration of jewellery or matrix. To make it practical and efficient we must consider some limitations.

A. Infrared mirror reflection spectroscopy

1. If no active first order dipole vibration in the medium infrared is observed, identification of the sample by means of the mirror reflection spectrum appears to be impossible. Then the band scanning must be expanded with registration of fine lines of higher order which means increasing the time to record any diagnostic information.
2. It is well known that most crystals are anisotropic and the IR reflection spectrum depends upon crystal orientation (Shaffer and Matossi, 1930). Such differences in spectra cover a considerable range for many minerals, and the spectra from three planes labelled a, b and c in an olivine crystal are shown in *Figure 1*. It is important to keep this fact in mind to avoid making a diagnostic mistake. On the other hand, this limitation can also be viewed as an advantage; with a mirror IR reflection spectrum the crystal orientation can be determined! With such information the optimum orientation can be chosen for cutting a gem to show lustre, sheen and colour.
3. *Gem and jewellery dimensions:* In order to obtain an IR mirror reflection spectrum it is necessary to have a flat mirror face (no less than 2 mm^2) which may be a natural crystal face or a polished surface of a cut gem. If the gem face is less than 2 mm^2 or the gem has a curved or spherical surface (cabochon, bead), it is very difficult or

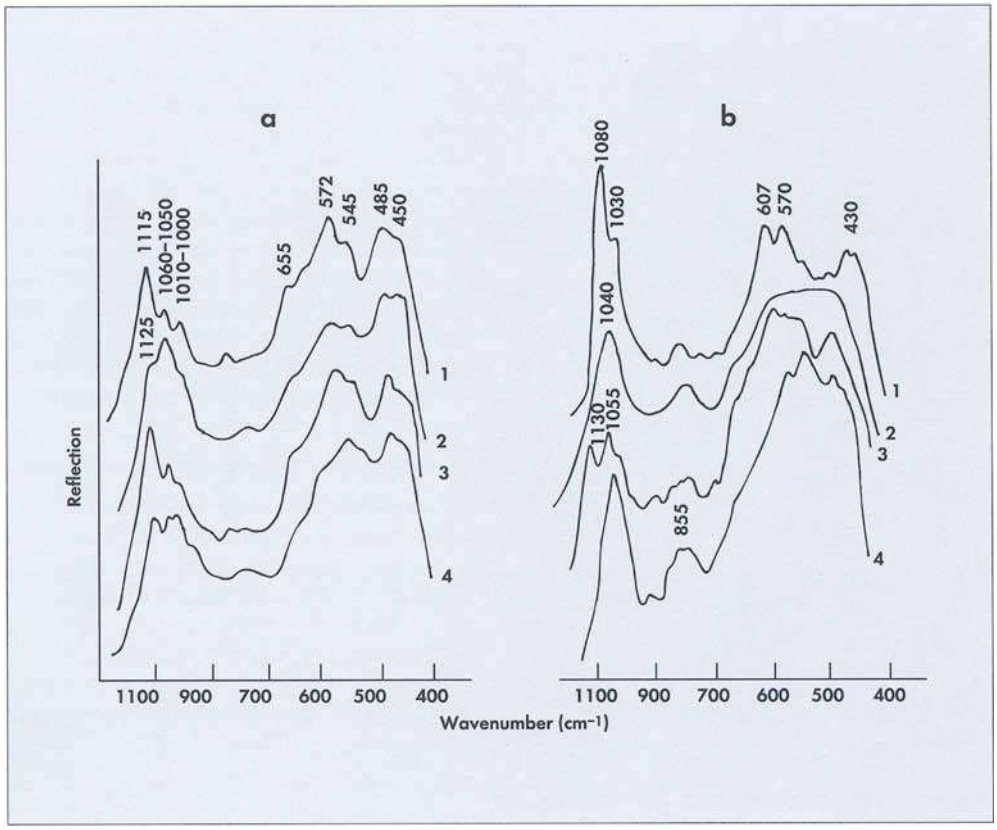

Figure 2: *The mirror reflection spectra in the medium infrared of turquoise: (a) natural: 1 blue, 2 light blue, 3 green, 4 green-yellow; (b) synthetic: 1–4 light blue*

impossible to obtain an IR mirror reflection spectrum. IR mirror reflection spectra are easy to record from loose gems and from gems mounted in small jewellery (for example a ring, earring, brooch, cuff-link, stud or a box). The limited size of the sample chamber in the IR equipment means that it is impossible to record IR reflection spectra from gems mounted in large items such as sceptres or crowns.

4. *Gem surface characteristics:* When dealing with non-ideal mirror surfaces one must recognize and differentiate mirror reflection lines from diffusion reflection lines in the infrared. When combined with or merging with mirror reflection lines the latter make gem spectra much more complicated. Ignoring this situation may lead to a serious mistake in identification.

B. Raman laser spectroscopy

Raman spectroscopy uses a focused laser beam (0.1 mm diameter) and spectra can be obtained from a wide range of stone sizes and forms. The spectrum can be measured from each free surface of the gemstone (mirror, rough or globular), whether mounted in jewellery or still in matrix. However, Raman laser spectroscopy is not so effective in the following cases:

1. When an object shows a strong luminescence background, especially under excitation in the blue-green region of the spectrum. Such materials include for example, some sulphurous aluminosilicates, amber, pearl and some synthetic emeralds. But it is true that this difficulty can be overcome to a considerable extent if an FTIR spectrometer is used and an

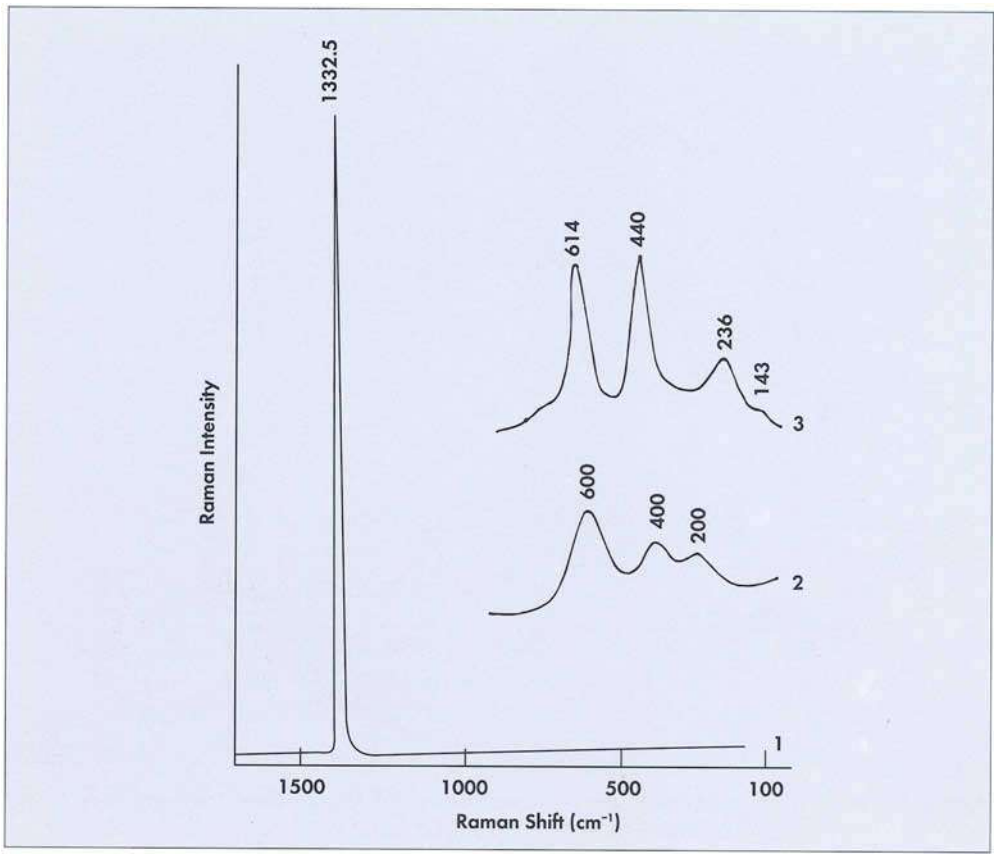

Figure 3: *Raman spectra of diamond (1) and two of its imitations; (2) phianite (zirconium oxide) and (3) rutile.*

excitation laser line of near infrared wavelength is selected.

2. One should be careful in the identification of gemstones containing rare-earth elements (for example apatite, fluorite, synthetic gemstones) as dopants which may cause colours. In this case the luminescence lines of rare-earth elements may be interpreted as Raman lines which could lead to a wrong identification. It is necessary to record Raman spectra from several excitation laser lines to correctly identify Raman lines.
3. It should also be noted that a few stones can be damaged by the laser. For example, some strongly absorbing gems such as malachite, azurite or turquoise, can be burnt by laser excitation in the blue-green region of the spectrum, and particular samples of synthetic auricalcite, natural blue sodalite or pink hackmanite can fade in laser radiation.
4. Minerals with amorphous or crypto-crystalline structures, such as opal or turquoise, produce low intensity Raman spectra that make identification difficult.
5. Low intensity Raman spectra are recorded from dark-colour (especially black) gemstones. Due to the strong absorption of both exciting and scattered light the Raman signal in such objects is found to be one to two orders of magnitude lower than in lighter-toned varieties of the same gems. Problems connected with the collection of Raman spectra from such objects are so difficult that it is more reasonable to use IR mirror reflection spectroscopy for identification.

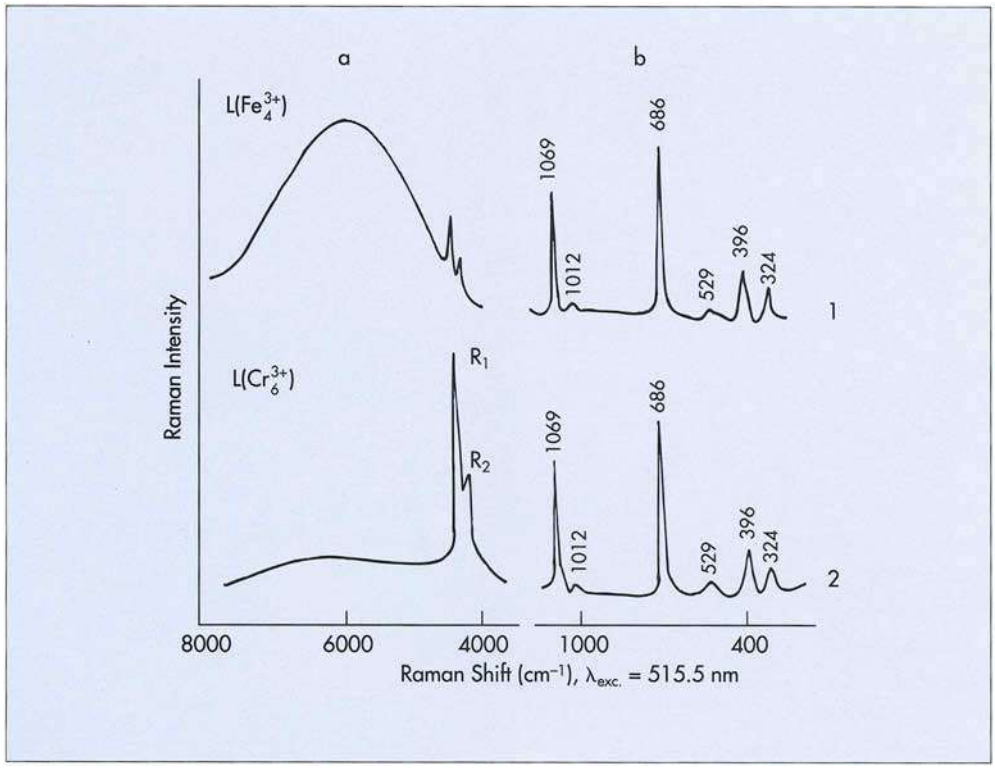

Figure 4: *Laser-excited spectra (a) luminescence lines, (b) Raman lines, of some beryl group minerals: 1 yellow beryl coloured by Fe^{3+}; 2 emerald coloured by Cr^{3+}.*

It should be noted that all the above-mentioned limitations can be reduced by longer counting times.

Obviously to obtain non-destructive diagnostic information for large gem items, it is reasonable to use both IR mirror reflection spectroscopy and Raman laser spectroscopy. Each method has its strengths and weaknesses. IR mirror reflection spectroscopy is preferable for gems with amorphous or cryptocrystalline structure, dark colour, mirror surfaces more than 2 mm^2, loose or mounted in small jewellery. Thus the IR reflection method is appropriate for turquoise identification *(Figure 2)*, since the Raman spectrum will not be very strong, and in addition a laser beam would spoil the gem.

It is better to use Raman spectroscopy for identification of cabochons, beads or gemstones with a badly polished surface and for gems smaller than 2 mm^2 or those mounted in large items of jewellery. For instance, Raman spectroscopy is very effective in identifying diamond which gives a non-distinctive IR reflection spectrum. The Raman spectrum of diamond is characterized by one intense line at 1332.5 cm^{-1} *(Figure 3)* which helps to distinguish diamond from its numerous imitations.

As mentioned above, a laser may excite in the crystal not only the Raman-shift but also luminescence. The use of the latter extends the diagnostic potential of laser spectroscopy. The Raman spectra of two varieties of one mineral – yellow and green – are shown in *Figure 4*. It is obvious that the Raman spectra are identical and allow easy identification of the mineral as beryl. But their luminescence spectra differ greatly. Analyses show that the colour of the first sample is caused mainly by Fe^{3+} ions and the colour of the second by Cr^{3+} ions. The second sample can be identified as

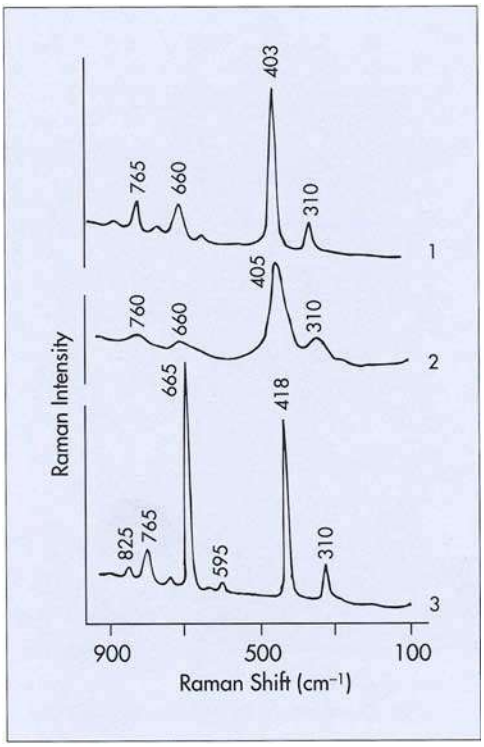

Figure 5: *Raman spectra of Mg–Al spinels: 1 natural; 2 and 3 synthetic.*

emerald. Therefore, the best laser diagnostics appear to be the simultaneous registration of two secondary glow components – the Raman and luminescence spectra. The crystal is easy to identify by means of the Raman spectrum, and data concerning the colour centres can be obtained from the luminescence spectrum.

III. Diffuse reflection spectroscopy in the UV/VIS/NIR range (200–2500 nm)

Absorption lines in the UV/VIS/NIR spectral range using diffuse reflection spectroscopy are caused by impurity or defect-impurity colour centres. These lines make it possible to diagnose some colour varieties of a mineral (for example ruby, emerald, pyrope). In general the spectra obtained in the UV/VIS/NIR range are used for colour studies and in some instances for origin determination of minerals (Platonov, 1976; Platonov *et al.*, 1984; Tarashchan, 1978). The diffuse reflection spectrum can be measured from a gem that is either loose or mounted in jewellery, provided it is larger than 2 mm^2; its shape and surface characteristics may vary as those found on natural crystals, cut gems, cabochons or beads.

IV. Origin determination for gemstones and a new approach to differentiating natural from synthetic gems by spectroscopic means

The problem of differentiating natural gems from their synthetic analogues requires an individual approach for each stone. The methods of Raman spectroscopy, IR mirror reflection spectroscopy or diffusion reflection spectroscopy in the UV/VIS/NIR range, either singly or in combination, are used. For example, it is simple to distinguish turquoise from its numerous imitations with IR mirror reflection spectroscopy *(Figure 2)* (Arnold and Poirot, 1975), natural spinel from its synthetic analogues with Raman spectroscopy *(Figure 5)*, and natural sapphire from its synthetic analogues with diffusion reflection spectroscopy in the visible range *(Figure 6)*. Ruby identification needs a combination of methods.

In studies of the Raman spectra of natural and synthetic zircons, the detailed spectral position of the line near 1008 cm^{-1} ($\Delta\nu$) has been plotted against its bandwidth at half height (γ) in *Figure 7*. A clear distinction between natural and synthetic zircons is demonstrated.

Using a combination of infrared, visible and ultraviolet reflection spectroscopy and Raman laser spectroscopy a range of colour-treated gems can be identified, including those coloured with chemical reagents (for example chalcedony and agate), thermally treated gems (such as corundum and zircon) and radioactively irradiated gems (for example, topaz, spodumene, citrine and amethyst). The fillings in glass-filled diamonds can also be determined.

