The Journal of Gemmology

Volume 37 / No. 8 / 2021

A Review of Photochromic Gems (Part 1)

Sapphires from Yenya-U, Myanmar

13th Century Gem Knowledge and the St Albans Jewels

History of London's Lapidaries (Part 2)

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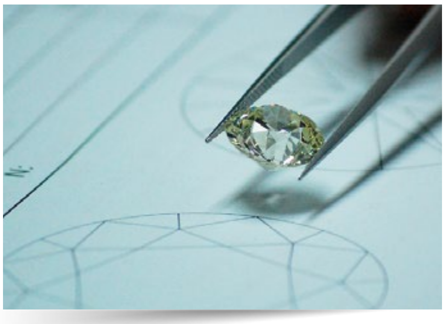

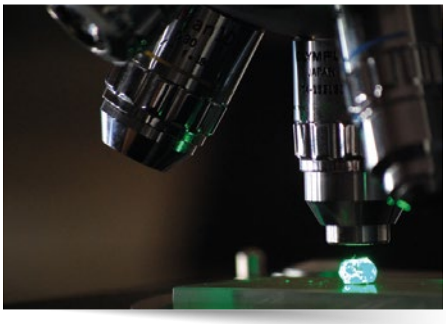

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The Journal of
Gemmology

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Cover photo: *Hackmanite is one of the gem materials covered in a review article on photochromism on pp. 780–800 of this issue. The crystal specimen (from Badakhshan, Afghanistan) is 9.14 cm wide and the cabochons (from Mogok, Myanmar) range from 4.76 ct for the unusual purplish red hackmanite to 14.93 ct for the rare bi-coloured purple/white stone. The samples are shown here after exposure to short-wave UV radiation, whereas on the inside back cover of this issue they are seen after exposure to intense incandescent illumination. Samples courtesy of Bill Larson (Pala International, Fallbrook, California, USA); photos by Orasa Weldon.*

COLUMNS

ARTICLES

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CONTENT SUBMISSION

The Editor-in-Chief is glad to consider original articles, news items, conference reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at https://gem-a.com/membership/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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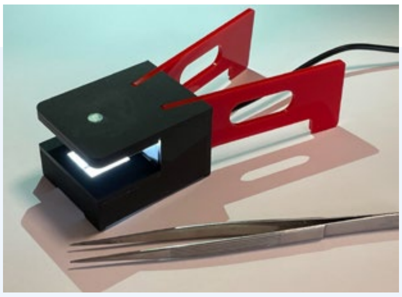
What’s New

INSTRUMENTATION

Advanced Solitaire Microscope

Vision 360 (Surat, India) recently released its Advanced Solitaire Microscope designed for gemmological (particularly diamond-related) applications. Its lighting system consists of flicker-free yellow and daylight-equivalent LED lamps (programmable from 3000 to 6000 K) that help reduce eye strain. Both darkfield and diffuse-ring lighting are provided, as well as a custom-programmable lighting control panel, Zeiss Stemi 508 lens optics, a vacuum-operated gem holder, a wide-range tiltable stand, and Wi-Fi and Bluetooth connectivity for Android devices. Visit http://aroyaltech.com/Advance-Solitaire-Microscope.aspx.

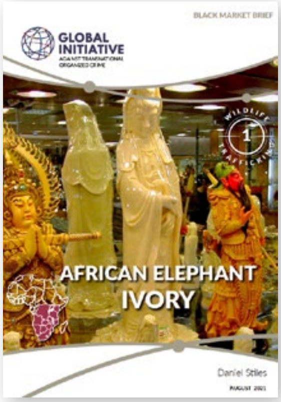


StrainView

In October 2021, BrankoGems (Vancouver, British Columbia, Canada) released the StrainView instrument for screening synthetic diamonds. It consists of a Gemetrix CPF (cross-polarised filters) system with a built-in magnifier that couples to a smartphone camera for easy viewing and image capture of samples, including melee. Its light source allows viewing even in a well-lit room, providing diagnostic evidence for natural diamonds (multicoloured strain pattern), HPHT-grown synthetics (absence of such a pattern), type IIa natural diamonds (‘tatami’ pattern) and CVD-grown synthetics (parallel-banded pattern). The instrument’s small size and smartphone interface make it highly portable. Visit www.brankogems.com/shop/instruments/strainview.

NEWS AND PUBLICATIONS

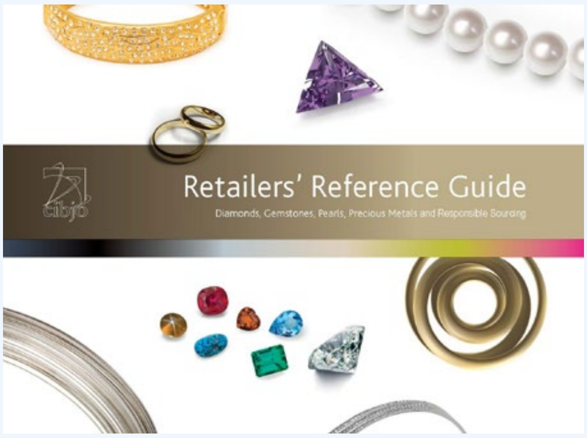
African Elephant Ivory Report



According to this August 2021 report from the Global Initiative Against Transnational Organized Crime (Geneva, Switzerland), the COVID-19 pandemic has affected wildlife conservation due to the reduction in funding available for anti-poaching efforts, enabling an increase in the illegal trade of African elephant ivory. Nevertheless, elephant poaching apparently decreased somewhat in 2020 compared to 2019, to the lowest level since systematic monitoring began in 2003. (The number of elephants poached fell from more than 30,000 in 2011 to around 11,000 in 2018, and the figures for 2019 and 2020 are estimated to be below 10,000 per year.) At the same time, and likely a result of reduced availability, prices for raw ivory have risen significantly. Download the report at https://globalinitiative.net/analysis/african-elephant-ivory.

CIBJO Congress 2021 Special Reports

Ten reports prepared in association with the November 2021 Virtual CIBJO Congress are available for download at www.cibjo.org/congress2021/special-reports. They review issues planned for discussion during the conference by the respective CIBJO commissions, and include: *CIBJO's Commitment to Responsible Sourcing Continues through the COVID Pandemic* (Responsible Sourcing Commission); *Crisis and Opportunity: An Industry Transformed* (Marketing & Education Commission); *With Environmental Protection Dominating Agenda, Scientific Research into Coral Gathers Pace* (Coral Commission); *Ethical Sourcing in the Fragile Coloured Stone Sector Demands a Nuanced and Holistic Approach* (Coloured Stone Commission); *An Industry Changed but Reinvigorated Nears the Goal of Full ISO Standardisation* (Diamond Commission); *The Jewellery Trade Disrupted: Technology as the Harbinger of Change* (Technology Commission); *Pearls Ride a Rollercoaster of Global Events, Punctuated by COVID and Climate Change* (Pearl Commission); *Precious Metals in the Era of COVID-19: Still a Safe Haven, but with New Applications* (Precious Metals Commission); *Taking on the Task of Determining What's in a Variety Name?* (Gemmological Commission); and *Traversing the Ethical and Legal Minefield Associated with Collecting and Handling Personal Data* (Ethics Commission).

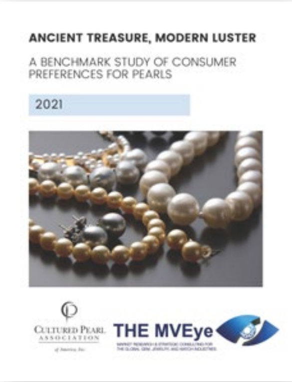


CIBJO *Retailers' Reference Guide*

In November 2021, CIBJO launched a new website (www.cibjo.org/rrg) to host the second edition of its *Retailers' Reference Guide*. The 154-page document is provided as a free resource for jewellery store staff, and can be viewed online or downloaded as a PDF file. The guide is designed to 'empower shop floor staff with the information they need for customers', with basic facts about diamonds, coloured stones, pearls and precious metals. The guide also describes how to follow responsible sourcing practices and protect the integrity of the supply chain.

Consumer Preferences for Pearls

In August 2021, the Cultured Pearl Association of America (CPAA) and USA-based The MVEye released *Ancient Treasure, Modern Luster: A Benchmark Study of Consumer Preferences for Pearls*, which gives the results of a July 2021 survey that was completed by 1,012 U.S. jewellery consumers (age 25–55, 73% female and 27% male, with household incomes greater than USD50,000 and who had purchased at least USD200 in fine jewellery during the past three years). The survey revealed that 66% of the respondents own at least one piece of pearl jewellery, and roughly half indicated that it's a popular purchase both for themselves and as gifts, especially for birthdays and anniversaries. In short, pearl popularity ranks among other top gems such as sapphire, ruby and diamond. Download the report at www.themveye.com/premium-reports.php by completing the online form and using the CPAA-provided promo code 'cpaamveye100'.



CPAA's *#thisispearl* Digital Magazine

The Cultured Pearl Association of America debuted its new bimonthly digital magazine in December 2020, and subsequent 2021 issues (February, April, June, August and November) are also now available online. Regular topics covered in each issue include: a market report, sales survey, pearl jewellery trends, pearl farming, profiles of pearl professionals, sustainability, design awards and product galleries. To sign up for a free subscription, visit www.cpaa.org/pages/thisispearl-digital-magazine.

De Beers's *The Diamond Insight Report 2021*

The 2021 edition of this informative annual report from De Beers, released in early November, is subtitled 'Sustainability: Shaping the Future of the Diamond Sector'. This focus came from a study commissioned by De Beers in July 2021 which indicates that sustainability is now equally as important as price and design when consumers choose diamonds. Sustainability considerations include environmental protection, fair worker treatment, conflict-free sourcing, support of local communities and diamond origin. A significant finding is that fine jewellery is the third category (after food and clothing) that is most frequently purchased on the basis of sustainability considerations. Thirty percent of consumers ranked sustainability as their most important consideration when choosing a diamond. In addition, many consumers indicated a willingness to pay a premium for natural diamonds accompanied by sustainability credentials. The report also includes a 'Value Chain Dashboard' covering global diamond production, sales, values and trends. Download the 59-page report at www.debeersgroup.com/reports/insights/the-diamond-insight-report-2021.

THE GEOLOGICAL SOCIETY OF AMERICA®
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Portland, Oregon, USA

Gem Abstracts from the 2021 GSA Annual Meeting

A session titled 'Gemological Research in the 21st Century—Gem Minerals and Localities' took place at the Geological Society of America's Annual Meeting (GSA Connects 2021), held in Portland, Oregon, USA, on 10–13 October 2021. Abstracts of the oral presentations can be viewed at https://gsa.confex.com/gsa/2021AM/meetingapp.cgi/Session/51632 and include topics such as the chemical and isotopic composition of sapphires from Montana (USA), defects in naturally irradiated green diamonds and seasonal variations in freshwater pearl composition. Poster session abstracts are available at https://gsa.confex.com/gsa/2021AM/meetingapp.cgi/Session/52146 and cover subjects such as the spectroscopic characteristics of heated blue-to-violet spinel and Cu-bearing tourmaline, and gem localities known during the time of the Taj Mahal (17th century).

Minerals of Arizona Symposium Abstracts

Abstract volumes for the annual Minerals of Arizona Symposium (sponsored by the Flagg Mineral Foundation) are available to download at https://flaggmineralfoundation.org/home/minerals-of-az-symposium. The most recent (28th) symposium was held in September 2021 in Tucson, Arizona, USA, and the 28-page abstract volume covers topics such as the significance of making donations to museums, fluorescence in petrified wood, fluorescent mineral and silver finds in Arizona, and more.

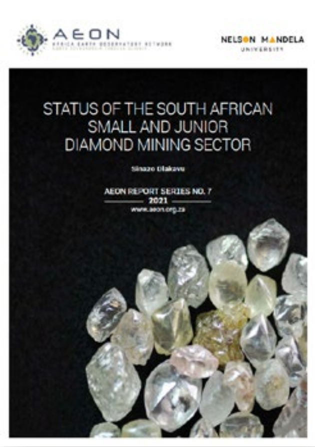
RJC Gender Equality Report

In September 2021, the Responsible Jewellery Council released this report, published in collaboration with Business for Social Responsibility and other key stakeholders, including CIBJO. The report calls for collective and immediate action on gender equality, a crucial building block for developing a strong and responsible supply chain that contributes to achieving United Nations' Sustainable Development Goal 5. The report was prepared following a series of regional roundtables—covering Europe, North America, Asia and Africa—and comprehensive research, including a Gender, Diversity & Inclusion Survey. Four key themes are covered: commitments and business policies; talent attraction, training and retention; creating a culture of inclusion; and value-chain initiatives. Download the report at https://responsiblejewellery.com/wp-content/uploads/RJC-Gender-Equality-Report-2021-Sep.pdf.

RJC Retailer Sustainability Toolkit

In August 2021, the Responsible Jewellery Council released *Building Sustainability and Responsible Sourcing into Supply Chains*, to help retailers become familiar with sustainability and understand the common terms used so that they can communicate better with customers. Knowledge in this area of the gem and jewellery trade is especially important because customers often research retailers online to find ones who align with their own values of responsibility and sustainability. This toolkit is designed to help retailers obtain information about the sources of their merchandise, as well as train store personnel to respond appropriately to customer enquiries. For more information and to download the toolkit, visit https://responsiblejewellery.com/support/retailer-sustainability-toolkit.

Status of the South African Small and Junior Diamond Mining Sector



The South African Diamond Producers Organisation released this report from the Africa Earth Observatory Network at Nelson Mandela University in September 2021. The small-scale and junior diamond mining sector is comprised primarily of alluvial operations and a few small kimberlite mines. This group produced a high proportion of diamonds in the 1950s to 1960s, prior to the development of major kimberlite mines in the 1970s and 1980s. Since 2004, this sector has declined significantly. The report reviews the status and challenges of small-scale (25 or fewer persons per shift) and junior (50 or fewer persons per shift) diamond mining operations in South Africa, and makes recommendations to revive this sector, including the creation of a charter and regulations, modernisation of the system to facilitate granting of mineral rights, effective permitting procedures and more. Download the report at https://sadpo.co.za/wp-content/uploads/2021/09/6127-AEON-SADPO-Report-July-2021_WEB-low-singles.pdf.

Tracing Coloured Stones from East Africa to Asia

Released in November 2021 by the Global Initiative Against Transnational Organized Crime, *Scratching the Surface: Tracing Coloured Gemstone Flows from Mozambique and Malawi to Asia* is a 56-page report that describes the complex process of how gem materials from Mozambique and Malawi reach international trade hubs, primarily in Asia, and then are distributed around the world to retail markets. The report focuses on the production of gems—notably ruby, sapphire and tourmaline—from mines in northern Mozambique and Malawi. Foreign traders purchase rough stones, often cheaply, and transport them to other countries to be cut and polished. The report ends with six recommendations to support local mining communities in the region: (1) increase engagement with source communities and gem traders; (2) identify solutions of interest to stakeholders; (3) adopt responsible sourcing requirements; (4) shift regulation to support mining and trade pathways; (5) promote cooperation between source, transit and destination countries; and (6) support anti-corruption and good governance initiatives. Download the report at https://globalinitiative.net/analysis/gemstone-flows-mozambique-malawi-asia.

OTHER RESOURCES

ColourWise Colour Grading System

In mid-2021, the World Gem Foundation launched the Colourwise Colour Grading System. It incorporates 1,550 digitised colour samples covering 37 hues, five saturation levels and seven levels of luminosity. The web-based system is suitable for coloured stones (including jadeite) and pearls. It can be used on a computer, tablet or smartphone, and includes information about screen calibration and lighting environment, as well as a colour vision test. For subscription options, visit www.colourwise.info/introduction.html.

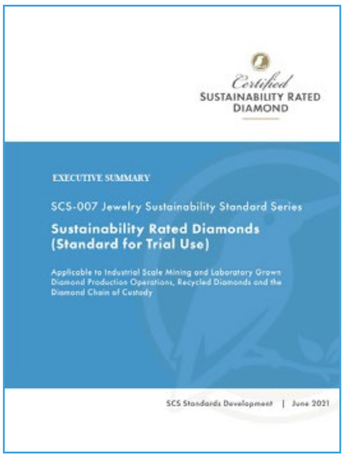
iTraceiT Digital Tools for Traceability

Belgian startup company iTraceiT launched its pilot programme in September 2021, inviting partners to join in their development of an independent digital tool to authenticate diamonds, including blockchain traceability and transparency to support the marketing of ethically sourced diamonds from mine to end user. The iTraceiT programme allows the user to input information about a diamond, create a QR code to access the data and manage the data available to purchasers. Any type of data can be input, including geolocation, date, time, etc., and data fields can be customised. The programme is scheduled for full release in late 2021. Visit https://itraceit.io.

SSEF Gems and Jewellery Course

SSEF's newest advanced training course—*Gems & Jewellery: History, Identification and Important Trends*—combines the study of both historic and modern gems and jewellery. The five-day course begins with the cultural history and evolution of gem use, and then examines technical issues, design, distribution of knowledge, and how trends and value have changed over time. The course is designed to enable students to identify gems and jewellery, as well as begin to learn about appraisal criteria. The course involves live workshops and practical work in small groups. First offered in October 2021, the next available session is 16–20 May 2022. Visit www.ssef.ch/courses/advanced-gems-jewellery.

Sustainability Rated Diamonds



Certified
SUSTAINABILITY RATED
DIAMOND

EXECUTIVE SUMMARY

SCS-007 Jewelry Sustainability Standard Series

Sustainability Rated Diamonds
(Standard for Trial Use)

Applicable to Industrial Scale Mining and Laboratory Grown Diamond Production Operations, Recycled Diamonds and the Diamond Chain of Custody

SCS Standards Development | June 2021

SCS Standards, a non-profit organisation committed to the development of standards that advance sustainable development goals and practices, has launched a new website to accompany its trial standards for rating diamonds issued in June 2021, as the first in its SCS-007 Jewelry Sustainability Standard series (which will cover gemstones and precious metals used in jewellery). The website introduces a rating scale, from A+ to D (and 'not rated'), depending on levels of traceability, environmental impact and human health impact. SCS Standards offers certificates for individual diamonds based on this rating scale, and retailers interested in carrying certified diamonds can register to become an accredited SCS-007 Certified Diamond Retailer. For more about the programme and to download a summary of the standards, visit https://sustainabilityrateddiamonds.com/about.

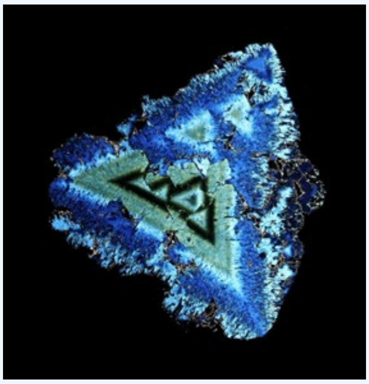
WDC System of Warranties Guidelines Updated

WORLD
DIAMOND
COUNCIL

System of Warranties
Guidelines

The World Diamond Council announced an updated second edition of its System of Warranties (SoW) in conjunction with the 40th anniversary of the United Nations International Day of Peace on 21 September 2021. The SoW is a self-regulation system for the diamond industry to help companies meet the requirements of the Kimberley Process Certification Scheme and adhere to SoW guidelines. It covers trade in rough and polished diamonds as well as diamond-set jewellery, and is intended to be applied at every step from mine to consumer. A warranty statement should be passed on each time a diamond changes hands, thus establishing a chain of evidence which assures the buyer that the diamond originated from a source complying with the Kimberley Process Certification Scheme. For more information and to download a copy of the SoW, visit www.wdcsow.org.

MISCELLANEOUS



Tourmaline Exhibit in Austria

In July 2021, a travelling exhibition titled *Crystal Magic – Fascinating Worlds in Dark Tourmalines* opened at the Haus der Natur within the Museum für Natur & Technik in Salzburg, Austria. Running through September 2022, the exhibit features more than 500 crystals and 1,500 slices of tourmaline. Prepared mostly from macroscopically black schorl, the slices reveal exceptional beauty, colour and microstructures when cut into thin plates and viewed with transmitted light, particularly when observed with a microscope. Visit www.hausdernatur.at/en/tourmalines.html.

Photo by Paul Rustemeyer.

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Gem Notes

COLOURED STONES

Alexandrite with an Uncommon Deep Red Colour

In September 2021, the American Gemological Laboratories received a parcel of stones from Henry F. Kennedy (New Jersey, USA) that included seven faceted alexandrite gems (0.70–2.25 ct), which presented an uncommon, richly saturated, deep red colour in incandescent light (Figure 1a). When observed with daylight-equivalent illumination, they displayed a distinct colour change to dark slightly greenish blue (Figure 1b). Kennedy informed us that these stones were all faceted from an 8.2 g twinned chrysoberyl found in 1976 in Malacacheta, Minas Gerais, Brazil (see figure 2 in Proctor 1988). Proctor (1988) described this crystal as a 'rare example of red chrysoberyl'.

Purple to reddish purple chrysoberyl from Brazil was also described by Schmetzer *et al.* (2014), and they concluded on page 39 that the 'high Cr contents of the studied chrysoberyls cause a distinct change in transmission in the blue-green spectral range'.

Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis of the seven faceted alexandrites with a Thermo Scientific ARL Quant'X spectrometer showed 0.90–1.41 wt.% Cr_2O_3 and 0.21–0.83 wt.% FeO (Table I). The highest Cr contents are consistent with the lowest values reported for purple to reddish purple chrysoberyl by Schmetzer *et al.* (2014), but are greater than in typical alexandrite from Malacacheta, which contains up to 0.74 wt.% Cr_2O_3 (see table II in Schmetzer *et al.* 2014).

The greenish blue colouration in daylight of alexandrite from Malacacheta has been attributed to the presence of Cr^{3+} and Fe^{3+} substituting for Al^{3+} in the mirror symmetry (C_s) sites, and the intensity of the blue colour is a function of the Cr^{3+}/Fe^{3+} ratio (Pinheiro *et al.* 2000). The intense colouration of the present alexandrites is probably the result of their high Cr contents (average 1.18 wt.% Cr_2O_3)—but not too high, which would result in only a purplish appearance in both incandescent and daylight-equivalent illumination, as documented by Schmetzer *et al.* (2014).

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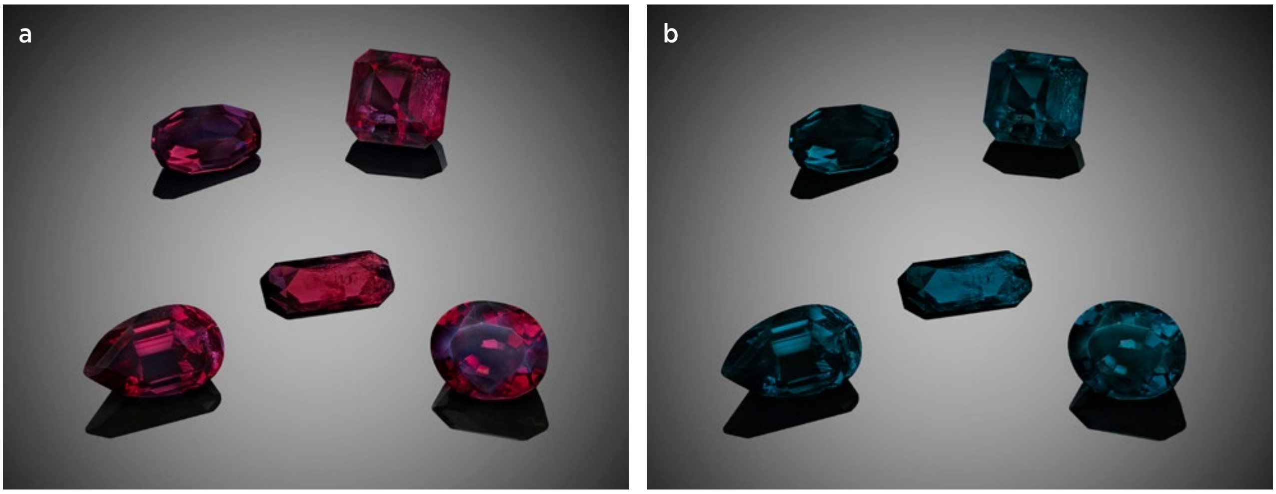

Figure 1: The colour change shown by some of the faceted alexandrite samples (0.70–2.25 ct) examined by the authors is seen here under (**a**) incandescent and (**b**) daylight-equivalent fluorescent light. Photos by Alex Mercado and Bilal Mahmood.

Table I: Chemical composition (in ppmw) of the studied alexandrite samples by EDXRF analysis.

	Ti	V	Cr*	Fe*	Ga	Sn
Range	57–346	53–77	6180–9640	1650–6450	112–135	17–178
Average	147	63	8130	3240	124	91
Median	108	65	8500	2690	123	85

*The values shown for Cr and Fe are equivalent to 0.90–1.41 wt.% Cr_2O_3 and 0.21–0.83 wt.% FeO, respectively.

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Amethyst with Trapiche-like Patterns and Other Quartz Materials from Rondônia, Brazil

Quartz showing trapiche-like patterns is relatively uncommon, but in the past several years such material has entered the gem and mineral specimen market from various localities—particularly the Huanggang Fe-Sn skarn deposit in Inner Mongolia, China (e.g. Farfan *et al.* 2021; Liu & Wathanakul 2021; and references therein). According to Farfan *et al.* (2021), the trapiche-like pattern in this rock-crystal quartz formed as a result of clay inclusions being preferentially trapped on rough surfaces during crystal growth. The rough surface texture resulted from the presence of multiple growth centres (e.g. related to 'split crystal' development and other growth disturbances) that may be indicative of environmental conditions such as a large amount of molecular-scale impurities in the hydrothermal fluid and/or a high degree of supersaturation that caused rapid crystal growth. Trapiche-like patterns are less commonly encountered in coloured quartz varieties, although in the past few years they have been documented in amethyst and ametrine from Brazil (Laurs 2018; Sun *et al.* 2018; Bui *et al.* 2020).

Recently, some new production of amethyst from the Amazon region of Brazil included specimens showing various colour-zoning patterns, including trapiche-like structures. The mine, called Amethyst Costa Marques, is located near the town of Costa Marques in Rondônia State, which is in north-western Brazil near the border with Bolivia. The deposit has been mined since 2018 by Mineração Costa Marques, a family-owned company founded by Henrique and Sávio Testoni. So far it has been worked as an open pit (Figure 2), which has allowed a broad view of the diversity of mineral formations present in the deposit. The quartz mineralisation is hosted by hydrothermal veins (Figure 3), and in the future the company plans to continue working the most favourable areas in underground tunnels. However, mining only takes place for six months of the year (from May through October) due to heavy annual rainfall in this region of the Amazon basin. Sávio Testoni indicated that a clear priority for the company has been fully complying with environmental regulations, while focusing on ethical mining and the safety of personnel during extraction. In addition, the company has started a forest recovery project in the surrounding area.

So far, Mineração Costa Marques has produced several tonnes of quartz showing a large diversity of patterns and colours (i.e. purple, smoky and white/colourless). In September 2021, the company exhibited a variety of rough and polished quartz materials at the Denver Mineral, Fossil, Gem & Jewelry Show in Colorado, USA. The products included crystal clusters, rough and partially polished single crystals, slabs, spheres, cabochons and faceted stones (Figure 4).

According to Sávio Testoni, the company has identified

Figure 2: Since 2018, amethyst and other quartz materials have been recovered from this mine in Rondônia State, north-western Brazil. Drone photo courtesy of Mineração Costa Marques.

several different types of colour-zoning patterns in the quartz. The trapiche-like structure is found in only about 20% of the mine's production, while dark 'black' amethyst constitutes 13%, and only 0.2% of the quartz is facetable into high-quality amethyst gemstones (some of which show interesting reddish colouration, as seen in Figure 5). The remaining material consists of 'chevron'-zoned crystals and pieces that are used for the production of tumbled amethyst. The commercially desirable rough material is typically present in relatively small portions of the crystals (averaging about 200 g), resulting in an approximately 25% yield after cutting into the various products listed above.

The trapiche-like pattern in the amethyst from this deposit is mostly characterised by dark spokes that separate lighter-coloured segments containing fibrous growth structures (again, see Figure 4). By contrast, the trapiche-like amethyst reportedly from Brazil that was documented by Bui *et al.* (2020) had light spokes that separated darker areas. The polished quartz points from the Amethyst Costa Marques mine show dark-coloured phantoms that somewhat resemble those from Minas Gerais that were documented by Laurs and Renfro (2017), but the latter ones had finer-scale zoning of the dark inclusion patterns. The diversity of quartz materials

Figure 3: The amethyst mineralisation is hosted by hydrothermal veins, which commonly yield comb-like aggregates of quartz crystals, as displayed here by Jacques Testoni. Photo courtesy of Mineração Costa Marques.

Figure 4: (**a**) Quartz materials displayed by Mineração Costa Marques at a recent gem and mineral show in Denver, Colorado, include crystal clusters, rough and partially polished single crystals, slabs, spheres, cabochons and faceted stones. Photo courtesy of Mineração Costa Marques. (**b**) Various colour zoning patterns are evident in these polished quartz slices (up to 8.8 cm). Photo by Jeff Scovil.

being produced by Mineração Costa Marques is notable, and according to the company's geologists and mining engineer, the deposit shows excellent potential for long-term production.

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Figure 5: Some of the gem-quality amethyst produced by Mineração Costa Marques shows reddish colouration when viewed down the *c*-axis. This piece is 3.6 cm wide and weighs 17.35 g. Photo by Jeff Scovil.

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Cassiterite from Yunnan Province, China

Cassiterite (SnO_2) is an ore mineral of tin that occurs worldwide, but the crystals are typically either opaque or small, making them unsuitable as a gem material. Large, euhedral cassiterite is known from the Viloco mine in Bolivia (Hyrsl 2002), but until now gem-quality material from China has not been well documented.

Two localities in China produce gem-quality cassiterite: the Amo area in Ximeng County and the Yalian area in Yongde County, both situated in western Yunnan Province. Cassiterite has been recovered from this region in the course of prospecting and mining for tin deposits since the 1980s. The Yongde deposits have received little attention in the literature, whereas the Ximeng tin-mining area has been the focus of extensive studies (mostly published in Chinese). A mineralisation age of 21.5 million years is based on Rb–Sr dating of micas from greisen-type ore bodies (Zhao & Tang 1991). Song (2017) concluded that the Ximeng deposits are related to hypothermal activity from granite intrusions. This is supported by earlier hypotheses of Zhang *et al.* (1983), Zhao and Tang (1991) and Zuo *et al.* (2013).

Cassiterite crystals from both localities in Yunnan Province may show euhedral forms and high transparency. Moreover, the crystals usually measure 1–2 cm and can attain more than 4 cm in dimension. Near-colourless to dark brown crystals are common, but rare 'golden' yellow, pink and red material is also encountered (Wu 2013). Twinning is common.

During two decades of mining, the production of high-quality cassiterite has been estimated to be several tonnes (Wu 2013). Some of this material has been cut and polished as faceted stones, whereas well-formed crystal specimens—often on a matrix of rock crystal quartz (e.g. Figure 6)—are coveted by mineral collectors. Faceted cassiterite can be up to 30 ct (Yongming Shi, pers. comm. 2021), though such large sizes are rarely seen for gems cut from this mineral. Most faceted stones on the Chinese market weigh less than 8 ct (e.g. Figure 7).

In the authors' experience, gem-quality cassiterite from Yunnan Province is generally homogeneous in colour, but sometimes may show oscillatory colour zones characterised by alternating light and dark layers. This banding is visible to the unaided eye and is especially obvious in thin sections prepared for fluid-inclusion studies. The dark zones may be related to trace elements (e.g. Ta, Nb and W) that substitute for Sn (Ollila 1985). Fluid inclusions are a relatively common internal feature in the Chinese cassiterite. They consist of liquid and vapour phases, and some contain solid daughter minerals (Figure 8), which are probably halite based on their cubic shape. This is consistent with observations of Zhao and Tang (1991), who also documented halite in fluid inclusions within cassiterite.

Six representative cassiterites from Ximeng were characterised for this study. Their hydrostatic SG values ranged from 6.88 to 7.02. They were inert to

Figure 6: Cassiterite crystals from Ximeng, Yunnan Province, China, are accompanied by rock-crystal quartz in this specimen, which illustrates the transparency and crystal form typical of cassiterite from this location. The largest cassiterite crystal is 1.1 × 1.1 × 1.3 cm. Photo by Junyi Pan.