V. Conclusion

Using a combination of spectroscopic methods, practically all gemmological objects can be identified (Reshetnyak and Tretyakova,

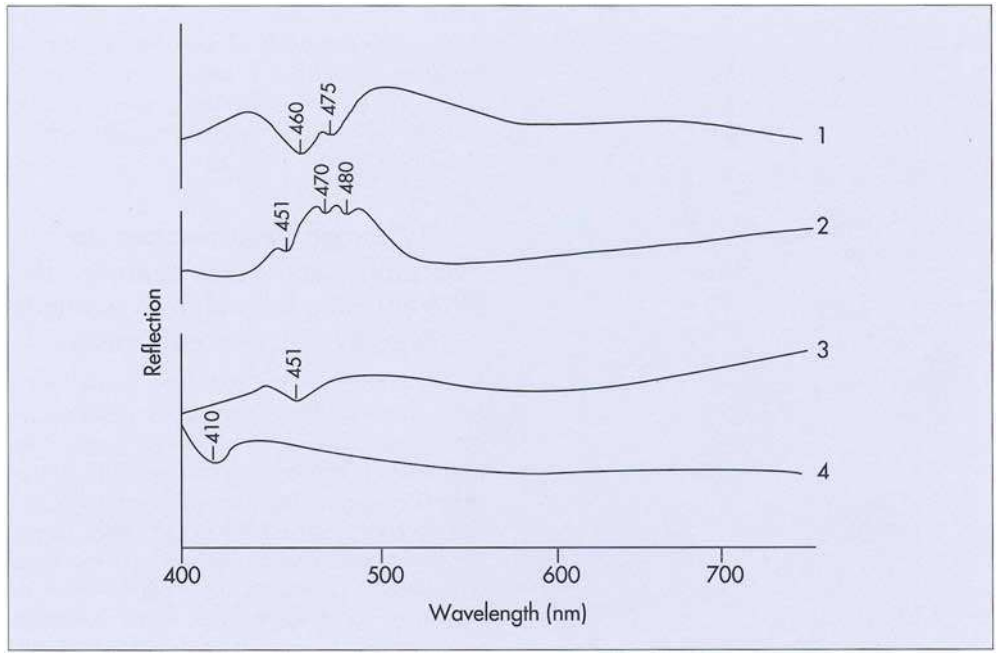

Figure 6: *Diffusion reflection spectra in the visible range of differently coloured natural and synthetic sapphires: 1–3 natural sapphires (1 green-blue, 2 violet, 3 blue); 4 synthetic blue sapphire.*

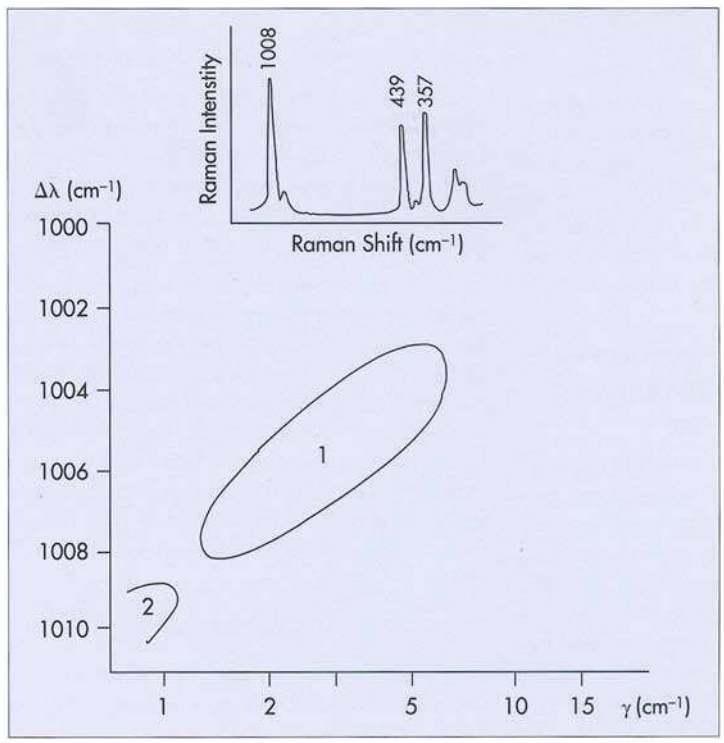

Figure 7:
The interdependence of the spectral position (Δν) and halfwidth (γ) of the Raman line vibration $\nu_2(B_{1g})$ = 1008 cm^{-1} in zircons of different genesis: 1 natural zircons, 2 synthetic zircons.

1994). With suitable safeguards, the methods are non-destructive and diagnostic, features which are very important during investigation of jewellery, museum exhibits, archaeological materials and antiques, because there is always a possibility that the original may be substituted by synthetics or simulants (Bank, 1973).

It is evident that the potential of these methods may be fully realized only when researchers have a comprehensive database of information on the Raman and reflection spectra for all gems (both natural and synthetic). For anisotropic crystals, the IR mirror reflection spectra of crystals in different orientations are needed also.

In support of these methods a database of IR mirror reflection and Raman spectra for 250 natural minerals and synthetic substances has been established; this is supplemented by diffuse reflection spectra in the UV/VIS/NIR range for colour varieties of these minerals.

Acknowledgements

The authors wish to thank Dr G. Christian Amshtutz (University of Heidelberg) and Natalia Pitomtseva (Saint-Petersburg Mining Museum) for discussion and some important remarks on the manuscript.

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Inclusions in synthetic rubies and synthetic sapphires produced by hydrothermal methods (TAIRUS, Novosibirsk, Russia)

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ABSTRACT: Synthetic rubies and synthetic sapphires are produced by hydrothermal methods in Novosibirsk (Siberia, Russia) by TAIRUS, a joint venture of the Russian Academy of Sciences and Pinky Trading Company, Bangkok, Thailand. The rubies and sapphires are grown at high temperatures and pressures in steel autoclaves from complex carbonate- and chlorine-bearing aqueous solutions. The different colour varieties imitate Burmese and Thai rubies, Sri Lankan 'Padparadscha' colours (orange or pinkish-orange) and Thai and Australian sapphires. Diagnostic fluid (three-phase inclusions) and solid (copper) inclusions are present. A simple heating and freezing test is provided to enable the gemmologist to distinguish the three-phase inclusions in synthetic rubies from their counterparts in natural rubies.

Keywords: synthetic rubies, synthetic sapphires, hydrothermal, solid inclusions, fluid inclusions, formation conditions

INTRODUCTION

Commercial production of synthetic ruby includes flame-fusion, flux-grown processes and hydrothermal growth methods, e.g. see Schmetzer, 1986 or Hughes, 1997. The latter, which reached its commercial production stage very recently (Peretti and Smith, 1993a,b), is related to the political transformations of the former USSR and its opening to the international market.

Previously, research laboratories in the USA, Japan, Russia, China and France have reported their experimental research on the production of synthetic hydrothermal rubies, see Belt, 1967; Kutznetsov and Shternberg, 1967; Marais, 1969; Kutznetsov *et al.*, 1968; Nguyen Duc Chinh, 1972; Weirauch and Kung, 1973; but significant commercial productions from these laboratories have not been made known. One of the authors (AP) first became aware of the recent commercial production of hydrothermal rubies in Russia in 1991, due to personal communication from Russian scientists. Not later than February 1993, synthetic hydrothermal rubies began to

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appear as fine faceted materials; they were first seen on the market in Bangkok (Thailand) and were marketed by the Pinky Trading Company (Bangkok), which has a joint venture (TAIRUS) with the Russian Academy of Science (Siberian Branch, Novosibirsk). Through this joint venture synthetic materials are now produced in Novosibirsk (Russia) and marketed in Bangkok and elsewhere.

Fundamental research on the production of synthetic gemstones was earlier carried out by different research laboratories in Novosibirsk (see published reports: Institute of Geology and Geophysics, 1986 and the USSR Academy of Sciences, Siberian Division, Novosibirsk Science Centre, 1987 a,b). Several products developed at one or several of these research centres have become well known in the gem industry; these include synthetic flux alexandrites (Schmetzer *et al.*, 1996), synthetic flux spinel (Mühlmeister *et al.*, 1993), synthetic flux emeralds, synthetic hydrothermal beryls of different colours, synthetic hydrothermal emeralds (Schmetzer, 1996) and synthetic diamonds (Shigley *et al.*, 1993; *Gem News*, 1994).

The different institutes in Novosibirsk were visited by one of the authors (AP) in August 1994, following an invitation of the Russian Academy of Sciences (Siberian Branch) at the opening of a new TAIRUS production facility in Novosibirsk. During this visit, it was possible to study the production of hydrothermal rubies and sapphires in an older TAIRUS facility. It was also possible to discuss with the Russian scientists the research data presented earlier by Peretti and Smith (1993 a,b), fluid inclusion analyses from one of the authors (JM), and analyses of materials growing over the rubies (whitish crusts). All these early preliminary data were obtained from faceted materials acquired from the open market in Bangkok. More recent productions were purchased from the market in Bangkok in late 1996 (see also: Banker, 1996 and 1997).

Figure 1: *A set of faceted synthetic rubies produced by hydrothermal methods. From left to the right, different colour varieties are shown, including colours imitating Thai rubies (type 1 and type 2, Table I), Burmese rubies (type 3, 4 and 5) and Sri Lankan rubies (type 6 and 7). Sizes of rubies around 1 ct each, largest are 1.6 ct and smallest 0.2 ct. These products were created by TAIRUS (Novosibirsk, Russia) and purchased in Bangkok (Thailand).*

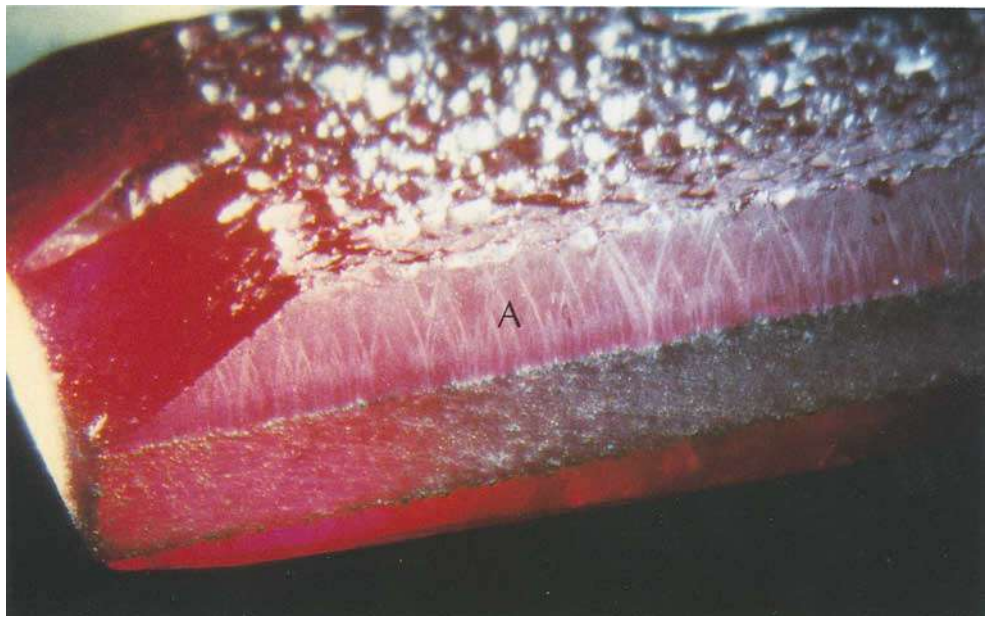


Figure 2: *Synthetic hydrothermal ruby of tabular habit. Note that the central portion of the rough synthetic ruby is covered with copper crystals and is produced by an earlier run (containing a very small colourless seed crystal, a slightly wedge-shaped plate which cannot be seen in this picture). A newly grown thick layer of synthetic ruby is overgrown. Note simultaneous growth in slightly different directions is created in the latest growth phase (see A). Thickness of the crystal is 5.5 mm.*

In a letter to the Editor of the *Journal of Gemmology* (Peretti and Smith, 1994), the distinction between synthetic rubies grown by flux and by hydrothermal methods was addressed. In this report, we concentrate on the inclusion properties of the hydrothermal synthetic rubies. A more detailed report on other gemmologically relevant properties, such as growth structures, chemical composition and the spectroscopic characteristics, will be presented in a successor to this paper (Peretti and Schmetzer, 1997, in prep.).

Materials

During 1993 and 1994, a series of rough and cut materials from different stages of corundum production were obtained through Pinky Trading Company in Bangkok. Prior to this, these kinds of rough materials were generally unavailable, but in February 1993 the authors were finally able to obtain three fragments of dark red rough, two containing very minor remnants of seed materials, and several faceted dark-red synthetic rubies.

In July 1993, two of the authors (AP and FM) obtained synthetic hydrothermal pink sapphires in Bangkok; they were marketed as the newest products with improved quality, particularly regarding the crystallinity of the materials, and weighed around 0.20 ct. Additionally, two rough fragments from production of synthetic hydrothermal dark-red rubies with whitish crusts and remnants of seed materials were acquired at that time.

The first complete crystals of synthetic hydrothermal dark red rubies with large variations in habit were studied at the Pinky Trading Company headquarters in Bangkok in 1994. Faceted synthetic rubies of various colours of approximately 1 ct (approximately 50 ct in total) were purchased in the second quarter of 1994 *(see Figure 1).*

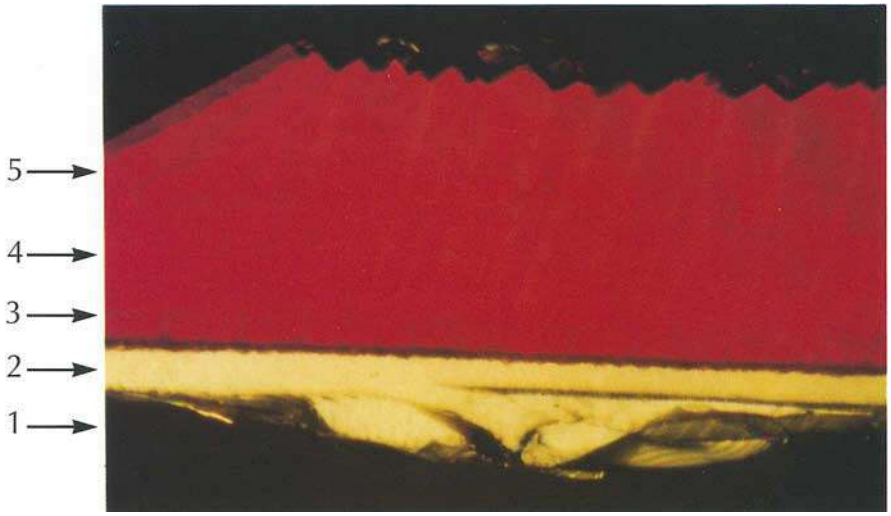
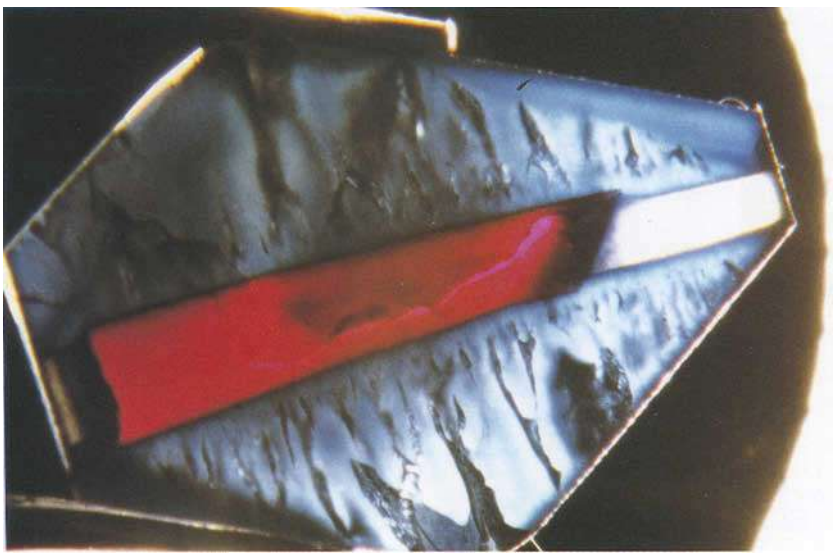


Figure 3: *Rough crystal with colourless seed and synthetic hydrothermal overgrowth. Note the irregular contact of the colourless seed with the synthetic ruby and the irregular ruby growth, the strong growth lines perpendicular to the seed crystal and the deposits of dust on the crystal on two different levels parallel to the seed crystal (phantoms of earlier growth stages). They are interpreted as indicating refilling of the autoclave and rerunning the experiments with the same crystals. In detail (from bottom to the top): the colourless seed crystal (1) is followed by synthetic white sapphire (2) and three synthetic ruby generations (3–5). Length of crystal section is 1 cm. Immersion, crossed polarizers.*

Figure 4: *A section through a rough crystal of a synthetic sapphire produced by hydrothermal methods (TAIRUS), cut perpendicular to the c-axis. The seed crystals are composed of Verneuil synthetic ruby overgrown by synthetic 'hydrothermal' white sapphire. Note the blackish irregular tubes that emerge in a direction perpendicular to the seed crystal within the synthetic sapphire portion of the rough crystal. Fluid inclusions are trapped in these tubes. Terminating crystal faces are prisms (11$\bar{2}$0). Diameter 1 cm. Transmitted light.*



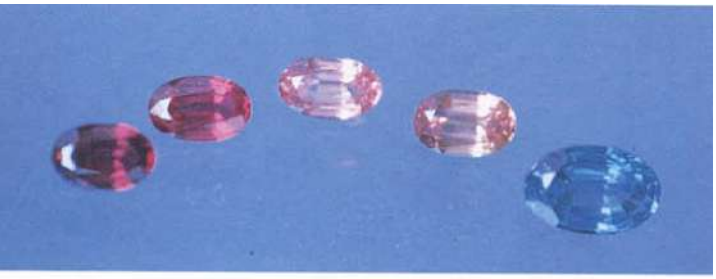


Figure 5: *Different types of synthetic rubies and sapphires produced by hydrothermal methods. From left to the right: approximately 1 ct each of dark-red and pinkish-red synthetic rubies (type 1 and 5, Table I), orangey-pink synthetic sapphire (imitating 'Padparadscha' colour) and orange synthetic sapphire (approximately 1 ct each, type 12 and 13, Table I) and a 2.65 ct large greenish-blue synthetic sapphire (type 10, Table I). TAIRUS products purchased in Bangkok.*

During our visit to the producing laboratory in Novosibirsk in August 1994, a range of complete synthetic hydrothermal crystals (mainly dark-red, *see Figures 2 and 3*) and synthetic hydrothermal sapphires were obtained for research purposes; these included first rough materials of synthetic hydrothermal dark blue sapphires *(Figure 4)* and synthetic pale-green sapphires produced by hydrothermal methods.

In December 1996 it was possible to purchase the newest production of various other hydrothermal synthetic corundums including rough orange synthetic sapphire (49.87 ct), faceted orange synthetic sapphire (1.18 ct), rough pinkish-orange synthetic sapphire (1.01 ct), and a newly manufactured intense greenish-blue sapphire (2.65 ct) *(Figure 5)*. Also, a large rough crystal of the intense greenish-blue sapphire was investigated in Bangkok.

Technical details of the production methods

A hydrothermal process for the production of synthetic corundum was patented by Bell Telephone Laboratories, US Patent 2,979,413; 1961 (see Ballmann *et al.*, 1961; Yaverbaum, 1980). This process may be summarized as follows.

A furnace and an autoclave *(Figure 6a)* consisting of a bomb tube without a liner or with one or two internal liners are used. The inner volume can be divided by a baffle into two chambers. The growing chamber contains seed crystals and the nutrition chamber contains solid nutrients, such as aluminium oxide, aluminium hydroxide or even crystalline corundum. Aqueous solutions with dissolved sodium carbonates are described as the most effective transporting media for dissolved alumina in the above literature. But other carbonates may be used as well *(Figure 6b)*.

The furnace produces the necessary heat and temperature gradients between the two chambers in order to create a convection current for the transportation of dissolved

Figure 6a: *The steel autoclave used for the production of the synthetic hydrothermal rubies in Novosibirsk (Siberia, Russia) in 1994. The weight of the autoclave is about 25 kg, the length is about 50 cm, the inner diameter is about 3–4 cm with slightly smaller estimated thickness of the steel walls. Inner liners of gold or platinum are fitted for production of Fe-free products, but their use is rare.*

alumina to the crystal seed located in the lower temperature chamber. Critical parameters for the growth of hydrothermal rubies include the nature of the mineralizer, the shape of the seed, the crystallographic orientation in the seed, the chemical composition of the aqueous solutions, the temperature gradients, the absolute maximum temperatures and the pressures reached in the autoclave. Such technical details as the permeability of the baffle and the volume of the autoclave filled by aqueous solutions (filling grade) must also be considered. The chemical composition of those parts exposed to the corrosive solutions is also critical. It may be necessary to cover the autoclave with precious metals such as silver, platinum or gold. Because the solutions will corrode iron, plating the interiors may be preferred if iron contamination of the growing crystals has to be minimized.

Recrystallization of pure aluminium oxide (corundum) under hydrothermal conditions is relatively easily carried out in solutions of alkali-metal-carbonates and bicarbonates (e.g. Na_2CO_3, K_2CO_3, Rb_2CO_3, $NaHCO_3$, $KHCO_3$). However, the formation of ruby, which also requires a solubility of chromic oxide in the same solutions, is much more difficult (see Kuznetsov and Shternberg, 1967). Ruby formation was, for example, successfully carried out in KCO_3- and $KHCO_3$- rich solutions by Kuznetsov and Shternberg (1967). Variations in the Cr_2O_3 concentrations were investigated by variations in other ingredients such as $KClO_3$, K_2SO_4, C_6H_6, and various hydroxides (Kuztnetsov *et al.*, 1968). Ballmann and Laudise (1963) have reported the production of rubies in aqueous solutions by adding sodium dichromate.

Table 1. *Characterization of different colour varieties of synthetic rubies and sapphires produced by hydrothermal methods on the basis of colour appearance, comparison with colours of natural rubies and UV-fluorescence. (Refractive indices as for other synthetic or natural equivalents.)*

Type	*Colour*	*Fluorescence under 365 nm radiation*	*Imitating*	*Remarks colouring trace elements**
1	very dark-red	weak red	Umba Valley (African) ruby	Cr very high, Fe high
2	dark red	medium red	Thai ruby	Cr high, Fe medium
3	intense red	strong red	Burmese ruby	Cr very high, Fe low
4	red	strong red	Burmese ruby	Cr high, Fe low
5	pinkish red to red	very strong red	Burmese ruby	Cr high, Fe free
6	purplish-pink	medium red	Sri Lankan purplish-pink-sapphire	Cr medium, Fe medium
7	pink	medium red	Sri Lankan pink sapphire	Cr low-medium, Fe medium
8	dark-blue	none	Thai or Australian sapphire	Fe very high, Ti low
9	pale greenish-blue	none	no equivalent	Ni low, Fe low
10	intense greenish-blue	none	no equivalent	Ni medium, Fe low
11	pale-green	none	no equivalent	V medium, Fe low
12	orangey-pink	medium-strong red	Sri Lankan 'Padparadscha' colours	Cr low, Fe low
13	light orange	medium red	Sri Lankan 'Padparadscha' colours	Cr very low to low, Fe low

N.B. 1. values in last column: low = 0.05–0.15, medium = 0.15–0.50, high = 0.5–1.0, very high = 1.00–2.00 oxide wt-%. 2. types 9 and 11 only seen as rough materials. 3. *for more details see Peretti and Schmetzer (in prep.)

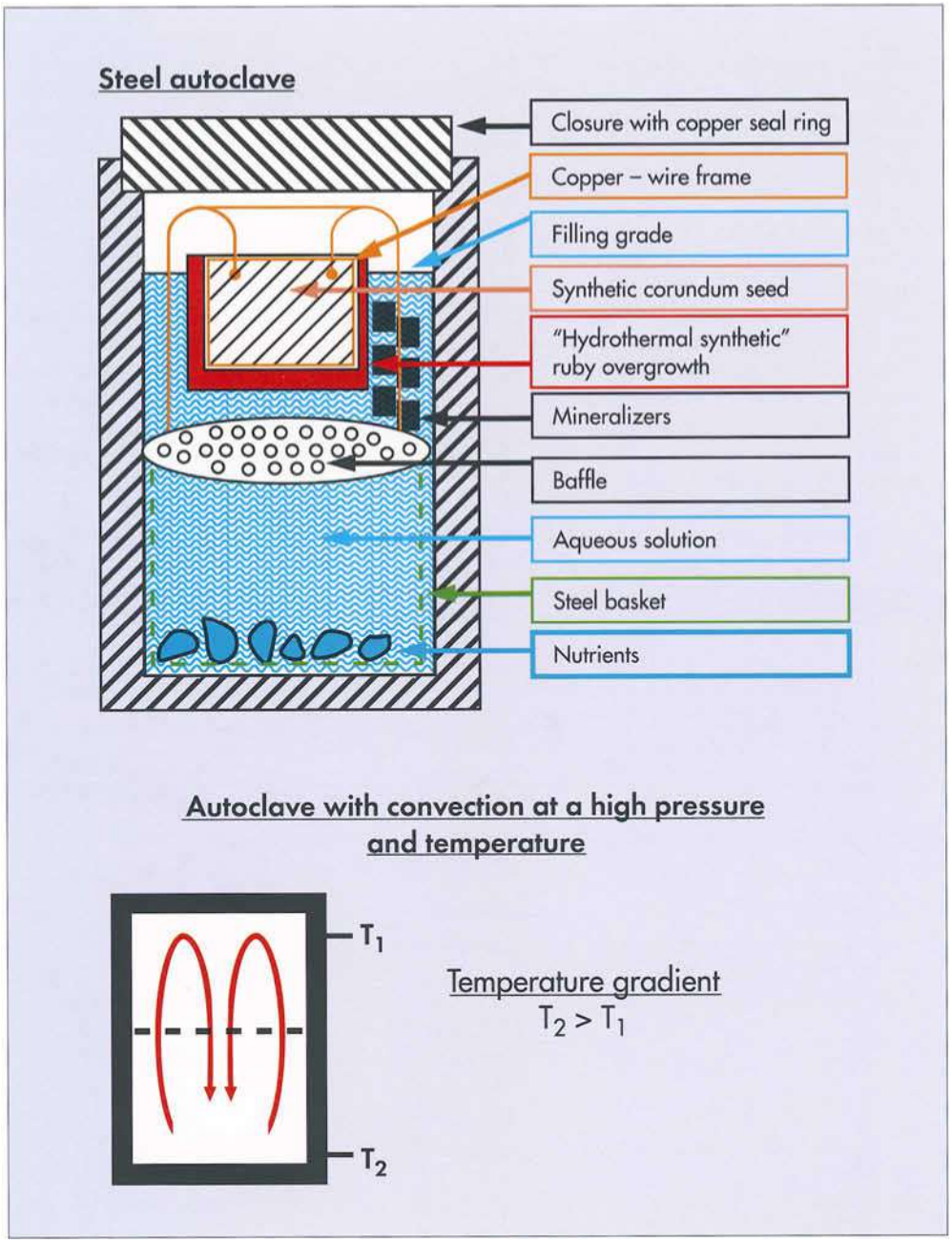


Figure 6b: *Simplified diagram of an autoclave used for producing hydrothermal synthetic ruby (after Ballmann* et al., *1961). Quantity of aqueous solution is indicated by the stippled area (filling grade). On heating, the solution will homogenize and fill the autoclave and above a certain temperature will produce internal pressure. Convection in the autoclave is produced by a temperature gradient. Mineralizers such as carbonates or chlorides are used to form metal complexes with Al and Cr-bearing nutrients and these can be transported to seed crystals in aqueous solutions. (Graphics by D. Mathys.)*

Visual appearance

The stones in this study possessed colours reminiscent of natural rubies from Thailand, Sri Lanka, Burma and Vietnam. The red hue of the synthetic rubies consisted of variable saturations, with tones ranging from medium to dark *(Figure 1, Table I)*. Orange and pinkish-orange synthetic sapphires imitate quite well the natural 'padparadscha' sapphires. The intense greenish-blue sapphires do not have natural colour equivalents *(Figure 5)*. Dark-blue colours are very similar to those natural counterparts which are found for example in Thailand, Australia or Vietnam (basaltic sources) (see also Bank *et al.*, 1996). The synthetic sapphires of weak greenish colours show a colour change to purplish-violet in tungsten light.

As described by Peretti and Smith (1993 a,b), some stones had a reduced transparency which had the effect of making the sharp facet edges of the pavilion appear diffuse when viewing the stones face-up. This effect was reduced in more recent productions which were characterized as 'Burmese-type colour' synthetic rubies or as 'Sri Lankan type colour' synthetic pink sapphires *(see Table I)*. No macroscopic colour zoning was present.

Inclusion analysis

A. Coatings on rough synthetic rubies and sapphires

Whitish crusts were found on different types of synthetic hydrothermal rubies and synthetic hydrothermal sapphires, mostly concentrated in indented naturals *(Figure 7)*. They were chemically analyzed by SEM-EDX using a Philips SEM 515 and a Jeol JSM6300F electron microscope at the University of Basel. The samples were coated with gold or carbon and the acceleration voltage mostly used was 20keV.

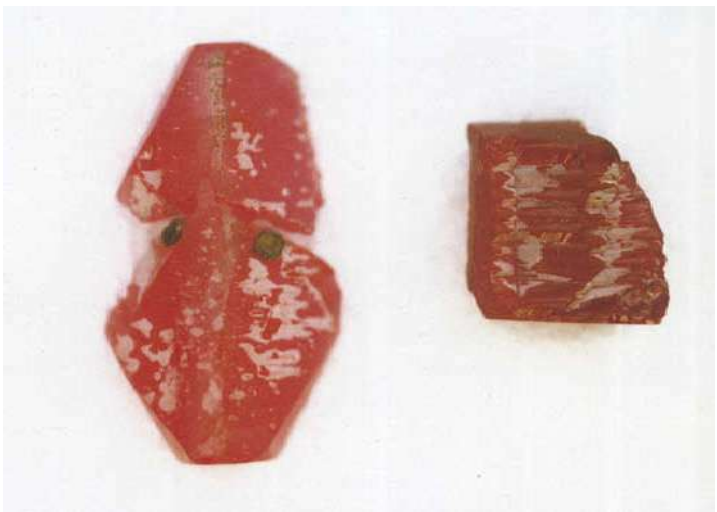
It was found that the whitish crusts have at least two different compositions:

1. *well crystallized materials* consistent with an Al-hydroxide and identified as boehmite *(see Figure 8a)* by X-ray determinations and
2. *irregular flakes or grains of amorphous appearance* and complex chemical compositions *(Figure 8b and Table IIa)*, (most probably *non-crystalline gel-like materials*). These irregular grains were formed on the top of the Al-hydroxides.

The chemical compositions of these minor amorphous or gel-like materials were determined by SEM-EDX-analysis and consisted of various combinations of the elements sodium (Na), calcium (Ca), potassium (K), carbon (C), oxygen (O), silicon (Si), barium (Ba), iron (Fe), copper (Cu), sulphur (S), chlorine (Cl), aluminium (Al) and phosphorus (P). Different particles of highly complex chemical compositions were found as overgrowths on different synthetic ruby generations *(Figures 8a, b and Table IIa)*.

These crusts are interpreted as depositions from oversaturated hydrothermal solutions, most probably formed at the end of the hydrothermal runs during cooling *(see Figures 8a, b)*. Corundum is thermodynamically stable in alkaline aqueous solutions above 400°C rather than diaspore (see Ballmann and Laudise, 1963). During cooling, however, diaspore or boehmite can be formed and may

Figure 7: *Synthetic rough rubies of two different varieties as defined in Table I (type 5 on the left and type 2 on the right side). Both rubies are coated with whitish crusts, which are deposited at the end of the hydrothermal runs. The rough fragment on the left shows in addition relicts of copper-wires which are used for the mounting of the seeds in the autoclaves.*



be precipitated on the surface of rough synthetic rubies and sapphires.

Based on the analyses of different generations and varieties of the synthetic materials by XRF-EDX as well as SEM-EDX *(Table IIa, b)*, it is concluded that different compounds were used during the production of hydrothermal ruby. The different chemical compounds may have been used (see Ballmann and Laudise, 1963; Kuznetsov and Shternberg, 1967; Kuznetsov *et al.*, 1968), for such purposes as:

- the joint transportation of aluminium and chromium in the solutions
- the production of different colour varieties
- optimizing the growth rates for commercial reasons
- optimizing the crystal habit

B. Solid inclusions in synthetic rough and faceted rubies

Different types of solid inclusions were found in rough as well as faceted materials

Figure 8: *SEM-images of the whitish crusts (synthetic hydrothermal ruby, types 2 and 12, Table I). Samples are gold-coated. The particles are mainly composed of boehmite with minor overgrowth of very poorly crystallized particles. Details: a) Well crystallized boehmite on the surface of a rough synthetic sapphire created by TAIRUS and a SEM-EDX-spectrum. b) Example of a Cu-chloride particle and poorly crystallized chloride-carbonate particles found in the crusts and their SEM-EDX spectra (see Table IIa).*

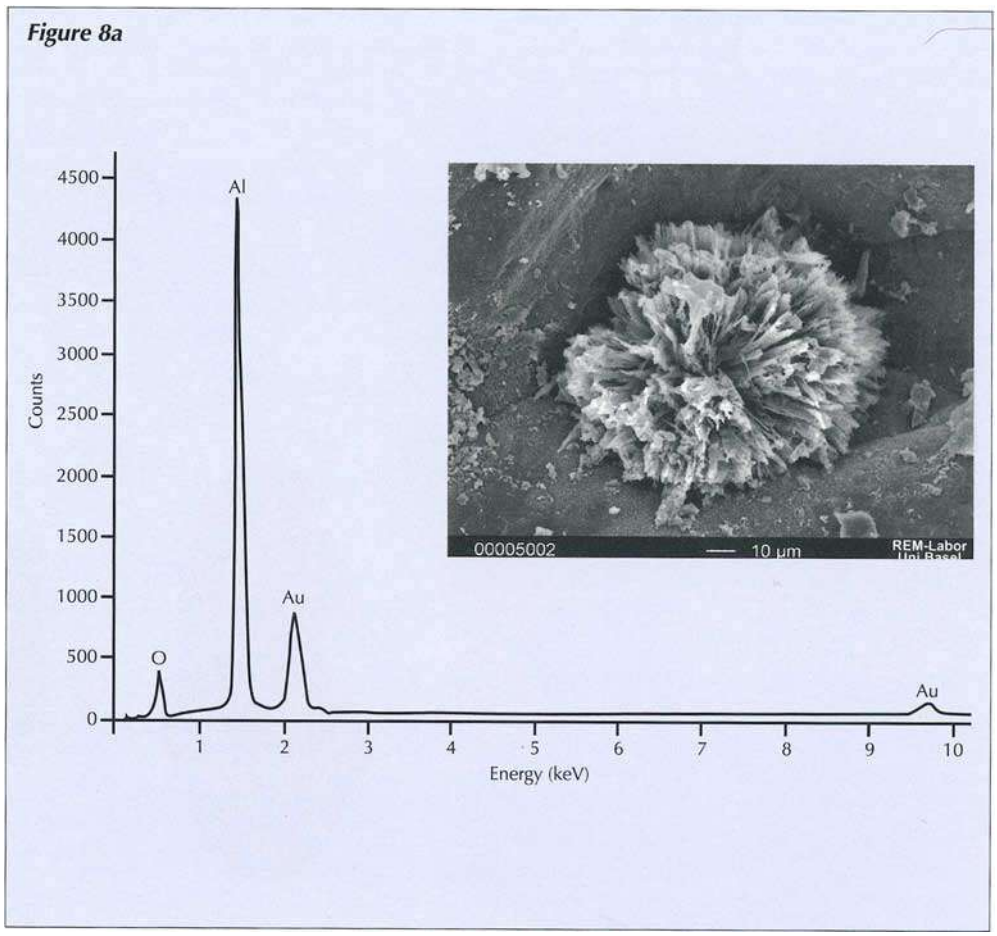
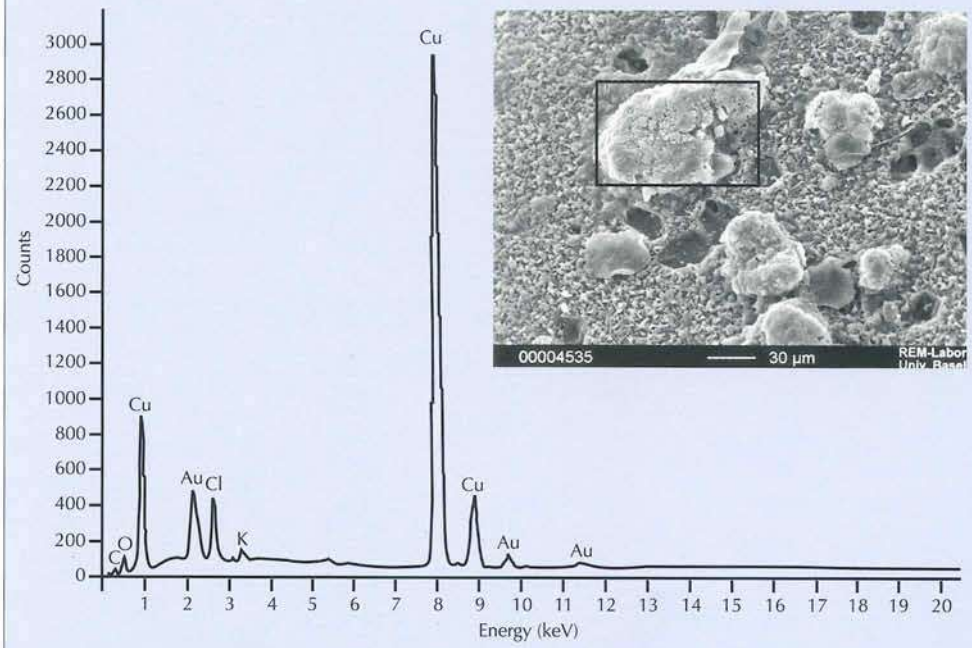