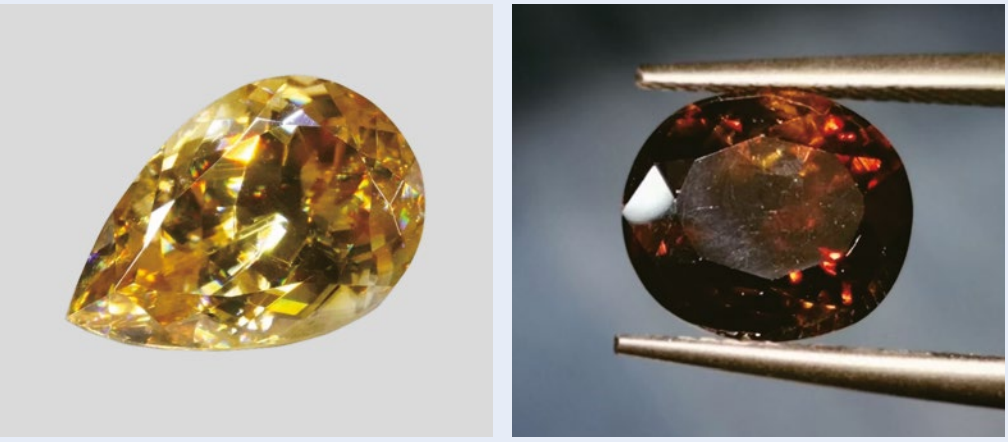

Figure 7: These faceted cassiterites (left, 6.43 ct; right, 7.50 ct) are typical of the gem-quality material from Ximeng, Yunnan Province. Photos by Yongming Shi (Emerald Industry Association of Malipo County, Yunnan Province).

long- and short-wave UV radiation and did not show any phosphorescence. Trace-element compositions were determined by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), and preliminary results show that the main impurities consist of W (0.94–2260 ppm), Fe (79.7–272.5 ppm) and Ti (28.2–92.5 ppm). High-field-strength elements were present in relatively low amounts: Zr = 5.58–18.1 ppm, Nb = 0.07–13.7 ppm, Hf = 0.22–0.69 ppm and Ta = 0.06–2.03 ppm.

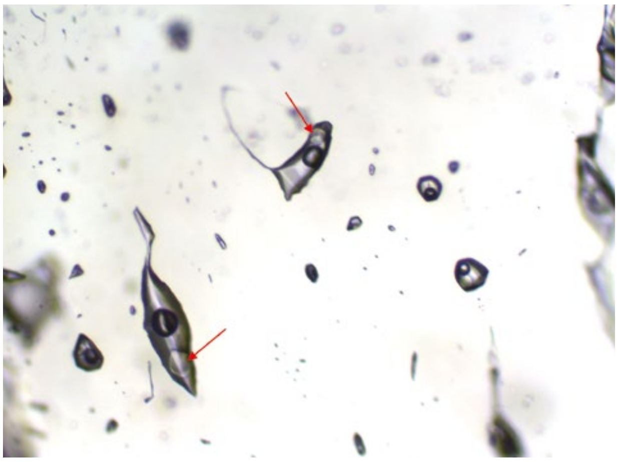

Figure 8: Some fluid inclusions in cassiterite from Ximeng, Yunnan Province, contain daughter minerals that are probably halite (see arrows). Photomicrograph by Junyi Pan; image width 0.3 mm.

In general, gem-quality cassiterite from Yunnan Province is comparable in size and transparency to material from the Viloco mine in Bolivia.

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Chrysoprase from Baluchistan, South-East Iran

Chrysoprase is a variety of chalcedony that shows an attractive green to yellowish green colour due to the presence of micro-inclusions of Ni-bearing aggregates (Sachanbiński *et al*. 2001). Chrysoprase is usually found within or associated with serpentinised peridotite. It forms by precipitating from silica-rich fluids circulating through fractures and cavities in these rocks (Hatipoğlu & Yardımcı 2014).

In Baluchistan, south-east Iran, chrysoprase is found associated with Fe-Cu mineralisation in ophiolites that have been altered by intrusive rocks. The chrysoprase is hosted by silicified alteration zones and is locally of gem quality. The authors collected about 10 kg of rough material, and 15 pieces were cut and polished as cabochons ranging from 2 × 2 cm to 4 × 5 cm (e.g. Figure 9). The samples were gemmologically characterised, and petrographic thin sections of the chrysoprase were also prepared, at the Center for Gemology at Shahid Beheshti University.

The brittle nature of the rough material and the presence of veins containing iron oxides, clay and other epigenetic material caused difficulties during the polishing of the samples, and a few of them broke in the process. The cabochons were opaque and deep green, with a Mohs hardness of 6½–7. The RI (obtained by the spot method) was 1.54 and the mean hydrostatic SG value was 2.58. All of the samples showed no reaction when viewed with the Chelsea Colour Filter and were inert to long- and short-wave UV radiation. In the chrysoprase thin sections, we observed quartz crystal inclusions, opaque minerals, radial quartz aggregates and quartz veinlets showing comb structures (Figure 10). Calcite, chlorite, epidote and metal-oxide minerals were also documented in our petrographic studies.

Figure 9: These cabochons, which range from 2 × 2 cm to 3 × 4 cm, were cut from Baluchistan chrysoprase for this report. Photo by B. Rahimzadeh.

Figure 10: Viewed in cross-polarised light, this image of a thin section of Baluchistan chrysoprase shows a veinlet of crystalline quartz, as well as radial aggregates of quartz (at the bottom of the photo). Photomicrograph by P. Hadipanah; magnified 40×.

Raman spectra of the Baluchistan chrysoprase were compared to those of Turkish chrysoprase and green-stained quartz (Hatipoğlu *et al*. 2011). As seen in Figure 11, all three materials showed comparable peaks at around 460, 200 and 122 cm^{-1}. Similar Raman features were attributed to α-quartz by Gillet *et al*. (1990). The Raman peak at 460 cm^{-1}, and also an additional peak at 498 cm^{-1} present only in the Turkish chrysoprase, are inferred to be due to substitution of Si by other cations (Hatipoğlu *et al*. 2011).

Chrysoprase from the Balochistan deposits is present in significant amounts, but further work is needed to evaluate whether enough of the material is of gem quality to enable commercial production.

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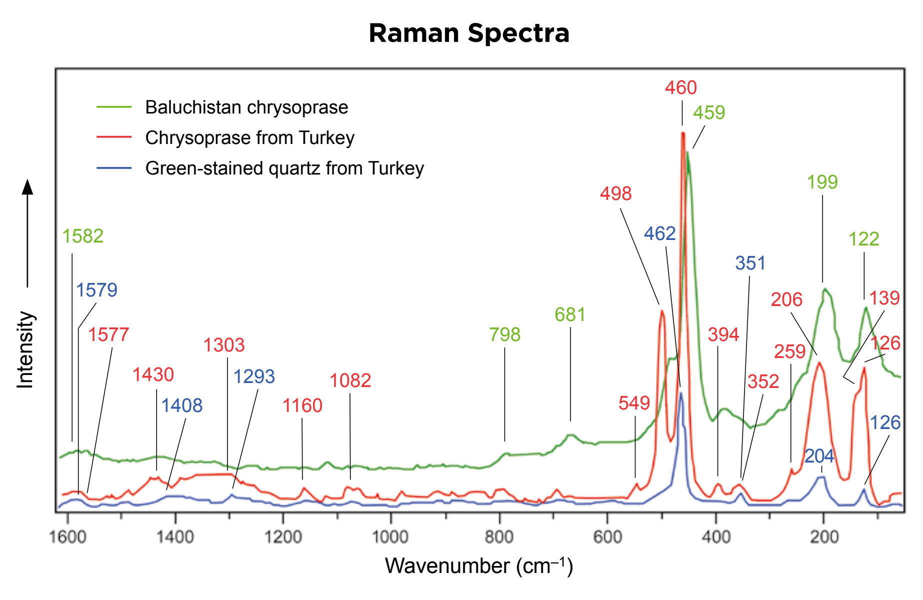

Figure 11: Raman spectra are compared for chrysoprase from Baluchistan and Turkey, as well as green-stained quartz from Turkey. Data for the Turkish samples is from Hatipoğlu *et al.* (2011). Spectra are offset vertically for clarity.

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New Emeralds from Musakashi, Zambia, Appear on the Market

Zambia has been known for many decades as a major source of gem-quality emeralds. Most of the production comes from the Kafubu area (e.g. Figure 12), about 45 km south-west of Kitwe in Zambia's Copperbelt Province. In early 2000, a new emerald source was discovered at Musakashi in the Solwezi District of

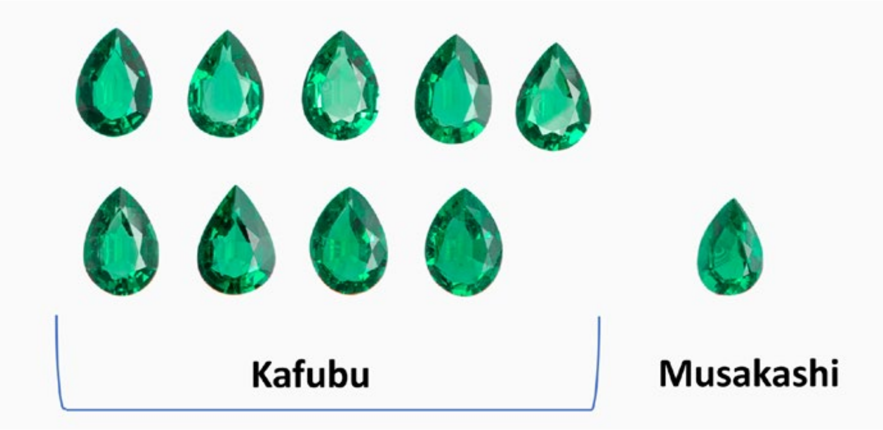

Figure 12: This parcel of ten Zambian emeralds (about 5 ct total weight) recently submitted to SSEF for testing was found to consist of nine stones from the Kafubu area and one from the Musakashi deposit. Photo © SSEF.

Figure 13: Spiky multiphase fluid inclusions are seen in an emerald from Musakashi, Zambia. Photomicrograph by M. S. Krzemnicki, © SSEF; magnified 50×.

central Zambia (Zwaan *et al.* 2005), about 160 km west of Kitwe. However, there has been limited production from Musakashi until somewhat recently, partly due to equipment problems and legal issues concerning the mining concessions (Klemm 2010; Pardieu *et al.* 2015).

Interestingly, Musakashi emeralds are very different in their formation and occurrence from the 'classic' schist-hosted Kafubu material. According to Manyepa and Mutambo (2021), Musakashi emeralds are found 'in random pockets' related to weathered metasediments that are cross-cut by hydrothermal veins. They are reminiscent of Colombian emeralds, and to some extent those from Panjshir (Afghanistan) and Davdar (China), notably in the presence of spiky three-phase and multi-phase inclusions (Figure 13), as well as fine hollow channels parallel to the *c*-axis (Figure 14; see also Zwaan *et al.* 2005; Saeseaw *et al.* 2014; Cui *et al.* 2020).

Recently, the Swiss Gemmological Institute SSEF received a parcel of ten emeralds weighing a total of approximately 5 ct (Krzemnicki 2021). Whereas nine of these stones revealed classic features of Zambian emeralds from the Kafubu area (e.g. brownish mica flakes, amphibole fibres and rectangular two-phase inclusions), one stone was quite different and showed characteristics consistent with emeralds from Musakashi. Chemical analysis by LA-ICP-MS (GemTOF, see www.gemtof.ch) confirmed a Musakashi origin by comparison to data from reference samples from this locality that were recently added to SSEF's collection.

The Musakashi emeralds investigated so far by SSEF chemically resemble Colombian stones in many aspects (see also Zwaan *et al.* 2005; Saeseaw *et al.* 2014). Their main chromophore is Cr (about 0.42–0.78 wt.% Cr_2O_3), together with V and Fe in similar concentrations (0.15–0.41 wt.% V_2O_3 and 0.22–0.42 wt.% Fe_2O_3). In addition, they contain only low-to-moderate concentrations of alkali elements, and—similar to Colombian emeralds—their Fourier-transform infrared and Raman spectral features show predominantly type I water (Wood & Nassau 1968). This all is very much in contrast to the more Fe-rich emeralds from classic schist-type deposits in the Kafubu area of Zambia. The Kafubu emeralds show an Fe/Cr ratio in the range of 6.5–20, compared to just 0.33–0.84 in the studied samples from Musakashi.

When comparing Musakashi emeralds to stones from Afghanistan, specifically those described in a recent article in this journal on Panjshir emeralds (Krzemnicki *et al.* 2021), we now have to assume that at least some of those samples might have originated instead from Musakashi. This is based on additional and new LA-ICP-MS data acquired on Musakashi emeralds. Further advanced testing in collaboration with other research institutions and gemmological laboratories is underway to define criteria to characterise samples from these different deposits, and is planned for publication in a future issue of *The Journal*.

It is often challenging for laboratories to investigate gem material from new sources. We commonly depend on obtaining reliable information from trade members and miners (e.g. Manyepa & Mutambo 2021), as accessibility to the deposits is not always allowed, especially in these difficult times of COVID-19. Nevertheless, studying samples from new and lesser-known deposits gives us greater insights into the different formation mechanisms of emerald deposits. This ultimately supports origin determination work, but it also means that occasionally we have to update our findings and conclusions when new scientific evidence is pertinent.

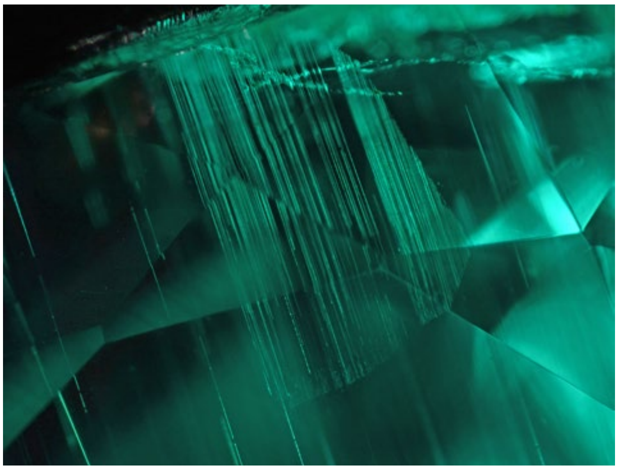

Figure 14: Fine parallel hollow tubes along the *c*-axis are present in this Musakashi emerald. Photomicrograph by M. S. Krzemnicki, © SSEF; magnified 50×.

Having now seen additional fine-quality Musakashi emeralds in the 2–5+ ct range, we assume that production from there has increased, and that more of these interesting emeralds will appear on the market in the near future.

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Two Holy Water Stoups Made from 'Lepidolite'

In 1792, H. Klaproth described a new mineral, lepidolite, from a quarry on Hradisko hill in the north-eastern part of Rožná village, Vysočina Region, Czech Republic. (The name *lepidolite* has subsequently been discredited and this lithium mica is now recognised as being in the polylithionite–trilithionite series.) Further information on the discovery and mining of lepidolite at Rožná can be found in Bohatý (1993) and Pařizek (1999). Probably the first person to recognise that it could be a new mineral was a count, Jan Nepomuk Mitrovský (1757–1799). According to a 1793 report by him, the lepidolite was processed into various objects, including paperweights and snuff boxes (Velebil 2002). The present report documents the use of this material in religious objects: two holy water stoups in the church of St Havel in Rožná, which dates to the second half of the 13th century.

The first stoup (Figure 15a) is located next to the main church entrance and dates from 1863. It is carved in the Baroque style and is semi-circular at its top, with a maximum outer diameter of 33.5 cm, an inner diameter of 25 cm and a depth of 6.5 cm. An inscription below the upper rim has the following characters: F, backwards letter J, K, O, 1863, K, U and probably two missing letters. The lower part consists of eight broad vertical ribs, which connect at the bottom of the stoup. It is deep purple and partially polished, with a dull waxy lustre.

The second stoup (Figure 15b) is located elsewhere on the first floor of the same church. However, it is smaller and not decorated. It has a maximum outer diameter of 24 cm, an inner diameter of 17 cm and a depth of 6 cm. Its upper rim overhangs the semi-circular bowl, which passes directly into the body of the stoup. It has a deep purple colour and a dull waxy lustre. Mrázek and Rejl (2010) stated that this stoup has the same date as the other one (1863).

In order to confirm the material composition of both stoups, we performed Raman analysis using a portable GL Gem Raman PL532 TEC spectrometer. The Raman spectra of both stoups were quite similar, and were consistent with a reference spectrum for 'lepidolite' collected at the University of Chemistry and Technology in Prague, Czech Republic.

The visual appearance of the 'lepidolite' of both stoups is consistent with material from the nearby Hradisko

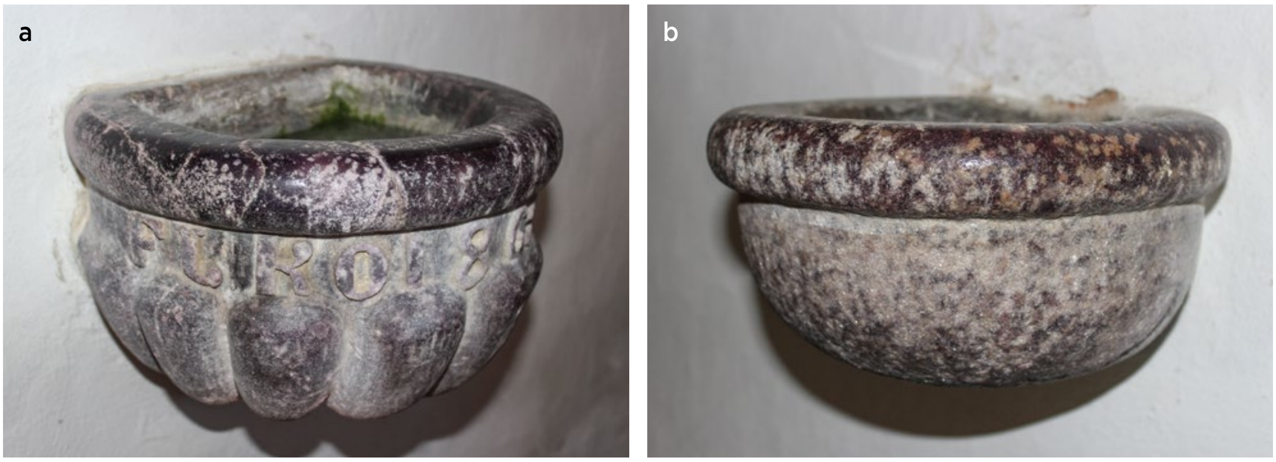

Figure 15: Two holy water stoups made of 'lepidolite' are present in the church of St Havel in Rožná, Czech Republic. The stoup next to the church entrance (**a**) is inscribed with the year 1863, and the other one (**b**) was probably carved at the same time. The colour of the material is deep purple, although this is not evident on the surfaces shown in these images. Photos by R. Hanus.

locality. To the authors' knowledge, this is the only use of 'lepidolite' for religious objects, probably worldwide.

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'Grey' Spinel from Ocua, Mozambique

In the past few years, Mozambique has emerged as a source of gem-quality spinel (e.g. Borenstein *et al.* 2018). In May 2021, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained from an East African supplier a parcel of small-sized 'grey' spinel from Ocua village, Cabo Delgado Province, eastern Mozambique (Figure 16). The lot consisted of broken fragments and weighed approximately 150 g, with most of the pieces ranging from 0.3 to 0.5 g. They varied from near-colourless to silvery grey and bluish grey (rarely violetish or greenish grey), in light to dark tones. Blauwet observed that some of them shifted from bluish grey in daylight to a more lavender colour in warm light of about 3000 K.

Blauwet loaned 11 rough pieces and ten faceted stones (round brilliants weighing 0.29–0.41 ct) to authors CW and BW for examination (e.g. Figure 17). The rough showed the colour range mentioned above, and the faceted samples were mostly pale bluish to violetish grey in light to medium tones, except for one stone that was dark greyish blue. Raman spectroscopy of all of the samples using a GemmoRaman-532SG instrument showed classic spectra for natural untreated spinel in the photoluminescent range, thus confirming their identity. RI values of the faceted stones ranged from 1.717 for the lightest specimen to 1.721 for the darkest one. Hydrostatic SG values (obtained for the rough samples due to their larger sizes) ranged from 3.56 for the lighter pieces to 3.62 for the darkest one. A comparison of these RI and SG values to those in the literature (e.g. Anderson & Payne 1937; Schmetzer & Bank 1986) shows that they are typical of spinel ($MgAl_2O_4$), with those of the darker stones trending slightly towards gahnite ($ZnAl_2O_4$)—that is, consistent with the more spinel-rich compositions recorded for 'gahnospinels' in the spinel–gahnite series. The darkest stone could be dragged by a rare-earth magnet, while the lightest ones exhibited minimal to no detectable magnetic susceptibility.

A cross-shaped strain pattern was observed in the faceted stones between crossed polarisers. All of them were eye-clean, and several showed no inclusions even with 30× magnification. One stone contained tiny octahedral negative crystals, and another one featured a zone with a dense cloud of tiny particles that created a slightly hazy appearance when viewed with darkfield illumination. A third sample contained several colourless crystalline inclusions and fine, curved dotted lines that had the appearance of partially dissolved silk (Figure 18).

Semi-quantitative EDXRF chemical analyses of four spinel samples representing the full range of colours obtained with an Amptek X123-SDD spectrometer showed varying amounts of Fe, Zn and Mn, with higher concentrations of all three elements in the darkest stone. (No Mg was evident since this relatively light element is not detectable by our instrument.) The presence of appreciable Fe and Mn in the darkest spinel is consistent with its stronger magnetic susceptibility compared to the lighter samples. Most of the light-to-medium-toned samples had approximately 2:1 ratios of Fe:Zn, whereas the darkest specimen showed Zn>Fe. In addition, there were small amounts of Ga and traces of Ti, Cr and Ni.

Ultraviolet-visible-near infrared (UV-Vis-NIR) spectra of a light bluish grey and a dark greyish blue sample obtained with a GemmoSphere spectrometer revealed

Figure 16: This parcel of rough spinel from Ocua, Mozambique, weighs approximately 150 g. Photo by Aria Agarwal, Dudley Blauwet Gems.

Figure 17: The Mozambique spinel samples exhibit pale colouration (mostly in the near-colourless to blue hue range) and light to dark tones, as shown by these rough and cut samples that were among those studied for this report. The faceted stones weigh 0.29–0.41 ct. Photo by D. Brennan, Stone Group Labs.

absorptions due to Fe^{2+} (371, 385, 556 and around 920 nm), Fe^{3+} (458 nm) and Fe^{2+}–Fe^{3+} intervalence charge transfer (IVCT; broad band at about 660 nm; see Figure 19). The darker sample showed a higher overall absorption and a stronger Fe^{2+} peak at 371 nm. Therefore, the absorption features in these Mozambique spinels are mainly due to a combination of Fe^{2+} and Fe^{2+}–Fe^{3+} IVCT (cf. D'Ippolito *et al*. 2013).

The availability of this 'grey' spinel from Mozambique is timely, given the current popularity of pale-coloured gem materials in the trade.

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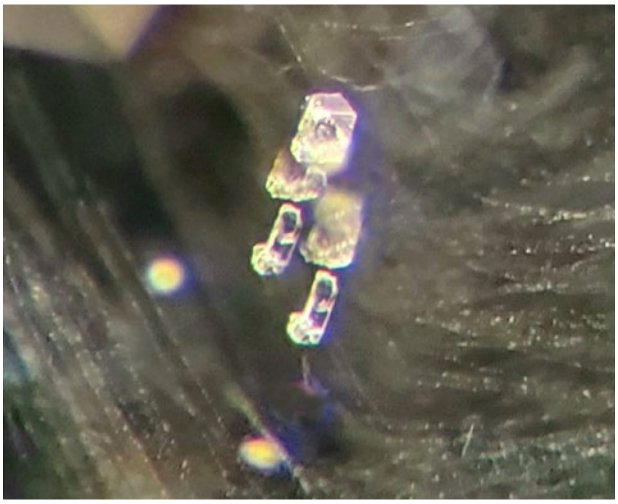

Figure 18: This spinel sample contains unidentified colourless crystal inclusions and curved fine dotted lines. However, most of the samples were found to be free of inclusions. Photomicrograph by B. Williams; image width 1.0 mm.

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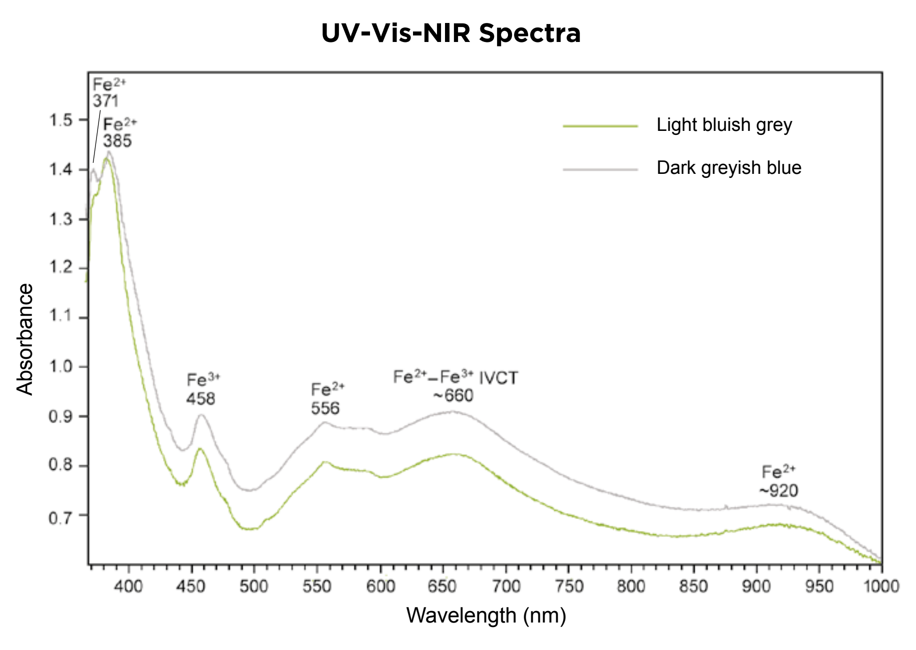

Figure 19: UV-Vis-NIR spectroscopy of light and dark spinel samples shows absorption features that are mainly due to a combination of Fe^{2+} and Fe^{2+}–Fe^{3+} IVCT. The spectra show a higher overall absorption and a stronger Fe^{2+} peak at 371 nm for the darker sample, which contains greater amounts of Fe, Zn and Mn (as determined by EDXRF spectroscopy). The spectra have been scaled according to the relative sizes of the samples, for a path length of the beam of approximately 2.7 mm for each sample.

Green Zircon in Early South-East Asian Jewellery

Two decades ago, this author studied a small group of gold jewellery items from Java, Indonesia, dating to the Early Classic Period (around the 7th–10th centuries CE). This research was related to connections between the Islamic and Far Eastern worlds as reflected in gold-jewellery manufacturing techniques (Ogden 2003, plate 1). Recently, this author had the chance to see these jewellery items again and examine them from more of a gemmological point of view. Two of the objects (Figures 20 and 21) are a type of ornament traditionally called 'bird rings' on the theory that they were used to decorate the legs of pet birds, although it is more likely they were ear ornaments like a modern 'ear cuff' (cf. Miksic 2011, pp. 162–167). One, the broken example shown in Figure 20, is set with two small cabochons, one pinkish red the other pale green. The other earring (Figure 21) is set with a single cabochon gem, also pale green.

The author's analysis of the red gem showed it to be straightforward: it is pyrope-almandine. However, the green gems proved more interesting, as both are zircon. These were identified using a handheld Oxford Instruments X-MET8000 EDXRF spectrometer—useful equipment for the jewellery researcher who is often presented with small, cursorily polished, set gems. The EDXRF spectra revealed clear Zr peaks along with those from the adjacent gold and other alloy metals of the setting (Figure 22). Moreover, visible-range spectra of both samples (obtained with an Ocean Insight Flame spectrometer with a halogen light source) showed the typical features of zircon that are well known to gemmologists as an 'organ-pipe' spectrum (Figure 23). The source of these green zircons has not been identified, as South-East Asia is better known as a source of brown zircon (commonly heat-treated to blue).

These are not the only early zircons recorded from South-East Asia. A bronze casket dated to the 9th–10th centuries CE and containing a variety of objects—including small pieces of goldwork and a group of gems—was excavated in the 1930s from a building foundation at 'Site 16' in Kedah, north-west Malaya (Quaritch Wales

Figure 20: This Javanese gold, garnet and zircon earring (1.1 cm high), circa 10th century CE, is one of two samples described here. Private collection; photo by J. Ogden.

Figure 21: This Javanese gold earring, circa 10th century CE (1.0 cm high), also contains a zircon. Private collection; photo by J. Ogden.

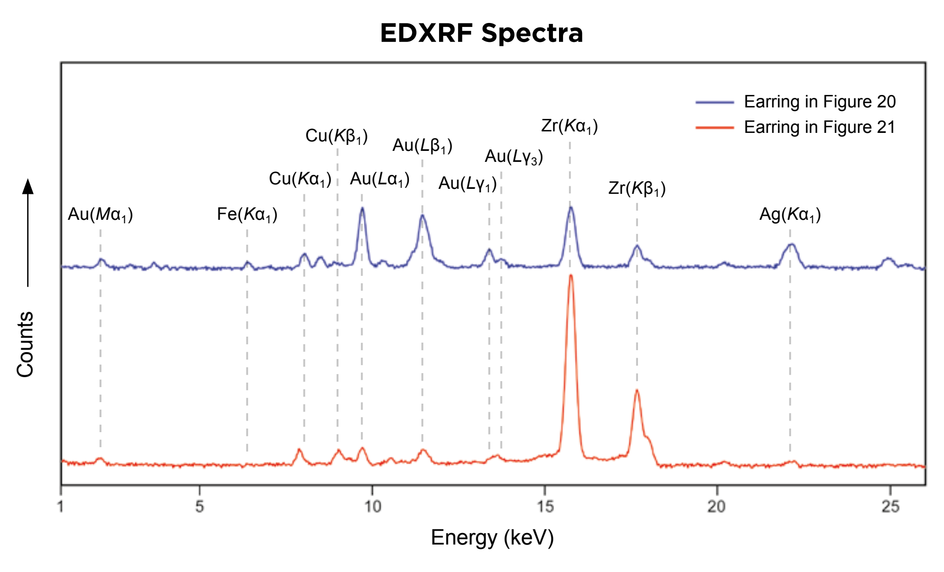

Figure 22: EDXRF spectra of the green zircon in the two earrings show prominent Zr peaks. In addition, because of the diameter of the X-ray beam (3 mm), the gold and other alloy metals of the settings are also recorded in the spectra.

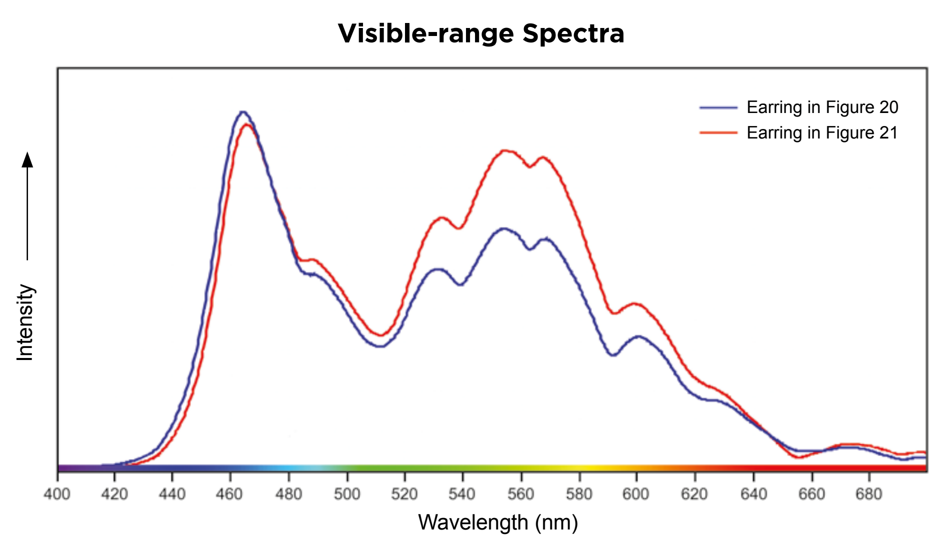

Figure 23: Visible-range spectra of the green zircons in the two earrings show features typical of this gem material.

1940, pp. 34–36). The gems were identified as consisting of a diamond (of minute size, but the earliest excavated example from South-East Asia known to this author), a large polished zircon (colour not indicated), an amethyst, an 'amethystine quartz', a sapphire, a pearl and two pieces of yellow glass (Quaritch Wales 1940, plate 61). These gems were identified at the laboratories of what was then the Imperial Institute in London (Quaritch Wales 1940, p. viii), but their present whereabouts are unknown. Several other sapphires were found at Kedah dating to between the 7th and 10th centuries (Quaritch Wales 1940, plates 47 and 61). It is impossible to say much about these sapphires from the published black-and-white photos. Nevertheless, their small size and their shape suggest that they were not imports from Sri Lanka but perhaps came from the magmatic deposits of Thailand or Cambodia. More research would be useful.

To date there seems to have been minimal study of the gems in early Javanese jewellery, and their descriptions are vague at best. For example, in the catalogue of the Hunter Thompson collection of Javanese jewellery (Miksic 2011), the gems are only described by their colours. That two green zircons from Java turned up together on the present author's desk must surely imply that there are others out there.

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Photochromic Zircon from Dong Nai, Vietnam

During a field trip to study the geological characteristics of zircon in Dong Nai Province in southern Vietnam, we noticed that this material displays unusual colour behaviour. We studied three transparent rough samples (0.34, 0.71 and 5.48 g) that were collected from secondary deposits in the field area. Their hydrostatic SG values ranged from 4.71 to 4.74, consistent with high (non-metamict) zircon. Raman spectra in the region of 100–1100 cm^{-1} showed peaks at 226, 352, 428, 972 and 1004 cm^{-1}, consistent with zircon.

The colour behaviour of the zircon samples was observed at room temperature. After storing the specimens in a dark environment for 24 hours, they appeared reddish orange. However, during exposure to daylight-equivalent illumination, all three samples gradually but dramatically turned slightly orangey brown (Figure 24), with the full colour transition taking about 30 minutes. To restore the reddish orange colour, it was necessary to keep the samples in the dark for at least 21 hours. We repeated the test five times—storing the samples in the dark followed by exposure to light—and all yielded a similar result, confirming that the photochromic effect was reversible and that the transition from orange to brown was much faster than from brown to orange. This reversible and repeatable photochromic effect has been previously noted for some unheated zircon from Cambodia (Smith & Balmer 2009).

The red-orange appearance of zircon is produced by a colour centre caused by radioactive elements such as U and Th (Klinger *et al*. 2012; Vương & Hương 2015). The cause of the orange-to-brown photochromic behaviour is not well understood. (*Editor's note*: See the article by F. Blumentritt and E. Fritsch in this issue of *The Journal* [pp. 780–800] for more information on this type of photochromism in zircon, which those authors categorise as 'behaviour 2'.)

A dilemma for the jeweller is that such zircon would display an attractive reddish orange colour after being

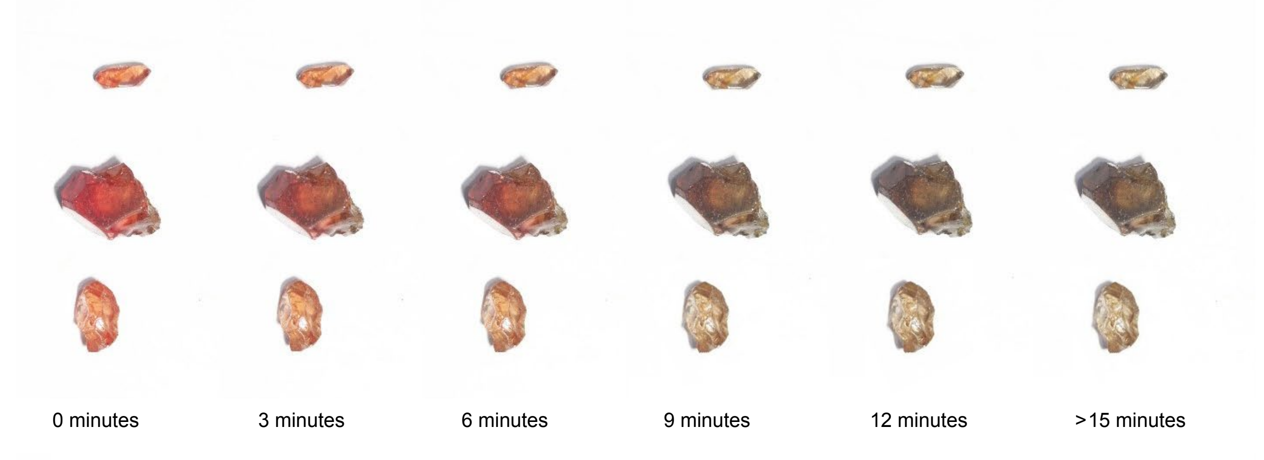

Figure 24: Photochromic zircon from Dong Nai, Vietnam, displays a bright reddish orange colouration after being kept in a darkened environment (for at least 21 hours), but within minutes of exposure to daylight the colour changes to slightly orangey brown. The colour of the three specimens is seen here at three-minute intervals for up to 15 minutes; the full colour transition takes about 30 minutes. The samples weigh 0.34 g (top), 5.48 g (centre) and 0.71 g (bottom). Photos by Le Ngoc Nang.

stored in say, a dark box, but then the material will change to a dull brown after being worn for less than 30 minutes in daylight. While some clients may appreciate this interesting behaviour, others may not like the brown colouration. Hence, it is essential to disclose the photochromism of such zircon to potential jewellery buyers.

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SYNTHETICS AND SIMULANTS

Synthetic Moissanite Testing as 'Diamond' Using Diamond Testers

The distinction of diamond from its various simulants, both loose and mounted, is frequently accomplished with the help of diamond testers. For best performance, it is preferable to use instruments that measure both thermal and electrical conductivity. However, the results produced by such devices can be affected by poor polish or surface contamination, and testing of small stones set in jewellery can also be problematic.

Griffith and Dupuy (2021) documented how some near-colourless HPHT-grown synthetic diamonds (containing traces of boron) can be falsely identified as synthetic moissanite using diamond testers. Recently, the German Gemmological Association (DGemG) has received reports from some of its members that their diamond testers identified synthetic moissanite (silicon carbide; Figure 25) as diamond. As seen by the example described below, it is necessary to perform such testing of loose stones while they are resting on a metal tray, with one hand touching the tray and the other one making contact with the metal plate(s) on the tester (Figure 26). The use of a metal tray is not necessary for a stone mounted in a metal jewellery item that is held in one's hand during testing.

Loose gems are sometimes sold within 'blister packs' or other containers made of plastic. Recently we encountered some round brilliants that had been sealed in such packaging, which were accompanied by grading and identification documents that 'proved' they were diamonds. The documentation appeared convincing at first glance, but the paperwork lacked detailed information about the associated laboratory. As seen in Figure 27, a hole had been drilled through the plastic covering directly above the gem's table to facilitate access by the tip of a diamond tester. Although the tester consistently

Figure 25: Visually, synthetic moissanite is a convincing diamond imitation. The samples of synthetic moissanite shown here display various colouration and cut styles; the middle one is 8 mm in diameter. DGemG collection; photo by U. Henn.

Figure 26: Use of a diamond tester that measures both thermal and electrical conductivity yields the best results for separating synthetic moissanite from diamond, but testing for electrical conductivity requires that the sample be placed in contact with metal. Photo by U. Henn.

Figure 27: A hole was drilled through sealed plastic packaging to allow access for the tip of a diamond tester to the table of this round brilliant (6.53 mm in diameter overall). However, electrical conductivity cannot be measured without metal contact, so distinction between diamond and synthetic moissanite is not possible using only a diamond tester while a sample is enclosed in such packaging. Although this sample was accompanied by a report indicating it is diamond, further testing showed it to be synthetic moissanite. Photo by U. Henn.

indicated 'diamond', examination of the sealed round brilliant with a loupe showed clear doubling of its facet edges, indicating double refraction, which excluded diamond. In addition, white needle-like inclusions could be observed, as commonly seen in synthetic moissanite.

For stones packaged in this way, only thermal conductivity (and not electrical conductivity) can be measured, which alone cannot distinguish between diamond and synthetic moissanite. Therefore, without removing the sample from the packaging and placing it on a metal surface as needed to test electrical conductivity, authentication with a diamond tester is not possible.

As a further note, the electrical conductivity of synthetic moissanite can vary depending on the presence of dopants in its chemical composition. For example, trivalent aluminium or boron can increase its semiconductor properties, while pentavalent nitrogen or phosphorus can reduce its conductivity (e.g. Kiefert *et al.* 2001). The electrical conductivity of diamond can also vary: although in most cases diamond is an insulator, this is not the case for boron-containing type IIb samples. Because of the above-mentioned variations in electrical conductivity, it is important to carry out further tests after probing a sample with a diamond tester. For example, both loose and mounted stones should be examined with a 10× loupe to look for doubling of facet junctions, rounding of facet edges or the presence of specific inclusion features. Diagnostic inclusions in synthetic moissanite are fine, white needles, which are particularly visible with dark-field illumination (e.g. Nassau *et al.* 1997; Nassau 1999).

In addition, RI can be measured with the help of a 'digital refractometer', or reflectometer. Diamond yields a value of 2.417, while the approximate RI of synthetic moissanite recorded by a reflectometer is about 2.648. (The two RIs for synthetic moissanite are $n_o = 2.648$ and $n_e = 2.691$.) Reflectivity and refraction are directly proportional, and the former can be converted using Fresnel's equation. However, the measurement of reflectivity also depends on the texture of the surface, and it can be affected by various factors such as polish, dirt, etc. For loose stones, SG can be determined hydrostatically with a balance or, for brilliant-cut stones, arithmetically using the Scharffenberg formula. The SG of diamond (3.52) is significantly higher than that of synthetic moissanite (3.22; Nassau *et al.* 1997; Nassau 1999). In a laboratory so equipped, Raman spectroscopy can also ensure identification.

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Photochromism and Photochromic Gems: A Review and Some New Data (Part 1)

Féodor Blumentritt and Emmanuel Fritsch

ABSTRACT: Photochromism is defined as the reversible change of colour caused by exposure to 'light' (visible and UV wavelengths, sometimes extended to X-rays). The species covered in part 1 of this article include sodalite (hackmanite), marialite (scapolite group), tugtupite, spodumene (kunzite), diopside and zircon. We review available data on such gems and provide a systematic approach to their photochromic behaviour, describing the discovery of the colour variation, the photochromic colours known, their corresponding UV-visible absorption spectra, and facts or hypotheses regarding the origin of the phenomenon. Where available we include new data to supplement the information available in the literature. Sulphur-based polyanions are thought to be responsible for photochromism in some aluminosilicates (i.e. hackmanite, marialite and tugtupite). More generally, the phenomenon can be explained by movement of an electron (either an electron centre or a hole centre) from one 'defect' ('colour centre') to a different one. However, the exact nature of the defects involved at the atomic and electronic levels are essentially unknown. This article also discusses proper use of terminology, and we propose that *photochromism* is more accurate than, for example, *tenebrescence*, *colour change* or *chameleon* effect.

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Photochromic gem varieties change colour, reversibly, upon exposure to visible light or UV radiation and sometimes X-rays (Figure 1). Such gem materials are rare, yet they are cherished by discriminating collectors and gemmologists who often prefer the unusual to the readily available. There is no indication that the colour cycling in such gems is limited either in time or in the number of cycles. The phenomenon is also known by various, less appropriate terms, such as *tenebrescence* or *colour change* (see below).

The gemmological community might not be fully aware that photochromic materials are used in everyday applications, such as light-sensitive glasses. However, the field of applications for these materials is expanding and could include, for example, erasable optical data storage and switching components (Irie 1989, 2000; Tian & Zhang 2016). Thus, photochromic gem materials might have industrial applications if they could be synthesised and made quickly reversible. In the large range of photochromic materials, distinction is commonly made between organic, inorganic and hybrid compounds. Organic (e.g. spiropyrans molecules) and hybrid (material with mixed organic and inorganic components, such as metal-organic frameworks) compounds are fairly well studied and present interesting photochromic characteristics, such as a rapid or marked change in colour (Dessapt *et al.* 2009; Tian & Zhang 2016). Inorganic photochromic materials are much less numerous but some have been extensively studied, such as silver-doped glass (Armistead & Stookey 1964). Others are understood in considerably less detail. This is particularly true for photochromic gem materials.

The aim of this article is to review our knowledge of inorganic photochromic gem materials. Those discussed in part 1 are the silicates sodalite (hackmanite), marialite (scapolite group), tugtupite, spodumene (kunzite), diopside and zircon. (Part 2 covers non-silicates: corundum, diamond and barite.) It is not the purpose of a review article to significantly add to existing knowledge, so our input is minor (mostly photographs with corresponding UV-visible absorption spectra). For each gem material, its photochromic property is described in the following order: (1) history of discovery, and possibly locality and first mention in the literature; (2) description of the photochromic colours (sometimes including several behaviours); (3) absorption spectroscopy; (4) hypotheses for cause of photochromism, if available; and (5) other information and optical properties possibly linked to photochromism.

Definition

For the purpose of this article, we define photochromism as the reversible change of colour observed in gems after exposure to visible light or UV radiation of any kind (long- or short-wave, using standard gemmological UV lamps as one example, but also the UV component of daylight).

There are many subtleties associated with defining this phenomenon. The word *photochromism* was apparently introduced by Hirshberg (1950) to name what he observed in a series of organic molecules (see also Bouas-Laurent & Dürr 2001). This generated scientific study of what is now known as *X-chromes*, *chromism* or *chromic phenomena*, terms that can also be found in the literature (Bamfield 2010), which concern changes of colour produced by some kind of excitation, generically referred to as *X* (photochromism, thermochromism, electrochromism, solvatochromism, tribochromism, etc.). In the case of photochromic behaviour, it is a change of colour caused by exposure to light (photons; hence *photo*chromic).

From a strict scientific point of view, according to the International Union of Pure and Applied Chemistry (IUPAC; see Bouas-Laurent & Dürr 2001, p. 642), photochromism is defined as follows:

> A reversible transformation of a molecular [or solid] entity between two forms, A and B, having different absorption spectra, induced in one or both directions by absorption of electromagnetic radiation. The spectral change produced is typically, but not

Figure 1: Some remarkable photochromic gems are shown in this composite image before (left) and after (right) exposure to UV radiation. Clockwise from top: sodalite (hackmanite; 0.48 ct), tugtupite (1.10 g), near-colourless zircon (0.43 ct), red zircon (21.3 ct) and marialite (0.91 ct). Photos by Thomas Hainschwang and Féodor Blumentritt.

> necessarily, of visible color and is accompanied by differences in other physical properties. The thermodynamically stable form A is transformed by irradiation into form B. The back reaction can occur thermally (photochromism of type T) or photochemically (photochromism of type P).

Although the IUPAC definition is fairly detailed, one point remains unclear: Which 'electromagnetic radiation' is concerned? Most examples of photochromic materials involve UV and visible light as the electromagnetic radiation of interest. However, some publications include X-rays (Claffy 1953), while infrared and lower energies are never mentioned. Although the IUPAC definition still applies, exposure to high-energy X-rays would be considered a treatment in gemmology, even if some loss of the induced colour might be observed over very long periods of time. Some historic discoveries of photochromic behaviours have been made under X-ray irradiation (see, e.g., the section on corundum in part 2 of this article) and later confirmed with UV radiation. However, we consider, at least for the purpose of gem materials, that near-UV (200–400 nm) is the highest-energy spectral range to induce a photochromic reaction.

Other details not included in the IUPAC definition (again, see Bouas-Laurent & Dürr 2001) concern the number of possible colouration-to-discolouration cycles. The notion of fatigue—progressive degradation of the induced colour, eventually leading to loss of the property—which is commonly associated with organic and hybrid materials (Zhang *et al*. 2013, 2014), does not appear in the literature for inorganic gems. Thus, photochromic minerals can be cycled a considerable number of times, which is of great interest for potential industrial applications.

Another point not explicitly discussed in the IUPAC definition is the speed of the colouration-to-discolouration process. This factor is key for many industrial applications (e.g. optical storage; Irie 2000), but it is not commonly mentioned for photochromic minerals in the gemmological literature.

An additional aspect not considered in the IUPAC definition, but which we faced during our research, is the notion of photon flux. This represents the quantity of energy (here, UV photons) reaching the sample per surface unit. For some gems, a 'classic' UV lamp, either short-wave or long-wave, is not able to induce photochromism. However, the property can be triggered by a more powerful UV source of similar wavelength (or energy). For example, a change in colour has been observed for blue sapphires that turn yellow on the outside, and yellow sapphires that turn orange, after illumination with a concentrated broadband near-UV 300 W xenon lamp (Thomas Hainschwang, pers. comm. 2020). This aspect of photon flux is also discussed in the spodumene section below, where three colour states (colourless, pink and green) are possible. With high-photon flux, a sample can change directly from the stable colourless state to the green state. With low-photon flux, the reaction is slowed, and a pink state is seen between colourless and green.

Terminology

From the point of view of terminology, the technical literature on minerals and gem materials is not always consistent. Some authors use the term *reversible photochromism* (Pizani *et al*. 1985; Tardío *et al*. 2003; Ramírez *et al*. 2005; Gaft *et al*. 2009; Williams *et al*. 2010; Friis 2011; Warner & Hutzen Andersen 2012; Byrne *et al*. 2014; Carvalho *et al*. 2018), which appears redundant in view of the IUPAC definition, in which reversibility is implicit.

Another term employed is *tenebrescence* (Claffy 1953; Kirk 1955; Chang 1974; Gaft *et al*. 2009; Williams *et al*. 2010; Friis 2011; Warner & Hutzen Andersen 2012; Norrbo *et al*. 2015; Renfro 2016; Carvalho *et al*. 2018). Although this term describes a change from a lighter to a darker colour, it does not include the key concept of reversibility. The same explanation applies to the term *darkening* also used in the literature (Medved 1953). Other descriptions that have been used but are obsolete today include *transichromism* (Copeland *et al*. 1960), *evanescence* (Miser & Glass 1941) and *phototropy* (Exelby & Grinter 1965).

Colour change has a very specific meaning in gemmology: a change of hue corresponding with a change of illumination or lighting (i.e. the *alexandrite effect*). Thus, although *colour change* is a convenient way to describe photochromism, this use is misleading, as it applies specifically to the alexandrite effect.

General Model

One accepted explanation for photochromism in solid crystals is linked with the presence of a defect in the crystal lattice (Medved 1953). This defect creates an electronic level in the band gap, which in this case makes visible-light absorption, and thus colour, possible. (For a definition of *band gap* and the related notions of *valence band* and *conduction band*, the reader is referred to classic physics texts such as Kittel [2004] or the summary at https://en.wikipedia.org/wiki/Electronic_band_structure.) This 'classic' model is convenient to explain photochromism at the atomic and electronic levels. The energy level of the defect in the lattice would, in fact, trap electrons (trap level; see Figure 2, left). When exposed to relatively high energy such as UV, electrons can fall in

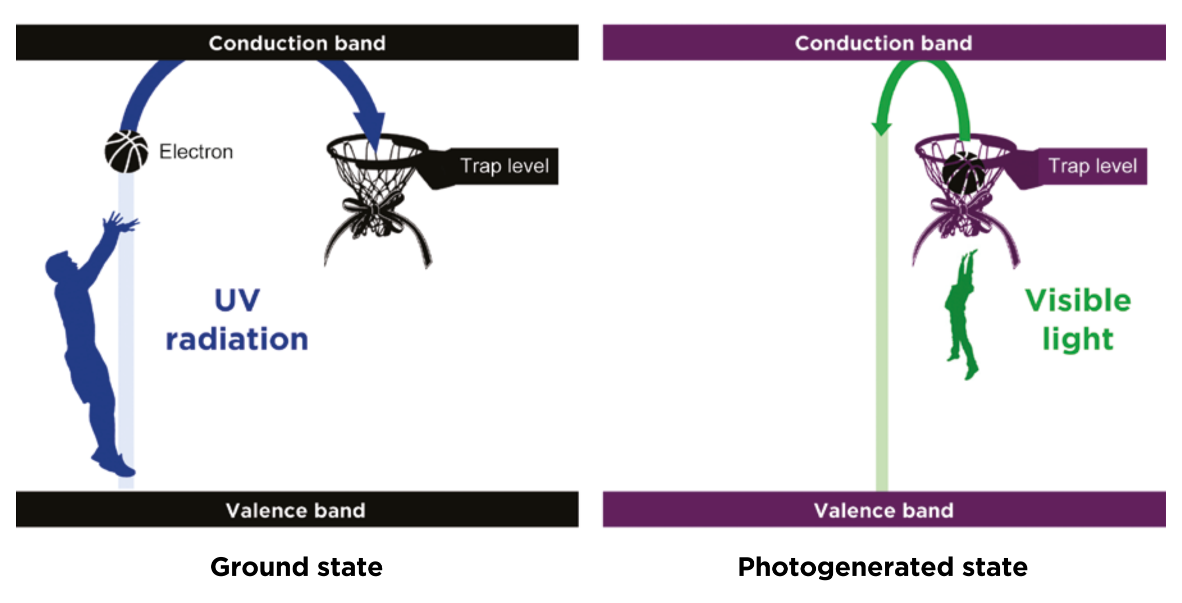


Figure 2: The 'classic' model of photochromism proposed by Medved (1953) involves two states. Left: High-energy (UV) radiation causes an electron to move from the valence band to the conduction band and then into a trap level at an energy slightly lower than the conduction band (the metastable position), yielding the photogenerated, coloured state. Right: Lower-energy visible-light radiation provides enough energy to enable the electron to escape from the trap level and return to its ground state, restoring the original colour.

this trap. This generates a colour centre—designated 'F' for *Farbe*, which means 'colour' in German (see definition in Fritsch & Rossman 1988)—responsible for a change in the absorption spectrum and, thus, a change in colour. In this coloured, photogenerated state, the electron in the trap level can absorb lower-energy visible-light radiation (Figure 2, right) and return to its initial position via the conduction band—the discolouration process.

However, there is no general, all-encompassing theory, and the above 'classic' model could be adapted or completely modified with future discoveries. For synthetic or industrial photochromic materials (mostly organic or hybrid compounds), the cause of photochromism often involves a change in the shape of an organic molecule (e.g. Tian & Zhang 2016). However, we do not yet have a full understanding of this photochromic mechanism for most of the gem materials presented in this work.

MATERIALS AND METHODS

We obtained natural, photochromic mineral samples (Table I) primarily to characterise their colours and absorption spectra for comparison with published literature and to provide a consistent presentation of the spectra in this article. The identification of the specimens studied was verified by standard gemmological techniques, Raman spectroscopy, and sometimes further chemical and structural analysis (including energy-dispersive X-ray spectroscopy and X-ray diffraction).

In addition, synthetic hackmanite powders were produced using the structure conversion method (Warner & Hutzen Andersen 2012) for comparison with natural samples and the existing literature.

Stable colours were observed using a daylight-equivalent (D65) lamp. The colours were modified using a UV lamp (Vilber-Lourmat VL-215-LC) with a total power of 30 W distributed between two UV tubes approximately 30 cm long and 15 W each. Exposures were performed at a fixed distance of 7 cm from the lamp, in a dark room and against an inert black background to avoid daylight contamination.

For this study, we limited the analysis of photochromism to ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra. The larger opaque samples were analysed with a PerkinElmer Lambda 1050 instrument in reflectance mode, while the smaller transparent samples were analysed with a Magilabs GemmoSphere spectrometer. Details of the experimental conditions are provided in Table II. The GemmoSphere records luminescence together with absorption, so additional features due to luminescence are visible in the scapolite spectra that do not participate in the photochromic behaviour.

Table I: Photochromic samples collected for this study.

Gem material	Chemical formula	Stable colour	Weight	Type	Origin (*lender**)
Diopside	$CaMgSi_2O_6$	Greenish yellow	8.37 g	Rough	Bazenovskoe, Russia (*J. Hyršl*)
Marialite (scapolite)	$Na_4Al_3Si_9O_{24}(Cl,S)$	Near-colourless	2.58 ct	Faceted pear	Afghanistan
Sodalite (hackmanite variety)	$Na_8Al_6Si_6O_{24}(Cl,S)_2$	White or near-colourless	1.15 ct	Cabochon	Mogok, Myanmar
Spodumene (kunzite variety)	$LiAlSi_2O_6$	Near-colourless	51.6 g	Rough	Afghanistan
Tugtupite	$Na_8Al_2Be_2Si_8O_{24}Cl_2$	Pink	1.27 g	Rough	Greenland (*B. Mocquet*)
Zircon (behaviour 1)	$ZrSiO_4$	Near-colourless	0.43 ct	Faceted round	Unknown
Zircon (behaviour 2)	$ZrSiO_4$	Orangey red	21.3 ct	Rectangular cushion	Cambodia (*M. Daufresne*)

* Samples for which no lender is indicated are in the collection of the University of Nantes.

Table II: Experimental details for UV-Vis-NIR spectroscopy.

Parameter	Magilabs GemmoSphere	PerkinElmer Lambda 1050
Spectral range used	365–1000 nm	365–1000 nm
Collection mode	100 mm PTFE[a] integrating sphere (transmission mode)	150 mm PTFE[a] integrating sphere (transmission mode)
Sampling interval	1 nm	1 nm
Spectral bandwidth	Automatic	1 nm
Integration time	0.54 s	0.54 s
Reference spectra[b]	0% and 100% lamp spectra	0% and 100% lamp spectra

[a] Abbreviation: PTFE = polytetrafluoroethylene (also known as Teflon).

[b] Two reference spectra were recorded without the sample to correct for the spectral characteristics of the lamp (100%) and for any residual light in the sphere (or light 'pollution'; 0%).

For the sake of consistency, the Kubelka-Munk approximation (Kubelka & Munk 1931; Yang & Kruse 2004) was implemented to transform the reflectance spectra to absorbance. Absorbance (A) is proportional to reflectance (R; absolute value) through the relationship:

$$A \propto \frac{(1-R)^2}{2R}$$

For each sample, we obtained spectra corresponding to the stable and excited colours in the photochromic reaction. We also calculated the difference spectrum between the most coloured state and the least coloured state to highlight the absorption feature(s) created by photochromism. A summary of the properties of the photochromic gems discussed in this article can be found in Table III.

SODALITE (HACKMANITE)

The first mention of a change in the colour of sodalite was made by Robert Allan (Allan 1834; Friis 2011) on samples from Greenland that were sent to his father, Thomas Allan, by Karl Ludwig Giesecke in 1806 (De Bournon 1811; Friis 2011). Allan (1834) reported that the light purple to pink colour shown by hackmanite upon being excavated disappeared with exposure to sunlight, thus returning the sample to its initial colourless, pale pink or green colour. The purple colour of sodalite (hackmanite) can then be induced by exposing it to short-wave UV radiation for a few seconds to a few minutes (Figure 3), depending on the specific sample (Kondo & Beaton 2009; Milisenda *et al.* 2015). The purple colour is due to a photogenerated absorption band with a maximum at about 545 nm

Table III: Properties of the photochromic gems sodalite, marialite, tugtupite, spodumene, diopside and zircon.

Gem material	Stable/metastable colour(s)	Photo-generated colour(s) induced by	Approximate time to induce photo-generated colour	Photo-generated colour(s) reversed by	Approximate time to fade photo-generated colour	Proposed mechanism (or suggestions, if possible)[a]	Principal reference[b]
Sodalite (hackmanite variety)	Colourless to pale pink/purple	Short-wave UV	Seconds to minutes	White light (or ~545 nm) Darkness	Seconds to minutes Several days	$S_2^{2-} + V_{Cl}^0 \leftrightarrow S_2^- + V_{Cl}^-$	Curutchet & Le Bahers (2017)
Marialite (scapolite)	Colourless/blue	Short-wave UV	Seconds to minutes	White light (or ~610 nm) Darkness	Seconds to minutes Several days	$X_n^{y-} + V_{Cl}^0 \leftrightarrow x_n^{(y+1)-} + V_{Cl}^-$	Blumentritt *et al.* (2020)
Tugtupite	Colourless to red/dark red	Short-wave UV	Seconds to minutes	White light (or ~500–545 nm) Darkness	Seconds to minutes Several days	$X_n^{y-} + V_{Cl}^0 \leftrightarrow x_n^{(y+1)-} + V_{Cl}^-$	Observation only: Sørensen *et al.* (1971)
Spodumene (kunzite variety)	Colourless/pink, green	Short-wave UV (and X-rays for green colour)	Minutes to hours	White light Darkness	Minutes to hours Several days	$Mn^{2+} \leftrightarrow Mn^{3+} \leftrightarrow Mn^{4+}$	Schmitz & Lehmann (1975)
Diopside	Yellow/green	Short-wave UV	Several minutes	White light Darkness	Seconds to minutes Several days	Unknown	Hyršl (2016)
Zircon (behaviour 1)	(1) Colourless/brown to orange; (2) blue/blue with brownish component	Long-wave UV Darkness	Seconds to minutes Several days	White light	Minutes to hours	Intrinsic defect	Zeug *et al.* (2018)
Zircon (behaviour 2)	Orangey red/dark reddish brown	Long-wave UV Daylight	Seconds Minutes	Heat (around 100°C) Darkness	Minutes to ~1 hour Several days	Intrinsic defect	Smith & Balmer (2009)
Zircon (behaviour 3)	Colourless or light brown/brown to brownish yellow	Long- or short-wave UV	Minutes (partial regeneration)	Heat	Minutes	Intrinsic defect	Michael Gray, pers. comm. (2019)

[a] For marialite and tugtupite, X_n^{y-} and $x_n^{(y+1)-}$ refer to different polyanions of sulphur or another, as yet unknown, electron donor.

[b] For clarity, only the major reference is cited in this table for each gem material, but additional articles are cited in the main text.

(Figure 3). We observed a relatively large number of hackmanites for which this photogenerated band is independent of the absorption spectrum of the sample in its stable state, whether it was near-colourless, pale pink, green or light blue. This indicates that the photogenerated colour centre responsible for the purple colour is not related to other colour centres present in the sodalite.

The photochromic variety of sodalite was named hackmanite by Leon H. Borgström in 1901 (Friis 2011) in honour of Victor Axel Hackman, who gave him a photochromic sample from the Kola Peninsula, Russia. The formula of hackmanite is $Na_8Al_6Si_6O_{24}(Cl,S)_2$, with sulphur as a minor component. The presence of sulphur is thought to be linked to the photochromism of hackmanite (Gaft *et al.* 2009; Williams *et al.* 2010; Norrbo *et al.* 2015, 2016; Carvalho *et al.* 2018). Detailed determination of the colour centre at the atomic level could confirm this by providing a clearer link between the element sulphur and the photochromism.

The structure of sodalite, including hackmanite, is formed by chains of SiO_4 and AlO_4 tetrahedra (Figure 4, left). These chains organise in a cubic system and form cavities, or 'cages', between them, big enough to admit one large anion at the centre (Cl^-, Br^-, I^-, SO_4^{2-}, SO_3^{2-}, SO_3^-, SO_2^-, CO_3^{2-}, etc.) surrounded by a tetrahedron of four alkali cations (Ca^{2+}, Na^+, K^+, Li^+, etc.; Zahoransky *et al.* 2016). In nominal sodalite, these cages are filled with one chlorine anion surrounded by a tetrahedron of four sodium atoms. In hackmanite, the central chlorine ion is partly substituted by a sulphur ion. This substitution is thought to be responsible for the photochromic property (Kirk 1955).

Since the quantity of sulphur in each sample of sodalite can change the intensity of absorption, and thus the colouration (Norrbo *et al.* 2015), the current and most accepted theory links the photochromism of hackmanite to the S_2^{2-} sulphur polyanion replacing a chlorine (Cl^-) anion in the structure (see details on sulphur anions in Box A). This defect requires the formation of a neighbouring chlorine vacancy for charge compensation (Norrbo *et al.* 2015, 2016; Carvalho *et al.* 2018; Norrbo

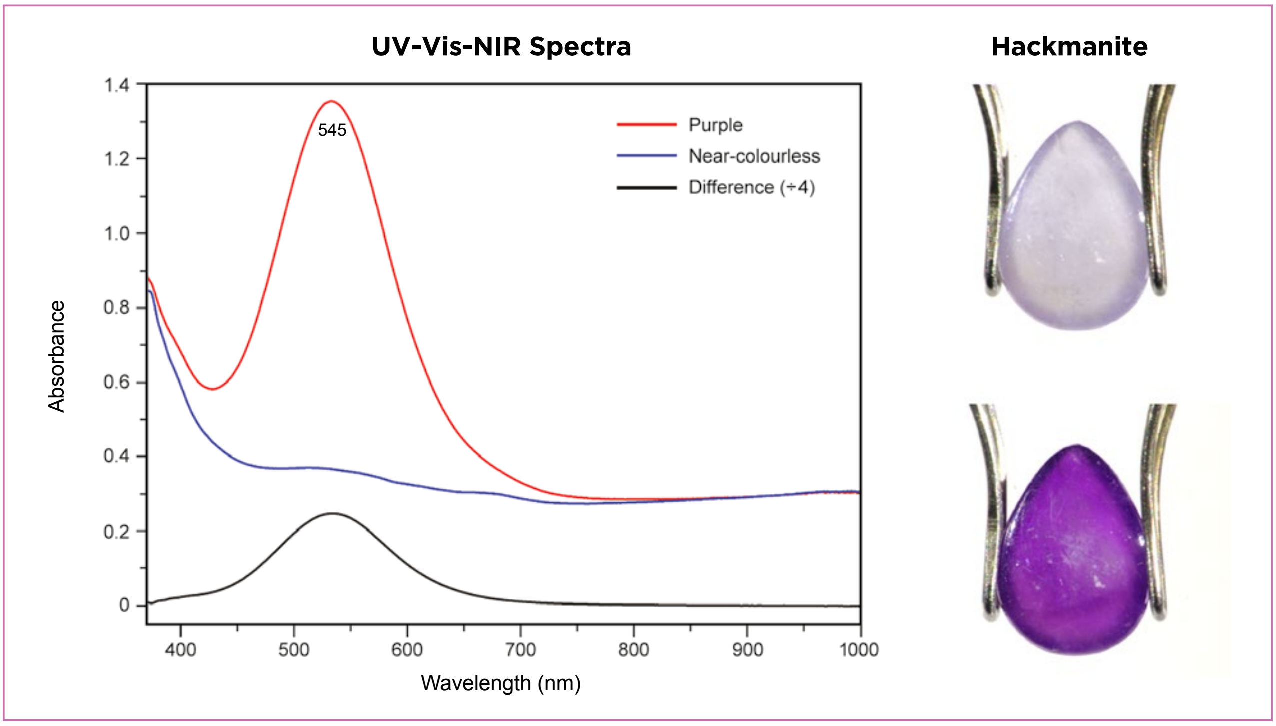


Figure 3: The absorption spectra of a 1.15 ct hackmanite cabochon from Mogok, Myanmar, before (near-colourless) and after (purple) exposure to UV radiation, correspond with the radical change in the sample's colour. The path length of the beam was approximately 3.1 mm, and the difference spectrum is divided by a factor of 4 for clarity. These spectra are consistent with others found in the literature (Ballentyne & Bye 1970; Chang 1974; Kondo & Beaton 2009; Milisenda *et al.* 2015). Photos by F. Blumentritt.