Figure 8b


Counts
Energy (keV)
Cu
Au
Cl
K
O
C
00004535
30 µm

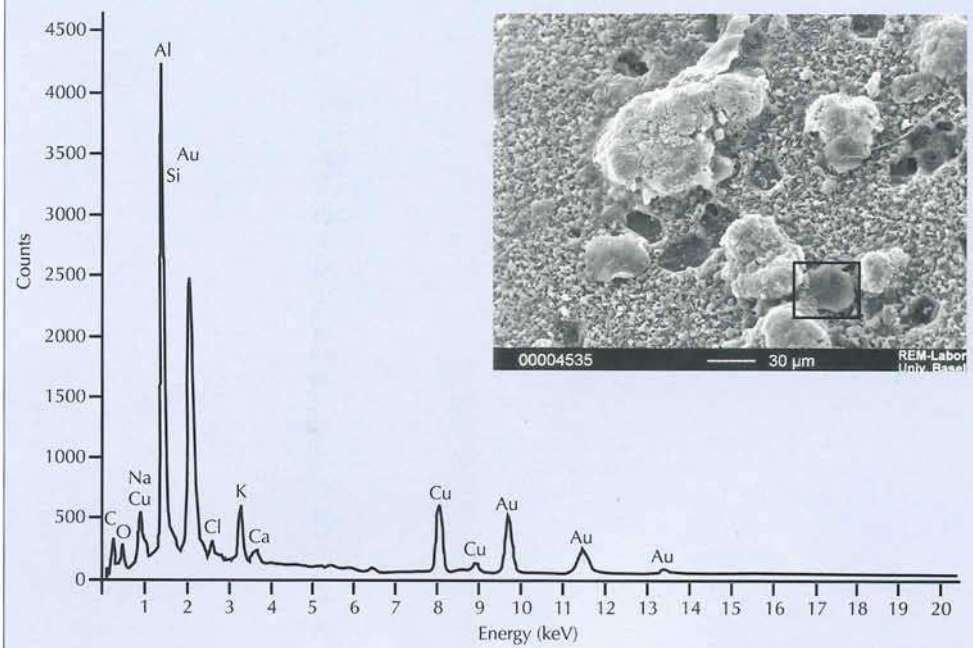

Counts
Energy (keV)
Al
Au
Si
Na
Cu
C
O
Cl
K
Ca
Cu
Au
00004535
30 µm

Table IIa. *Chemical analyses of whitish crusts covering synthetic rough hydrothermal rubies (products of TAIRUS). Qualitative SEM-EDX analyses of isolated 'gel-like' particles found on the surface of various rough synthetic ruby and sapphire materials.*

Colour	Type	C	O	Al	Na	K	Ca	Cl	Mg	Ba	Si	S	Cu	Fe
Orangey-pink	13	x	x	x	x	x	x	x			x			
Pinkish-red	5	x	x	x	x	x		x		x	x		x	
(Figure 7 left)	5	x	x	x		x	x	x	x		x			
Red	2	x	x			x	x				x			x
(Figure 7 right)	2	x	x	x		x		x						x
Intense red	2	x	x	x	x	x	x					x		

Table IIb. *Semi-quantitative analyses of crusts by XRF-EDX using a Tracor Northern TN5000 system at the University of Basel (Prof. W. Stern). Carbonates, hydroxides, chlorides and other substances may contribute to the analyses.*

Sample (ct)	Colour	Type	K	Na	Ca	Si	Cl	S	P
53.56	orangey-pink	13	x	(x)	x		x		
37.47	red	2	x	x	(x)	x	x	x	x
1.15	red	2	x		x		x	x	
1.48	red	2	x		x	x	x		
1.31	red	2	x	(x)	x		x		
2.4	red	2	x	x	(x)		x		
1.52	red	2	x	x	(x)	x	x		
1.29	red	5	x	x	x		x		
5.35	red	2	x	(x)	(x)	x	x		

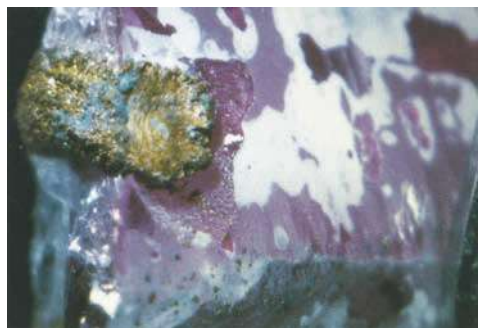
(x) = relatively minor concentrations

and characteristic opaque solid inclusions have been found in all the different colour varieties.

Irregularly shaped, highly reflecting opaque inclusions

Remnants of copper-wires, strongly corroded by the hydrothermal solutions, were found in rough ruby crystals *(Figures 7, 9 and 10)*. These fragments were of irregular shape and may be found as inclusions in faceted synthetic ruby (Peretti and Smith, 1993a,b). Some of the corroded fragments were composed entirely of copper (Cu), but others also had minor amounts of iodine (I) and sulphur (S) (Peretti and Smith, 1993 a). Copper chlorides were found as corrosion products on copper wires *(see Figures 8b and 9)*.

Figure 9: *Corroded copper wires are found as relicts in rough synthetic hydrothermal rubies (type 5, Table II). In addition to this diagnostic feature, characteristic whitish crusts are present. Corroded fragments of the copper wires are included in the synthetic ruby crystal near the copper wires (e.g. copper-chlorides). Diameter of copper wire is approximately 1.5 mm. Fibre optic illumination, reflected light.*



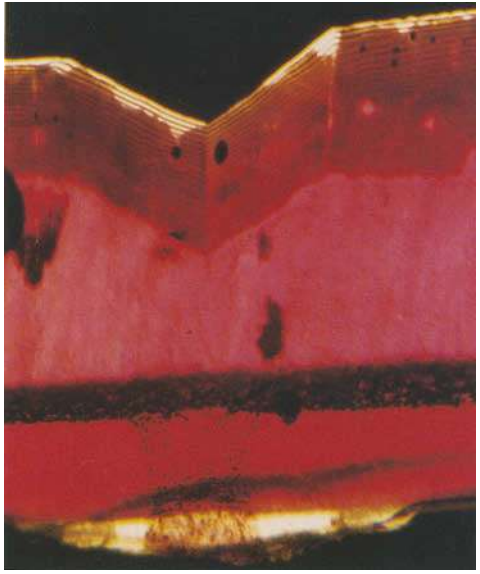


Figure 10: *Section through synthetic ruby rough with the following characteristics from bottom to top: synthetic white corundum seed, first generation of synthetic ruby with cloud of copper inclusions, second generation of synthetic ruby (cloud of copper inclusions discordantly cut off). Note that copper inclusions in the ruby are concentrated at the contact to the previously present copper-wires. The different colour concentrations of the synthetic ruby were most probably produced in different runs.*

Idiomorphic highly reflecting opaque inclusions

Another type of copper inclusion is composed of well shaped isometric crystals or hexagonal platelets consisting predominantly of copper (Cu) with minor amounts of iron (Fe), nickel (Ni), titanium (Ti) and chromium (Cr) (Peretti and Smith 1993a,b). Large amounts of copper crystals were found at the initial stage of the ruby growth at the seed contact *(Figures 2, 11, 12 and 13).* Isolated single crystals with this type of copper inclusion or cloud can be found in the crystal during later growth phases.

Other solid inclusions

In addition to the various types of copper inclusions, whitish reflecting particles the size of pinpoints were found. They appear as clouds of isolated pinpoints or occur as linear series of pinpoints (especially in the pinkish synthetic products). Extremely small needles, as yet unidentified, have also been detected in these areas. Larger whitish particles are found in the intense greenish-blue synthetic sapphires.

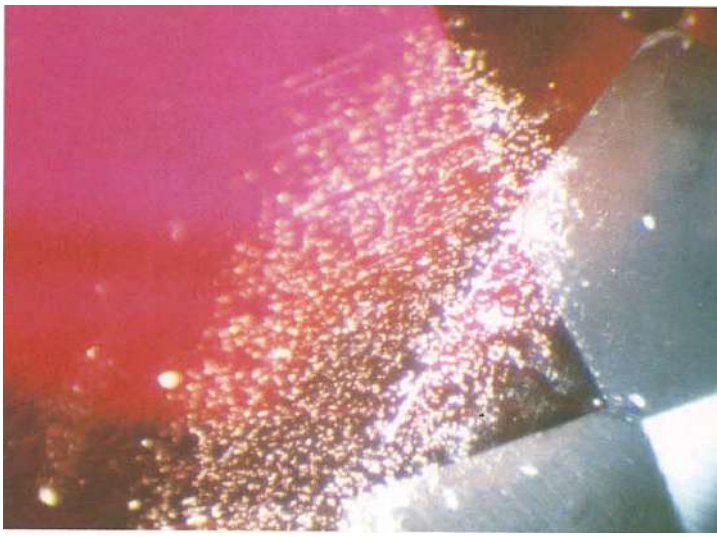
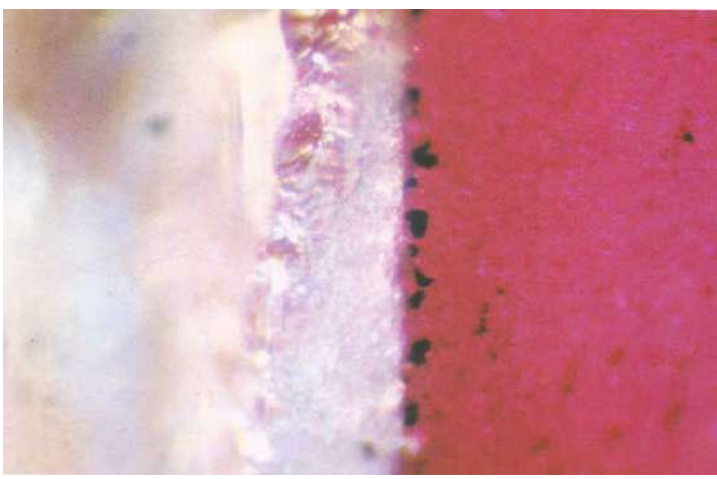


Figure 11: *Solid inclusions in a faceted synthetic hydrothermal ruby occurring as dense clouds. They occur as enrichments parallel to the original seed crystals. In this sample the seed has been cut off during faceting and only the copper enrichments close to the original seed crystal remain. Transmitted and reflected light. Fibre optic illumination. Magnification 75x.*

Figure 12: *Contact zone between a colourless synthetic sapphire seed and the overgrown synthetic hydrothermal ruby. Note the presence of opaque solid inclusions which are concentrated at the initial growth phase of the synthetic hydrothermal ruby close to the seed crystal. Magnification 120x. Transmitted light.*



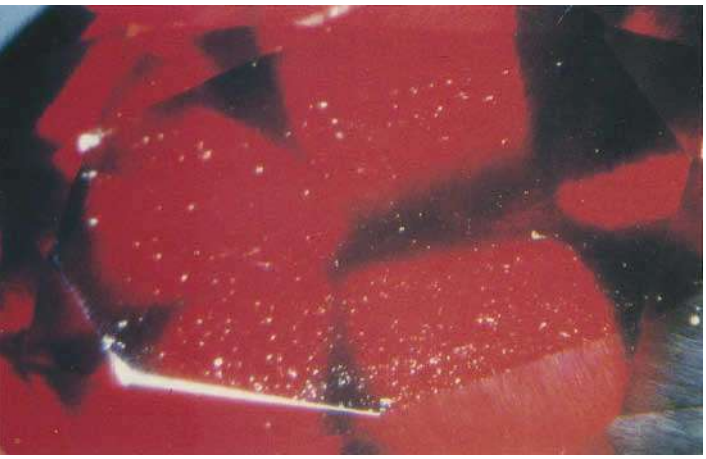


Figure 13: *Isolated copper inclusions in a synthetic hydrothermal ruby. Transmitted and reflected light. Classification of material as type 1 (Table I). Note also the diffuse facet edges as seen through the crown. This is due to irregular growth structures which are present in the rubies.*

Figure 14a: *Series of partially healed cracks in a rough ruby (polished thick section). Reflected and transmitted light, fibre optic illumination. Length of shown portion of the crystal is 5 mm (type 5, Table I).*

Figure 14b: *Partially healed crack extending into the colourless synthetic sapphire seed (polished thick section). Reflected and transmitted light, fibre optic illumination. Length of shown portion of the crystal is 3 mm (type 4, Table I).*

Figure 14c: *Fluid inclusion feather with trapped aqueous solutions in a faceted synthetic pink sapphire (type 7, Table I). In larger cavities, three-phase inclusions can be identified (see Figures 16 to 18). Note the irregular shape and the isolated occurrence of the single tubes and the similarity of the appearance of this type of fluid inclusion feathers with those found in natural rubies. Weight 0.22 ct, immersion, crossed polarizers, magnification 200 x.*

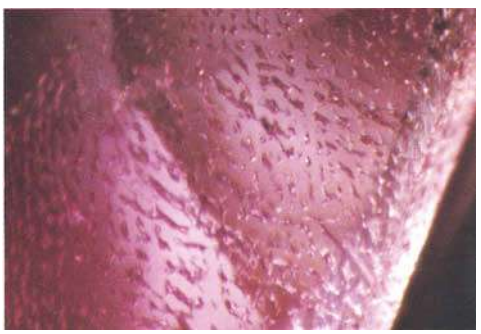


Figure 15: *Large negative tubes found in faceted synthetic 'hydrothermal' ruby (type 5, Table III). Note the irregular walls of the tubes. Weight of ruby is 0.95 ct, magnification 100 x, transmitted and reflected light, fibre optic illumination.*

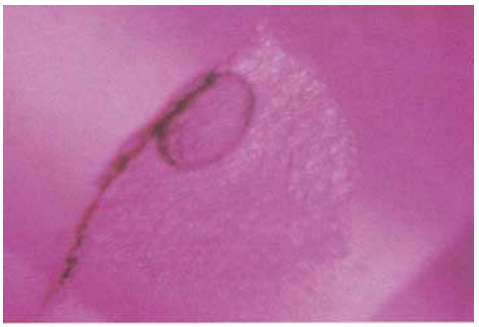


Figure 16a: *Three-phase inclusion in a negative crystal of a faceted synthetic hydrothermal ruby of 0.95 ct (type 5, Table III). The three phases are composed of H_2O liquid, H_2O vapour and a solid crystal (most probably a calcium-carbonate). Transmitted light, fibre optic illumination, magnification 200 x.*

Interpretation

The origin of the copper inclusions lies in the dissolution and corrosion of copper materials used in the autoclave, such as seals and copper wires *(Figure 7)*. The contamination of copper crystals by Fe and Ti may originate from other ingredients in the solutions or from corrosion of the steel autoclave. This is confirmed by the presence of Fe-chloride particles on the surfaces of some rough synthetic rubies.

The whitish particles are interpreted as resulting from contamination from the mineralizers, such as alkali-carbonates or calcium-carbonates.

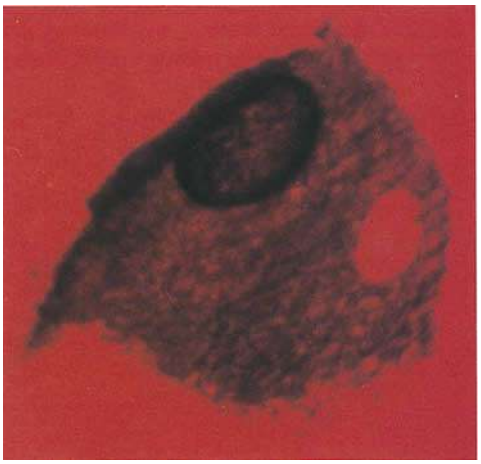


Figure 16b: *Three-phase inclusion of Figure 16a as seen in immersion with crossed polarizers. The solid phase is more clearly visible because it is birefringent.*

C. Fluid inclusions

In the early production of synthetic hydrothermal rubies, healed fracture systems resembling fingerprint inclusions were observed (Peretti and Smith, 1993a, b). Such fingerprint inclusions also occurred in later productions of different crystalline quality and colour *(Figures 14c and 15)*. Series of partially healed cracks occur in rough samples *(Figure 14a)* and some extend into the seed materials *(Figure 14b)*. This indicates that synthetic rubies were intentionally thermally shocked to produce fractures which were later repaired hydrothermally (see Koivula, 1983). In the pinkish-red to red synthetic hydrothermal rubies (Burmese-type imitations) more recently purchased (1994), however, relatively large three-phase inclusions were detected. These are composed of a liquid, a vapour and a solid daughter mineral *(Figures 16a, b)*. The three-phase inclusions are associated with the formation of large tube-like negative crystals *(Figures 4 and 15)*. Optical testing in

Table IIIa. *Phase transformations observed during the heating and freezing runs on two different samples A and B with different fluid populations (FP)*

Sample No.	Fluid Inclusion Population	Inclusion Type	Number of inclusions studied	V(%)	Temperature of first melting	Melting temperature of ice	T (melt, solid II)	T (hom)
A	1	I, II	10	10–12	–22	–5.9 –6.0; –5.8	44	346 345; 347
B	1	I, II	14	10–15	–22	–6.1; –6.2; –6.0	51; 50; 52	decrepitated
	2	I, II	16	10–15	–12	–5.2 –5.4; –5.0	50	363 359; 367
	3	I, II	7	10–15	–13	–5.4 –5.4; –5.3	36 36; 38	357 356; 358

Inclusion type — I: primary fluid inclusions; II: secondary fluid inclusions
V% — Volume % of the volatile part at room temperature
Melting temperature of ice (°C). — First number: mean value; second and third number: extreme values
T (melt, solid II) — Temperature of salt melting of solid II
T (hom) — Homogenization temperature of fluid inclusions (°C) to the liquid phase

Table IIIb. *The derivation of the chemical composition based on the observed phase transformations of ruby type 5 (Table I) on two different samples A and B.*

Sample No.	Fluid population	NaCl (wt%) a	KCl (wt%) b	$Na_2CO_3H_2O$ (wt%) c	$KHCO_3$ (wt%) d	$CaCO_3$ (wt%) e
A	1	9		32	32	3–6
B	1	9 equiv.		33	35	3–6
	2	0	8		34	3–6
	3	0	8		30	3–6

a NaCl is derived from T melt (ice) (at T eutectic of –22°C) as NaCl-equivalent after Potter *et al.* (1978)
b KCl is derived from T melt (ice) (at eutectic of –13 to –12°C) after Schäfer and Lax (1962)
c $Na_2CO_3 \cdot H_2O$ appears as yellow crystals after cooling. Its T (eutectic) is –2.1°C ($Na_2CO_3 \cdot H_2O$) lowering slightly the eutectic of NaCl from –20.8 to –22°C
d $KHCO_3$ appears as violet crystals within fluid inclusions after cooling down to –120°C. Its T (eutectic) of –5.43°C lowers slightly the T (eutectic) of KCl from –10.6°C to about –13°C
e Small anisotropic white solid crystals of 2–4 vol.%, which are insoluble at T of 400°C, are interpreted as $CaCO_3$ (density of 2.6–2.8 g/cm³)
All data after Schäfer and Lax (1962) if not otherwise stated

immersion liquids under crossed polarizers showed that the daughter minerals are optically anisotropic *(Figure 16b)*, which is consistent with their identification as carbonates (see freezing/heating experiments).

In order to obtain further information on the chemical composition of the fluids and to further identify the solid daughter minerals within fluid inclusions, fluid inclusion analyses were carried out using a Chaixmeca freezing and heating stage mounted on a transmitted light microscope, designed to work in the range of –180°C to 600°C (Poty *et al.*, 1976). After freezing to –120°C, the inclusions were slowly heated at a constant rate of 1–2°C/min. Temperatures were calibrated with the triple points of distilled water (0.0°C) and various chemicals of high purity (hexane and pure CO_2-bearing fluid inclusions). Calibration at high temperatures was made with appropriate chemicals from the Merck Corporation. The uncertainty of the measurements was about ±0.1°C for –60 to

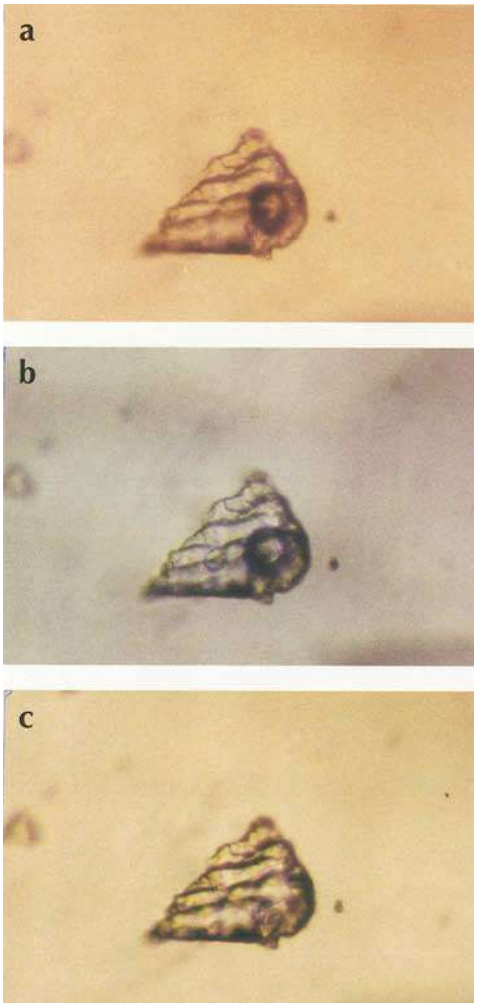


Figure 17: *Microphotograph of a three-phase inclusion at different temperatures. Inclusion found in a synthetic hydrothermal ruby of 0.64 ct (type 2, Table I). Transmitted light, picture length is 270 µm. Three temperatures are selected as examples (a–c). a) At –100°C. the inclusion at this temperature is composed of probably calcite, ice and H_2O vapour. The vapour bubble is deformed (compare with Figure 17b) due to the expansion of ice during freezing. b) At +30°C; at this temperature the inclusion is three-phase with solid phases (carbonates), a liquid phase (H_2O-rich) and a vapour phase (H_2O). c) At +350°C; the inclusion at this temperature is composed of a homogeneous liquid aqueous solution with a calcite daughter mineral (not visible here, see Figure 16b).*

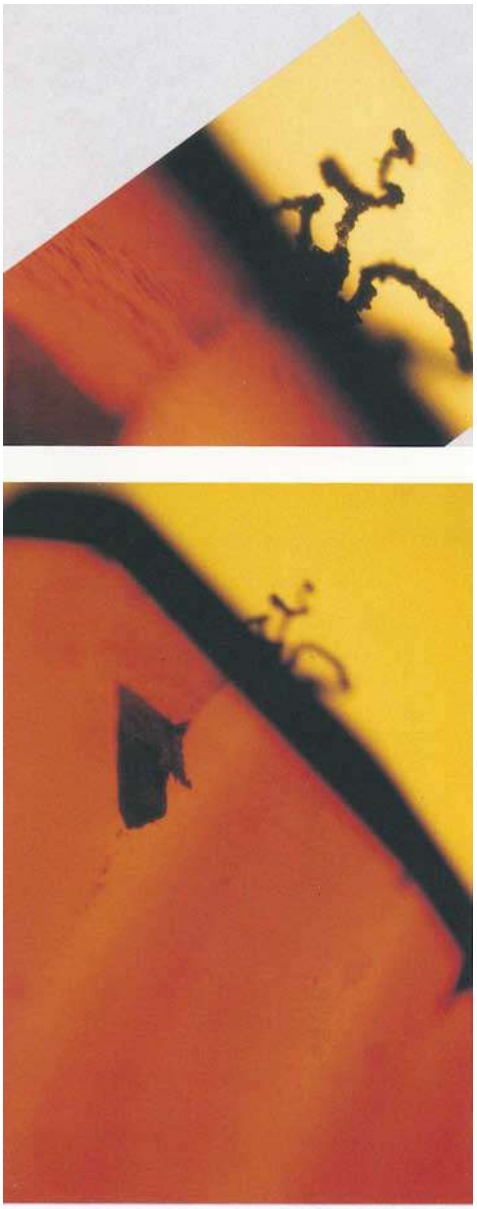
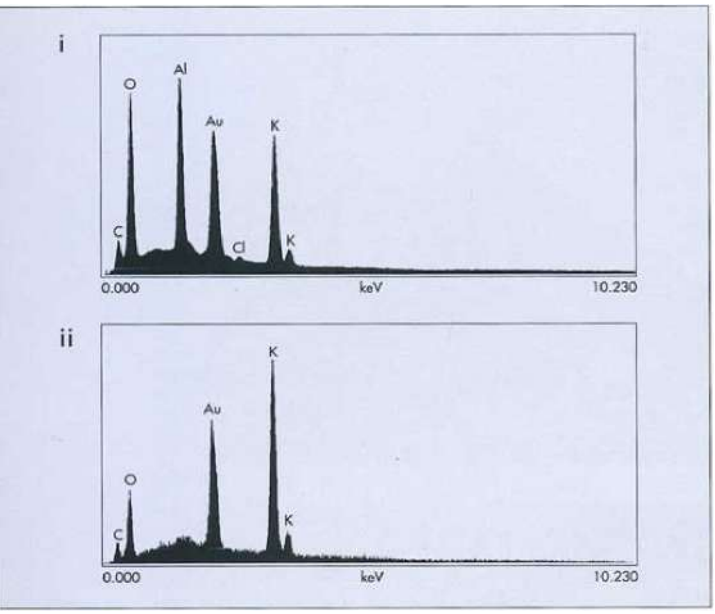


Figure 18a: *Thin section of a faceted synthetic ruby with fluid inclusion and after fluid inclusion analyses. The 'worm-like' solid materials on the surface of the ruby were formed from decrepitation of fluid inclusions during heating above 300°C, the escape of the fluids to the surface after decrepitation, the immediate drying of the aqueous solutions and the contemporaneous crystallization of the original dissolved materials.*



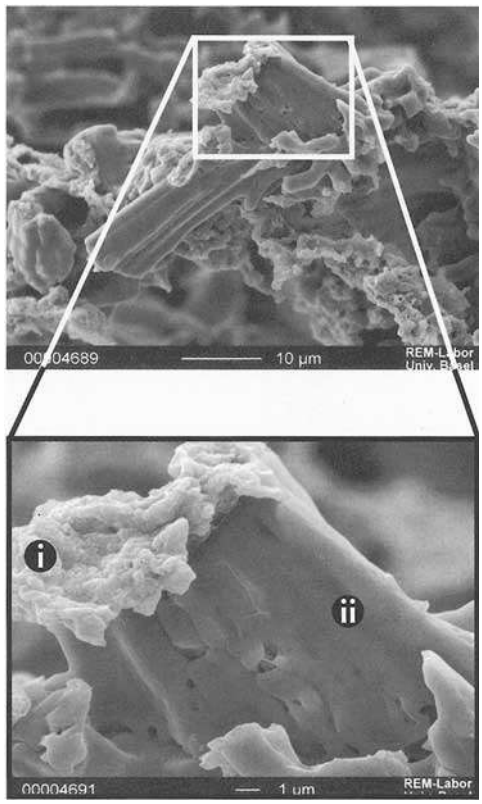


Figure 18b: *The chemical analyses (SEM-EDX, Au coating) in combination with fluid inclusion analyses showed that the worm-like aggregates formed after decrepitation are composed of: 1) about 90 per cent potassium bicarbonate ($KHCO_3$) and 2) about 10 per cent of potassium aluminium carbonate.*

40°C and ±1°C outside this range. Two faceted ruby samples were cut and polished to obtain parallel plates suitable for quantitative microthermometric investigations.

The results are given in *Table II*. In sample A *(Table III)*, only one fluid inclusion population was detected, whereas in sample B, three different inclusion populations could be recognized. The earliest inclusion population (1) in every ruby sample contains a NaCl-dominated fluid with 9 wt-% NaCl equivalents and 32 to 35 wt-% $NaCO_3 \cdot H_2O$ or $KHCO_3$. Fluid inclusion populations 2 and 3 of sample B are characterized by 9 wt-% KCl and 30 to 34 wt% $KHCO_3$. In addition fluid inclusions of every population contain 3 to 6 wt% of calcite as small daughter minerals. Complete microthermometric results are given in *Table III* and are discussed in detail below.

Example of a heating and freezing run and observed phase transformations in a synthetic ruby sample (Figures 17a–c and 18c)

1. At room temperature, a H_2O-vapour and a solid 'I' (daughter mineral) are present;
2. –120°C: ice, water-vapour and a second violet daughter mineral are present (see deformed gas bubble, *Figure 17a*);
3. –12°C: first melting of the ice;
4. –5,2 ± 0.2 °C: final melting of the ice; the two daughter minerals are still present *(Figure 17b);*
5. +50°C: melting (i.e. dissolution) of the violet solid daughter minerals (solid 'II');
6. above 60°C: the multiphase inclusion, as seen at lower temperatures, has been transformed to a 3-phase inclusion (liquid and vapour of H_2O and solid 'I');

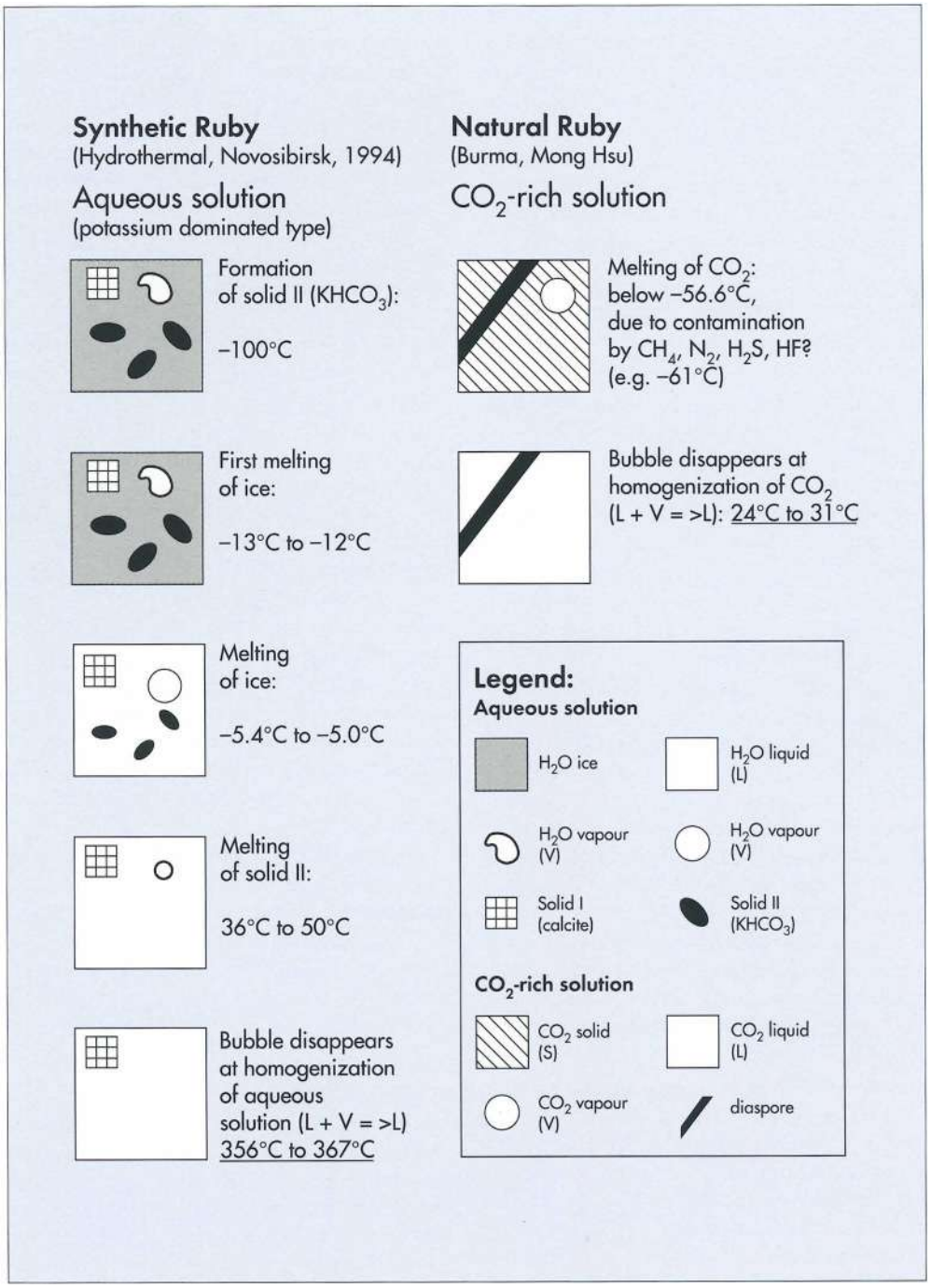


Figure 18c: *Comparison of phase transitions in fluid inclusions during heating and freezing experiments in two selected types of synthetic (left) and natural rubies (right). Solid II crystals were generated by cooling down to very low temperature liquid nitrogen. Note characteristic differences in the homogenization temperatures (bubble disappearance).*

7. +363 ± 4°C: homogenization of the vapour bubble with the aqueous phase (liquid + vapour = liquid), *Figure 17c;*
8. one fluid inclusion of one population decrepitated at this high temperature and the liquid was released through a small crack to the surface *(see Figure 18a);* solid 'II' crystallized during cooling on the surface of the ruby (SEM-EDX analyses *see Figure 18b*).

Phase transformations and reconstruction of chemical composition

Other types of phase transitions were found and are summarized in *Table III;* these indicated that different types of solid 'II' crystals could be created in the fluid inclusions during freezing. The chemical compositions of such solid 'II' crystals were reconstructed according to ideas described by Schäfer and Lax, 1962.

The fluid inclusion phase transition temperature measurements permit the following interpretations:

Where first melting of ice takes place between –12 and –13°C the fluids are interpreted as KCl-dominated (T eutectic of KCl–H_2O = –10.7°C) and where the first melting takes place at –22°C the fluids are interpreted as NaCl- dominated (T eutectic of H_2O–NaCl = –20.8°C). The amount of dissolved KCl and NaCl is 8 and 9 wt.% respectively *(Table III).*

Because of the presence also of such minerals as $Na_2CO_3 \cdot H_2O$ and $KHCO_3$ the first melting temperatures of KCl–H_2O and NaCl–H_2O are slightly lower than those of the pure binary systems.

The melting of the daughter minerals at 51 ± 1°C in the potassium dominated fluid indicates that they are $KHCO_3$, as its eutectic temperature lies above the observed eutectic temperature of –12 and –13°C at –5.43°C (Schäfer and Lax, 1962). K_2CO_3 is less likely as a possible daughter mineral 'II', as its eutectic temperature lies at –36°C, and there was no evidence of transition at this temperature.

The solid 'II' of a decrepitated fluid inclusion from population No. B2 *(Table III)* was analyzed by SEM-EDX-analysis and the results are consistent with our conclusion that the solid 'II' (daughter mineral) is $KHCO_3$. A mixture of a 90 vol.% potassium carbonate and of only approximately 10 vol.% K–Al–carbonate was found *(see Figure 18 b).* As the aqueous solutions in both fluid populations 1 of both crystals are sodium dominated, the chemical composition of daughter minerals 'II' is therefore interpreted as $Na_2CO_3 \cdot H_2O$ but $KHCO_3$ and a mixture of both cannot be excluded without direct chemical analyses (Table IIIb). Other hydrates of Na_2CO_3 are unlikely because the observed volume of solid 'II' at room temperature is much smaller than would be expected for such as $NaHCO_3$ (compare Rankin, 1975).

The solid 'I' crystals, which were present in fluid inclusions at room temperature and which were not grown by repeated heating and freezing experiments within the fluid inclusions, were not transformed during heating to over 400°C. They are anisotropic and are interpreted as $CaCO_3$, a conclusion supported by the traces of calcium found during XRF-analyses of the faceted rubies.

The heating runs showed that the fluid inclusions from all populations were homogenizing to the liquid phase (liquid + vapour = liquid) between 345° and 367°C, which proves that the liquid phase consists of aqueous solutions.

Combining the information from the heating/freezing runs with the analyses of the whitish crusts *(Table II),* it can be concluded that the concentrations of sodium and potassium varied in the mineralizers used in the different runs.

Interpretation of variations in chemical compositions of fluid inclusions

The importance of potassium carbonates, particularly of $KHCO_3$ in the hydrothermal growth of rubies, was described by Kutznetsov and Shternberg (1968). It is interesting to note that in such solutions the Cr_2O_3 concentrations in hydrothermal synthetic rubies can be controlled by variations in the formation conditions (*P,T*) above 700°C, as well as by $KClO_3$ concentrations and other ingredients (Kuznetsov *et al.*, 1968). Theoretically, variations in the formation

conditions (*P,T*) can be produced by variations in the salt-concentrations (see Roedder, 1984), by changing the filling grades *(see Figure 6b)* of the autoclave at room temperature, or by variations in the temperature at constant filling grades. The slightly different homogenization temperatures of the fluid inclusions may reflect slight variations in the filling grade.

Kutznetsov and Shternberg (1967) described the use of $KClO_3$ in the solutions for producing different colour varieties. They reported that $KClO_3$ is decomposed at high temperatures, evolving oxygen. The inferred presence of KCl in the fluid inclusions is therefore consistent with a possible use of $KClO_3$ in the production runs.

Fluid inclusions in synthetic and natural rubies and how to distinguish them

Comparing the fluid compositions of the hydrothermal synthetic rubies with those in natural rubies and natural sapphires (Schmetzer and Medenbach, 1988; Peretti *et al.*, 1990, 1995; Bruder, 1996), it is evident that they are very different *(Figure 18c)*. Natural fluid inclusions are often rich in CO_2. In contrast, fluid inclusions in the synthetic hydrothermal rubies contain aqueous (H_2O) solutions. Three-phase inclusions in natural rubies and sapphires are often composed of CO_2-liquid, CO_2-vapour and diaspore, with additional daughter minerals such as graphite and mica (Peretti *et al.*, 1990, 1995; Bruder, 1996). Daughter minerals in the H_2O-rich solutions of the synthetic rubies are carbonates. The CO_2-rich solutions (fluid inclusions in natural rubies) and H_2O-rich solutions (fluid inclusions in synthetic rubies produced by hydrothermal methods) can be distinguished by heating and freezing experiments between –10 and 31°C (Roedder, 1984). For example, two-, three- or multi-phase inclusions in natural rubies or sapphires will homogenize at temperatures below 31°C (Peretti *et al.*, 1995; Bruder, 1996). In contrast, vapour bubbles in the synthetic hydrothermal rubies are almost unchanged around these temperatures, and homogenization will occur at much higher temperatures, well above 300°C.