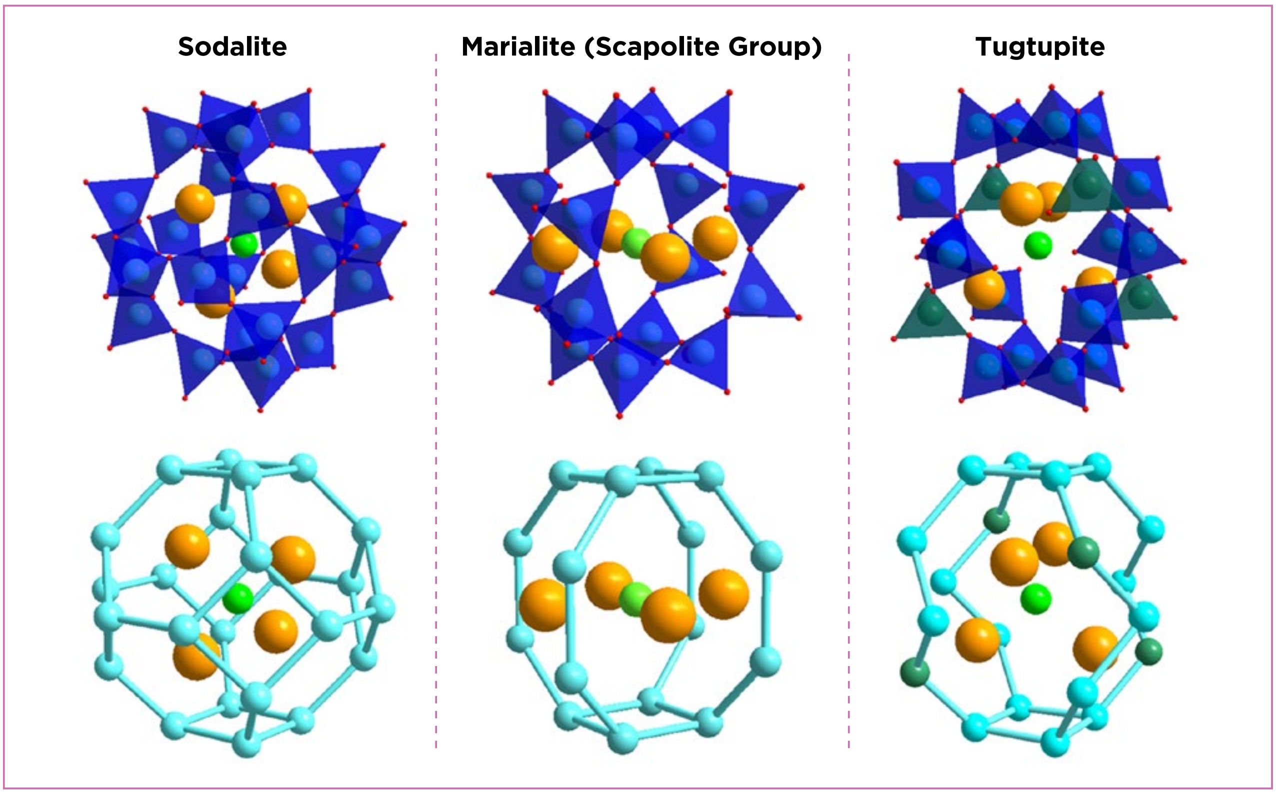


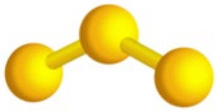
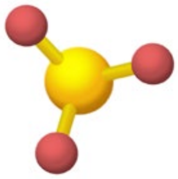
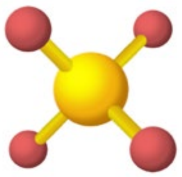
Figure 4: Photochromic aluminosilicates are characterised by the presence of 'cages' in their structures. These structural units enclose a large central area, as shown here (left to right) for sodalite, marialite and tugtupite. Top row: The cages are built of SiO_4 and AlO_4 tetrahedra (blue) and, for tugtupite, BeO_4 tetrahedra (dark green). Oxygen atoms are symbolised by small red dots. Each cage is nominally filled with four atoms of sodium (orange) around a central atom of chlorine (green). Bottom row: The cages are shown without oxygen atoms to highlight structural similarities. Drawings by F. Blumentritt.

BOX A: SULPHUR ANIONS IN SILICATES AND OTHER GEM MATERIALS

Sulphur is an important major or minor component of many mineral structures, and may occur as various ions (Table A-1), always with a negative charge (i.e. as an anion). Those that contain more than one sulphur atom are often referred to as sulphur polyanions. The polyanions S_2^- and S_3^- play a role in the colour or fluorescence of gems. For example, the S_3^- ion is responsible for the blue colour of lapis lazuli (lazurite) and several ultramarine minerals such as sodalite, haüyne, nosean, possibly afghanite, etc. (Fleet & Liu 2010). The S_2^- ion is responsible for the orange luminescence of sodalite, scapolite and tugtupite (Povarennykh *et al.* 1971; Blumentritt *et al.* 2020; Colinet *et al.* 2020).

Sulphur has a large number of oxidation states, resulting in many anions, as shown in Table A-1. These ions can be either impurities acting as colour centres, such as S_3^-, or constituents of the material, such as SO_4^{2-} in sulphate minerals.

Table A-1: Principal sulphur polyanions.

Sulphur anion	Schematic representation (S = yellow, O = red)	Main characteristics
S_2^-		Ion responsible for yellow-orange emission with vibronic structure found in the luminescence spectra of sodalite (hackmanite) and scapolite. Also gives a yellow colour to sodalite when present at elevated concentrations (Seel 1984).
S_2^{2-}		Ion theoretically responsible (i.e. lacking experimental evidence) for the photochromic property of hackmanite, acting as an electron donor.
S_3^-		Ion responsible for the blue colour of ultramarine, as seen in lazurite, sodalite, nosean, etc.
SO_3^{2-}		Ion possibly responsible for the light blue colour of celestite (Bernstein 1979) and barite.
SO_4^{2-}		Ion that constitutes sulphate minerals such as barite. It is also often present in the cages of the sodalite and scapolite structures.

2019). Hence, the photochromism could be due to a charge transfer between the sulphur polyanion and the associated chlorine vacancy (V_{Cl}):

$$S_2^{2-} + V_{Cl}^0 \leftrightarrow S_2^- + V_{Cl}^-$$

This hypothesis has not yet been fully justified experimentally; in particular there is no physical evidence that S_2^{2-} in the above equation is, in fact, involved in the process. A recent study tends to support this mechanism with theoretical calculations (Curutchet & Le Bahers 2017), but it still provides no actual proof of the presence of S_2^{2-}. On the contrary, the presence of S_2^- has been proved experimentally, by the study of its associated orange luminescence in natural and synthetic hackmanite (Colinet *et al.* 2020), similar to the presence of S_2^- in scapolite (Blumentritt *et al.* 2020).

The colour centre—supposedly an electron trapped in the chlorine vacancy—is somehow naturally stabilised in some natural samples in which the purple colour remains even after long exposure to visible light or laser radiation (with a wavelength around the absorption maximum at 545 nm).

However, this model has been undermined by some authors, who consider that sulphur is not necessary for the photochromic property of hackmanite (Bye 1970; Bye & White 1970; Goettlicher *et al.* 2013). If sulphur can be considered an electron donor, then it could easily be replaced by another, as yet unknown, electron donor that is not related to sulphur.

The synthesis of sodalite is relatively easy, in theory, since the aluminosilicate framework already exists as a zeolite, used mostly as a molecular sieve and commercially available in powder form (Kowalak *et al.* 1995). This aluminosilicate framework makes it possible to replace the ions present in the sodalite cages with some unusual ones. Hence, it has been possible to synthesise bromosodalite ($Na_8Al_6Si_6O_{24}Br_2$) and iodosodalite ($Na_8Al_6Si_6O_{24}I_2$), for example. According to Williams *et al.* (2010), both of these are photochromic owing to the presence of sulphur as an impurity. Williams *et al.* (2010) further observed that the replacement of the major anion (Cl by Br, I, etc.), as well as substitution of atoms inside the aluminosilicate structure (Al for Ga; Si for Ge), induces a change in sodalite's photochromic colour, as illustrated in Figure 5.

The control of photochromism in sodalite is promising for its use in industrial applications such as a switching material (Irie 2000), optical data storage material (Irie 1989), and UV and X-ray dosimetry (Tian & Zhang 2016; Norrbo *et al.* 2018; Vuori *et al.* 2021). Research on hackmanite is probably the most advanced and closest to attaining industrial applications compared with other photochromic gem materials.

MARIALITE (SCAPOLITE GROUP)

Photochromic marialite was reported for the first time in 2005 and was originally mistaken for hackmanite because of its 'comparable' photochromism (McClure *et al.* 2005). This scapolite came from Afghanistan, and is colourless in its stable state but turns deep blue upon UV irradiation (Milisenda *et al.* 2015), preferentially with short-wave UV (Figure 6). The blue colouration disappears when the stone is illuminated with visible light. Chemical analyses revealed these gems to be marialite (McClure *et al.* 2005).

Marialite is the NaCl-rich member of the scapolite group with the ideal formula $Na_4Al_3Si_9O_{24}Cl$. However, the pure end-member composition does not appear to exist naturally because pure marialite has never been found (Shaw 1960). Gems of the scapolite group always have an intermediate composition in the solid solution between marialite (NaCl-containing pure end member) and meionite ($CaCO_3$-containing pure end member). Yet, the name *marialite* is not only used to define the NaCl-containing end member, but is also usually extended to samples containing less than 20% meionite (Shaw 1960). All the natural samples examined by Shaw (1960) plotted between these two end members with a composition that mostly ranged between two intermediate species, formerly known as 'dipyre' (20–50% meionite) and 'mizzonite' (50–80% meionite).

Nevertheless, the properties of the photochromic samples studied by McClure *et al.* (2005) showed them to be close to the ideal marialite end member, consistent with our own laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analyses of the sample presented in Figure 6 and the many other photochromic scapolites in our collection. The main difference between the UV-Vis-NIR absorption spectra of the two colour states is a broad band centred at around 600 nm in the

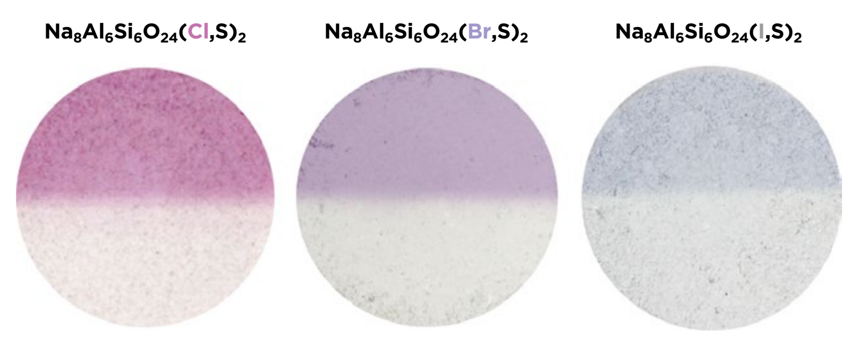


Figure 5: From left to right, synthetic powders of chlorosodalite, bromosodalite and iodosodalite (synthesised by F. Blumentritt), all containing a sulphur impurity, show photochromism. The images were taken after the top half (coloured) was exposed to short-wave UV radiation for 20 minutes, while the bottom half (near-colourless) was masked. Photos by F. Blumentritt.

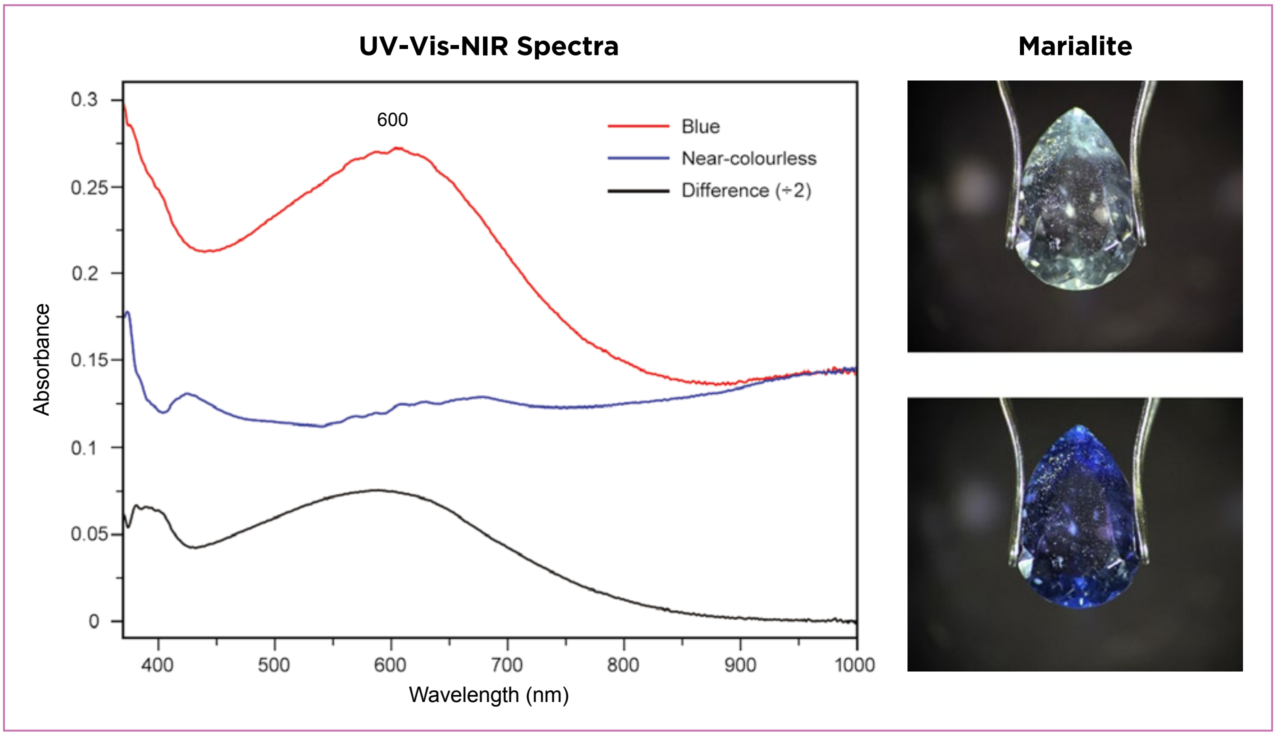


Figure 6: Photos and absorption spectra for a 2.58 ct photochromic marialite from Afghanistan are shown before (near-colourless) and after (blue) exposure to short-wave UV radiation. The wiggly vibronic structure around 600 nm is caused by trapped S_2^{2-} and is present due to the mode of operation of the spectrometer (see Materials and Methods section). The path length of the beam was approximately 4.2 mm, and the difference spectrum is divided by a factor of 2 for clarity. The spectra are consistent with those presented by Milisenda *et al.* (2015). Photos by F. Blumentritt.

excited state that absorbs in the orange-to-red region and thus produces the blue colour (again, see Figure 6).

Allen *et al.* (2014) documented increased photochromism in Afghan marialite that had reportedly been irradiated, in which the treated samples exhibited a deeper blue colouration under UV radiation than untreated ones. The exact details of the treatment are unknown, but it is believed that a nuclear reactor was used (Dudley Blauwet, pers. comm. 2021), so neutrons could have been involved, but gamma rays are also a possibility.

Marialite has been studied less than hackmanite but presents some similarities. As with sodalite, the scapolite structure can be described as a stacking of cages formed by intertwining chains of SiO_4 and AlO_4 tetrahedra (Figure 4, centre). In these cages the central anion is surrounded by a planar square of four cations. Regarding the solid solution of the scapolite group, marialite has cages filled mostly by chlorine surrounded by four atoms of sodium, and meionite mostly has carbonate surrounded by four atoms of calcium (Lin & Burley 1973).

Because the discovery of photochromic scapolite is relatively recent, earlier research targeted other properties such as its yellow-orange luminescence (Burgner *et al.* 1978) and its thermal expansion (Baker 1994). The characteristic yellow-orange luminescence of scapolite was first ascribed to the presence of uranium (Iwase 1937), but the currently accepted explanation is the presence of polysulphides (Kirk 1955; Burgner *et al.* 1978; Sidike *et al.* 2008). In particular, recent research has shown that the yellow-orange luminescence is caused by S_2^- ions (Blumentritt *et al.* 2020; Colinet *et al.* 2020), which could indirectly contribute to the understanding of the photochromism. One model proposed to explain the photochromic reaction in hackmanite includes sulphur polyanions and vacancies (Norrbo 2019). We recently demonstrated with chemical and spectroscopic considerations that photochromism in marialite also fits a reaction involving a vacancy (Blumentritt 2021). Even if sulphur has been conclusively shown to induce photochromism, it is still possible that sulphur might not be necessary in all cases.

TUGTUPITE

Henning Sørensen first discovered tugtupite in southern Greenland in 1957 (Sørensen *et al.* 1971). He immediately noticed the colour instability of this mineral: samples that were initially white, pink or deep red all took on a dark red appearance after X-ray irradiation (Sørensen *et al.* 1971). It was later realised that UV

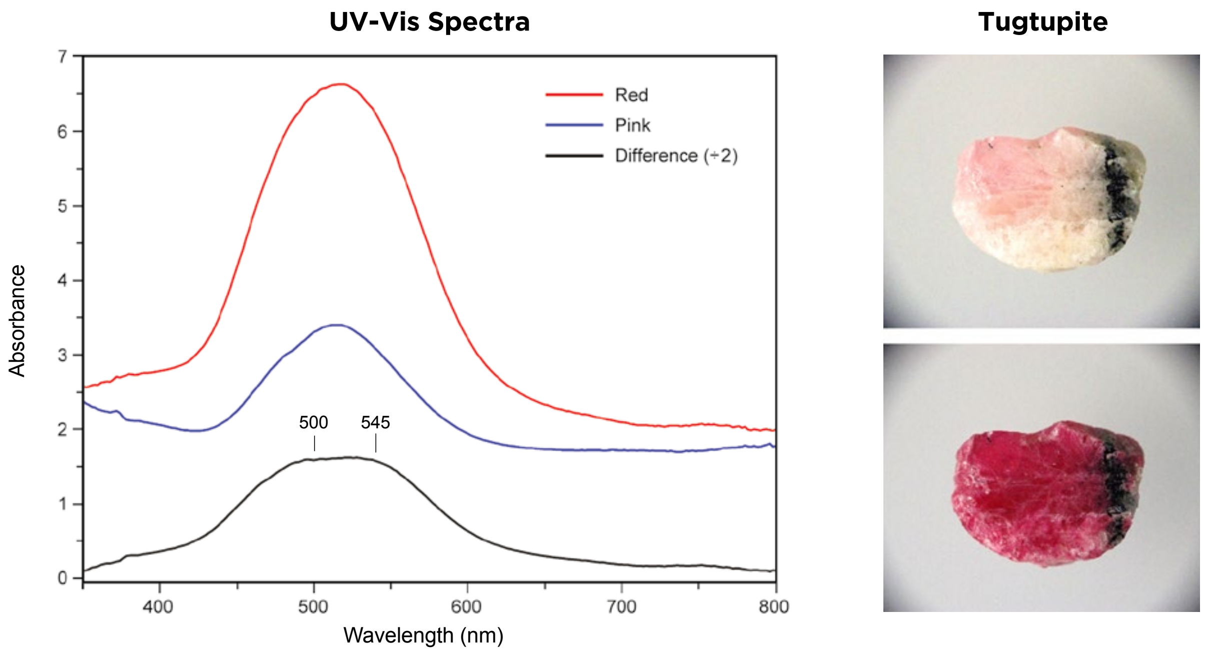


Figure 7: Photos and absorption spectra for a 1.27 g tugtupite from Greenland illustrate the difference in colour before (pink) and after (red) UV exposure. The absorbance was calculated from reflectance spectra using the Kubelka-Munk approximation. The difference spectrum is divided by a factor of 2. The red colouration seems to be due to two almost completely overlapping bands peaking at about 490 and 535 nm. This observation is consistent with published spectra (Milisenda *et al.* 2015). Photos by F. Blumentritt.

radiation also produces photochromism in tugtupite (Tunzi & Pearson 2008; Milisenda *et al.* 2015). The darkened gem returns to its initial colour when kept in the dark, or exposed to artificial visible-light radiation or standard natural daylight (D65) for a few minutes (Figure 7). The large photogenerated feature seen on the difference spectrum (black curve) in Figure 7 could be explained by two Gaussian contributions, thus two photogenerated colour centres. One of these Gaussian contributions is similar to the one observed in the spectrum of photogenerated purple hackmanite (again, see Figure 3) with a maximum at about 545 nm. However, unlike hackmanite, a second Gaussian contribution is photogenerated with an absorption maximum at about 500 nm. This second contribution explains the difference between the photogenerated purple colour of hackmanite and red colour of tugtupite.

Gem-quality tugtupite samples (Dragsted 1970; Jensen & Petersen 1982)—mostly as cabochons but exceptionally as transparent faceted gems—are relatively rare. Only three localities are known for tugtupite: the Ilímaussaq complex in Greenland, Kola Peninsula in Russia, and eastern Canada (Dragsted 1970; Sørensen *et al.* 1971; Jensen & Petersen 1982; www.mindat.org/min-4044.html). This could explain a relative lack of scientific studies on the mineral. However, tugtupite is of a great interest because the photochromic property seems to be intrinsic to this mineral. To the best of our knowledge, there is no documented natural, colour-stable tugtupite. The photochromic property has even been reported in rare light blue to very light blue tugtupite, with exposure to UV radiation causing a reddish purple to purplish red colouration (Jensen & Petersen 1982).

Tugtupite, $Na_8Al_2Be_2Si_8O_{24}Cl_2$, is a member of the helvite group, which can be considered a subgroup of the sodalite group because of structural similarities (Danø 1966; Jensen & Petersen 1982). In tugtupite, which shares the same 'cage' structure with sodalite (Figure 4, right), two Al^{3+} ions are replaced by one Si^{4+} and one Be^{2+} ion (Semenov & Bykova 1960). The majority of elemental analyses have revealed the presence of a sulphur impurity, some with replacement of up to 5% of chlorine in samples probably from Greenland (Danø 1966). Sørensen *et al.* (1971) proposed the structural formula $Na_8Al_2Be_2Si_8O_{24}(Cl,S)_2$, but sulphur does not appear to be a basic constituent of tugtupite, so the International Mineralogical Association has kept the formula without sulphur (IMA 2021).

The published literature does not provide any explanation for tugtupite's photochromism. However, its luminescence properties have been extensively studied. Gaft *et al.* (2009) reported at least five different emissions: yellow-orange, red, green, blue and violet. The yellow-orange luminescence is well known for related minerals such as sodalite and scapolite. It has long been suggested to be due to S_2^- (Povarennykh *et al.* 1971; Gaft *et al.* 2009; Friis 2011). The red luminescence is ascribed to the substitution of tetrahedral Al^{3+} or Si^{4+} by Fe^{3+}, as in feldspar (White *et al.* 1986; Krbetschek *et al.* 2002) or sodalite (Gaft *et al.* 2009). The other emissions—green, blue and violet—are ascribed to the presence of Mn^{2+}, Ce^{3+} and Eu^{2+} impurities, respectively (Gaft *et al.* 2009).

Investigations of tugtupite photochromism could help consolidate data on photochromic aluminosilicates (sodalite, scapolite and tugtupite). Synthetic tugtupite has been produced (Armstrong & Weller 2006), but since tugtupite contains beryllium, synthesis of such a material presents many Be-related health risks. In addition, synthetic tugtupite has not been tested for photochromism. Because of many similarities with the previously discussed aluminosilicates (structure, composition and presence of sulphur), the cause of tugtupite's photochromism is possibly similar, if not identical, to that of sodalite and scapolite—that is, an electron trapped in a Cl vacancy and associated sulphur polyanions, possibly S_2^{2-} and/or S_2^-. If so, the two photogenerated Gaussian contributions in the absorption spectrum of tugtupite (Figure 7) could be related to two different environments around the electron trapped in the Cl vacancy, and more research is needed to elucidate these two environments.

SPODUMENE (KUNZITE VARIETY)

George F. Kunz, after whom this variety is named, noted that the 'spodumene crystals are beautiful in their colour tones, varying from deep rosy lilac at some depth to pale or almost colourless, doubtless due to weathering or to the action of sunlight, in striking contrast to the rich deep pink-purple found in a greater depth' (Kunz 1903, p. 264). He was the first to indicate that sunlight could have an influence on the colour of spodumene.

Claffy (1953) reviewed the photochromic behaviour of spodumene, and mentioned that it can rapidly change from pink to green due to exposure to a high-energy source such as X-rays. In addition, the present authors have verified that this also happens with only UV radiation, although it takes much longer. Some giant gem-quality spodumene crystals found in Laghman Province, Nuristan, Afghanistan, were green upon discovery and turned pink shortly after being excavated (Bariand 2008). This modification of the colour can continue to near-colourless if exposed for a very long time to direct sunlight.

The photochromism of spodumene is unique because it has three colour states—colourless, pink and green—rather than the two of 'classic' photochromism (Claffy 1953). According to Claffy, any colourless spodumene exposed to X-rays turns green. This green colouration is completely different from the 'emerald-green' stable colour of hiddenite caused by Cr^{3+} (Cohen & Janezic 1983; Liu *et al.* 2017). In rare cases, hiddenite exposed to X-rays turns blue (Claffy 1953), but the reversibility of this colour behaviour has not been established. According to Claffy, after a colourless sample has been X-ray irradiated to green, it then returns to its initial state with visible-light exposure or heating, but a third (pink) state can be observed between the green and colourless states (Figure 8). However, these processes of colouration and discolouration are

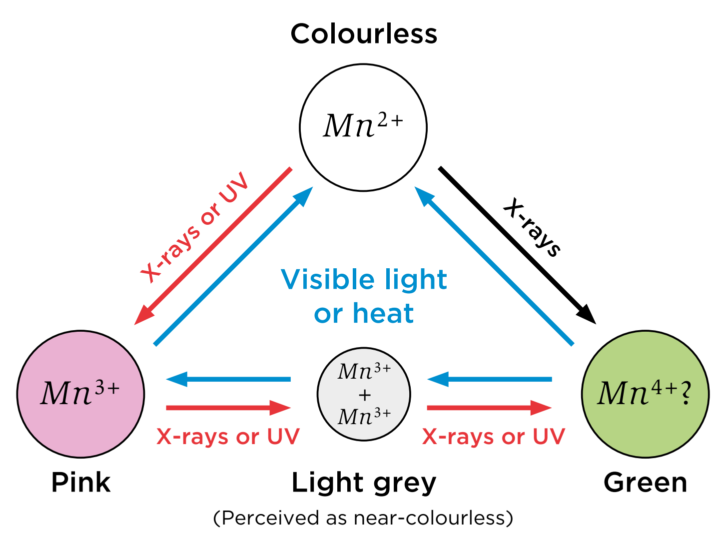


Figure 8: The relationship between the colours of photochromic spodumene is shown here, adapted from Claffy (1953) and Schmitz and Lehmann (1975). Depending on the X-ray energy and flux, the colourless state can change directly to green (high energy and flux) or pass through the pink and light grey states (low energy and flux). The return from the green state to the colourless state, in both ways, is achieved by visible-light exposure or heating.

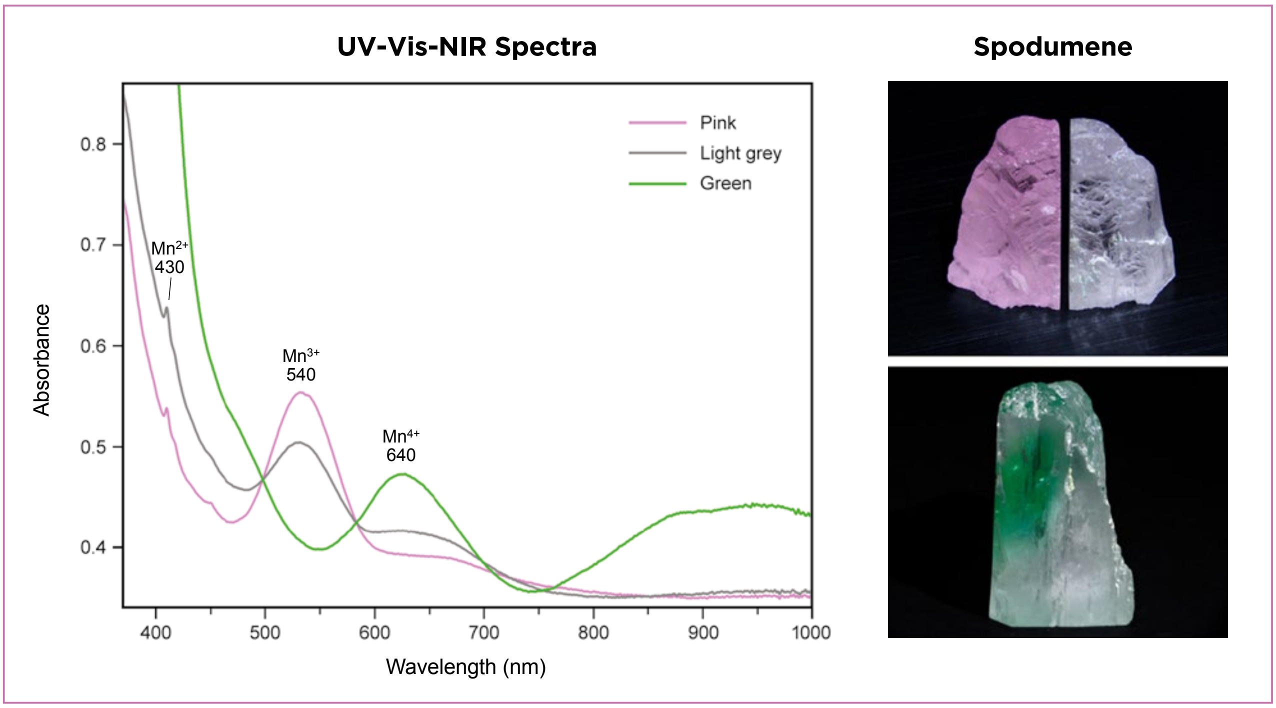


Figure 9: Photos and absorption spectra of a 51.6 g photochromic spodumene from Afghanistan that was cut into two parts show one half, initially near-colourless, which was exposed to short-wave UV until the deepest possible pink colouration was attained (1 hour), alongside the other part, which underwent more UV exposure until the pink colouration disappeared and it thus appeared light grey (4 hours). The latter half of the sample was then partly exposed to X-ray irradiation for 48 hours to obtain the 'emerald-green' colour. The pink colouration is due to the prominent Mn^{3+}-related band at about 540 nm. The green spectrum results from a dominant Mn^{4+}-related 640 nm band, absorbing the red spectral region. The sharp feature at about 430 nm is due to Mn^{2+}. The path length of the beam was approximately 26 mm. Photos by F. Blumentritt.

quite slow compared to other photochromic gems such as sodalite or scapolite. Also, according to Claffy (1953), the photochromism appears only in samples with very low Cr content.