The following straightforward test is proposed for the gemmologist:

1. freeze a corundum down to –10°C (in a freezer) and inspect whether a gas bubble develops in the inclusion (Y/N);
2. heat the corundum with a lamp to approximately 40°C and simultaneously inspect the inclusion in the microscope; determine whether the gas bubble has disappeared (Y/N). (Caution: temperatures higher than 40°C will increase internal fluid pressures leading to potential gemstone damage).

If the answer is (Y,Y) this indicates that the corundum is natural ruby. This is true for more than 99 per cent of primary or early secondary fluid inclusions in natural corundum containing one CO_2-rich phase at temperatures above 31°C.

Conclusions

Synthetic hydrothermal rubies and sapphires are produced in Novosibirsk (Siberia, Russia) by TAIRUS, a Russian Academy of Sciences and Pinky Trading Company (Bangkok, Thailand) joint venture. Hydrothermal synthetic rubies of TAIRUS origin are grown at high temperatures and pressures in steel autoclaves from complex aqueous solutions under complex conditions. This is evident from the analyses of the fluid and solid inclusions, the composition of the synthetic materials and from the variability of the chemical composition of the whitish crusts which are found as overgrowths on the synthetic ruby and sapphire crystals.

Fluid inclusions found in natural sapphires and rubies differ significantly from those found in synthetics. The fluid inclusions in the synthetic materials are composed at room temperature of H_2O (liquid), H_2O (vapour) and carbonate solid daughter minerals (such as $CaCO_3$ and $KHCO_3$). The salt concentrations in trapped fluid inclusions contain between 8

and 9 wt.% of KCl and NaCl respectively. Carbonate concentrations were either almost pure $KHCO_3$ of approximately 30–35 wt.% or mixtures of $Na_2CO_3 \cdot H_2O$ and $KHCO_3$ in similar total concentrations. It is concluded that for the production of hydrothermal synthetic rubies and sapphires, complex chloride and calc-alkali-carbonate-bearing aqueous solutions were used. Such compositions are not present in the fluid inclusions of natural rubies and sapphires. The fluid inclusions found in the natural counterparts, including the heat-treated ones, are composed of CO_2-rich compositions with completely different reactions to heating and freezing. By studying these reactions, it is therefore possible to identify the new synthetics.

Further proof of identification is obtainable from the different types of solid inclusions in the synthetic rubies and sapphires, including various types of copper alloys, formed from items of apparatus. Such inclusions have not been found in the natural counterparts. Additional whitish pinpoints and streamers have been found in a few of the more recently produced synthetics. They are interpreted as remnants of the mineralizers, such as carbonates.

Regarding the hydrothermal process used for the production of the synthetic rubies and sapphires it is evident that the aqueous solutions were very complex, with chemical compounds of the system Al–Fe–Ti–Cu–Cr–Mg–Si–Na–Ca–K–Ba–C–O–H–Cl–I–S–P. The combined results of fluid inclusion analyses, SEM-EDX analyses and XRF-EDX-analyses indicate that different aqueous solutions were used for the production of different varieties and generations of synthetics (e.g. different Ca, Na, K, Si, Ba and Cl-bearing solutions for the production of intense red to pink or orangey-pink varieties). The solutions were also changed during the production of single rough crystals indicated by fluid inclusion analyses and analyses of the growth structures and colour zoning.

Acknowledgements

The authors are grateful to the following persons, companies and organizations: TAIRUS (Novosibirsk, Russia) and Pinky Trading Co. (Bangkok, Thailand), United Institute of Geology, Geophysics and Mineralogy of the Russian Academy of Sciences (Novosibirsk, Russia) and their managers, directors and research scientists; Mouawad Bangkok Co. (Bangkok, Thailand), Prof. W. Stern, Geochemical Laboratory, MPI, University of Basel (Switzerland), C.P. Smith, formerly Gübelin Gemmological Laboratory, Luzern (Switzerland), Dr K. Schmetzer, Petershausen (Germany), M. Düggelin and D. Mathys from the SEM Laboratory, University of Basel (Switzerland) and Linda Pfotenhauer (Editor Momentum) for editorial work.

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Letters

From William C.F. Butler

Sir,

Priority in diamond synthesis

Priority in science is usually given to the first to publish, and on this criterion Nassau was correct to attribute[1] the first successful synthesis of diamond by high pressure solution to GEC (USA) who announced their achievement by press release[2] on 15 February 1955. The formal scientific report[3] came five months later but revealed little, constrained by a US Government secrecy order; a full account of the resarch[4] appeared in 1959.

However, there now seems little doubt that the first indisputable high pressure synthesis was achieved on 15 February 1953 by ASEA (Allmänna Svenska Elekriska Aktiebolaget – now Asea Brown Boveri). The diamonds they produced in 1953 were investigated not only in their own laboratories but also in the Crystallographic Institution of the University of Stockholm. Publication[5] was delayed until 1955 when, coming after the similar announcement by GEC, the priority of the Swedish claim went almost unnoticed. A fuller account[6] of the ASEA work appeared in 1960, but it was not until 1962 that the inventor of their remarkable synthesis apparatus gave a detailed account[7] of its design and operation.

Lundblad has explained[8] that the reason ASEA did not immediately publish their results was that they believed they were the only people working on diamond synthesis. Bridgman had told them he knew of no American research and Sir Ernest Oppenheimer of De Beers had professed himself entirely uninterested in synthetic diamond. ASEA was planning in the first place to produce diamonds of a suitable size for cutting and polishing. The diamonds they produced in 1953 were less than 1 mm in size and seemed to them too small to warrant publicity.

In 1959 when I was collecting material for a paper on diamond synthesis, Dr Kistler, the then Dean of the College of Engineering at the University of Utah, but previously with the Norton Company, informed me[9] that, prior to the successful ASEA experiments, the Norton Laboratory had succeeded in synthesising diamond by the reaction between cubic silicon carbide and sodium carbonate at 45,000 atm. In a series of experiments some dozens of minute crystals of about 20 microns in diameter were produced. These were identified by specific gravity, refractive index, ability to scratch polished boron carbide and by micro-combustion analysis. Because of the very small size of the crystals no attempt was made to obtain X-ray patterns. Kistler said that diamond could also be made to grow on a natural seed by this process, the growths appearing as tiny pyramids on smooth surfaces. So far as I am aware, this work remains unpublished.

Diamond synthesis by vapour phase reaction at low or atmospheric pressure, which once seemed incredible, has been shown to be practicable. Perhaps therefore the time has come to re-examine the work of Von Bolton of Siemens and Halske. In 1911 he reported[10] that when wet town gas was bubbled though 14 per cent sodium amalgam at 100°C the hydrocarbons in the gas were dissociated by the mercury vapour and deposited in the form of diamond on seed crystals. The quantities involved were too small for analysis, but it was shown that the deposit was insoluble in hot mixed hydrofluoric and sulphuric acids and burnt completely in oxygen. The report was illustrated with photomicrographs of the seeds before the experiment and after four weeks treatment.

If this really was diamond deposition, it was almost certainly the first successful synthesis by any route.

Yours etc.
W.C.F. Butler
Hatfield, Herts
28 July 1997

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From Peter G. Read

Sir,

K. Nassau's excellent paper 'The chronology of synthetic gemstones' (*J. Gemm.*, **25**(7), 1997 pp 483–490) has filled an important gap in the gem literature and will form a very useful work of historical reference for both student and gemmologist.

However, for those who may be puzzled at the omission of the Swedish ASEA company in the diamond section of *Table I*, may I direct them to the following two references[1,2]. In the first of these Kurt Nassau (in 'A note on the history of diamond synthesis') states the ground rules for the claiming and verification of priorities in scientific achievements. In the second reference Erik G. Lundblad, Vice President of ASEA and former member of their diamond development team in 1953, responds (in a Letter to the Editor) with a brief report on the sequence of events which led to their commercial production of industrial quality synthetic diamond in the early 1960's.

Yours etc.
Peter Read
Bournemouth, Dorset
18 August 1997

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Abstracts

Diamonds | Synthetic and Simulants

Gems and Minerals | Techniques and Applications

Diamonds

Gem news from Tucson.

MARY L. JOHNSON AND JOHN I. KOIVULA. *Gems & Gemology*, **33**, 1997, pp 60–70, 27 coloured illustrations.

On show at Tucson were white diamonds, which are sometimes called opalescent due to the flashes of spectral colours caused by dispersion from the back facets. Five diamonds from the Kelsey lake Mine, Colorado, and a 'Star of David' twinned macle from South Africa were also on view. Diamond 'pearls' are formed from rough that has been ground into spherical shapes and then 'cooked' in sodium carbonate at 800°C to produce the pearly surface. J.J.

Gems and Minerals

Gemmologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **46**, 1997, pp 63–70.

Some mint-green chrysoberyls have been found in the Tunduru-Songea district of Tanzania which have the daylight colour of alexandrites but do not change colour in artificial light. A 10 ct specimen had RI 1.740–1.749, DR 0.009 with distinct zoning typically found in chrysoberyl as well as euhedral crystal inclusions. Sapphires as well as pyrope garnets from China were examined. A kunzite cat's-eye weighing 113.32 ct from Brazil is described as are phosgenites from Morocco. Schungite is a vitreous black material, essentially carbon with low water content; the specimens came from Schunga in Olenetz in Russia, have conchoidal fracture, hardness 3½, SG 1.84–1.98 together with faceted stones weighing 1.84 ct and 1.85 ct. From the Kola peninsula in Russia two faceted examples of brownish yellow vlasovite weighed 0.34 ct each, with SG 2.95, RI 1.608–1.627, DR 0.019. E.S.

Physicochemical structural characteristics of ambers from deposits in Poland.

F. CZECHOWSKI, B.R.T. SIMONEIT, M. SACHANBIŃSKI, J. CHOJCAN AND S. WOLOWIEC. *Applied Geochemistry*, **11**(6), 1996, pp 811–34.

The physical and chemical properties of eight samples of amber from various localities in Poland (Baltic Coast, Belchatów Tertiary brown coal and Jaroszów clay mine) have been investigated, using positron annihilation for chemical analysis, together with FTIR, ^{1}H and ^{13}C NMR, GC and GC-MS. The porosity of the ambers consists of narrow micropores with diameters of 0.8 ≈ 0.9 nm and a volume of 0.025 cm^3/g. The proportion of organic material extractable with 1:1 chloroform ≈ methanol ranges from 15 to 50% and correlates inversely with the average reflectance of polished amber surfaces (1.7 ≈ 0.2%). All these ambers belong to a common class of fossil resins, succinite (class Ia), irrespective of the sample location. An early enzymatically controlled (bacterial) process is suggested to have taken place during resin diagenesis from the biotic precursors. R.A.H.

Auf den Spuren Alexander von Humboldt im Ural.

F. DAMASCHUM. *Lapis*, **22**(7/8), 1997, pp 25–30, illus. in colour.

Alexander von Humboldt's 1829 journey through the Urals and Altai regions of Russia is followed with reference to the present state of some of the mines and mineral deposits his party encountered. Gem deposits of the Mursinka area are mentioned as some stones from that area were used in the Russian crown. Fine-quality malachite comes from Nishne Tagil, now the site of a large ironworks. M.O'D.

Gemmologie pratique.

Revue de gemmologie, **131**, 1997, pp 28–33.

A new section for this journal, including, in this issue, notes on the De Beers synthetic diamond: garnet with the alexandrite effect from Sri Lanka: the distinction between yellow chrysoberyl and yellow sapphire and a device to detect the magnetic properties of synthetic diamond. M.O'D.

Abstractors

R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	I. Sunagawa	I.S.
J. Johnson	J.J.	E. Stern	E.S.		

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

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Jade – Verwechslungsmöglichkeiten, Imitationen und künstliche Eigenschaftveränderunge.

U. Henn and E.-M. Pintar. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **46**(2), 1997, pp 71–84, 4 photographs, 3 tables, 2 graphs, bibl.

The jade group consists of jadeite and nephrite, but a series of different materials are known as 'jade' in the international trade. This is incorrect and confusing. When examining sculptures which do not allow measurement of RIs and SGs, X-ray diffraction and infrared spectroscopy may be helpful. Furthermore, glass, doublets and triplets and most opaque green materials can be used to imitate jade. The appearance of jade can be enhanced by coating with paraffin or wax, or with artificial resins; it can also be dyed. Such treated material can be detected by infrared spectroscopy or under the microscope. The article includes an interesting table including hardness, SG and RI, naming pseudo-jades and their common misnomers, and another table listing additional jade substitutes and imitations.

E.S.

Sherryfarbener Topaz von der Thomas Range, Utah, USA.

G. Holzhey. *Gemmologie. Zeitschrift der Deutschen Gemmologische Gesellschaft*, **46**, 1997, pp 85–92, 5 photographs, 1 map, 2 tables, 2 graphs, 1 diagram, bibl.

Some famous occurrences of sherry-coloured topaz are located in the Thomas range in the west of Utah. The fluorine-rich gem crystals up to 3 cm long may fade in strong sunlight. RI 1.607–1.617, SG 3.56. Physical properties depend on ratio of fluorine to hydroxyl ions. There are quartz inclusions and secondary fluid inclusions.

E.S.

Gem grade diaspore: an account of its original discovery.

J.L. Liniger. *Canadian Gemmologist*, **18**, 1997, pp 50–1.

The first discovery of gem-quality diaspore is reported to have taken place in 1866 at a site close to the village of Unionville, Chester County, Pennsylvania, USA. Details of the occurrence, of the diaspore and of its subsequent mining are given.

M.O'D.

Synthetic and Simulants

Growth of high temperature β-quartz from supercritical aqueous fluids.

V.S. Balitsky, T.M. Bublikova, L.V. Balitskaya and A.G. Kalinichev. *Journal of Crystal Growth*, **162**, 1997, pp 142–6, 5 figs.

High temperature β-quartz crystals were grown on bar-like α-quartz seeds at temperatures from 580 to 900°C and pressures from 0.5 to 5 kbar under isothermal and thermal gradient conditions, using gas and hydrothermal high-pressure vessels, with internal volume of 10–12 ml and autoclaves of 20, 75 and 100 ml internal volumes. Pure water and NaOH, K_2CO_3, NH_4F, AlF_3, HF, Li_3PO_4 solutions, and nutrients similar to quartz bars and amorphous silica were used. Oxides of Fe, Al, P, Ti, Ge, etc, were added as impurities. It was found that only the faces $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$ and higher-indexed $\{h0\bar{h}1\}$ faces were stable, and the growth rates of the former two faces were nearly the same, ~0.02 mm/day, giving rise to isometric dipyramidal or prismatic habits. At temperatures above 600°C noticeable growth was observed under the temperature gradient conditions even from fluids of rather low density, 0.05–0.15 g/cm³. The intensity and direction of silica transfer substantially depended on temperature, temperature gradient, density and the alkalinity of the solutions, as well as on the fluoride ion concentration in acidic solutions. Impurity incorporation into the crystal was rather low, 0.001%, except for Ge. The results may provide useful information for understanding the origin of β-quartz crystals in miarolitic pegmatites and gas cavities of volcanic rocks.

I.S.

Gemological properties of near-colorless synthetic diamonds.

James E. Shigley, Thomas M. Moses, Ilene Reinitz, Shane Elen, Shane F. McClure and Emmanuel Fritsch. *Gems & Gemology*, **33**, 1997, pp 42–53.

Since 1984 the GIA have examined 51 near-colourless synthetic diamonds, both faceted and crystals, from various manufacturers, with the largest being 0.91 ct. The results have been presented in a very comprehensive tabular form. The main differences between natural and synthetic near-colourless diamonds can be summarized as follows. All the synthetic diamonds were found to be type IIa with a few showing a type IIB or type IaB component, whereas near colourless diamonds are usually type Ia. Also the type IIa diamonds do not show the 'Cape Lines' in the absorption spectra as would normally be seen in the natural type Ia diamonds. The De Beers DiamondView instrument uses growth variations for separating natural diamonds from synthetics and is particularly useful when testing small stones. The crystal morphology of the synthetics is cuboctahedral with growth having emanated from the seed location at the base of the crystal. Some of the crystals showed dendritic/striation patterns very unlike the abrasion/chemical etching to be bound on natural diamond crystals. Forty-one of the samples observed showed magnetism and many exhibited metallic inclusions, especially in the Russian grown synthetics. Most of the samples were inert to long-wave UV radiation; all except one diamond fluoresced yellow under short-wave UV radiation and some exhibited intense phosphorescence.

J.J.

BOOK REVIEWS

De juwelen van het Huis Oranje-Nassau.

R. Brus, 1996. Schuyt & Co., Haarlem. pp 168, illus. in colour, hardcover. Price on application. ISBN 90 6097 403 4.

The House of Orange-Nassau is the present ruling house of the Netherlands. A genealogy of the house is provided at the end of the book so that readers can see its descent from Jan, Graaf van Nassau-Vianden-Dietz (1455–1516). In passing it is worth mentioning that while this table is given in the customary tree form, entries at the relevant points are shown by large-font numerals, keys to which are provided on the two facing pages. This makes the table particularly easy to read. The book, neither large nor heavy, is attractively produced, with high-quality reproductions of jewellery, designs and persons.

The age, position and country of residence of the Orange-Nassau family make it likely that a variety of jewels and of diamonds in particular would become their property at some time. A chapter of the book is devoted to diamonds associated with the family: the diamonds include the 'Kleine Sancy' [little Sancy] for which 80,000 guilders were paid in 1642 and fine diamonds are contained in other pieces owned today. Diagrams of designs and pages from the ledgers of suppliers with connections to the royal house are reproduced, some from British sources. As the family was linked by marriage with the Stuarts (Frederick V married Elizabeth Stuart, Willem II married Mary Stuart, and Willem III married Mary Stuart II, becoming King of England in the 17th century) attention is paid to jewellery relating to the English connection.

Chapters describing a miscellany of gem materials follow, with photographs of the wearers, details of the pieces and some design reproductions. Wedding jewellery and pieces associated with other special occasions are described next: here, particular attention is paid to bridal tiaras. Interesting final chapters deal with jewellery manufacture and with the regalia of the Netherlands.

The book, dealing with an area of European royal jewellery not often covered by jewellery historians, is well constructed with close referencing to the royal and other archives and a useful bibliography in which many references to Dutch publications are given. A similar study for England would be welcome! M.O'D.

Chinese jades.

Scott, R.E. (ed), 1997. Percival David Foundation, School of Oriental and African Studies, University of London, London. pp 262, illus. in black-and-white, softcover. £25.00. ISBN 0 7286 0273 3. [*Colloques on art and archaeology in Asia*. No. 18.]

The series of *Colloques on Asian art and archaeology* began in 1970 and has set a high standard of scholarship which is maintained by the present volume, enriched as it is by many contributions from Chinese workers in the field of jade artefacts and history. I can assure potential readers and buyers that the book is excellently produced and illustrated and that the price represents very good (if not ridiculous) value. While aspects of jade testing are not included (they can be found in every textbook) some gemmologists and jewellery historians will find the book invaluable as a series of studies covering the role of jade in different Asian cultures, the nomenclature of artefacts and notes on major collectors and their collections.

Papers include a review of three origins of jade culture in ancient China, the use of jade in burial rituals, a chronology of Liangzhu jades, the function of the jade Bi and Cong (these regularly shaped objects, their names differently Romanized, have been the subject of speculation since well before my Chinese studies began in the 1960s): there are also papers on jade and stone epigraphy from the Shang and early Zhou periods, on a geoarchaeological study of Chinese archaic jade [while this paper does cover the mineralogy of jade artefacts, many gemmologists will have to brush up their mineralogy to get the best from it – but useful and relevant information is not too difficult to find]. The same paper notes many of the Chinese names used to denote the jade minerals, giving their characters too. A similar mineralogical theme pervades the following paper, on the alteration of *Yu* [one Chinese name for jade] artefacts. Here the reader is shown how most Yu artefacts were found to be manufactured from tremolite Yu or bowenite Yu (the latter mainly antigorite or serpentine). The alteration of the two types is shown in several ways on the objects: they may display calcification, changes in hardness or colour, whitening, recrystallization, secondary mineral coating or modification of reflectivity. Details of some of the tests are described.

Other papers include a review of jade carving in China from the tenth to the fourteenth centuries, a study of the re-use of ancient jades and the idea of *Gu Yu* [archaic jades] in texts of the Ming and Qing periods. A short biography of the jade collector Ferdinand Schiller and his collection [in Bristol City Museum and Art Gallery] precedes a note on the Sonnenschein collection in the Art Institute of Chicago.

While the papers are of great interest, their value is enhanced in almost all cases by comprehensive lists of references in which Chinese sources are widely cited. This compilation is an important addition to the literature of jade. M.O'D.

Gemstones of North America. Volume III.

J. Sinkankas, 1997. Geoscience Press, Tucson, AZ. [PO Box 42948, Tucson AZ 85733–2948, USA.] pp xvi, 526, 16 pages of colour plates, hardback. US$65.00. ISBN 0945005 22 9.

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First a short bibliographical account of the work as a whole. The gemstones of North America (including the United States, Canada, Greenland, Mexico and other central American countries) are described over the three-volume set, the two later volumes acting as supplements to the first rather than attempting coverage of entirely new and additional topics. The reader seeking details of spodumene, for example, will have to look in all three volumes and the latest information will be found in the third. The first volume was published by the D. Van Nostrand Company of Princeton, New Jersey, in 1959, and the second by the Van Nostrand Reinhold Company of New York in 1976. This volume also includes the first-rate and very comprehensive bibliography of 2661 entries. Jumping ahead, there are references for each gem species in the third volume: here the references are placed with the species and there is no general bibliography. The interested reader must obtain all three volumes to attempt a serious study of the subject.

Entries in the new volume are arranged in alphabetical order of species. Each species entry is divided into occurrences by state, which are not themselves arranged alphabetically. Without running species headings on the top of each page it is hard to know which gemstone is being discussed and unless the reader has some knowledge of the order in which the states are placed, the index will have to be consulted more than usual in a work when strict alphabetical principles are the rule. This is not a serious shortcoming and it is true that during a search (whose ultimate success is usually assured) the reader will come across a good deal of information which might otherwise have been missed and which will certainly come in useful one day.

This is my only criticism of a book whose arrival I have awaited for some years! Not only are we given the latest reported if not the present state of some of the classic mines (Yogo, Tourmaline Queen, the Rutherford pegmatites of Virginia) but when a locality is producing more or less as before, we are told as much. References bringing location reports up-to-date are given and quite a lot of references which have escaped the first two volumes find a place here. Species are also described with chemical composition, mode of occurrence, colours and other phenomena: important gemstones and sites have ownership and mining details, in some cases including recent prices paid for major specimens. Maps are also provided for a number of important sites: examples include the sapphire deposits of south-western Montana and the tourmaline mines at Mount Mica, Maine. A table at the end of the book lists the largest cut gemstones known from North American localities, giving species (more than one example for major species), colour, weight and locality (the largest cut blue benitoite cited weighs 15.42 ct and the largest orange willemite from Franklin, New Jersey, weighs 29.66 ct. There is also a well-constructed index and, preceding the text, sixteen pages of the highest quality colour photographs giving a variety of cut and rough stones, some set in jewellery. These are Van Pelt photographs and among the best available today.

This book, reasonably priced, is well worth getting and the publishers should make an effort to get all three volumes into press together (perhaps this is under way) so that readers can obtain the complete survey. In every sense this is a book to keep by the bed for constant delight as well as information. M.O'D.

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

OBITUARY

An appreciation of Eunice Miles by David Callaghan

Eunice Miles was unique – and that is no exaggeration. When Eunice joined GIA in 1953 she entered a trade which was very much a male preserve. I am sure New York was no different from London in this respect, but her work for GIA was primarily in the gem diamond world at that time. This within the trade was an exclusively male world and Eunice told me personally of the suspicion bordering on hostility she encountered at first. However, the powers of her personality soon prevailed and, in the end, many diamond merchants were leaving their stones at the GIA Lab. specifically for her attention.

Eunice was born in Connecticut and read Mineralogy at University. Before joining GIA in 1953 she had been the Assistant Curator at the American Museum of Natural History from 1942–1952. What a background of experience to bring with her to GIA. Some of her early work at GIA was the study of the coloration in diamond, and a number of articles appeared in the GIA journals of the period. This led her into the educational field of GIA and when I first met her some 20 years ago education had become her main task. She taught gemmology for many years and she always took a keen interest in the work and careers of her students. She was a great supporter of the FGA course and because of this became a good friend of the Gemmological Association.

This refers only to her career but doesn't help you to know her. What was she like as a person, what would be your first impression? That would depend on whether she was at work or 'off duty'. For me the first impression of her at work was one of complete pre-occupation, and therefore 'not to be disturbed'. I think this was a 'front' to remind her that her impish sense of humour was to be held in check and not let out to play! Eunice had a great sense of fun, enjoyed the use of the English language and particularly enjoyed the use of a pun. I did not work with her but I can well imagine her to have been very exacting for she set herself high standards and expected the same of others. She spoke quietly and quite slowly, but she was always a joy to listen to. All in all she made a lasting impression on you when you had broken through her 'defence' and got to know her.

Eunice was a great Anglophile and loved coming to London. In recognition of her work in the field of education in gemmology she was awarded the Honorary Fellowship of the Gemmological Association in 1984 and it was my privilege as Chairman to make the presentation to her. Eunice was very proud to receive this award and treasured it. She has left behind her many, many friends in the trade in the USA and, although she retired from GIA some time ago, kept in touch with many of them. I, for one, count myself fortunate to have known her and to be counted as a friend.

THE 1998 GAGTL PHOTO COMPETITION

Gems in fashion

What gem do you think typifies a particular period in history – Roman cameos, Renaissance jewellery, Victorian jet, Art Deco diamonds? What are the most sought after or fashionable gem varieties today?

Enter your pictures taken by yourself on this theme for the 1998 Photographic Competition. Three prizes of £100, £75 and £50 will be awarded for the most appropriate entries and we again plan to produce a calendar showing a range of entries. We are pleased to announce that the prizes are being sponsored by Quadrant Offset Ltd, Hertford, and the GAGTL is most grateful to them for their generosity.

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FORTHCOMING EVENTS

31 October	**Midlands Branch.** *The sapphires of Scotland.* Brian Jackson.
9 November	**London.** Annual Conference – Collector's gems.
10 November	**London.** Visit to the Natural History Museum.
16 November	**Midlands Branch.** Practical gemmology training day.
19 November	**North West Branch.** Annual General Meeting.
20 November	**Scottish Branch.** *Scottish river pearls.* Fred Woodward.
28 November	**Midlands Branch.** *Opals.* David Callaghan.
3 December	**London.** *Fluid inclusions: solutions for mineral genesis and gem identification.* Andrew Rankin.
6 December	**Midlands Branch.** 45th Anniversary Dinner.

1998

14 January	**London.** *Chinese snuff bottles: the use of stone in Chinese art.* Clare Lawrence.
30 January	**Midlands Branch.** Bring and Buy Sale; Practical Gemmology Quiz.

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Irene Knight on 0151 924 3103
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

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

NEWS OF FELLOWS

Michael O'Donoghue lectured on *The geology and gemstones of Pakistan* to the Ravensbourne Geological Society on 8 July 1997.

MEMBERS' MEETINGS

London

On 9 July at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Dr Robert Young gave a talk entitled *Exploring for diamond, emerald and alexandrite in Europe.*

Midlands Branch

On 26 September at the Discovery Centre, 77 Vyse Street, Birmingham, Howard Vaughan gave an illustrated talk entitled *Diamonds I have known.*

Scottish Branch

Two field trips to localities in Scotland were held during the summer months. On 5 to 7 July trips were made to Glen Clova, Glen Esk and Mount Batock looking for hyaline and quartz, and on 9 to 11 August the venues were the Cairngorms and Lochan Na Lairige, sources of beryl and topaz.

GIFTS TO THE ASSOCIATION

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

Mrs Mary Burland, Hoddesdon, Herts., for 60 various pieces including an opal, small diamonds and synthetic spinels.

Mr C.R. Cavey, FGA, Greenford, Middx., for 36 red spinel crystals.

Exclusive Merchandisers, Inc., Buffalo, New York, USA, for various pieces including natural and synthetic star corundum, peridot, quartz and opal.

Mr Ronald Ferrell, FGA, Downtown DeLand, Florida, USA, for 300 various pieces including diamond, emerald, garnet, iolite, apatite, turquoise, lapis, natural and imitation pearls, and synthetic materials.

Mr Lawrence J. Fifield, FGA, Pinner, Harrow, Middx., for 62 various pieces including jadeite, beryl, quartz, opal and pearls.

Mr A.G. Flewelling, FGA, Arthur, Ont., Canada, for a bag of rough corundum and zircon from Australia.

Mr John Fuhrbach, FGA, Amarillo, Texas, USA, for an exceptional collection of turquoise from the SW United States and for stones sold as imitations of this turquoise.

Robert James, Caribbean Gemological Institute, for two imitation tanzanites.

Harold Kipp of Exclusive Merchandisers Inc., Buffalo, New York, USA., for a bag containing various materials.

Miss Lucy Monje, FGA, Santa fe da Bogota, Colombia, for emerald on carbonaceous, pyritiferous shale from the Coscuez Mine in Colombia.

Mrs Margaret Pout, Worplesdon, Guildford, Surrey, for three hydrogrossular garnets.

Ami, Eitan and Yoram Siman-Tov of Siman-Tov Brothers, Gem Importers, New York, USA, for a tanzanite.

Mr Peter Truman of W. Truman Ltd., London, for a conch pearl.

G.F. Williams, London, for two coated topaz and one coated topaz subsequently heated.

On 18 September at the Royal British Hotel, Princes Street, Edinburgh, John Levy gave a talk entitled *A stone buyer abroad*.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 30 June 1997 at 27 Greville Street, London EC1N 8SU. Terry Davidson chaired the meeting and welcomed those present. The annual Report and Accounts were approved and signed. Roger Harding and Vivian Watson were re-elected to the Council of Management.

It was announced that Keith Penton and Ian Roberts had expressed the wish to retire from the Members' Council. Peter Read, Richard Shepherd and Colin Winter were re-elected to the Members' Council. Messrs. Hazlems Fenton were re-appointed Auditors. Amendments to the By-laws were announced by the Secretary, Roger Harding, and accepted by the meeting.

Following the Annual General Meeting, the winners of the 1997 Photographic Competition were announced and presented with their prizes by the President, Professor Bob Howie. The members then enjoyed a Reunion and Bring and Buy Sale and a rolling display of selected entries in the Photographic Competition.

ISLAND OF GEMS

An exhibition of the gems of Sri Lanka is to be held at St. Albans Centre, 18 Brooke Street, London EC1S 7RD, on 19 and 20 December. Further details from Sri Lanka Gems, PO Box 1837, London N17 9BW (telephone/fax 0181 808 4746).

SUBSCRIPTION RATES 1998

The following are the subscription rates for the four categories of membership for 1998. Existing Ordinary Members, Fellows and Diamond Members will be entitled to a £5.00 discount for subscriptions paid before 31 January 1998.

	UK	*Europe*	*Overseas*
Ordinary Member *Fellow* *Diamond Member*	£55.00	£62.00	£70.00
Laboratory Member	£250.00 + VAT	£250.00	£250.00

GEM DIAMOND EXAMINATIONS

In June 1997, 76 candidates sat the Gem Diamond Examination worldwide of whom 49 qualified, 7 with Distinction. The Bruton Medal for the candidate who submitted the best set of answers in the Gem Diamond Examinations of 1997 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Miss Rita Tsang Wai Yi, Hong Kong. The names of the successful candidates are listed below:

Qualified with Distinction

Cadby, John H.V., Trowbridge, Wilts.
Stather, Lorne Francis, Charlton, London
Ball Edwards, Chantal, Cheltenham, Glos.
Lingyun Mao, Beijing, PR China
Lin Hsin Pei, Wuhan, Hubei, PR China
Stead, Graham Scott, Tillsonburg, Ont., Canada
Jiang Renyi, Wuhan, Hubei, PR China

Qualified

Brooke-Webb, Susannah, London
Carlsson, Johanna A., London
Chu Kam Chiu, London
Churamani, Pooja, London
Cookson, Ian, Darnall, Sheffield, Yorks.
Dempster, Stuart, Shettleston, Glasgow, Scotland
Edwards, James, St. Albans, Herts.
Feeney, Eileen, Uddingston, Glasgow, Scotland
Feng Hsiu Yun, Wuhan, Hubei, PR China
Fielding, Geoffrey Ian, Tottington, Bury, Lancs.
Fitzmaurice, Karl, Dunboyne, Co. Meath, Ireland
Fu Ye, Beijing, PR China
Harris, Annette Mia, Hanbury, Worcs.
Heilpern, Helene, Epping, Essex
Hoare, G.M., Maynooth, Co. Kildare, Ireland
Hopley, Katharine Bridget, Coventry, West Midlands
Hsu, Robert, Wuhan, Hubei, PR China
Josyfon, Bruce Michael, Brighton, Sussex
Law Yiu Sing, Hong Kong
Li Ping, Beijing, PR China
Lo Shuk Lan, Hong Kong
MacDonald, Karen J., Dundonwell, Inverness, Scotland
Mak, Tsui Sim, Hong Kong
Martin, James, Leigh, Lancs.
Martin, Jennifer Frances, Acton, London
Michelson, Max J., London
Ocloo, Charles Seth, Eastcote, Middx.
Papadopoulos, A. Dimitrios, Athens, Greece
Pattni, Unnat Nagindas Gordhandas, Kingsbury, London
Randall, Gary Marshall, Kingston, Surrey
Shah, Jignesh Vinodbhai, Surat, India
Simpson, Peter Robert, Richmond, Surrey
Suchde, Aditya Ajit, Hendon, London
Thornton, Timothy John, Wimbledon, London
Tong Lai Ming, Kowloon, Hong Kong
Varey, Irena Maria, Ullesthorpe, Leics.
Verny White, Catherine, Fulham, London
Veryis, Anastassios, Athens, Greece
Wai Hung Raymond Law, Kowloon, Hong Kong
White, Robert, Kingsthorpe, Northants.
Wong, Yik Shih, Kuala Lumpur, Malaysia
Wu Ming Hsun, Wuhan, Hubei, PR China
Wu Tien Hsien, Wuhan, Hubei, PR China
Xia Songyao, Beijing, PR China
Yam Hang Ha, Hong Kong
Yan Yee Mei, Hong Kong
Yang Menghua, Wuhan, Hubei, PR China
Yip Shu Leung Christopher, Hong Kong
Yu Kam Chi, Hong Kong

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology, held worldwide in June 1997, 201 candidates sat the Preliminary Examination of whom 134 qualified. In the Diploma Examination 248 sat, of whom 110 qualified, one with Distinction. The Tully Medal for the candidate who submits the best set of answers in the Diploma Examinations in 1997 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Ms Li Liping, Wuhan, P.R. of China. Ms Li Liping was also awarded the Anderson Bank Prize for the best non-trade candidate of the year in the Diploma Examination.

The Diploma Trade Prize for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Ms Mary I. Garland, London, Ontario, Canada.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Miss Melloney Vanessa Ng, London.