For our own sample from Afghanistan (which was originally near-colourless; locality details unknown), the pink colour is due to a 540 nm band, attributed to Mn^{3+} produced by UV irradiation from Mn^{2+} (the latter seen in the spectrum mostly as a sharp band at about 430 nm).[1] Irradiation with X-rays turned the sample 'emerald green' (Figure 9), coincident with the disappearance of a persistent orange luminescence (commonly called phosphorescence) after several hours. This comes from decay of the Mn^{3+} band in favour of a band at 640 nm, classically linked to Mn^{4+} (see discussion below). The green colour faded slowly (over weeks to months) in artificial light, and at some point there was a combination of green and pink which appeared light grey, which could be perceived as near-colourless (again, see Figure 9, light grey trace). Then the colour of the stone changed further to purplish pink.

Spodumene is a member of the clinopyroxene subgroup, with the formula $LiAlSi_2O_6$. It is mainly exploited for its high Li content (Salakjani *et al.* 2017), but most interestingly, the photochromism of kunzite has been used for dosimetry (Oliveira *et al.* 2009; Olivieri 2011). The pink colour of kunzite is due to the presence of small amounts of Mn (about 0.07 wt.%; Schmitz & Lehmann 1975). Manganese is also suspected of participating in the photochromic reaction. Stuhlman and Daniel (1928) proposed a redox reaction to explain the different colour states. This was later supported by Schmitz and Lehmann (1975) and Hassan and Labib (1978), who proposed that the 536 nm broad band of Mn^{3+} in distorted Si^{4+} sites is responsible for the 'lilac' tint, and Mn^{4+} for the green colouration (again, see Figure 8). In the colourless state, the manganese would be present as Mn^{2+} (Hassan & Labib 1978), and possibly responsible for the orange luminescence classically associated with Mn^{2+} in octahedral coordination in spodumene and other minerals (Aguilar & Osendi 1982). Thus the substitution of Si^{4+} in the tetrahedral

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[1] Pink colouration in kunzite is typically due to natural gamma-ray irradiation from surrounding minerals in the granitic pegmatite environment in which it forms.

site by Mn^{3+} (or Mn^{2+}) is unlikely and has not been proven. The Mn^{2+} ion is more likely to substitute in the Al^{3+} octahedral site, as in tourmaline or beryl (Neiva & Neiva 2005; Sugiyama *et al.* 2016), which necessitates a charge compensation of +1.

Hassan and Labib (1978) and Bosshart *et al.* (2011) pointed out that the increase of the Mn^{4+} absorption band (about 640 nm; see Figure 9, green trace) that occurs upon irradiation is linked to adjacent Fe^{3+}, which possibly acts as a charge compensator by trapping the holes produced during irradiation, although no charge compensation has been proposed. Further, Bosshart *et al.* (2011) showed a correlation between the area under the Mn^{3+}-related peak at about 540 nm (see Figure 9, pink trace) and the amount of MnO + Fe_2O_3—a correlation that is not found for the 640 nm band. Thus the role of Mn is undeniable in the photochromism mechanism, while that of Fe remains to be clarified.

Recently, Czaja *et al.* (2020) proposed an alternate explanation by hypothesising that the octahedral M2 site (among M1 and M2 crystallographic octahedral sites), in which Mn substitutes for Al, changes dimension as a consequence of irradiation. This work also excludes the possibility of Mn^{4+} being responsible for the green colour. Unfortunately, no structural information is provided to support the purported deformation of the M2 site, and the article overlooks the relationship with Fe pointed out by Bosshart *et al.* (2011).

Thus, curently we can only be sure that the photochromism of kunzite is related somehow to Mn, but the specific origin of the green colour remains the subject of debate.

DIOPSIDE

Diopside ($CaMgSi_2O_6$) belongs to the pyroxene group, like spodumene, with related crystallographic structures and possibly a related photochromism mechanism. It is rarely considered a gem material. The first and possibly only published note on photochromic diopside was by Hyršl (2016) on non-gem-quality material from Bazenovskoe, Russia. It was initially yellow or dark yellow, but turned brownish green after UV irradiation. It returned to its initial colour when exposed to visible light. The phenomenon can be repeated at least over months without any observable fatigue.

We obtained an opaque, non-gem diopside sample (also from Bazenovskoe) for which we recorded reflectance spectra of its greenish yellow and yellowish green colour states (Figure 10). The difference spectrum is characterised by a very broad band peaking at around 700 nm, or possibly showing a change in the absorption continuum. We have as yet no hypothesis for the origin of this absorption change. Additional work and samples are obviously needed. By analogy with the absorption spectra of other pyroxenes (e.g. hedenbergite, jadeite and

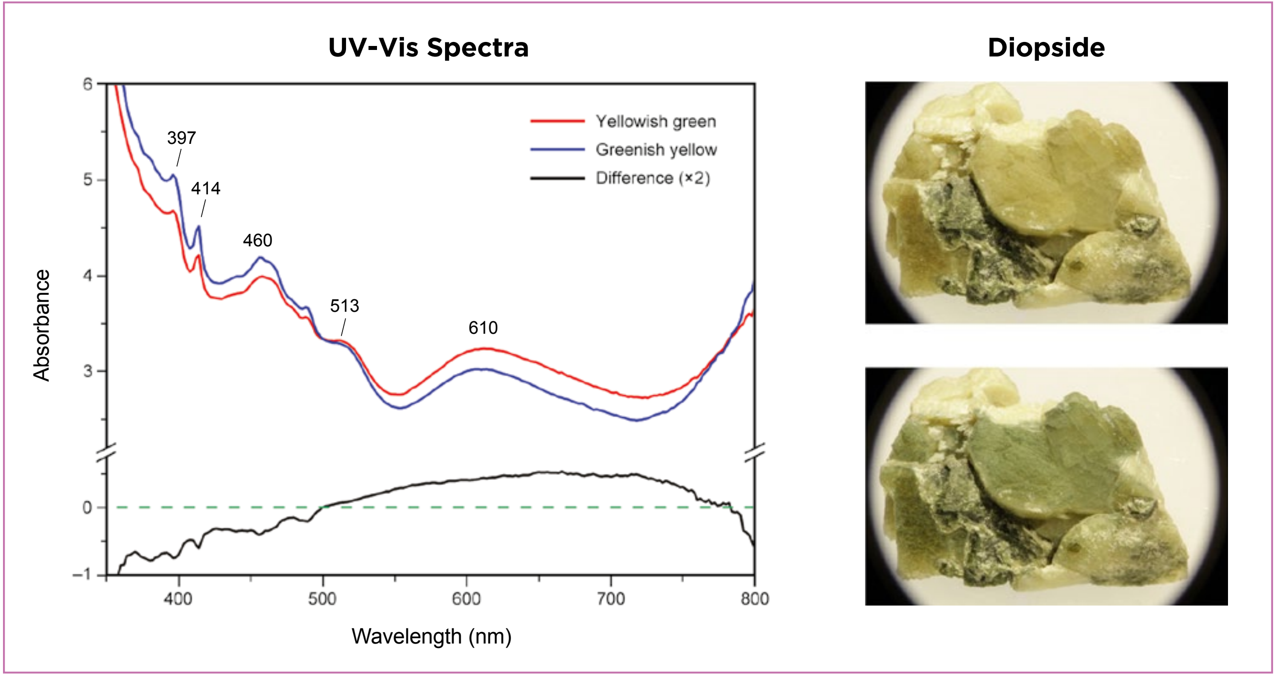

Figure 10: Photos and absorption spectra of an 8.37 g photochromic diopside from Russia are shown before (greenish yellow) and after (yellowish green) short-wave UV illumination. The absorbance was calculated from reflectance spectra using the Kubelka-Munk approximation. The difference spectrum is multiplied by a factor of 2 for clarity. Photos by F. Blumentritt.

spodumene; http://minerals.gps.caltech.edu), it does not seem that bands related to Fe^{2+} or Cr^{3+} are involved in the photochromism.

ZIRCON

In 1904, Max Bauer published probably the first account of photochromic zircon (Bauer 1904, p. 342):

> The color and lustre of some hyacinths is liable to change even at ordinary temperatures if the stones are exposed to light, especially to the direct rays of the sun. In some cases the color becomes pale, while in a few stones it changes to a brownish-red which gradually becomes more decidedly brown.

He also indicated that the initial colour returns when samples are stored in the dark for a few hours, and that the time necessary for this reversal differs among stones. So from the start, several different photochromic behaviours were observed in zircon. However, it is difficult from this short description to understand if the modification is due to 'white visible light' (sunlight) or to the action of natural UV irradiation (also in sunlight). Recent discussions with a gem dealer familiar with zircon (Michael Gray, pers. comm. 2019) are consistent with Bauer's observations and also provide more detail. Three behaviours stand out, as described below.

Behaviour 1. When exposed to visible light, the brown-to-orange colour fades to a stable near-colourless state (Figure 11). Then, the brown colour can be produced by exposure to long-wave UV radiation or by keeping a sample in the dark (McClure 2011). Such zircon is often sold as colourless or, if presented in its coloured state, as 'chameleon zircon'—a trade term with no precise definition. According to several rare-stone and mineral dealers, this behaviour appears to be the most common for photochromic zircon. Figure 11 shows that the absorption of those brown zircons is a continuum with superimposed broad features at about 510 and 800 nm. The few sharp peaks (at 654 and 691 nm) are due to uranium (U^{4+}). The 510 nm feature has been attributed to a complex colour centre related to yttrium (Y^{3+}) trapping an oxygen hole centre (Zeug *et al*. 2018). The difference spectrum reveals that actually all features change together, which complicates the interpretation of the photochromism.

Behaviour 1 could also apply to heat-treated blue zircon for which a brownish component appears upon exposure to UV radiation and then fades under artificial light (Koivula & Misiorowski 1986; Renfro 2016; Zeug *et al*. 2018).

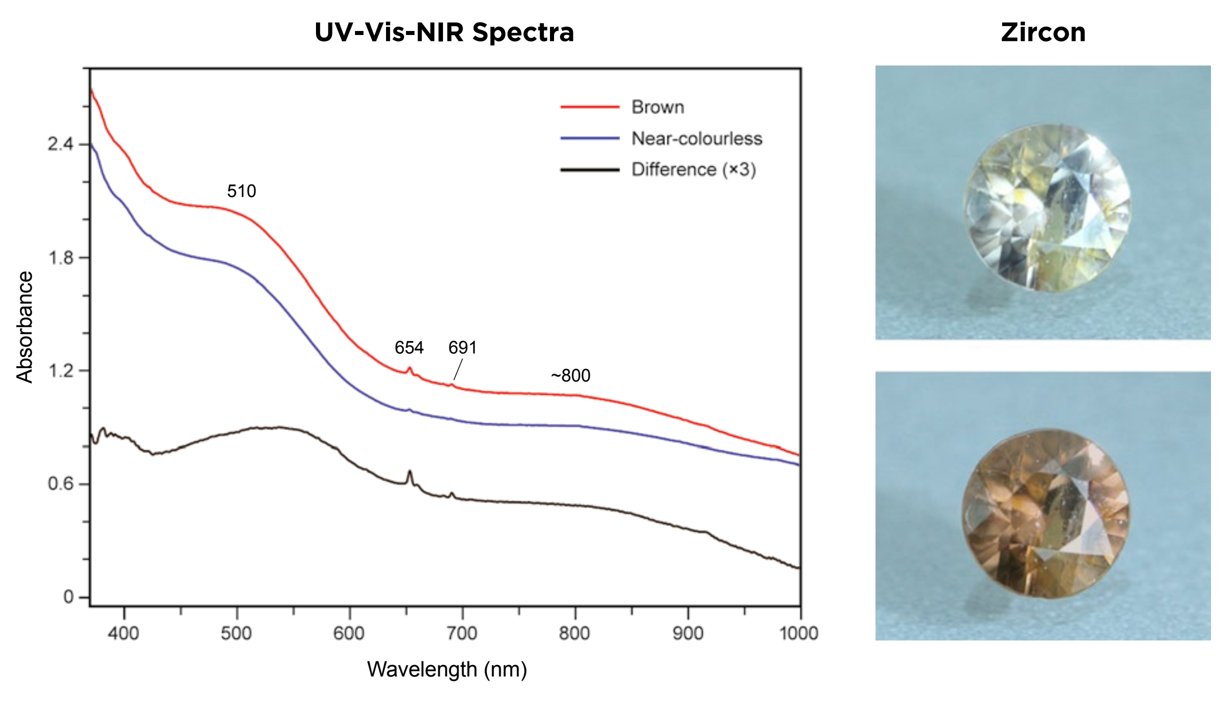

Figure 11: These photos and absorption spectra of a 0.43 ct photochromic zircon were taken before (near-colourless) and after (brown) long-wave UV exposure. This photochromism corresponds to behaviour 1 (see text). The path length of the beam was approximately 1.8 mm, and the difference spectrum is multiplied by a factor of 3 for clarity. Photos by F. Blumentritt.

Figure 12: This 62 ct light brown photochromic zircon of unknown locality (left) shows an impressive change, becoming dark brown after exposure to long-wave UV radiation (centre). It returned to lighter brown with exposure to visible light. Interestingly, after heating at about 400°C it became bright yellow-orange (right), but that colour was not stable. Photos courtesy of Thomas Hainschwang.

It has been pointed out to us (Thomas Hainschwang, pers. comm. 2021) that at least in some cases, brown zircon becomes orange after heating, but not permanently (Figure 12). The blue colour of zircon is typically not a natural colour but the result of heat treatment of certain brown zircons in a reducing atmosphere (Smith & Balmer 2009). One wonders if a brown zircon used to produce a photochromic blue zircon would itself be photochromic.

Behaviour 2. This behaviour refers to dark reddish brown zircon that changes to a stable orangey red colour (Figure 13) when slightly heated (about 100°C) or kept in the dark for several days. The dark brown colour returns upon exposure to daylight for several minutes (Smith & Balmer 2009), but this change is faster (a few seconds) under long-wave UV radiation. This is an alternative to behaviour 1 described above because the brown photogenerated

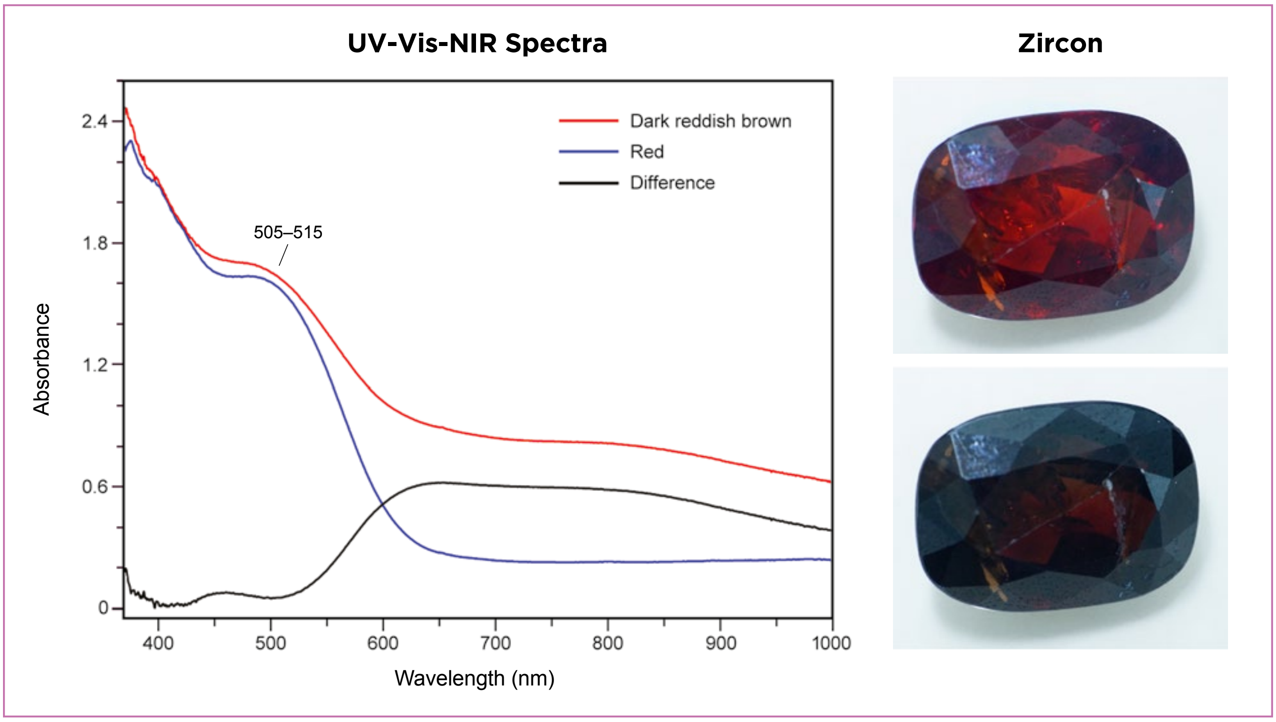

Figure 13: Photos and absorption spectra of an exceptional 21.3 ct photochromic zircon from Cambodia show its stable orangey red colour (top photo, shown after heating the sample at about 100°C) and its dark reddish brown appearance induced by brief exposure to long-wave UV radiation (bottom photo). This photochromism corresponds to behaviour 2 (see text). The path length of the beam was approximately 6.2 mm. Photos by F. Blumentritt.

colour is removed with heat (a non-radiative process), rather than with visible radiation, corresponding to type T photochromism (see Definitions section). Note that the UV-Vis-NIR spectrum of the brown zircon in Figure 11 is similar to that of the dark reddish brown gem in Figure 13. So far this behaviour has been observed in brown zircon from Ratanakiri, Cambodia (Smith & Balmer 2009), Dong Nai, Vietnam (Le & Pham 2021) and Jemaa, Nigeria (Michael Gray, pers. comm. 2021).

As shown in Figure 13, this photochromic effect is mainly due to a decrease in the absorption continuum (of unknown origin), thus removing the brown component, and an increase in the band around 505–515 nm (related to Y^{3+} trapping an oxygen hole centre; Zeug *et al.* 2018), which removes the green and reinforces the red appearance.

Behaviour 3. In some colourless to light brown zircon (reportedly from Australia), exposure to long- or short-wave UV radiation for a few minutes causes the colour to turn brown to brownish yellow. The stable colouration can be returned by heating in an alcohol flame, which causes the zircon to fade to an unstable orange (which always disappears upon cooling) before turning colourless or light brown. This is reversible by exposure to UV radiation, although the brown colour does not always return to the same intensity (Michael Gray, pers. comm. 2019).

Regarding the possible origin of zircon photochromism, McClure (2011) indicated that LA-ICP-MS analysis did not reveal any clear differences between the chemical composition of photochromic and non-photochromic stones. Energy-dispersive X-ray fluorescence analysis by Suthiyuth (2014) also did not show any chemical evidence for photochromism, only normal impurity elements. The lack of correlation of photochromism with any particular impurity or trace element (such as a rare earth), and its occurrence in zircon from various geographical origins, suggest that the phenomenon involves an intrinsic defect (as in corundum; see part 2 of this article). However, little is known about colour centres in zircons, especially brown colour centres. The work of Kempe *et al.* (2017) suggests that the brown colour originates from either hole or electron centres. A hole represents the lack of an electron, with a charge of +1. If Kempe *et al.* are correct, an electron transfer from one centre to another could explain some of the photochromic behaviours in zircon.

CONCLUSION

Photochromism in silicates is quite varied. However, there may be a consistent explanation for the change in colour shown by the three aluminosilicates with cage structure (sodalite, marialite and tugtupite), in which the optical phenomenon is principally related to chlorine vacancies, possibly induced by the presence of sulphur polyanions (e.g. Figure 14).

In other silicates, we are at best limited to conjectures involving possible electron movement. For spodumene this electron is associated, at least in part, with the Mn impurity ion. The absence of any detailed description and interpretation of photochromic zircon behaviours points to a need for further studies.

In general, this review illustrates the need for fundamental knowledge about photochromism in inorganic materials. In the second part of this article, we will explore photochromism in diamond, corundum and barite. Not surprisingly, the large amount of research on diamond results in greater understanding of the phenomenon.

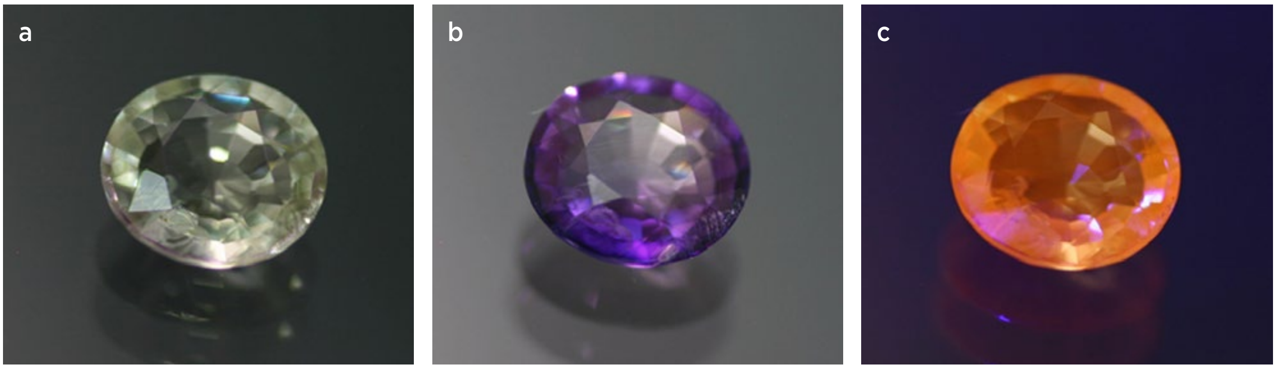

Figure 14: The photochromism of aluminosilicates with cage structure—sodalite, marialite and tugtupite—is thought to be related to chlorine vacancies, possibly induced by the presence of sulphur polyanions. One such polyanion, S_2^-, is also responsible for the yellow-orange luminescence of sodalite and scapolite. This 0.47 ct faceted hackmanite from Myanmar provides a nice example of this photochromism (**a**, **b**) and luminescence (**c**). Photos by Brad Payne (The Gem Trader, Cave Creek, Arizona, USA).

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Figure 1: Attractive blue colouration is shown by these sapphires, which were recently mined from the Yenya-U area of Myanmar. The samples include one faceted (0.30 ct) and 11 rough stones (0.08–0.30 g). Photo courtesy of S Gemmological Institute.

Characterisation and Genesis of Sapphires from the Yenya-U Area, Thabeikkyin Township, Mandalay Region, Myanmar

Khin Mar Phyu, Khin Zaw, Terrence Patrick Mernagh and Thu Zar Aung

ABSTRACT: The Yenya-U area in the Mandalay region of central Myanmar hosts two primary sapphire deposits, at Kyauk-tagar and Kyar-gaung. The sapphires form disseminated crystals within syenite pegmatite and nepheline syenite, respectively. Kyar-gaung is a source of relatively large crystals (up to 12 g) that are translucent to opaque, while Kyauk-tagar produces fine-quality vivid-blue sapphires in smaller sizes (up to 0.4 g). Alluvial deposits in the region yield high-quality sapphires of various colours (including colourless, yellow, purple, pink, greenish blue and blue), as well as quartz, topaz, spinel, garnet, zircon, tourmaline and fluorite. The studied Yenya-U sapphires contained solid inclusions of albite, biotite, graphite, melanophlogite and diaspore. In addition, pennantite is reported here for the first time as an inclusion in corundum. CO_2-rich fluid inclusions were commonly observed in most of the sapphires. Trace-element analyses of the sapphires are consistent with a metamorphic-metasomatic origin, mostly accompanied by desilicification processes.

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Although Myanmar is famous for producing high-quality rubies, it is not well documented that some of the world's finest blue sapphires are also mined in the Mogok Stone Tract (Hughes & U Hla Win 1995; Hughes 1997; Kyaw Thu 2007; Hughes 2017; Kyaw Thu & Khin Zaw 2017). Nowadays, Myanmar sapphires are renowned for their beautiful 'royal blue' colour and unusual large size, although this was not always the case (Hughes 1997). Nevertheless, fine-quality sapphires have been mined from several localities in the Mogok and Thabeikkyin areas for centuries. Notably, classic blue sapphires have been obtained from the Baw Mar area of Mogok since 2008 (Hpone-Phyo Kan-Nyunt *et al.* 2013; Soonthorntantikul *et al.* 2017). The geological setting and gemmological characteristics of the sapphires from Mogok and Thabeikkyin are generally similar.

In the Thabeikkyin area, sapphires have been mined from various deposits, including those near Nyaung-bin-thar, Kyet-saung-Taung, Kyauk-kyi, On-baing and Yenya-U. Sapphires from Yenya-U are highly sought after in the local gem market due to their vivid blue colour (Figure 1). The Yenya-U area is located about 25 km north-east of Thabeikkyin Township, which is situated in the Mogok Metamorphic Belt (Khin Zaw *et al.* 2015; Khin Zaw 2017; Searle *et al.* 2017; see Figure 2). The township is located on the east bank of the Ayerwaddy (Irrawaddy) River, about 45 km west of Mogok and 100 km north of Mandalay. The area near Yenya-U is used for agriculture (Figure 3a) and is surrounded by submontane forest where small-scale mining for sapphires and other gems has taken place (Figure 3b).

Although Yenya-U has been known as a source of sapphires since the 1870s, and fine gem-quality material has been recovered there since the dynasty of King Thibaw (r. 1878–1885; U Khin Maung Gyi 1938), these sapphires have received little attention in the literature. The aim of this study is to investigate the gemmological and geochemical characteristics of sapphires from the Yenya-U area and to unravel the genesis of these deposits.

GEOLOGY AND PRODUCTION

The Yenya-U area lies in the Mogok Metamorphic Belt (again, see Figure 2), which dates from the Jurassic to Miocene, and hosts several primary and secondary sapphire occurrences (e.g. Barley *et al.* 2003; Khin Zaw *et al.* 2015; Khin Zaw 2017; Searle *et al.* 2017). According to Khin Mar Phyu (2009), rocks in the Yenya-U area consist of metamorphic units such as gneiss, calc-silicate and marble that have been intruded by dykes and small

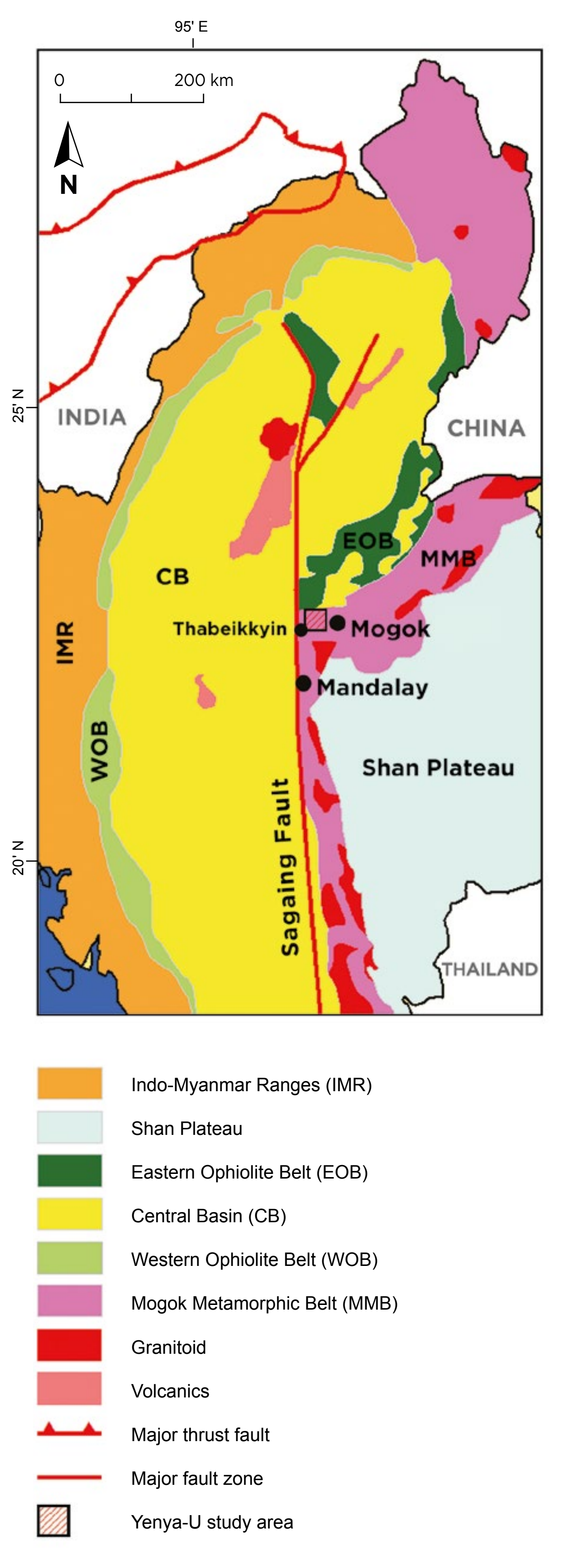


Figure 2: The Yenya-U area is situated in the Mogok Metamorphic Belt, as shown in this regional geological map of north-central Myanmar (modified after Barley *et al.* 2003; Searle *et al.* 2017).

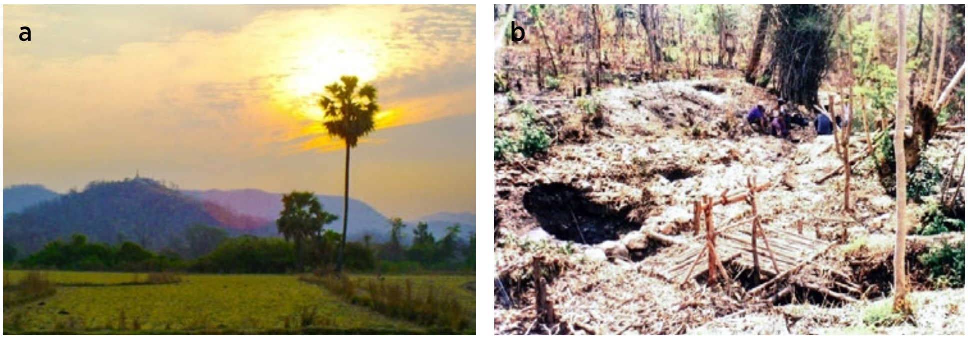


Figure 3: (**a**) Agricultural fields give way to hills in the Yenya-U area. The Yenya-U pagoda sits on the hill at left centre, which is underlain by marble. (**b**) Shafts known as *lay-bin-twin* (seen here at Kyar-gaung) are typical of small-scale traditional mining in the Yenya-U area. Photos by San Shwe.

stocks of granitic and syenitic composition. The granitic rocks include augite granite, leucogranite, biotite microgranite and minor monzodiorite. Outcrops are limited in extent and poorly exposed. The augite granite forms small dykes, and results from zircon crystallisation age determinations suggest this rock unit was emplaced approximately 145 million years ago (Ma). Leucogranite is widespread, and occurs as small stocks and dykes that are associated with quartz syenite and syenite pegmatite to the north-east of Yenya-U. Foliation is well developed at the margins of the intrusions. Zircon age dating indicates that the leucogranite was emplaced in the Early Cretaceous which, combined with its geochemical characteristics, suggest that it formed in a subduction-collision transition zone (Khin Mar Phyu 2009).

Syenite is found as a small stock north-east of the Yenya-U pagoda and is associated with leucogranite. This syenite shows well-developed foliation that is concordant with the surrounding regional trend. Small dykes of foliated syenite pegmatite are locally associated with leucogranite (Figure 4). In addition, dykes of nepheline syenite intrude marble and are associated with syenite. The characteristics of these dykes are similar to those of nepheline syenite from Ondan (Mogok), which is located south-east of the Yenya-U area, and they are inferred by the authors to have formed during the same geological events. The syenite pegmatite and nepheline syenite are both aluminium rich, which may have favoured the growth of sapphire. According to Myo Min (2016), nepheline syenite in the Ondan area has a U-Pb zircon age of 57.81 ± 0.5 Ma (Lower Paleocene). Recently, secondary ion mass spectrometry U-Pb dating of acicular rutile inclusions in an Ondan sapphire yielded an age of 13.43 ± 0.92 Ma (Shi *et al.* 2021). In addition, Elmaleh *et al.* (2015) obtained an age of 67 ± 5 Ma for zircon inclusions in a blue sapphire from Mogok, and Link (2016) reported U-Pb ages of 26.7 ± 4.2 Ma and 27.5 ± 2.8 Ma for zircon inclusions in two faceted sapphires from Mogok. However, the spatial locations of the samples are not known.

Most exposures in the Yenya-U region are highly weathered. The main igneous unit consists of biotite microgranite, which intrudes marble layers and their related rocks. Granitic pegmatites generally form small dykes and veins in the marginal area of the biotite microgranite and in the surrounding metamorphic rocks. Aplite forms dykes that intrude into marble, and skarn zones are found at the contact between igneous intrusions and marble in the Yenya-U area (Khin Mar Phyu 2009).