The Preliminary Trade Prize for the best candidate for the year who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Simon Richard Millard, Corsham, Wiltshire. The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Yu Hailing, Wuhan, Hubei, PR China

Qualified

Arsenikakis, Helena, Blackwood, SA, Australia
Bae, Chai Soo, Seoul, Korea
Bappoo, Reenabai, Croydon, Surrey
Barsk, Christer, Pello, Sweden
Bienemann, Andre, Polsbroek, The Netherlands
Cao Weiyu, Wuhan, Hubei, PR China
Chang, Circle H., Toronto, Ont., Canada
Chaudhari, Ruchi, Bombay, India
Chen Qi, Shanghai, PR China
Chen Shiyi, Wuhan, Hubei, PR China
Chen Tao, Shanghai, PR China
Christou, Angelos G., Limassol, Cyprus
Cowley, Jacalyn G., Wimbledon, London
Davies, Maggie, Wareside, Herts.
Deligianni, Christina, Athens, Greece
Gilad, Deutscher, Kiryat, Ono, Israel
Dykhuis, Luella Woods, Tucson, Ariz., USA
Edwards, Heidi Louise, Burntwood, Staffs.
Endo, Masahiko, Osaka, Japan
Feng Hsiu Yun, Wuhan, Hubei, PR China
Forward, Stephen, London
Garland, Mary I., London, Ont., Canada
Glaser, N.V.K., Sonja, I., Galle, Sri Lanka
Hainschwang, Thomas N., Ruggell, Liechtenstein
Hazelius B., Wiveca, Lidingo, Sweden
Hill, Emma, Maida Vale, London
Hu Aiping, Wuhan, Hubei, PR China
Hu Shu, Wuhan, Hubei, PR China
Hutton, Katie, Twickenham, Middx.
Ikeda, Noriko, Takarazuka City, Hyogo, Japan
James, Robert C., Naples, Fla., USA
Jankowiak, Anna, Toronto, Ont., Canada
Jin Yingrui, Wuhan, Hubei, PR China
Juan, Ku-wei Hsieh, Taipei, Taiwan, Rep. of China
Karandikar, Surendra, Bombay, India
Kataoka, Noriko, Machida-City, Tokyo, Japan
Kazemi, Sima, Vancouver, BC., Canada
Kim, Amy, London, Ont., Canada
Kjendlie, Ole-Richard, Larvik, Norway
Kong Wei, Wuhan, Hubei, PR China
Konstantara, Aikaterini, Thessaloniki, Greece
Koshiba, Shoko, Sagamihara City, Kanagawa, Japan
Lam, Jill, Rochester, Kent
Lee, Dongjae, Masan, South Korea
Lei Lihong, Wuhan, Hubei, PR China
Leng Yanyan, Wuhan, Hubei, PR China
Li Ting, Wuhan, Hubei, PR China
Li Wei, Shanghai, PR China
Liao Yang, Guilin, PR China
Lindroos, Anna, Rauma, Finland
Liu Hui, Shanghai, PR China
Long Dan, Wuhan, Hubei, PR China
Lui, Alice, Richmond, BC, Canada
Lu Xiaomin, Wuhan, Hubei, PR China
Luo, Xia Ying, Guilin, PR China
Ma, Huei-Chi, Taipei, Taiwan, Rep. of China
McCabe, Marianne Carole, Guildford, Surrey
McCarthy, Keiran, M., London
Maehara, Tamao, Gunma, Japan
Makarainen, Paivi, Helsinki, Finland
Mo Yiming, Shanghai, PR China
Monje M., Lucy E., Santa fe da Bogota, Colombia
Moore, Rowan Duggan, Stoke, Coventry, Warwicks.
Ng Wai Ching, Hong Kong
Niemi, Markku, Lappeenranta, Finland
Nottbusch, Jurgen Uwe, Appel, Germany
Ohtsuka, Mayumi, Neyagawa City, Osaka, Japan
Pan Jie, Shanghai, PR China
Qin Hongyu, Guilin, PR China
Rees-Wardill, Tanya, Wallington, Surrey
Renard, Joelle M., Ruislip, Middx.
Rimmer, Ray Ian, Bootle, Merseyside
Rollings, Alexander, London
Roper, Bebs, Rokeby, Tasmania, Australia
Seki, Shoko, Osaka City, Osaka, Japan
Semenets, Elena, Vancouver, B.C., Canada
Shen Beiqi, Shanghai, PR China
Shih Shu-Chuan, Hampstead, London
Shu Yiqiang, Wuhan, Hubei, PR China
Skogstrom, Helena Anneli, Klaukkala, Finland
Soderstrom, Jenny, Lannavaara, Sweden
Stossel, Hilary Jeanne, Perth, WA, Australia
Sun Xingqun, Wuhan, Hubei, PR China
Suninmake, Virpi Kristina Annika, Helsinki, Finland
Suzuki, Noriko, Ikoma City, Nara, Japan
Tashiro, Hisami, Uji City, Japan
Teskeredzic, Senada, London
Than, Tin Kyaw, Yangon, Myanmar
Tsang Wai Wan, Kowloon, Hong Kong
van der Vijgh, Caroline E., Diemen, The Netherlands
Vernon, Penny, High Wycombe, Bucks
Verny White, Catherine, Fulham, London
Wang Yilong, Guilin, PR China
Wang Chien Ling, Taipei, Taiwan, Rep. of China
Wang Jianmin, Wuhan, Hubei, PR China
Wang Yi Fei, Guilin, PR China
White, Joanne Clare, Sheffield, S. Yorks
Wong, Yik Shih, Kuala Lumpur, Malaysia
Xia Jiancheng, Wuhan, Hubei, PR China
Xie Yujun, Guilin, PR China
Xu Lei, Shanghai, PR China
Xu Zhiyi, Shanghai, PR China
Yang, Jin Mo, Seoul, Korea
Yao Huali, Wuhan, Hubei, PR China
Yau Hau Yeung, NT, Hong Kong
Yogalingam, Nirupa, Kandy, Sri Lanka
Yu Ping, Guilin, PR China
Yuan Jia, Wuhan, Hubei, PR China
Yoshitake, Yumi, Oita, Japan
Zeng Shan, Wuhan, Hubei, PR China

Gem Tutorial Centre
Autumn/Winter 1997/1998

28 October — **Diamonds Today**
An up-to-date review of all aspects of diamonds; rough and cut stones, and treated (laser-drilled and filled), synthetic and imitation materials.
Price £104 + VAT (£122.20) – includes sandwich lunch

4 November — **Review of Diploma Theory**
A day for Gemmology Diploma students to review their theory work and to prepare for the Diploma theory examinations. 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.
Price £44 + VAT (£51.70) – includes sandwich lunch

4 and 5 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, can you afford to miss these two days of investigation?
Price £198 + VAT (£232.65) – includes sandwich lunches

11 November — **Jade – The Inside Story**
A panel of jade experts including Roger Keverne and Rosamond Clayton will cover the history and carving, geology and make-up, simulants and factors affecting the price of jade.
Price £99 + VAT (£116.33) – includes sandwich lunch

24 to 27 November — **Four-Day Diploma Workshop**
This 4-day course includes a one-day theory review and three days of practical tuition which will cover both observation and testing – crystals, 10x loupe, microscope, refractometer, spectroscope, dichroscope, Chelsea colour filter, polariscope, heavy liquids and hydrostatic weighing to determine specific gravity. The final day will also incorporate a half-length mock exam (practical only).
Price £262 + VAT (£307.85) – includes sandwich lunches
GAGTL Student Price £187.45 + VAT (£220.30)

2 December — **Review of Preliminary Theory**
A day for Gemmology Preliminary students to review their theory work and to prepare for the Preliminary examinations. Tips on the consolidation and revision of facts, figures and principles. Let us help you to review your examination technique with the help of past questions.
Price £44 + VAT (£51.70) – includes a sandwich lunch
GAGTL Student Price £32 + VAT (£37.60)

3 December — **Seeing Red**
An opportunity to see a variety of red gemstones, not just rubies. How do you tell them apart? How are they treated? What man-made products look like them?
Price £99 + VAT (£116.33) – includes a sandwich lunch

13 and 14 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 £120 + VAT (£141.00) – includes sandwich lunch

7 to 9 January 1998 — **Three-Day Preliminary Workshop**
This 3-day course incorporates a theory review, an introduction to instruments used in the course and a review of the materials discussed in the preliminary notes.
Price £156 + VAT (£183.30) – includes sandwich lunches
GAGTL Student Price £111.49 + VAT (£131.00)

10 and 11 January 1998 Saturday and Sunday — **Two-Day Diploma Practical Workshop**
The long-established intensive practical course to help students prepare for the Diploma practical examination or for non-students to brush up on technique. This is the course to help you practise the methods required to coax results from instruments which can be difficult or awkward to use. The course includes a half-length mock exam for you to mark yourself.
Price £145 + VAT (£170.38) – includes sandwich lunches
GAGTL Student Price £104 + VAT (£122.20)

Other Workshops and Tutorials being planned for Winter and Spring:
Photographing Gemstones, Bead Identification, Bead Stringing 2
Contact the Education Office on 0171 404 3334 for further information

Zhang Wansong, Guilin, PR China
Zhao Ying Ying, Nanning, PR China
Zhou Huifang, Wuhan, Hubei, PR China
Zhou Wei Ning, Guilin, PR China
Zhu Ye, Shanghai, PR China

Preliminary

Aho, Jouko, Oulu, Finland
Aladin, Naila, London
Anagnostou, Christina, Athens, Greece
Ancell, Sarah Jane, Salisbury, Wilts.
Anderson, Fiona Margaret, West Acton, London
Andre, Cindy Marie, Chertsey, Surrey
Arentsen, Ernst Willem, Lopik, The Netherlands
Armati, A.V., Henley-on-Thames, Oxon.
Batchelor, Philip, Surrey Docks, London
Bavu, Godza M., Epsom, Surrey
Blampied, Julie Karen, Kempten, Germany
Boels, Vigdis Nike Lotte, Ypres, Belgium
Booth, Roderick McKenzie, Greenwich, London
Boucher, Garry Mark, Leeds, West Yorks.
Burgoyne, Sheila, Totteridge, London
Butler, Patrick John, Ringwood, Hants.
Butt Lai Wah, Kowloon, Hong Kong
Carr, Susan Elizabeth, Stamford, Lincs.
Chan Lui, N.T., Hong Kong
Chang Chien Sheng, Taipei, Taiwan, Rep. of China
Chaudhari, Ruchi, Bombay, India
Chen Qi, Shanghai, PR China
Cheng Mu Sen, Taipei, Taiwan, Rep. of China
Cheung Suk Yin, Central, Hong Kong
Chirichella, Maria Vittoria, Notting Hill, London
Cho Ka Wah, Kwai Chung, Hong Kong
Christou, Maria Socratous, Nicosia, Cyprus
Chu Yuk Ying, N.T., Hong Kong
Combee, Mireille Marcella, Capelle a/d yssel, The Netherlands
Constantinou, Maria, Kentish Town, London
Cooksey, Brian Derek, Colchester, Essex
Cox, Lois Margaret, London
Daniel, Eliena, London
den Boer, Arie Jan, Bleiswyk, The Netherlands
Finlay, Louden Beveridge, Brighton, E. Sussex
Fok Ki Yu, Hong Kong
French, Thomas, Woking, Surrey
Gallant-Botham, Susan K., Colchester, Essex
Gao Peng, Guangzhou, PR China
Garbis, Nicolaos, Kefalonia, Greece
Gill, Jessica, Battersea, London
Gu Jiyang, Shanghai, PR China
Hagendijk, M.C.G., Schoonhoven, The Netherlands
Haris, Mohamed Thowfeek Mohamed, Maggona, Sri Lanka
Hashimasa, Mitsuyo, Kanazawa City, Ishikawa, Japan
Hashimoto, Hiroko, London
Ho Chuan-Hsiang, Taipei, Taiwan, Rep. of China
Ho Wing Tat, Kowloon, Hong Kong
Hodgson, Jane E., Watford, Herts
Hofer, Francoise, Chaux-de-Folds, Switzerland
Honda, Minoru, Osaka City, Osaka, Japan
Hu Chin Ching, Taipei, Taiwan, Rep. of China
Iconomou, Politimi, Athens, Greece
Ioannou, Alkis, Nicosia, Cyprus
Ji Tianxi, Shanghai, PR China
Jones, Emily Charlotte Josephine, Tealby, Lincs.
Karandikar, Surendra, Bombay, India
Keating, Elaine, Hackney, London
Kerger, Michele Louise, Sutton Coldfield, W. Midlands
Kiefert, Lore, Basel, Switzerland
Kim, Jung Shin, Wimledon Park, London
Kim, Mi Young, Taegu, Korea
Kong, Kit Chee, N.T., Hong Kong
Koukou, Katerina, Athens, Greece
Krzemnicki, Michael S., Basel, Switzerland
Kuo Su-Hwa, Taipei, Taiwan, Rep. of China
Lam Lai Chun, Kowloon, Hong Kong
Landham, Rowena Roshanthi, Tunstall, Kent
Latumena, Warli, Jakarta, Indonesia
Lau Stella Shuk Kam, Shatin, Hong Kong
Law Siu Ying, Kowloon, Hong Kong
Lee Carmen, Kowloon, Hong Kong
Lee Pui, Yiu, Phyllis, Kowloon, Hong Kong
Lee Wai Kwun, Christina, N.T., Hong Kong
Lee Yin Wa, Kowloon, Hong Kong
Lempinen, Marita, Lahti, Finland
Lewinsohn, Lisa, Sharpthorne, Sussex
Liang Weizhang, Guangzhou, PR China
Liu Huai, Wuhan, Hubei, PR China
MacLeod, Mariola, Mitcham, Surrey
Maddison, Steven James, Benfleet, Essex
Matsumura, Yasunao, Kadoma City, Osaka, Japan
Morgan, Jacqueline Elizabeth, Gerrards Cross, Bucks.
Ng Florence C.N., Hong Kong
Nichols, Jacqueline Mechelle, Chelmsford, Essex
Okumura, Ayako, Osaka City, Osaka, Japan
Olivares, Elka Marie, Chatham, Kent
Oliver, Jessica, Glasgow, Scotland
Owen, Charryn Pamela, Northwich, Ches.
Pagan, Sabine, Bern, Switzerland
Park, Sung Ok, Taegu, Korea
Pavlou, Marios Georgiou, Nicosia, Cyprus
Photiou, Maria, Berkeley, Calif., USA
Pitt, Edward Benjamin William, Sutton Coldfield, W. Midlands
Rajkumar, Aparna, Bombay, India
Reed, Inga Elizabeth, Castle Yard, Kilkenny, Ireland
Reijinga, Jetze, Huizen, The Netherlands
Sale, Paul Anthony Robert, Sutton Coldfield, W. Midlands

Schaars, Suzanne Joanna Wilhelmine, Hertogenbosch, The Netherlands
Sethi, Barti, London
Shah, Varsheet, Kingston, Surrey
Sharples, James, Bolton, Lancs.
Shein, Aung Myint, Yangon, Myanmar
Smith, Louise Verna, Hatfield, Herts.
Smits, Cyntha Arianne Nicole, Alphen a/d Rijn, The Netherlands
Solomou, Andreas, Nicosia, Cyprus
Song, Ruohan, Shanghai, PR China
Sonoda, Natsumi, Kobe City, Japan
Sopers, Margarita Bernarda Maria, Den Haag, The Netherlands
Sparkes, Beverley Joy, Colchester, Essex
Sujanani, Ramesh K., Ocho Rios, Jamaica
Swe, Zin Aye, Yangon, Myanmar
Tanaka, Sakura, Kobe City, Hyogo Pref., Japan
Tang Maggie, Taipei, Taiwan, Rep. of China
Tang Yu-Lung, Taipei, Taiwan, Rep. of China
Thomas, Caan Marcus, South Harrow, Middx.
Tong Tao, Guilin, PR China
Tse, Yiu Yu Stephen, Hong Kong
Tuukkanen, Mervi, Mikkeli, Finland
van der Made, S.A.M., Schoonhoven, The Netherlands
Vassilios, Kabiotis, Athens, Greece
Wallinger, Victoria Joanne, Selby, Yorks.
Wang Kuang Yi., Taipei, Taiwan, Rep. of China
Wang Mei-Hui, Taipei, Taiwan, Rep. of China
Waring, Paul Michael, East Dulwich, London
Wei Zhimei, Shanghai, PR China
Welstead, William Aldan, Orford, Suffolk
Wilson, Raymond, Dorking, Surrey
Wolf, Peter Andrew, San Anselmo, Calif., USA
Wu Shizhou, Guilin, PR China
Wu Shuk Ting, N.T., Hong Kong
Wu Tsai-Yi, Taipei, Taiwan, Rep. of China
Xu Lizhen, Guangzhou, PR China
Yang Sibo, Guilin, PR China
Yeung Mui Fung, Sheung Wan, Hong Kong
Yiu Shui King, Hong Kong
Young, Geoffrey, Surbiton, Surrey
Zhang Caixia, Shanghai, PR China
Zhao Yanzeng, Guilin, PR China
Zheng Zizi, Guilin, PR China

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 25 June 1997, the business transacted included the election of the following:

Diamond Membership (DGA)

Scott, Michael, Harpenden, Herts. 1992

Fellowship (FGA)

Civitello, Odile, Montreal, Quebec, Canada. 1989
Gatward, Anna Bradly, Hitchin, Herts. 1966
Sharma, Maryada, Mumbai, India. 1983

Ordinary Membership

Boutle, David, London
Butcher, Elsbeth, Blandford Forum, Dorset
Carmona, Charles, Los Angeles, Calif., USA
Jayakody, Geetha Kamani, Saitama Ken, Japan
Johnson, Janet Mary, Friern Barnet, London
Kabangi, Antoine, London
McCabe, Marianne Carole, Guildford, Surrey
Nabukeera, Zamu Night, Forest Hill, London
Poole, Iain, Market Harborough, Leics.
Sillero-Arroyo, Andrés, Córdoba, Spain
Tan, Jee Yong, Singapore
Umeda, Evelyn Y., Sacramento, Calif., USA

Laboratory Membership

Kikuchi Trading Co. Ltd., London W1Y 2LD

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 23 July 1997, the business transacted included the election of the following:

Fellowship (FGA)

Mindry, Ernest Roy, Chesham, Buckinghamshire. 1980
Yang, Ruzeng, Zhenjiang, Jiangsu, PR China. 1996

Ordinary Membership

Bryan, Ian Robert, London
Collins, John Raymond Frank, Clydach, Swansea, Glamorgan
Curtis, Mark, Chemainus, BC, Canada
Edwards, Heidi, Burntwood, Staffordshire
Gascoigne-Pees, Carol Anne, Dorking, Surrey
Sayed, Mahta Bali Shah, Karachi, Pakistan
Sheppard, Gary Richard, Wellington, New Zealand
Siripaisarnpipat, Seitatip, Bangkok, Thailand
Srithai, Boontarika, London

CORRIGENDA

In the Contents list, back outside cover, Vol. 25(6), April 1997, third entry, the authors should read H.A. Hänni, L. Kiefert, J.-P. Chalain and I.C. Wilcock.

On p. 468 above, in the labels to Figure 22, for 'F-apatire' read 'F-apatite' and for 'melonite' read meionite'.

On p. 485 above, Figure 6, the moissanite should be colourless, not brownish-pink.

On p. 486 above, Table 1, Beryl; the entry for Emerald produced by Zerfass should have been included under the flux method rather than the hydrothermal method. A replacement page is enclosed with this issue of the *Journal*.

On p. 510 above, second column, under *Transfers from Ordinary Membership to Diamond Membership (DGA)*, the sub-heading *Transfers from Ordinary Membership to Fellowship (FGA)* was omitted and we apologize for any misunderstanding and embarrassment caused by the error. The section should read as follows:

Transfers from Ordinary Membership to Diamond Membership (DGA)

Kenny, Sark, Hong Kong. 1997
Kepel, Arthur Mvuta, London. 1997
Lemessiou, Maria A., Nicosia, Cyprus. 1997
Lodge, Tim, London. 1997

Transfers from Ordinary Membership to Fellowship (FGA)

Battiscombe, Brigid, London. 1997
Davies, Paul, B., Great Missenden, Bucks. 1997
Jackson, Stephen, D., Perranporth, Cornwall. 1997
Johnston, Dale, Dundonald, Co. Down, N. Ireland. 1997
McInnes, Catriona, O., Edinburgh. 1997
McInnes, John L., Edinburgh. 1997
Mao, Lingyun, Beijing, P.R. China. 1997
Starreveld, Francis M.M., Hilversum, The Netherlands. 1997

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 25 mm. 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.

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

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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.

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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.

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Cover Picture
From sparks to sparkle
Wheel-lock gun mechanism. Photograph courtesy of the Victoria and Albert Museum.

Marcasite brooch-pendant. Photograph courtesy of the British Museum. (See Fool's gold?... The use of marcasite and pyrite from ancient times. pp. 517–531.)

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Compiled by Robin W. Sanderson

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

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