The Kyauk-tagar mining area is situated at 23°6′40.9″ N, 96°6′18.2″ E, which is 1.6 km north-east of Yenya-U village along the footpath to Kyaukpyu (Figure 5). The rock types consist of spinel-chondrodite marble, graphite-phlogopite marble and pure marble that are underlain by garnet-biotite gneiss, as well as leucogranite that cuts all of these units. Sapphire-bearing syenite pegmatite is associated with the leucogranite body and forms a north-east-trending irregular dyke intruding marble. According to unpublished Raman and petrographic

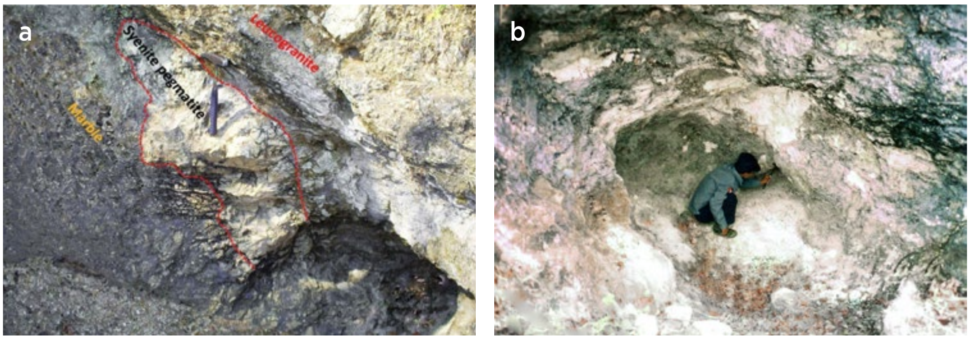


Figure 4: (**a**) At Kyauk-tagar, a sapphire-bearing syenite pegmatite dyke intrudes marble adjacent to leucogranite. (**b**) Another sapphire-bearing syenite pegmatite at Kyauk-tagar is shown here. Photos by San Shwe.

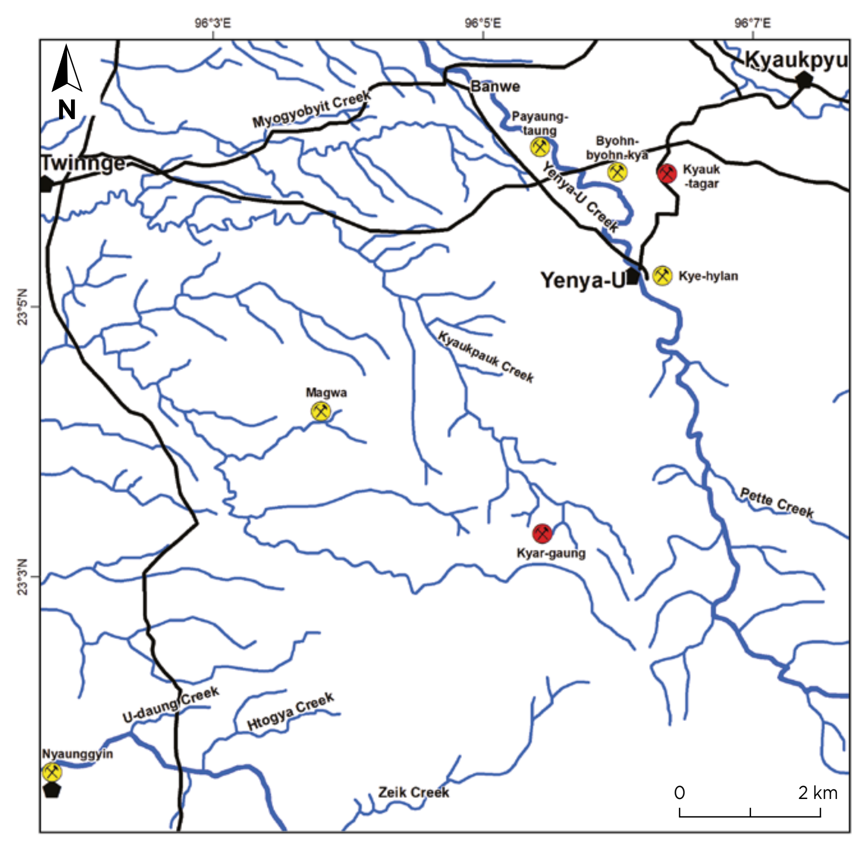


Figure 5: In the Yenya-U area, primary sapphire deposits are located at Kyauk-tagar and Kyar-gaung, and secondary (alluvial) occurrences include Byohn-byohn-kya, Kye-hylan, Magwa, Payaung-taung and Nyaunggyin.

analyses by the authors, the pegmatite contains alkali feldspar, biotite, garnet, spinel and sapphire (Figure 6a). Most of the sapphires from Kyauk-tagar are small—about 0.2–1.5 cm in size (0.3–1 ct when faceted)—but of fine colour.

The Kyar-gaung mining area is located at 23°3′42.9″ N, 96°5′26.4″ E, which is 2.5 km south-west of Yenya-U village (Figure 5). Sapphires are extracted from nepheline syenite, which forms a dyke some tens of metres thick that intrudes marble and calc-silicate rock. Unpublished Raman and petrographic analyses indicate that the nepheline syenite consists mainly of alkali feldspar (anorthoclase) with plagioclase (andesine), biotite and sapphire (Figure 6b). The size of the sapphires from Kyar-gaung is commonly around 0.5–3 cm, but the larger stones tend to be mostly opaque.

Secondary deposits are found at Byohn-byohn-kya, Kye-hylan, Magwa, Payaung-taung and Nyaunggyin (Figure 5). Sapphires and other gem materials are extracted from gravel (*byone*) along stream banks and alluvial placers. Gem-bearing *byone* is situated at shallow depths of about 2–3 m below the surface. In general, the sapphires from the secondary deposits weigh up to about 2 g.

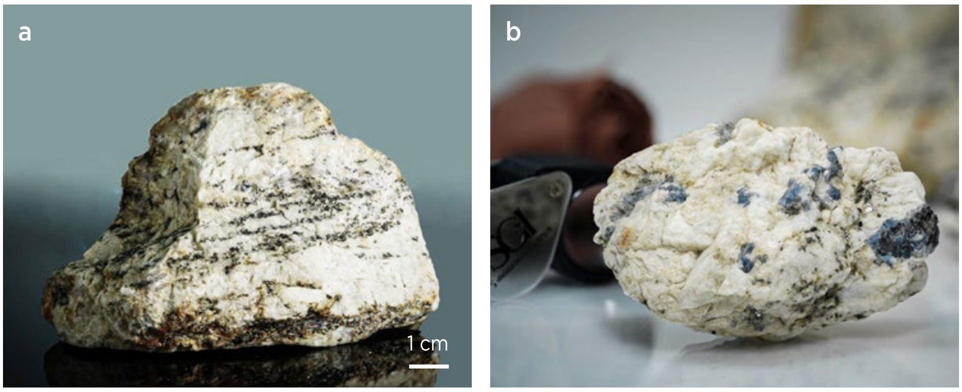


Figure 6: (**a**) Sapphire-bearing syenite pegmatite at Kyauk-tagar consists of megacrysts of alkali feldspar with biotite, garnet, spinel and sapphire. (**b**) Sapphire crystals are visible in this sample of nepheline syenite from Kyar-gaung, which mainly contains plagioclase (andesine) and alkali feldspar (anorthoclase). Photos courtesy of S Gemmological Institute.

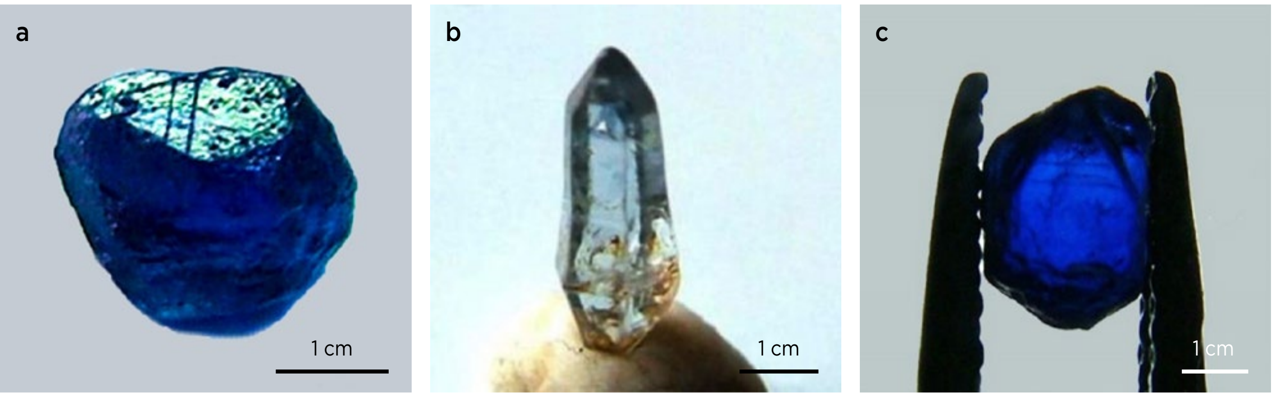


Figure 7: (**a**) This sapphire crystal from Kyauk-tagar shows a typical short-prismatic form and displays fine 'royal blue' colouration. (**b**, **c**) Sapphire crystals from secondary deposits in the Yenya-U area sometimes form hexagonal prisms and dipyramids. Photos by Khin Mar Phyu.

The sapphire crystals from the primary deposits are mostly tabular or short-prismatic and truncated by pinacoids (Figure 7a). Those from secondary deposits are mostly waterworn, but well-formed crystals are sometimes found that consist of hexagonal prisms and dipyramids (Figure 7b, c) and occasionally pseudo-cubic habits in sizes of 0.2–1 cm. Raised triangular steps are sometimes seen on the basal pinacoid (Figure 8a), and some crystals display etch marks (Figure 8b).

Sapphires from the Yenya-U area are typically 'sky' blue to deep blue, as well as greenish blue, yellow, purple, pink and colourless. The best 'royal blue' colour is seen in the relatively small stones from Kyauk-tagar (Figure 9a) and in some sapphires from the secondary deposits (e.g. Figure 9b). Trapiche sapphires (Figure 9c) are rarely found in secondary deposits near Yenya-U, whereas a secondary deposit in the Nyaung-bin-thar area (about 60 km south of Yenya-U) is notable for producing them.

Gem mining is usually carried out by local people after the crops have been harvested. They believe that a deposit will soon be exhausted if machines are used, so mining is still done in the traditional way using hand tools. Most of the workings consist of small mining shafts (e.g. Figure 3b) called *lay-bin-twin* (or *lebin*) that measure 1.5 × 1.5 m and up to 10 m deep. During 1958–1959, alluvial deposits at Byohn-byohn-kya (meaning 'obtaining lots of gemstones') produced abundant sapphires. Although many fine stones were recovered there, production is now dwindling. The Magwa area is well known for producing star sapphire. Kye-hylan is being mined by a private company, but only limited amounts of gems have been produced. Recent production from Payaung-taung and Nyaunggyin is also minimal. According to local miners, a large quantity of sapphires was discovered in the Yenya-U area during construction of the Twinnge-Momeik road more than 16 years ago.

Although sapphire production from Yenya-U has declined in recent years, small quantities of high-quality material continue to be supplied to the local market, where it is highly valued due to its rarity and beautiful blue colour. Myanmar sapphires are sold regularly at international gem markets and auction houses, but stones are not labelled according to their specific mining area. Hence, international dealers do not know whether the sapphires came from Mogok or the Thabeikkyin (including Yenya-U) area.

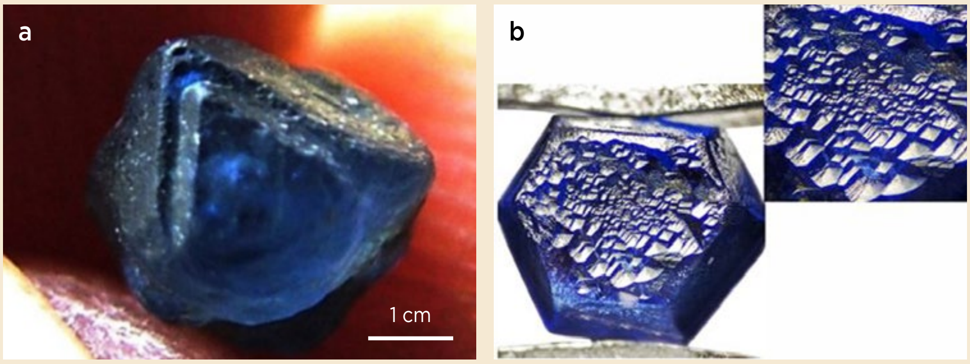


Figure 8: Surface markings on Yenya-U sapphires include (**a**) raised triangular steps on a basal pinacoid and (**b**) etch marks that are also present on a basal pinacoid. The image width of the inset is 0.5 mm. Photos by Thu Zar Aung.

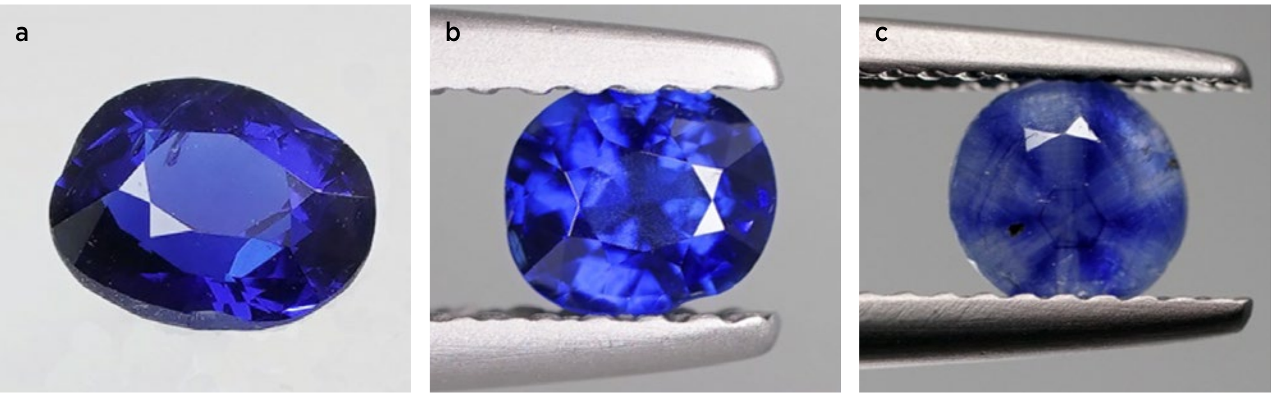
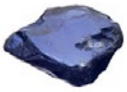


Figure 9: The faceted specimens shown here consist of (**a**) a 1 ct sapphire of the finest 'royal blue' colour from Kyauk-tagar and, from alluvial occurrences in the Yenya-U area, (**b**) a 0.3 ct sapphire and (**c**) a 0.8 ct trapiche sapphire. Photos courtesy of S Gemmological Institute.

MATERIALS AND METHODS

For this investigation, 35 sapphire samples were collected from different mines in the Yenya-U area. Twenty samples from Kyauk-tagar, Kyar-gaung, Byohn-byohn-kya, Kye-hylan, Magwa, Payaung-taung and Nyaunggyin were used for gemmological and inclusion studies. Nine samples from Kyauk-tagar, Kyar-gaung and Nyaunggyin were selected for ultraviolet-visible (UV-Vis) spectroscopy, and six samples (from the locations mentioned above, except for Payaung-taung) were used for trace-element analysis (Table I).

Table I: Characteristics of some of the studied sapphires from the Yenya-U area.

Photo	Sample no. (mine site)	Origin	Weight (g)	Colour	Diaphaneity	Inclusions*
	1 (Kyauk-tagar)	Primary	0.17	Blue	Transparent	Diaspore, graphite, pennantite, rutile
	2 (Magwa)	Alluvial	0.16	Blue	Transparent	—
	3 (Byohn-byohn-kya)	Alluvial	0.24	Blue	Transparent	Albite, biotite, diaspore, melanophlogite
	4 (Nyaunggyin)	Alluvial	0.45	Light blue	Transparent	Diaspore
	5 (Kyar-gaung)	Primary	2.87	Blue	Opaque	Apatite, rutile, zircon
	6 (Kye-hylan)	Alluvial	0.78	Violet-blue	Transparent	—

* Sapphire inclusions were identified in thin sections from the respective mine sites. Apatite, rutile and zircon were identified by optical microscopy, and albite, biotite, graphite, melanophlogite, pennantite and diaspore and were identified by Raman micro-spectroscopy.

Gemmological properties, including RI, hydrostatic SG and long- and short-wave UV fluorescence, were studied using standard equipment. A gemmological microscope and Raman micro-spectroscopy were used to investigate mineral and fluid inclusions. Raman analysis was undertaken at Geoscience Australia, Canberra, using a Dilor Super LabRam spectrometer equipped with a holographic notch filter, gratings of 600 and 1,800 grooves/mm, and a liquid nitrogen-cooled CCD detector (2,000 × 450 pixels). The analyses were done with 514.5 nm excitation from a Spectra-Physics 2017 argon-ion laser using 5 mW power at the sample and a single accumulation of 30 s.

Mineral identification in petrographic thin sections of both host rocks and sapphires was also performed by Raman micro-spectroscopy, at S Gemmological Institute, Yangon, Myanmar, using a Renishaw inVia confocal Raman microscope. UV-Vis spectra were collected at S Gemmological Institute using a Cary 5000 spectrophotometer in the 200–800 nm range with a scan speed of 600 nm/minute.

The trace-element content of the sapphires was determined using laser ablation inductively coupled plasma time-of-flight-mass spectrometry (LA-ICP-TOF-MS) at the Swiss Gemmological Institute SSEF, Basel, Switzerland. Three spots were analysed on each of the six samples. The analyses were performed using a 213 nm solid-state Nd:YAG laser coupled with an ICP-TOF-MS (model icpTOF from Tofwerk AG, Thun, Switzerland). Laser conditions included a spot diameter of 40 μm, a fluence of 15 J/cm^2 and a repetition rate of 20 Hz. Helium was used as the carrier gas at a flow rate of 1.0 L/min. The ICP-TOF-MS unit was operated at a power of 1,400 W. Argon was used as the nebuliser gas at a flow rate of 0.8 L/min. Before each measurement, five pre-ablation shots were done to remove any surface contamination from the sample. In all measurements, the first 30 s were recorded as background without ablation, and then the sample was ablated for 20 s. Without losing key information, the TOF detector collected 10,000 spectra and then reported one averaged spectrum (3.3 spectra per second with a maximum of 1,000 spectra per second). NIST SRM 610 standard reference glass was used for external calibration and Al was used as an internal standard. Element concentrations and limit-of-detection values were calculated using the methods of Longerich *et al.* (1996).

RESULTS

Gemmological Properties

Our study samples ranged from light blue to blue to violet-blue. The RIs of the tested sapphires were 1.760–1.768 (birefringence 0.008) and SG values varied from 3.99 to 4.10. All samples tested were inert to both long- and short-wave UV radiation except for one sample that displayed a very weak orange patch to long-wave UV.

Internal Features

The mineral inclusions found in the Yenya-U sapphires are summarised in Table I. Those in sapphires from Kyauk-tagar included diaspore, disordered carbon (graphite), pennantite and rutile. The diaspore occurred mostly in association with abundant CO_2-bearing inclusions (identified by Raman micro-spectroscopy; see Figure 10a). Pennantite, a member of the chlorite group with the formula $Mn_5Al(AlSi_3O_{10})(OH)_8$, formed colourless transparent crystals with low relief (Figure 10b). To our knowledge, this is the first identification of pennantite as an inclusion in corundum. Graphite occurred as black, opaque, scaly masses with irregular outlines that were found in association with polysynthetic twin lamellae (Figure 10c).

Sapphires from Byohn-byohn-kya contained albite, biotite, diaspore and melanophlogite. Albite formed transparent colourless crystals (Figure 11a). Biotite occurred as tabular or elongated brownish crystals (Figure 11b). Diaspore was present as colourless to pale yellow subhedral crystals. Melanophlogite, a rare polymorph of silica with the formula $46SiO_2 \bullet 6(N_2,CO_2) \bullet 2(CH_4,N_2)$,

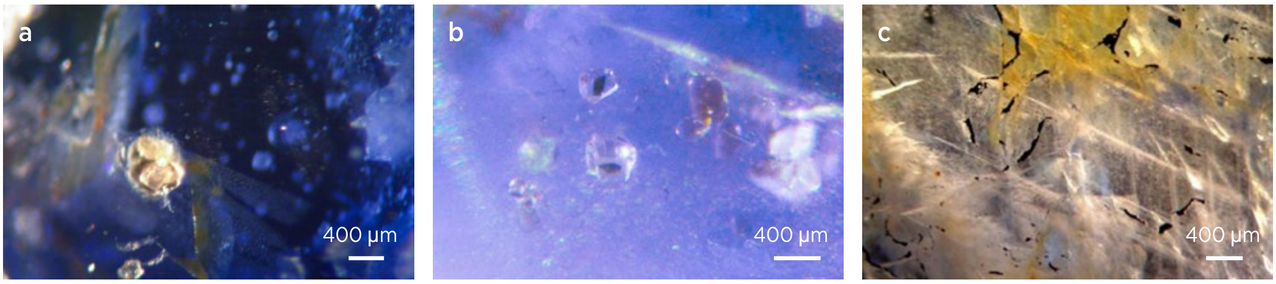


Figure 10: Solid inclusions in sapphires from Kyauk-tagar include (**a**) diaspore crystals, typically occurring in association with vapour-phase CO_2 inclusions; (**b**) pennantite in the form of transparent crystals with low relief; and (**c**) irregular masses of graphite associated with polysynthetic twin lamellae. Photomicrographs by Thu Zar Aung.

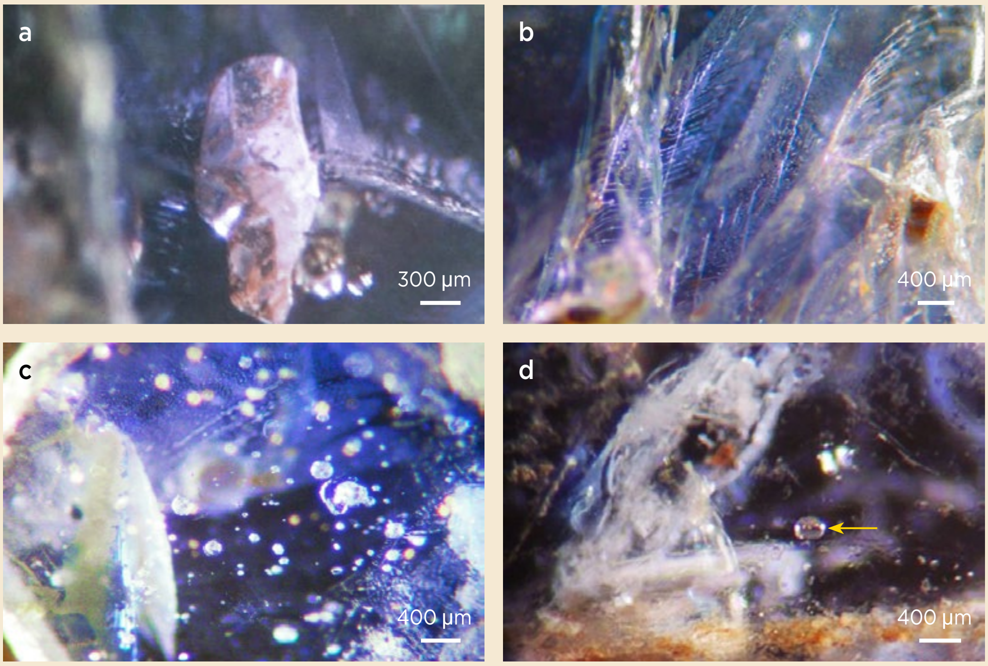


Figure 11: Sapphires from Byohn-byohn-kya contain inclusions of (**a**) albite; (**b**) biotite, here associated with liquid-bearing feathers; and (**c**) melanophlogite, usually as aggregates of minute crystals. (**d**) A sapphire from Kyar-gaung contains an isolated inclusion of apatite (see arrow). Photomicrographs by Thu Zar Aung.

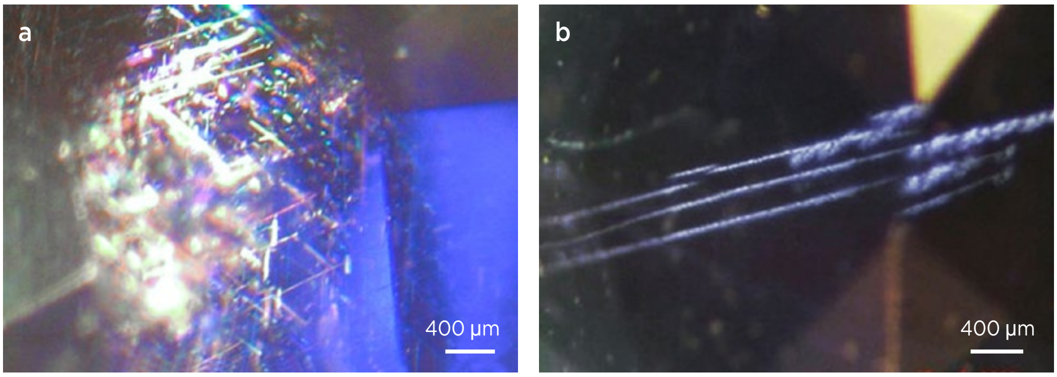
was observed as rounded to sub-rounded white grains with low relief. These usually occurred as aggregates of minute crystals in the host sapphire (Figure 11c).

Included in sapphires from Kyar-gaung were apatite, rutile and zircon. With high magnification, apatite was seen as euhedral prismatic crystals (e.g. Figure 11d) and occasionally as anhedral grains. Transparent colourless crystals of zircon occurred as single crystals or in groups.

Many of the sapphires contained needles of rutile, present as isolated crystals, as well as arrays of fine needles oriented parallel to three horizontal crystallographic directions in the host sapphire (Figure 12a). Rutile needles also occurred as short or long, acicular crystals forming a silk-like network, probably as a result of exsolution phenomena. In some samples, these rutile needles showed a whitish or silvery sheen and a string-like appearance (Figure 12b).

Other internal features included twinning (again, see Figure 10c) and colour zoning (Figure 13a), which were common in the study samples. Partially healed fractures consisted of planes of fluid inclusions (Figure 13). Some of the fingerprint-like inclusions were filled with iron oxides. Raman micro-spectroscopy showed that the fluid inclusions in most of the sapphires from Yenya-U contained CO_2 in the form of two phases (liquid and gas) or one phase (liquid). Only two samples contained CH_4-bearing inclusions. Sapphires from Byohn-byohn-kya contained abundant CO_2-bearing inclusions, some with a diaspore daughter crystal. Most of the sapphires from Nyaunggyin also contained CO_2 as two-phase and one-phase inclusions (Figure 13b). One Nyaunggyin sample contained a CO_2 inclusion with a small daughter crystal that was identified by Raman micro-spectroscopy as diaspore.

Figure 12: Rutile inclusions in sapphires from Kyauk-tagar form (**a**) fine needles oriented in three directions and (**b**) parallel elongate needles. Photomicrographs by Thu Zar Aung.



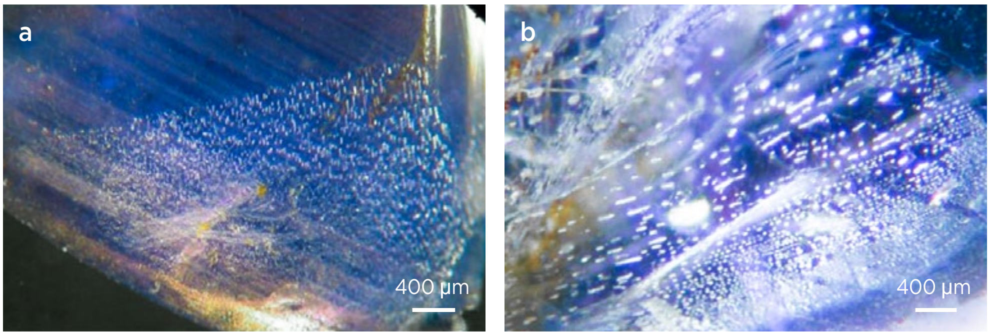


Figure 13: (**a**) Colour zoning and a partially healed fracture consisting of CO_2-bearing fluid inclusions are present in this sapphire from Kyauk-tagar. (**b**) A sapphire from the Nyaunggyin alluvial deposit also contains a plane of CO_2-bearing fluid inclusions. Photomicrographs by Thu Zar Aung.

UV-Vis Spectroscopy

UV-Vis spectroscopy of the Yenya-U sapphires showed typical patterns of metamorphic and metasomatic sapphires. A sample from Kyauk-tagar displayed absorption peaks related to Fe^{3+}–Fe^{3+} interactions at 376 and 450 nm, as well as Fe^{3+} at 387 nm (Figure 14a). This sample also showed a broad Fe^{2+}–Ti^{4+} intervalence charge-transfer (IVCT) band centred at 621 nm that was responsible for the blue colour (Ferguson & Fielding 1971). The spectrum of a Nyaunggyin sapphire showed similar features, except that the broad Fe^{2+}–Ti^{4+} IVCT band was centred at 565 nm (Figure 14b). A sapphire from Kyar-gaung displayed weaker Fe^{3+}-related features and the broad band due to Fe^{2+}–Ti^{4+} was centred at 565 nm (Figure 14c).

Trace-Element Composition

LA-ICP-TOF-MS trace-element analyses of the six sapphire samples are shown in Table II. Relatively high Fe contents were recorded in the sapphires from the two primary deposits (Kyauk-tagar and Kyar-gaung). Distinctly higher Cr and V were found in the sapphire

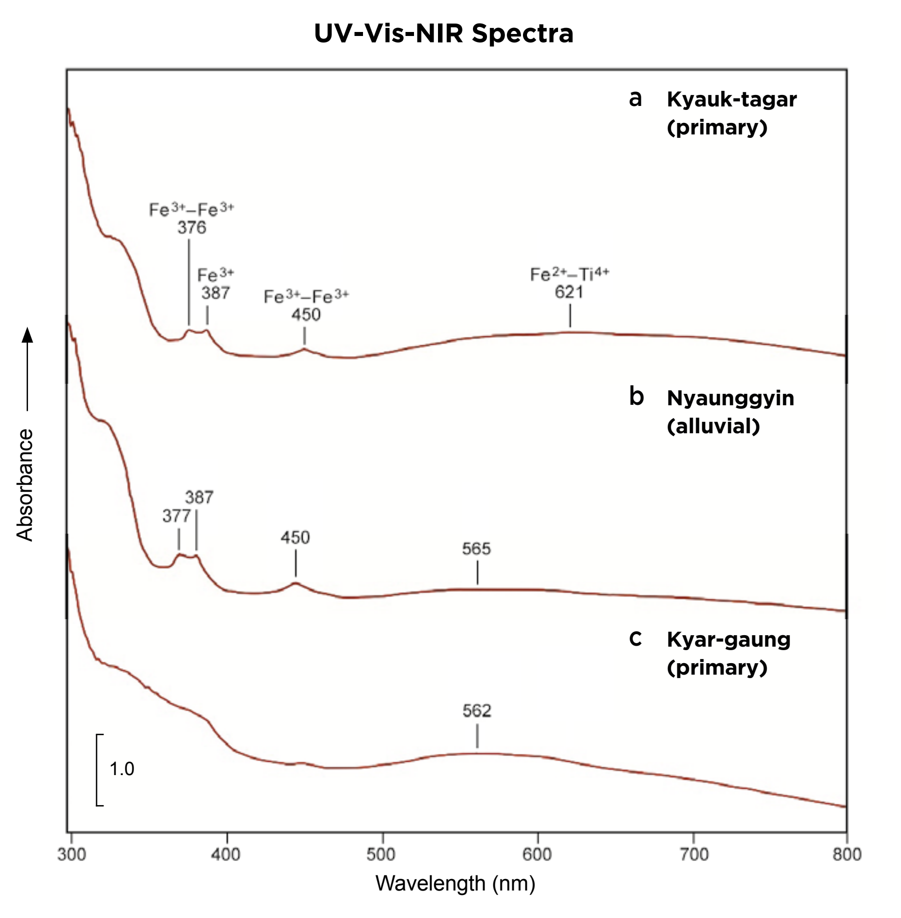


Figure 14: The UV-Vis absorption spectra (for the o-ray) of sapphires from (**a**) Kyauk-tagar, (**b**) Nyaunggyin and (**c**) Kyar-gaung show absorption peaks of Fe^{3+}–Fe^{3+} (376/377 and 450 nm) and Fe^{3+} (387 nm). The Kyauk-tagar sample also shows a broad Fe^{2+}–Ti^{4+} intervalence charge-transfer band at 621 nm, while for the Nyaunggyin and Kyar-gaung sapphires this band is weaker and is centred around 565 nm. The path length of the beam was approximately 2 mm for each sample. The spectra are offset vertically for clarity.

Table II: Trace-element composition (in ppm) of sapphires from the Yenya-U area, as measured by LA-ICP-TOF-MS.*

Sample no. (mine site)	Be	Mg	Ti	V	Cr	Fe	Ga	Sn	Ba	Ta	Nb	Ga/Mg
1 (Kyauk-tagar)	nd	15.87	43.47	0.24	0.96	2670	169	0.88	nd	0.04	0.13	10.65
	nd	21.63	58.57	nd	0.82	2740	164	0.34	nd	0.02	0.10	7.58
	1.69	38.74	85.47	nd	0.64	3200	166	0.28	nd	0.01	0.10	4.28
2 (Magwa)	nd	0.47	40.06	0.34	0.62	1920	174	0.42	nd	nd	nd	370
	nd	nd	55.25	0.49	0.71	2350	195	0.39	nd	nd	nd	—
	nd	0.42	40.92	0.36	0.48	2290	183	0.38	nd	nd	nd	436
3 (Byohn-byohn-kya)	nd	22.16	54.37	48.79	401	2210	124	0.40	nd	nd	nd	5.59
	nd	24.67	47.91	45.85	382	2100	117	0.26	nd	nd	nd	4.75
	nd	27.23	53.13	49.97	411	2230	119	0.51	0.11	nd	nd	4.38
4 (Nyaunggyin)	nd	35.95	61.22	1.12	nd	1710	188	0.59	nd	nd	nd	5.24
	nd	37.78	74.21	1.03	0.68	1690	179	0.55	nd	nd	nd	4.73
	nd	37.27	70.25	0.85	0.92	1670	179	0.64	nd	nd	nd	4.79
5 (Kyar-gaung)	nd	nd	60.52	0.91	0.84	3080	197	0.92	nd	0.02	nd	—
	2.78	1.06	57.59	0.72	nd	3060	194	1.04	nd	nd	nd	183
	nd	0.70	36.04	0.94	nd	3200	213	0.49	nd	0.05	nd	304
6 (Kye-hylan)	nd	15.34	29.43	4.71	2.76	953	146	0.37	nd	nd	nd	9.52
	nd	18.48	36.26	4.71	2.79	991	148	0.57	nd	nd	nd	7.99
	nd	11.99	23.48	4.66	1.96	911	148	0.47	nd	nd	nd	12.34

* Zn, Hf, W, Pb and Th were not detected in any of the analyses. Abbreviation: nd = not detected.

from Byohn-byohn-kya. Relatively low Mg occurred in the samples from Kyar-gaung and Magwa, resulting in high Ga/Mg ratios for those samples. All of the sapphires contained detectable Sn (approximately 0.3–1 ppm), and minute traces of Ta and Nb (up to 0.13 ppm) were found in the Kyauk-tagar sapphire. Beryllium was typically not detectable except for 1.69 ppm in the Kyauk-tagar sapphire and 2.78 ppm in the stone from Kyar-gaung.

DISCUSSION

Sapphire deposits are formed due to metasomatic/metamorphic/magmatic processes. Localised metasomatism mostly involves desilication reactions between silico-aluminous rocks (pegmatites, gneisses, etc.) and silica-poor rocks (ultramafics or meta-carbonates) that lead to the formation of deposits of limited size (e.g. Sutherland & Coenraads 1996; Simonet *et al.* 2008; Sutherland *et al.* 2009, 2014, 2019; Giuliani *et al.* 2014; Wong *et al.* 2017; Harris *et al.* 2017; Keulen *et al.* 2020). The higher Mg concentrations in sapphires from some occurrences in the Yenya-U area point to a metamorphic/metasomatic-related origin.

The ratio of Ga/Mg can help differentiate between magmatic and metamorphic blue sapphires (Peucat *et al.* 2007; Sutherland & Abduriyim 2009). This ratio is generally high (10 or much greater) for magmatic sapphires, and low (generally <10) for metamorphic and metasomatic ones. The sapphires from Kyauk-tagar and three of the placer deposits (samples 1, 3, 4 and 6 in Table II) have low Ga/Mg ratios consistent with a metamorphic source, whereas those from Kyar-gaung and the Magwa alluvial occurrence (samples 5 and 2 in Table II) are characterised by much higher Ga/Mg values associated with a magmatic source.

In the geochemical discrimination diagrams of Peucat *et al.* (2007; see Figures 15a and 15b), the sapphires from Kyauk-tagar and three alluvial occurrences (1, 3, 4 and 6 in Table II) fall within the overlapping fields of metamorphic

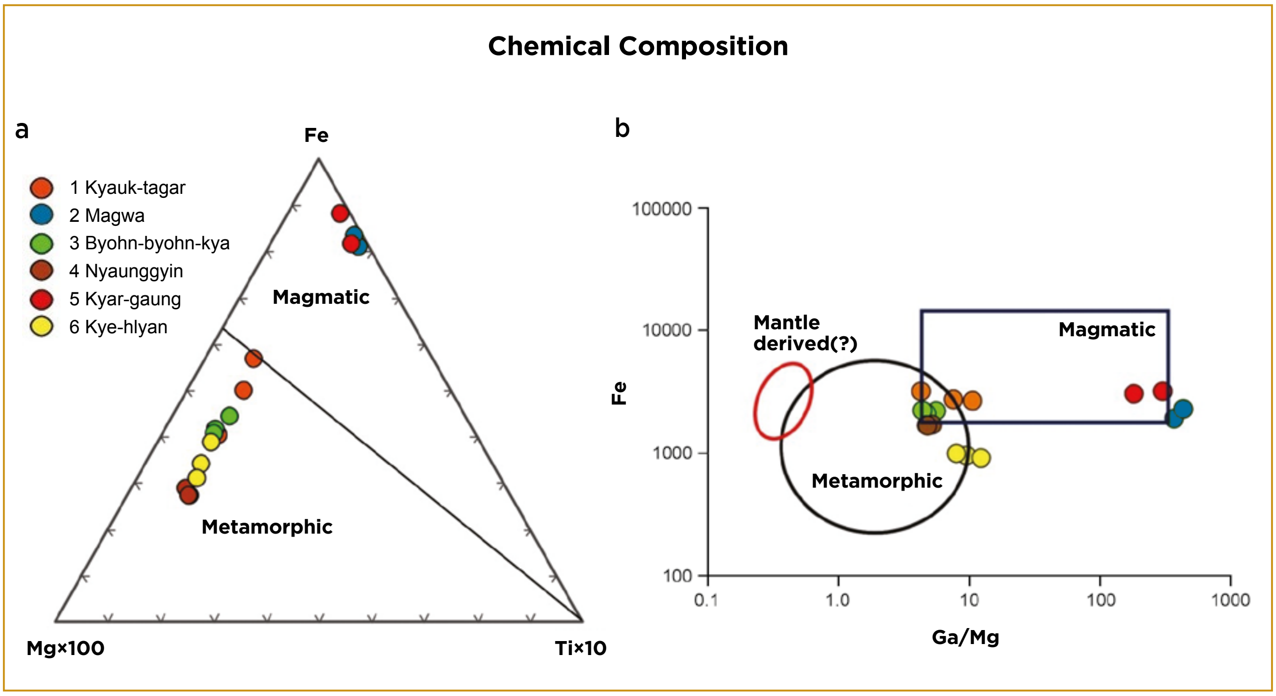


Figure 15: (**a**) A ternary diagram of Fe vs (Mg×100) vs (Ti×10) from Peucat *et al.* (2007) shows that data for most of the Yenya-U sapphires fall within the metamorphic field. (**b**) Another plot from Peucat *et al.* (2007), for Fe vs Ga/Mg, indicates that most analyses fall in a region of overlapping magmatic and metamorphic origin. Only the samples from Magwa and Kyar-gaung lie clearly in the magmatic region.

and magmatic sapphires, while the stone from Kyar-gaung and one alluvial sapphire (samples 2 and 5 in Table II) are associated with a magmatic origin, consistent with the trends indicated by the Ga/Mg ratios mentioned above.

In Table III, trace-element contents for sapphires from the Yenya-U area are summarised along with those from Mogok and other metamorphic deposits in Sri Lanka and Madagascar (data from Abduriyim & Kitawaki 2006). Compared to Mogok sapphires, those from Yenya-U have lower Ti and higher V, Cr, Fe and Ga. The concentration of Zn is lower than in Mogok sapphires, while Nb, Sn, Ba, Ta and Pb are comparable to Mogok sapphires. Compared to sapphires from metamorphic deposits in Sri Lanka and Madagascar, stones from Yenya-U contain relatively low Mg and Ti, and high V, Cr, Fe and Ga. Madagascar sapphires have higher Sn and Ta than in those from the other localities. However, some different trends are noted by comparing to trace-element data from Palke *et al*. (2019): Yenya-U sapphires show lower Ti, Mg, V, Cr, Fe and Ga than those from Mogok, Sri Lanka and Madagascar. It is likely that the trace-element data provided by various references show considerable differences because of sample quantities, specific localities and sample preparation/analysis processes. In addition, only a few Yenya-U sapphires were analysed for this report, and data from a greater number of samples are needed in the future.

Table III: Comparison of trace-element data (measured using LA-ICP-TOF-MS) for sapphires from this study and other selected localities (from Abduriyim & Kitawaki 2006).

Element (ppm)	Yenya-U	Mogok	Sri Lanka	Madagascar
Mg	nd*-38.74	19–21	12–210	7–140
Ti	23.48–85.47	29–240	18–300	28–590
V	nd–49.97	3–5	2–13	0.7–12
Cr	0.48–411	4–31	3–120	2–66
Fe	953–3200	1030–1630	180–1140	89–1160
Zn	nd	1–15	nd	nd
Ga	117–213	8–43	7–40	7–66
Nb	nd–0.13	<0.2	nd	nd
Sn	0.26–1.04	0.5–2	<2	0.2–21
Ba	nd–0.1	0.1–2	nd	nd
Ta	nd–0.05	nd	nd	0.5–2
Nb	nd–0.13	<0.2	nd	nd
Pb	nd	0.2–2	nd	nd

* Abbreviation: nd = not detected.

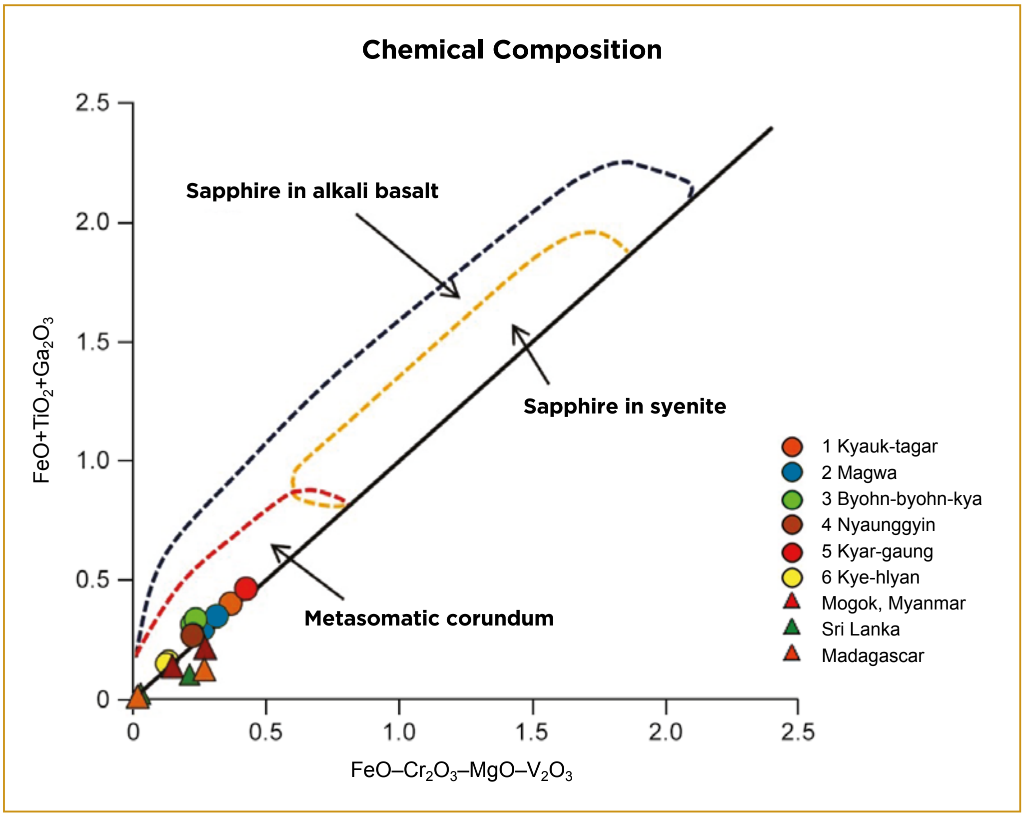


Figure 16: According to this diagram (from Giuliani *et al.* 2014), all the Yenya-U samples lie within the field of metasomatic origin. Also included for comparison are summary data points from Abduriyim and Kitawaki (2006) for sapphires from Mogok, Sri Lanka and Madagascar, which also plot in the metasomatic field.

In Figure 16, the chemical data for sapphires from Mogok, Sri Lanka and Madagascar (from Abduriyim & Kitawaki 2006) are plotted together with data for stones from Yenya-U in a diagram from Giuliani *et al.* (2014), which shows that all of them fall in the metasomatic field. Their Fe concentrations are too low for magmatic sapphires, although stones from Yenya-U show relatively high Fe compared to other metamorphic sapphires (cf. Abduriyim & Kitawaki 2006).

Overall, based on their geological setting and the trace-element plots, we suggest that sapphires from Kyauk-tagar (and those from the three alluvial occurrences of similar composition) formed as a result of metasomatism mostly accompanied by a desilication process at the contact of pegmatite or meta-carbonate rocks associated with leucogranite. The sapphires from Kyar-gaung (and probably those from the Magwa alluvial occurrence) are associated with rocks deficient in silica, consistent with formation in nepheline syenite intruding marble.

CONCLUSIONS

The mineral inclusions in Yenya-U sapphires include albite, biotite, diaspore, graphite, rutile, melanophlogite and pennantite, which are strongly associated with metamorphic/metasomatic processes (Khin Mar Phyu 2009). Pennantite was found as an inclusion in corundum for the first time. CO_2-rich fluid inclusions are commonly observed in most sapphires from Myanmar (e.g. Palke *et al.* 2019), and the fluids are probably of metamorphic origin. The UV-Vis spectral features of sapphires from Yenya-U (especially those from Kyar-gaung) show patterns similar to metamorphic/metasomatic sapphires (cf. Palke *et al.* 2019). In addition, the Yenya-U sapphires have geochemical features consistent with metasomatic corundum in the diagram of Giuliani *et al.* (2014; Figure 16). However, the geochemical diagrams of Peucat *et al.* (2007) indicate that the sapphires from Kyar-gaung (and the Magwa alluvial occurrence) are related to a magmatic origin (Figures 15a and 15b). Therefore the sapphires from the Yenya-U area could be transitional from magmatic to metasomatic/skarn-metamorphic origin.

For the Myanmar gem-mining industry, no new concessions will be granted until the by-laws, rules and regulations associated with the Myanmar Gemstone Law of 2019 have been passed and approved. According to this new law, artisanal and small-scale gem mining will be allowed under the national gem strategy, providing a strategic framework for the responsible and sustainable development of the sector in the future. As the Yenya-U area is mined mostly by artisanal and small-scale methods, additional production is plausible in the future.

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Gem Knowledge in the Thirteenth Century: The St Albans Jewels

Jack M. Ogden

ABSTRACT: Medieval documents can provide information about the types of gems in use at that time and their terminology. Some such texts show a level of sophistication regarding what we might consider to be early gemmology, prompting questions as to how such knowledge was passed on. This article considers the range of gems used in thirteenth-century England and the level of gemmological knowledge at the time, based on an inventory of the treasures owned by St Albans Abbey that was drawn up in 1257. The compiler was the monk and polymath Matthew Paris (*ca.* 1200–1259), and the inventory is noteworthy for its detailed descriptions and colour paintings of each object. From these we can learn about the range of gems familiar during that period, as well as the way in which different qualities and origins were described, and even some terminology used for jewellery settings.

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The history of the use of gem materials has been an expanding part of gemmology over the last half century, giving rise to articles on various gems (and their sources) set in historic objects, published in this and other gemmological journals (e.g. Hänni *et al*. 1998; Schmetzer & Gilg 2020). This growth has been partially fuelled by the development of portable non-destructive analytical methods such as X-ray fluorescence analysis and Raman spectroscopy. The range of topics has been extraordinary: from Mycenaean amber to Roman emeralds, from Saxon garnets to Renaissance book covers, and more.

One period that has received little attention, however, comprises what is called the High Middle Ages, an interval of European history around 1000–1300 CE. This is largely due to the dearth of surviving examples of jewellery from that time and, often, limited access to those that do still exist. Rings are the most common surviving type of English jewellery of this period, and one good example set with a sapphire is shown in Figure 1. Now in the Metropolitan Museum of Art in New York, it has a Latin inscription naming Rutilans ('Rufus'), a cantor of the episcopal see of York. A cantor was an important cathedral dignitary, as this splendid ring suggests.

In general, though, the best source of information about gem use, including the level of gem knowledge at the time, is the abundant documentation of the pieces. These manuscripts fall into two main categories. First are inventories, such as details of royal or church treasures, as well as records of purchases or gifts. Then there are the 'lapidaries' and early studies of natural history with

Figure 1: A fourteenth-century gold ring (2.9 × 2.2 × 1.1 cm), set with a large sapphire and bearing a Latin inscription, provides an example of surviving English medieval jewellery. The inscription seemingly names Rufus of York, a cantor. Courtesy of the Metropolitan Museum of Art, New York, New York, USA, The Cloisters Collection, 1994 (inv. no. 1994.40).

Figure 2: Folios 146r and 146v of the 1257 *Liber Additamentorum*, written and illustrated by Matthew Paris at St Albans Abbey, document and illustrate the jewels discussed in detail in this article. British Library, Cotton MS Nero D I. © British Library Board.

their encyclopaedic descriptions of various types of gems, typically with their medicinal, astrological or other properties and, initially, often tied to the 12 gems in the High Priest's breastplate (*Ḥōšen*) described in the Book of Exodus (Exodus 28:30), or the 12 gems representing layers in the foundations of the walls of New Jerusalem (Revelations 21:19–20).

For the modern gemmologist, one particular European illuminated manuscript of the thirteenth century stands out because it provides relatively detailed descriptions of gem-set jewellery and illustrates each piece in colour. This manuscript, now in the British Library, is the *Liber Additamentorum*—literally 'The Book of Additions' (Cotton MS Nero D I[1]; see also Luard 1882, pp. 283–289). Folios 146r and 146v (Figure 2) contain a list of the jewels in 1257 that had been donated to St Albans Abbey in England (located some 32 km northwest of London) by previous bishops, wealthy patrons of the abbey and others. The cathedral, founded in the eighth century and modified over time, still stands and is the oldest site of continuous Christian worship in Britain. The extent of the entire monasterial complex as it was before the sixteenth-century dissolution of the monasteries is shown in Figure 3.

The *Liber Additamentorum* was originally compiled by Matthew Paris (*ca*. 1200–1259), who entered St Albans Abbey as a monk in 1217 and has been called the greatest chronicler of late-medieval England. He was an accomplished mapmaker—he illustrated a pilgrim's route map from London to Rome which also survives—and he was also an artist. The chronicler Thomas Walsingham (?– *ca*. 1422), also a monk at St Albans, indicated that Paris was a skilled goldsmith (Riley 1867, p. 395). Given his many talents, it is not surprising that, when Paris compiled this inventory, he did it in a meticulous and beautiful way.

Much of the information in the *Liber Additamentorum* is repeated, albeit more briefly, in a record of the benefactors to the abbey that was started at the end of the following (fourteenth) century. This, the *Chronica et Registrum Benefactorum Monasterii S. Albani*, is also preserved in the British Library (Cotton MS Nero D VII[2]; see also Dugdale 1846, pp. 217–223). Although it lacks

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[1] The manuscript can be viewed online at www.bl.uk/manuscripts/FullDisplay.aspx?ref=Cotton_MS_Nero_D_I.

[2] The manuscript can be viewed online at www.bl.uk/manuscripts/FullDisplay.aspx?ref=Cotton_MS_Nero_D_VII.

Figure 3: This painting by Joan Freeman hanging in the nave of St Albans Cathedral depicts the abbey complex during the thirteenth to fifteenth centuries, before its dissolution in 1539. Image courtesy of LepoRello, via Wikimedia Commons.

detailed images of the jewels, it often has a small painting of the donor, sometimes proudly holding the object in question (Figure 4). A somewhat abbreviated copy of this *Registrum Benefactorum* is in the library of Corpus Christi College at the University of Cambridge (Walsingham *ca.* 1400–1422[3]; Riley 1866). There is also a record of the vestments, plate and jewels at St Albans compiled around 1400–1410 (*Inventarium Ornamentorum, Vestimentorum, et Jocalium, Monasterii Sancti Albani, Regnante Henrico Quarto*), which provides some supplementary information (British Library, Cotton MS Claudius E IV, ff. 350v–358v; transcribed in Riley 1871, pp. 322–361).

The gems illustrated and described in Paris's *Liber Additamentorum* are a 'balas ruby' (*rubibalois*), an almandine (*almandinus*), a peridot (*peridotus*), a 'topaz' (*topazius*, but probably citrine or yellow sapphire), six sapphires (*saphirus*), a purple amethyst-like gem and a magnificent cameo (*kaadmau*). Smaller gems set in some of the jewellery include pearls (*perlae*), garnets (*granatae*) and some small gems not specifically described but coloured blue and green, so probably sapphires and emeralds. The manuscript describes and illustrates the shapes of the gems, often with notes on their settings, and gives the weight of the complete jewels in pennyweights (*denarius*).[4] As far as is known, none of the jewels survive today, although it is possible some of the gems do, perhaps, after being recut and reused over the centuries.

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[3] The manuscript can be viewed online at https://parker.stanford.edu/parker/catalog/fm985xq3462.

[4] In the thirteenth century, the pennyweight was 1/240th of the so-called tower pound and equivalent to about 1.46 g today. It is abbreviated *dwt*, derived ultimately from the Latin *denarius* coin.

petronilla de Bensted

Willis de Hortoñ vicarius de Sandrugge contu
lit ad opus ecclie viginti marcas.
Dña petronilla de Ben
stede dedit sc̄o Albano unū
superaltare rotundū de la
pide iaspidis. subtus ꝛ mar
ginatu argento inclusū. sup quod ut fertur sc̄s
Augustinus anglorꝝ apostolus celebravit.
Optulit ꝛ duas fialas quarū corpora cristal
lina sunt. orificia vero ꝛ pedes argentea. que

Figure 4: One of many images of donors in the *Chronica et Registrum Benefactorum Monasterii S. Albani* is this one depicting Petronilla de Benstede (*ca.* 1280–1342) with her donation of a pendant with a superb jasper. British Library, Cotton MS Nero D VII, f. 101v. © British Library Board.

BLUE SAPPHIRES

Among the St Albans Jewels

Seven sapphires—set in four rings and three pendants—are listed in the *Liber Additamentorum*. The elaborate ring in Figure 5 was donated by Henry de Blois (*ca.* 1099–1171), bishop of Winchester and papal legate. It is described as 'a magnificent ring of precious materials and workmanship' (*annulum noblissimum, materia et opere preciosum*) with a pale sapphire (*saphirus remissi coloris*) in a setting with four gold florets (*quatuor aureos flosculos collocatur*) surrounded by four pearls and four garnets.

Of simpler design, but equally impressive, is the ring in Figure 6, which had 'a most beautiful oriental sapphire of marvellous size' (*saphirus quidam orientalis pulcherrimus miraeque magnitudinis*) held with 'four prongs commonly called peconi' (*qutuor tenaculis quae vulgariter peconi dicuntur*). *Tenaculi* literally meant 'grippers'. The origin and meaning of the term *peconi* is uncertain, although Dr Annibale Mottana (pers. comm. 21 July 2021) has suggested a possible link with the modern Neapolitan-dialect word *pecon*, which means 'hard bristle'. This ring was donated by John, Bishop of Ardfert, who also gave the pendant in Figure 7, described as an oblong triangular oriental sapphire, perforated in length and on the top. The little gold dot seen in Paris's drawing near the top of the sapphire might represent this latter perforation, possibly plugged with gold wire, maybe also used to secure it in the setting.

Another sapphire pendant (Figure 8) was a gift to the abbey from a prior of Wallingford by the name of Thomas. The sapphire was described as 'intense sky blue' (*aerei intensi*)[5]. The gem is noted as being especially secure in its setting because of the gold band across it, as is clearly shown in Paris's drawing. Another pendant with a more

Bona contulit dn̄s ep̄c huic eccl̄e. q̄ alibi
diligens perscrutator invenire poterit annotata
Hunc anulū De magno anulo
nobilissimū Rotundo ꝛ gemma
materia ꝛ opere p̄ciosū. In cui⁹ to.
medio saphir⁹ remissi colo
ris int̄ iiii. aureos flosculos
collocat̄. ꝛ in circuitu ei⁹ octo gem
me. q̄tuor .s. perle. ꝛ q̄tuor gnate: dedit

Figure 5: The sapphire, pearl and garnet ring in this painting was presented to St Albans Abbey by Henry de Blois. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

tur R. In alia: A. R: pro Ric. A: p aīal.
Ponderat aūt decē den̄. de Anulo ep̄i Joh̄is
Hunc Anulū dedit deo cum magno
et huic eccl̄e dn̄s Joh̄s Saphiro.
ep̄c quidam Ardfertensis. In cui⁹
castone continet̄ saphir⁹ q̄dam orien
tal⁹ pulcherrim⁹ mireq; magnitudinis.
quatuor tenaculis que vulgarit̄ peconi
dicunt̄ circumseptus. Qui dicto saphir⁹ per

Figure 6: A gold ring set with 'a most beautiful oriental sapphire of marvellous size' was donated to St Albans Abbey by John, Bishop of Ardfert. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

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[5] *Aerei* literally means 'air' and is the origin of the word. Air makes up the sky, which is blue; the adjective *intense* shows that colour rather than clarity was being described.

Figure 7: The sapphire in this pendant, also donated by John, Bishop of Ardfert, is shown with a gold dot possibly indicating a gold wire or plug. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

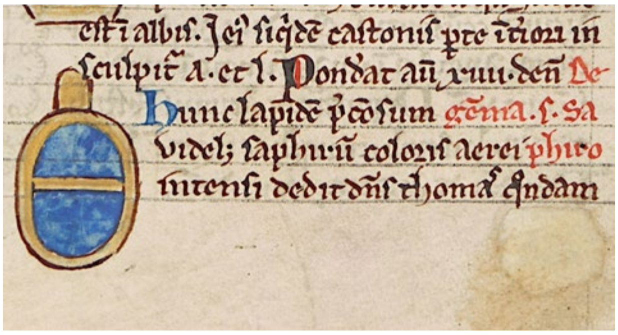

Figure 8: Another sapphire pendant, presented to St Albans Abbey by Thomas of Wallingford, shows a gold band securing it to its setting. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146r. © British Library Board.

Figure 9: This sapphire pendant—presented to St Albans Abbey by Nicholas, a goldsmith—came with a history: it had belonged to Edmund, Archbishop of Canterbury from 1233 to 1240. Possibly this information derives from an inscription mentioned as being on the back of the pendant. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

circular sapphire (Figure 9) was the gift of a St Albans goldsmith by the name of Nicholas, but in this case the gem was described as being poor or pale coloured (*coloris remissi*). Despite this shortcoming, this pendant (or at least the gem) has a known history. Paris recorded that it had belonged to Edmund, Archbishop of Canterbury from 1233 to 1240, and then to his brother Robert. Possibly this information came from the pendant itself—it is described as having a minute inscription in black letters, presumably *niello* (a black silver sulphide inlay).

Rings given to the abbey by John of Wymondham and Richard Animal (Figure 10) each contained an oriental sapphire of intense colour (*saphirum orientalem intensi coloris*). Paris noted that Richard Animal had been given his ring (or at least the gem) by Queen Eleanor I, who had been his companion in his youth when they were students. He mentioned that one side of the ring bore an inscribed *R* (as seen in his drawing), and the other side an *A*, most likely for 'Richard' and 'Animal'. It is perhaps tempting to suggest that they actually stood for 'Richard' and 'Eleanor', whose name Paris spelled in the medieval manner *Alienorae*—a suggestion also made recently by historian Jitske Jasperse (2021, p. 73). Nothing further is known of Richard Animal, but Eleanor was almost certainly Eleanor of Aquitaine (*ca.* 1122–1204), queen of Henry II of England (r. 1154–1189). Her friendship with Richard Animal was, presumably, prior to her first marriage, to Louis VII of France in 1137. If the given history of the ring is accurate, it would make it the earliest recorded sapphire-set ornament in England known to this author.

Figure 10: (**a**) The colour of the 'oriental' sapphire in this ring given to St Albans Abbey by John of Wymondham is described as 'intense' (*intensi coloris*). (**b**) Another sapphire ring, inscribed with 'R' on one side and 'A' on the other, was given to St Albans Abbey by Richard Animal. From the 1257 *Liber Additamentorum*. British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

Historical Context

The use of sapphires in jewellery in Western Europe during the twelfth and thirteenth centuries is well known. Some were of the paler Sri Lankan type, and many of those might have been recycled from Early Byzantine jewellery. However, the smaller, darker ones could have come from the deposits of Le Puy-en-Velay in the Massif Centrale of France (Forestier 1993; Gaillou 2003), a source also likely for the small, dark sapphires in early Roman jewellery.[6] The rings in Figure 10, of so-called stirrup form, are likely examples. In addition, St Albans had a fine *safirum lupum*, donated after Matthew Paris's time, and an inventory of Christ Church, Canterbury, compiled in about 1315 included 'one oblong sapphire which is called *loup*' (Riley 1866, p. 453; Legg & Hope 1902, p. 71). The French locality name *Le Puy* was rendered in various ways in medieval documents, often contracted to *loup* or *lup*. The description of most of the sapphires in Paris's list as 'oriental' (*orientalis*), suggests that their size, colour or both were recognisably eastern in contrast to the Le Puy-en-Velay stones. The earliest mentions of these French sapphires seem to be in the thirteenth century, when they were described as less valuable than 'oriental' sapphires. (Studer and Evans 1924, pp. 120 and 140–141; Wyckoff 1967, p. 115).

The use of the word 'sapphire' in some other medieval texts may have sometimes meant lapis lazuli. Paris's remarkably modern-sounding approach in describing the sapphires' colours as 'pale', 'intense' and 'sky blue' could, in theory, also apply to lapis lazuli. However, the surviving rings of the type illustrated by Paris (e.g. Figure 11) are almost invariably set with blue sapphires, not lapis lazuli. The qualities or colours of sapphires that are given in other manuscripts of the period are usually described in simpler terms. The 1315 inventory noted above of Christ Church, Canterbury, described some sapphires as 'dark' or 'watery' (*saphiro nigro* and *saphiro aquoso*; Legg & Hope 1902, pp. 71–72). Particularly attractive sapphires have been described as 'beautiful', such the one in Figure 6, or a 'most beautiful sapphire' (*saphirus pulcherrimus*) in a remarkable 1267 inventory of gems and jewellery that Henry III had extracted from Westminster Abbey, which included treasures taken from the shrine of Saint Edward there (Lyte 1913, pp. 135–140). The latter sapphire was exceptional also for its size—it weighed 42 pennyweights, or just over 300 modern carats—and was valued at £100, an immense sum then (Lyte 1913, p. 140). Charles King suggested that it might be the so-called 'St Edward's Sapphire' still in the Imperial State Crown in the British Crown Jewels (King 1865, p. 406 n.).[7]

Figure 11: This medieval gold ring (2.8 × 2.1 × 0.5 cm), set with a small dark sapphire, is typical of the kind often worn by clergy and is a surviving example that is very similar to the ring in Figure 10b. It dates to the late thirteenth or early fourteenth century, and is probably from England. Courtesy of the Metropolitan Museum of Art, New York, The Cloisters Collection, 2015 (inv. no. 2015.697).

Blue sapphire should not have presented many problems for the persons compiling the inventories. There was no other hard transparent blue gem with which it might be confused. Glass imitations and occasional doublets existed, although none of these were noted by Paris. There was one documented in the long Treasure Roll of Richard II (Stratford 2012, item R432, p. 185), but it is not the one in the Crown of Blanche of Lancaster, listed in that same inventory, where a blue sapphire doublet with a partly-decomposed joining layer has been noted (Schmetzer & Gilg 2020, p. 45 and figure 26). This latter stone did not fit its setting and might have been a later replacement. Red doublets were seemingly more prevalent (see below).

This section only considers blue sapphires, so the possibility that the 'topaz' in the St Albans list might have been yellow sapphire is considered below in the 'Topaz and Peridot' section.

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[6] The distribution of these small dark Roman sapphires—predominantly in Europe and Asia Minor, rather than Syria, Egypt or the Levantine coast—would seem to rule out an eastern origin.

[7] As with the 'Black Prince's Ruby' (Ogden 2020), also in the Imperial State Crown, there seems to be no chain of ownership back to its supposed medieval roots.

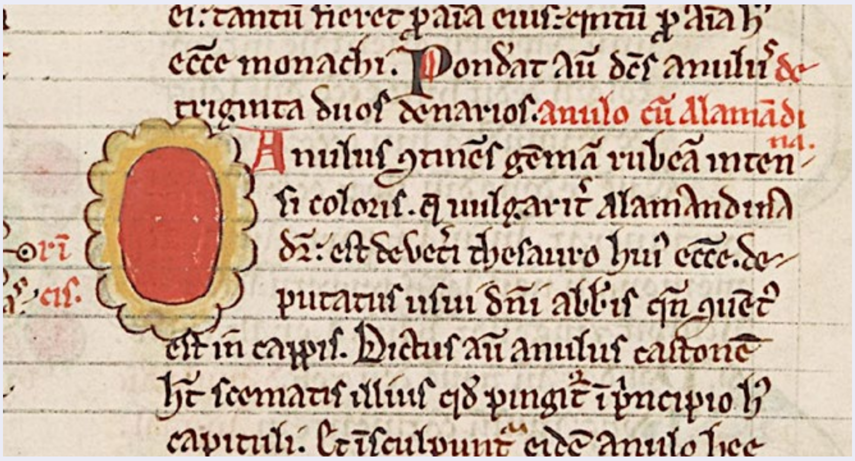

Figure 12: Among the inventory of jewels presented to St Albans Abbey is this gold ring set with an intense red gem 'commonly called almandine' (*alamandina*). From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146r. © British Library Board.

CARBUNCULI: GARNET, *BALAS* AND RUBY

The Roman writer Pliny commented on the difficulty of distinguishing the different types of red gems, known as *carbunculi* (Eichholz 1962, book 37.25). All of Pliny's *carbunculi* were probably varieties of garnet. When Matthew Paris differentiated between *granatae* and *almandinus* in the St Albans inventory, this was presumably on the basis of colour, using Pliny's assertion that 'many writers' said that the *carbunculi* of Alabanda (almandine) were darker than the rest (Eichholz 1962, book 37.25). By the early thirteenth century the varieties of *carbunculi* had grown to include ruby and, soon after, *balas* (spinel), both gems not familiar to the Romans.

Although the medieval writers of the inventories described various gems as *balas*, ruby or garnet, there is no guarantee that they were right. One particularly revealing insight can be gleaned from the fourteenth-century Crown of Blanche of Lancaster (Schmetzer & Gilg 2020). It is the only known survivor of the 1,206 objects in the 28-m-long inventory of the treasures of Richard II compiled in 1399 (Stratford 2012). The red gems in the crown, all described in the inventory as *balas*, actually comprised 53 pink spinels, ten pink sapphires, three almandine garnets, two pyrope garnets and one red glass (Stratford 2012, item R7, p. 146; Schmetzer & Gilg 2020, pp. 46–47). With medieval gem distinctions mainly based on colour, and probably not even magnification to help, this is perhaps not an unexpected success rate for the time.

Garnet

Among the St Albans Jewels. The St Albans ring in Figure 5, with its sapphire in a floret setting, also has four *granatae* (garnets). These are shown as bright red, like the seeds of a pomegranate—*granatus* in Latin, from which the garnet group of minerals gets its name. The *Liber Additamentorum* also includes a ring with an intense red gem (Figure 12) 'commonly called almandine' (*quae vulgariter alamandina*).

Historical Context. Several *granata* are also mentioned in the very long list of jewels that King Henry III took from the shrine of Edward the Confessor and Westminster Abbey in 1267 (Lyte 1913, pp. 135–140). The thirteenth-century spelling seems pretty consistent, but the 1399 inventory of Richard II had *garnettes*, *garnettz* and *garnettis* (Stratford 2012, items R74, R413, R512, R556, R955 and R978). By the fifteenth century, variants really flourished, including *garnades*, *grenaz*, *garnades*, *grenas*, *granate* and even *gernad*. The present author suspects that at the end of the medieval period a greater demand for copied texts—or perhaps a more hierarchical division of labour—led to the use of dictation so that multiple scribes could generate copies of the same document simultaneously. These scribes might have had little idea of the accepted spelling of unfamiliar words only heard rather than seen.

The word used to describe the garnet shown in Figure 12, *alamandina*, means 'of Alamanda' (an alternative spelling of Alabanda). At about this time, Albertus Magnus used the same name and spelling, and we also find *alabandica* (Wyckoff 1967, p. 72; Studer & Evans 1924, *passim*). Pliny indicated that a variety of *carbunculi* came from Orthosia, near the modern village of Karpuzlu in Turkey, and these stones were 'perfected' (presumably polished[8])

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[8] The original Latin term was *perficiantur,* which means to complete or bring to perfection (it is the origin of the word 'perfection').

at Alabanda, 15 km to the east (Eichholz 1962, book 37.25). Almandine-rich garnet occurs in this area—the Menderes Massif—which is well documented in the geological literature as producing crystals up to 3 cm (Iredale *et al*. 2013, p. 327). The diverse medieval spellings over subsequent centuries included *alabantina*, *alabaundarynes*, *alebandyns*, *elamaundines* and *alemaundine*.

Balas

Among the St Albans Jewels. An oval red *rubibaleis* in a large, elaborate ring (Figure 13) donated to St Albans Abbey by John de Crundale was, or at least was thought to be, a *balas* ruby.

Historical Context. The name *balas* derives from Badakhshan (now comprising parts of Tajikistan, Afghanistan and China) and was known as a gem material in the Islamic world by at least the ninth century when al Kindi mentioned it and its source in his *Book on the Properties of Precious Gems* (*Kitab khawas al-jawāhir*).[9] *Balas*, also commonly spelled *baleis*, was known in northern Europe by the beginning of the thirteenth century at the latest. The earliest specific mention of *balas* in England known to this author is from a list of jewels delivered to King John (r. 1199–1216) in 1204 (Bayley 1830, 177–178 n.). This includes several ornaments containing *balas*, including a clasp or brooch set with four emeralds and four *balas* (*unum firmaculum cum iiii smaragdinibus et iiii baleis*). Around 1220–1230, Arnold of Saxony explained that *balas* was a type of carbuncle (Rose 1875, p. 430).

Today we know that *balas* or *balas ruby* refers to what we presently call spinel. It is advisable, however, not to translate *balas* in old texts as spinel. The gem name *spinel* first appeared in Europe around 1500, and the German author Johann Pinicianus listed *spinella* alongside ruby, *balas* and garnet as a type of carbuncle in his 1516 *Promptuarium Vocabulorum* (Pinicianus 1516). The earliest mention from England known to the present author described rings with *spynes* in a list of jewels drawn up in 1528 (Brewer 1872, p. 2243). This inventory also included gems that were called *balas* and *ruby*. Perhaps the use of the term *spinel* in Europe began with the first arrival there of such gems from what is present-day Myanmar. Portuguese traveller Duarte Barbosa (*ca*. 1480–1521), in his account of his travels to the East between 1501 and 1516, distinguished *balas* from 'Balazayo' (i.e. Badakhshan) and *espinelas* (spinels) from the Kingdom of Pegu, today's Myanmar (Stanley 1866, pp. 211–213; for the Portuguese text see Machado 1946, p. 223). He explained that *balas* sold for the same price as spinel. In 1572, though, Juan de Arfe y Villafañe gave remarkably different values for ruby, spinel (*espinelas*) and *balas*, with a 1 ct spinel worth more than 50 times the value of a 1 ct *balas* (de Arfe y Villafañe 1572, pp. 46v, 50v and 58r; Stanley 1866, p. 213).[10] This distinction between spinel and *balas* long remained. In 1652 Thomas Nicols commented that 'it is not yet determined whether they [*balas*] be *Spinels* or no: expert jewellers do not take them for *Spinels*…' (Nicols 1652, p. 60). Nearly two centuries later, Abraham Hertz—the London diamond dealer who is best remembered for cataloguing the Hope Collection—said, 'The spinelle is distinguished from the balais ruby by the peculiarities of

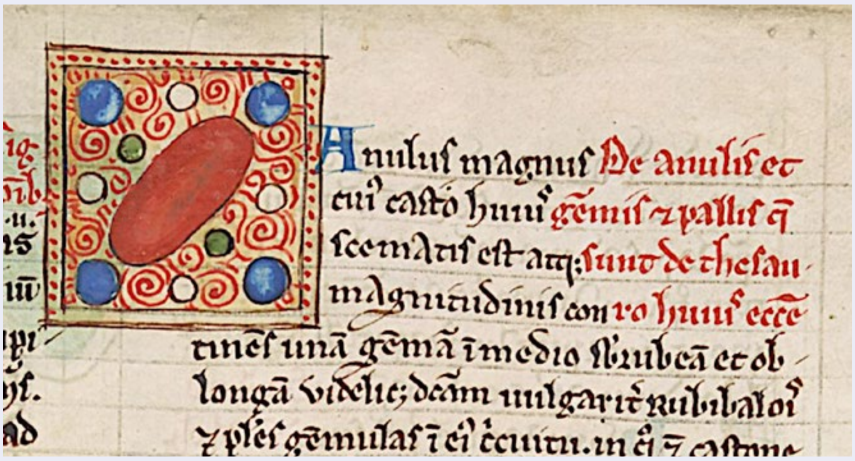

Figure 13: This elaborate gold ring presented to St Albans Abbey by John de Crundale is described as being set with an oval *balas* and other gems. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146r. © British Library Board.

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[9] The sole surviving manuscript seems to be that in the National Library and Archives of Egypt, Cairo (see www.wdl.org/en/item/2864).

[10] In the mid-thirteenth century, Albertus Magnus noted that *granatus* (garnet) was considered less valuable by jewellers than other types of carbuncle (Wyckoff 1967, p. 41).

its colour, the balais being of a light and pink colour, and the spinelle usually of a darker and more crimson tint' (Hertz 1839, p. 35). Clearly, to avoid confusion, it is best to retain the terms *balas* and *spinel* as applicable when transcribing or translating from old texts.

It is noted below that a purple gem in the St Albans inventory had been 'estimated' to be a *balas*. If correct, it was not unique. The extensive inventory of Charles V of France, compiled in 1380, included a cross set with what were described as both red and purple *balas* (Labarte 1879, p. 113, no. 840).

The only other source of *balas* in the Islamic and Medieval European worlds might have been Sri Lanka. Hänni *et al.* (1998) identified a cabochon of pink spinel in the Dorothy Monstrance—dating to the early 1400s—in Basel Cathedral as being of Sri Lankan origin.

Ruby

Among the St Albans Jewels. No rubies are mentioned in Matthew Paris's manuscript, but there might be one there. An annotation in the margin at the end of his list briefly notes a ring given to the abbey by a cleric named Laurence, which had been owned by Hubert de Bourg, chief justice of England and Ireland between 1215 and 1232 (Figure 14a). The later list of benefactors to St Albans mentioned above (see footnote 2) describes this ring as set with 'a carbuncle which is commonly called ruby' (Dugdale 1846, p. 221) and has an illustration of Laurence holding the ring (Figure 14b). The text below this mentions the *balas* ring given to St Albans Abbey by John of Crundale and the sapphire ring given by Richard Animal, both with small sketches of the donors' hands holding their rings.

Historical Context. Rubies have been known since antiquity, and early examples—most of which were probably what we would call pink sapphires today—likely came predominantly from Sri Lanka (Content 2016). Such stones were set in jewellery from about 300 BCE onwards, but usually in Central and South-East Asia; examples are extremely rare further west. Mention of rubies in European texts only started in the early thirteenth century and were sometimes described as 'rubies of Alexandra', reflecting their trade from the East (e.g. Stratford 2012, items R23, R58 and R429, and p. 267). Mention of 'oriental rubies' seems less frequent than 'oriental sapphires' in medieval European documents, but one example is from 1376 (Du Cange 1886, p. 229). The main source was probably still Sri Lanka, but by the thirteenth century some rubies might have been arriving from what is present-day Myanmar. There is an often-quoted legend that rubies were first found there in 1217 by hunters, the gems having been revealed by an earthquake. However, a comprehensive study by Themelis (2000, pp. 22–23) noted evidence that

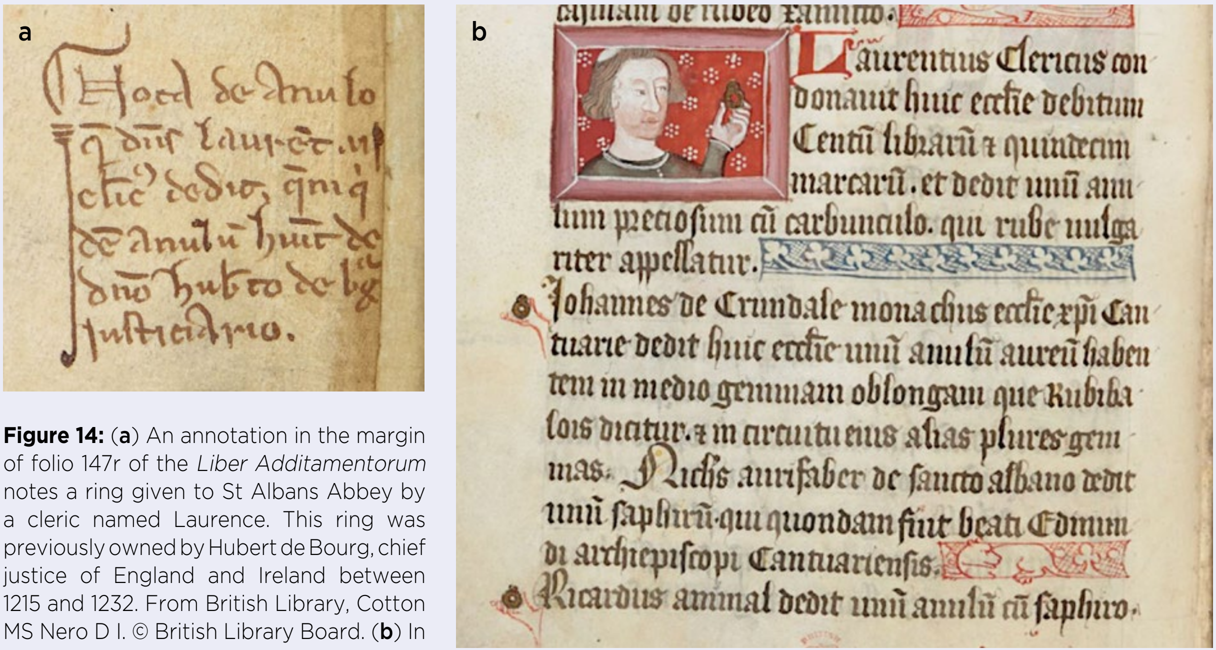

Figure 14: (**a**) An annotation in the margin of folio 147r of the *Liber Additamentorum* notes a ring given to St Albans Abbey by a cleric named Laurence. This ring was previously owned by Hubert de Bourg, chief justice of England and Ireland between 1215 and 1232. From British Library, Cotton MS Nero D I. © British Library Board. (**b**) In the *Chronica et Registrum Benefactorum Monasterii S. Albani*, Laurence is shown presenting a ring set with a ruby to St Albans Abbey. Below that entry are listed the rings presented by John de Crundale and Richard Animal with diminutive sketches in the margin showing their hands holding the rings. From British Library, Cotton MS Nero D VII, f. 100v. © British Library Board.

Burmese rubies had been traded into China for at least a couple of centuries prior to this. The first European to mention Burmese rubies is commonly reported to have been the Venetian merchant and explorer Nicolò de' Conti, who travelled there in the 1420s and perhaps early 1430s (for the timing, see Breazeale 2004, pp. 100–102). However, the present author can find no mention of rubies or other gems from Burma in Conti's account (Winter Jones 1857), and the earliest mention seems to have been by the Genoise merchant Girolamo da Santo Stefano, who visited the region in 1495–1496, just a year or so before Vasco da Gama discovered the direct sea route from Europe (Major 1857, p. 6).[11] Jegdalek, Afghanistan, might also have been a source for some early rubies.

Figure 15: This ornament, described as being set with a 'greenish' peridot, with a sapphire 'of beautiful colour' set in its centre, was presented to St Albans Abbey by John, Bishop of Ardfert. The shield shape was supposedly able to ward off spasms. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

Figure 16: A ring set with a 'topaz', described as an 'ancient treasure of the church', was in the treasury at St Albans Abbey. The descriptive word *cerulia* in the text, usually associated with blue, likely referred to the colour of a brownish yellow wax and means 'yellow' in some medieval texts. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146r. © British Library Board.

TOPAZ AND PERIDOT

Among the St Albans Jewels

The *Liber Additamentorum* includes a jewel set with a gem 'commonly known as peridot' (*peridotus*) and a ring containing a 'topaz' (*topazius*). These are shown in Figures 15 and 16. Here they are discussed together because *topazius* was originally a name for peridot, and the presence of both gem types in this manuscript provides an opportunity to reconsider their somewhat tangled nomenclature history.

The peridot ornament in Figure 15 was also presented to the abbey by John, Bishop of Ardfert, who served in that position (in Ireland) until 1224. The gem was described as *subviridis*, which is probably best translated as 'greenish', and had a sapphire 'of beautiful colour' set in its centre. It was mentioned as having a shield shape that was able to ward off spasms. The manuscript does not say what type of ornament it was, but from the illustration it appears to be a pendant. The jewel was described as a ring in the *Liber de Benefactoribus* of about 1315, so possibly it had been remounted (Riley 1866, p. 442). The later record of it from the early 1400s makes no mention of the setting but does not include it with the other rings (Riley 1871, p. 332). Another peridot ring had come to the abbey by about 1400, although that one was described as broken at the top (Riley 1871, p. 331).

The topaz ring in Figure 16, termed 'an ancient treasure of the church', is described and depicted as yellow. The word here translated as 'yellow' is *cerulia* in the text, a term more usually associated with blue—cerulean blue is still a colour description. However, *cerulia* originally referred to a brownish yellow wax and confusingly means yellow in some medieval texts.

Historical Context

Greek and Roman jewellery set with peridot is known but not common, and this author cannot recall seeing a surviving medieval example, although they are quite frequently mentioned in medieval inventories.[12] There is a huge variety of spellings in Latin, Middle English

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[11] Possibly the confusion about Conti and rubies derives from what is the most accessible English edition, that of Winter Jones (1857), in a volume which also includes Stefano's account (Major 1857).

[12] Albertus Magnus described peridot as 'not rare' (Wyckoff 1967, p. 82). George Kunz mentioned large peridot gems set in the Shrine of the Three Kings in the Cologne Cathedral (Kunz 1913, p. 66). This shrine was built *ca.* 1180–1225. Of the 1,000+ gems on it, some may, of course, have been replaced over succeeding centuries.

and Anglo-French manuscripts—*peridotus*, *perdotus*, *peredeta*, *perdot*, *peridita*, *pereditis*, *peridol*, *peridon*, *peredo*, *pelido*, *peridita*, *peridod*, *peredet*, *pelidor* and maybe *pedoire*, to list just some of them.

Peridot might be recorded in medieval European jewellery as early as the 1100s. The annals of Glastonbury Abbey tell us that Adam Sodbury, who became abbot there in 1312, donated a gold ring with a stone called *peritot* that was worn by Thomas Becket when he was slain (in 1170; Dodsworth & Dugdale 1655, p. 6). We might doubt the veracity of the story that the ring belonged to the man who became St Thomas, because fake saintly relics were big business in medieval Europe. However, it is not impossible that it was of Becket's time, and in any case would surely have dated back at least to the 1200s. It is also true that describing it as a peridot in the 1300s did not mean it had been called that a century or more earlier. But there is the second piece of evidence. Around 1160 the French poet Benoît de Sainte-Maure composed his very long poem *Roman de Troie*, a retelling of the Greek Aeneid—the legend of the Trojan War. He mentioned four pillars which, in the spellings of the various extant manuscripts, are described as being of *piedoire*, *pedoire* or *pedore* (Constans 1907, p. 98). It is plausible that peridot was intended here (Du Cange 1885, p. 276).

The origin of the word *peridot* has been much debated. The Arabic *faridat* (pearl) has been suggested but seems unlikely. The Latin *paederos* (possibly linked to *pedra*—a stone) and likely a type of opal, is more plausible, and in its favour is the use of *pederotes* as an alternative to peridot in some medieval manuscripts. The later fourteenth-century *Registrum Benefactorum* described the green stone in Figure 15 as being *peridotus* or *pederotes* (Dugdale 1846, p. 219). A fifteenth-century manuscript of Thomas of Cantimpré (1201–1272) included a gem called *perites* or *pederotes*, although a late thirteenth-century version has *perites* or *pidonius* (Bodleian Libraries, MS Rawl. D. 358; de Cantimpré *ca.* 1280, f. 172v; Evans 1922, p. 233). This could substantiate the link between *paederos* and peridot, but it is also possible that the medieval scribes were confused by the apparent similarity.

Another word for peridot, current into recent times, is *chrysolite*—usually spelled *chrysolithus* in medieval manuscripts. This derives from the Greek *chrysolithos* and simply means 'gold stone'. It was described as a golden-coloured gem by Pliny in the first century BCE and Ephiphanius of Salamis in the fourth century BCE (Blake & de Vis 1934, pp. 209 and 223; Eichholz 1962, book 37.126; Maxwell-Stuart 1977).[13] Isidore of Seville, however, at the start of the seventh century, said that it is the colour of gold, but with green of the sea (Lindsay 1911, book 16, chapter 15). Over the following few centuries we find some descriptions of it being like gold, while others mention the sea. For example, Hrabanus Maurus in the early ninth century, and some twelfth-century Anglo-Norman lapidaries, described it as gold coloured (Studer & Evans 1924, pp. 152, 166, 221 and 379). Other lapidaries compared it with the sea and Albertus Magnus described it as being of 'a pale, bright green colour' (Studer & Evans 1924, pp. 99 and 122; Wyckoff 1967, p. 82). The present author suggests that, as the French language began to supersede Latin in medieval texts, *chrysolithus*—'gold stone'—was simply translated into French as *pierre d'or* ('stone of gold'), a small leap to *piedoire*, *pedoire*, *pedore* and such-like. However, Prof. Ian Short, a specialist in medieval and Norman French language, considers this unlikely on philological grounds (pers. comm. November 2021).

Pliny described topaz as being green and from an island in the Red Sea (Eichholz 1962, book 37.32)[14]—clearly referring to peridot (Thoresen & Harrell 2014). On the other hand, Pliny's near contemporary, the Greek geographer Strabo, and the earlier Greek historian and geographer Agatharchides (lost, but quoted by the Greek historian Diodorus Siculus) both said that the topaz found on the Red Sea island was the colour of gold (Jones 1930, book XVI.4.6; Oldfather 1935, book 3.39). The Greek *topazion* was initially *to pazion* (*to* being the Greek definite article), and it has been suggested that *pazion* is likely from the Semetic *paz* meaning gold.

The apparent confusion as to whether topaz was yellow or green might stem simply from ancient colour descriptions. Giving colour names to different sections

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[13] Although, seemingly bizarrely, Epiphanius described *topazius* as bright red (Blake & de Vis 1934, *passim*).

[14] Pliny said he learned about topaz and its sources from Archelaus (Eichholz 1962, book 37.107). This is presumably the Greek geographer who was possibly a contemporary of Alexander the Great. If so, then it might date a knowledge of peridot back to the fourth century BCE. Unfortunately, no works of Archelaus, including his book on rivers and stones, have survived. It also seems quite possible that peridot was meant by Theophrastus's *hyaloeides*—'glass-like stone'—that was used for seals (Caley & Richards 1956, p. 51). There are not many options. His description of it being glass-like has been taken to indicate that it was colourless, although ancient glass was not colourless, but rather typically pale green to yellowish green due to the inevitable small iron content. Diodorus Siculus described peridot as glass-like (Oldfather 1935, book 3.39).

of the visible spectrum is arbitrary, and the ancients did not necessarily classify colours the way we do today. A clear example of this is a description of the rainbow by the sixth-century BCE Greek philosopher Xenophanes (fragment 32: see Diels 1903, p. 56). For him the rainbow, which he considered to be a type of cloud, had only three colours: purple (*porphureon*), red (*phoinikeon*) and *kloron*. The word *kloron* has been variously translated as yellow, green or yellowish green. Isidore of Seville, presumably following Pliny, described *topazion* as green around 600 CE (Lindsay 1911, book 16, chapter 7). Then, just a century later in England, the Venerable Bede (*ca*. 672–735) described *topazius* as the colour of pure gold, but resembling the colour of chrysoprase, a gem he had described as green (Migne 1862, columns 200 and 201). The variation, if not confusion, regarding the colour terminology might relate to whether the scribes were working from texts that were ultimately derived from Greek (with its yellow topaz) or Latin (where it was green; Kitson 1978, p. 42). In the so-called *Old English Lapidary* of the eleventh century, the oldest vernacular lapidary in Western Europe, topaz was just ‘like gold’, with no mention of any green (Evans & Serjeantson 1960, p. 15). Marbode of Rennes (*ca*. 1035–1123) shortly later described topaz as yellow, although occurring in two varieties—one the colour of pure gold and the other a little paler (Kitson 1978; Herrera 2005, pp. 52–53). In the mid-thirteenth century, Albertus Magnus repeated what Marbode had said when he listed the types of gems, but confusingly described *topasion* as green when he discussed the causes of colour in gems (Wyckoff 1967, pp. 41 and 122). Nevertheless, generally speaking, ‘topaz’ had come to describe a yellow gem in Britain by about 1000 CE.

Some lingering confusion is only to be expected. Frédéric Godefroy, in his monumental *Dictionnaire de l’Ancienne Langue Française*, cited a document of 1380 in the municipal archives from Douai, France, that described a gold ring with a yellow stone which some call *peridos* and others call *topasse* (Godefroy 1889, p. 101). Thoresen and Harrell (2014) suggested that this passage might reflect a medieval understanding that the *topazius* of the ancients was the same as what was, by then, called peridot. This is possible, but the text says that the gem was yellow[15], although peridot is not purely yellow. Du Cange (1885, p. 276)[16] gives an earlier example, from 1295: *topacio obscuro vel Poriodo. (sic)*, meaning ‘dark topaz or peridot’. ‘Dark’ would be the usual translation for the Latin *obscure*, but in this context it possibly meant ‘opaque’ or even just ‘uncertain’, so we do not know if its colour or transparency made its identity a puzzle. Or was the writer not well versed in gems? Apparently, uncertainty lingered for centuries. In the 1680s, Randle Holme, a herald under King Charles II, noted that ‘The *Topaz* is of a Golden colour…. *Pliny* saith it is of a grassie colour’ (Holme 1688, Book 2, Chapter 2, p. 39).

Like other gems, topaz was subject to a large array of spelling variations in medieval times. One of Chaucer’s characters was Sir Thopas, presumably named after the gem, and a fifteenth-century poem about gems in the British Library based on Marbode has the remarkable spelling *pthopacius* (British Library, Royal MS 8 G VI[17]; Garrett 1909, p. 29).

The *topaz* in medieval inventories is unlikely to have been the topaz of today. Citrine is possible—a gem that has been erroneously called topaz into recent times—but this author is not aware of surviving examples in thirteenth-century jewellery.[18] Yellow sapphire is a stronger contender. It was clearly described in medieval Arabic texts and listed in medieval European manuscripts. The 1267 inventory of jewels from Westminster Abbey mentioned above includes a yellow sapphire in a gold setting (*saphirus citrinus*) and a large unset one (*magni saphiri citrini nudi*; see Lyte 1913, pp. 138 and 139). Also listed in this 1267 inventory is an ornament set with four sapphires (presumably blue) and two *citrini* (Lyte 1913, p. 39). The latter are not described as sapphires, but that might have been implied. A *saphir citernie* is also found in the 1399 list of Richard II’s treasures; it was set in a brooch with a diamond, three *balas* and three large pearls (Stratford 2012, item R89).

It might be significant that both of the above medieval English lists of jewellery which possibly mention a yellow sapphire do not include any topaz, despite their length and the wide variety of other gems they do contain. Yellow sapphire has often been known as ‘oriental topaz’ into recent times.

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[15] The Godefroy citation describes the stone as *gaune* (= *jaune*, which means ‘yellow’ in French), but this was miscopied as the meaningless *ganne* when quoted by Conley (1976, p. 48), and this was repeated by Thoresen and Harrell (2014, p. 35).

[16] The present author has been unable to trace the original manuscript from the abbreviated reference provided.

[17] The manuscript can be viewed online at www.bl.uk/manuscripts/FullDisplay.aspx?ref=Royal_MS_8_G_VII.

[18] One was identified in the mid-fifteenth century reliquary cross of the Basel Cathedral (Hänni *et al*. 1998).

Figure 17: A gold ring set with a purple gem 'similar to amethyst' (*consimilem ametisto*) was presented to St Albans Abbey by Hanno the sacristan. The wording used by Matthew Paris shows his conscientious approach to the description of a gem unknown to him. From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146r. © British Library Board.

AN AMETHYST-LIKE GEM

Hanno, a former sacristan, presented St Albans Abbey with a four-pronged gold ring set with a purple-coloured gem, which Paris called 'similar to amethyst' (*consimilem ametisto*; Figure 17). This suggests Paris recognised that it was not amethyst, nor a glass imitation of amethyst, but rather a purple gem with which he was not familiar—a conscientious and honest approach. One suggestion about its identity appears in the revised list of the St Albans treasures drawn up around 1400–1410 that was mentioned above (British Library, Cotton MS Claudius E IV; Riley 1871, p. 331). The compiler of this list clearly had a copy of Paris's inventory on hand, since some of the objects are described in identical terms (although not all the jewels in Paris's inventory appeared there, and some might be listed but with briefer descriptions). The revised list includes what is described as a gold ring with four prongs containing a purple-coloured gem 'estimated to be a balas ruby' (*aestimatur rubyebalis*; Riley 1871, p. 331).[19] Regardless of whether it was the gem that Paris had puzzled over, this is a remarkably sophisticated gemmological suggestion. Purple sapphire is, of course, another possibility. Such stones are known to occur in Sri Lankan gem gravels, and many years ago the present author found one in a Byzantine pendant, probably of the sixth or seventh century. More recently, 17 gems in an earring from the tenth-century Preslav Treasure of Bulgaria, which were described as amethyst in the 1990s, were identified as consisting of 16 violet-coloured sapphires and one garnet (Strack & Kostov 2010).

THE 'CAMEO'

The final illustrated treasure on the St Albans list is a gold pendant set with a large and beautiful 'cameo' (*kaadmau*; Figure 18) that reportedly was given to the abbey by King Æthelred the Unready (r. 978–1016), father of Edward the Confessor. A picture of it being presented to St Albans Abbey by Æthelred appears in the list of benefactors (Figure 19). The *Liber Additamentorum* shows the cameo in a gold mount not seen in Figure 19, which might mean that it had been mounted after it was given to St Albans. Paris stated the material simply as onyx, but the list of benefactors indicated it was sardonyx, chalcedony and onyx (*sardonice, calcedonio et onic*) and also described the engraved (*insculpitur*) representation (Riley 1871, pp. 332–333).

Although its present whereabouts are unknown, this cameo—called the Great Cameo of St Albans—has been discussed fairly recently (Henig & Heslop 1986; Gołyźniak 2020, pp. 248–249, p. 444 [object no. 854] and p. 574 [figure 1010]). It is thought to be an example of a 'State Cameo' of the first half of the first century that likely portrays the divine Augustus (Henig & Heslop 1986, p. 151). If the drawing in Figure 19 is realistic, it

Figure 18: The Great Cameo of St Albans, presented to the abbey by King Æthelred the Unready, was described as onyx, but the list of benefactors says it was of sardonyx, chalcedony and onyx (*sardonice, calcedonio et onic*). From the 1257 *Liber Additamentorum*, British Library, Cotton MS Nero D I, f. 146v. © British Library Board.

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[19] This listing specifies the four prongs holding the gem as *crampons*—essentially 'hooks'. This term is also used in the description of the setting for a sapphire in the 1361 Christ Church, Canterbury, inventory (Legge & Hope 1902, p. 71). The French word *crampon* was defined in English dictionaries of the later nineteenth century as a type of a gem setting, although sometimes noted as being obsolete.

Figure 19: In the *Chronica et Registrum Benefactorum Monasterii S. Albani*, King Æthelred is shown presenting the cameo in Figure 18 to St Albans Abbey. From British Library, Cotton MS Nero D VII, f. 4v. © British Library Board.

shows that it was a laterally banded onyx (Oman 1930, p. 32), rather than the layered stone usual for cameos. This suggests that the gem was an intaglio rather than a cameo. Its large size (about 15 cm long) might count against this, but the possibility that medieval 'cameos' included what we would term *intaglios* (engraved gems with the design sunk rather than raised) is supported by the numerous 'cameos' listed in medieval inventories of the period, with no recognisable term for intaglios, although the latter greatly outnumbered cameos in the Roman world. As an example, the 1267 list of jewels taken from Westminster Abbey by Henry III included almost 60 'cameos' (Lyte 1913, p. 136). We do find mention of engraved sapphires (*saphiro inciso*), which perhaps just meant they had inscriptions, possibly Arabic. Surviving examples of medieval European rings set with sapphires having Arabic inscriptions are known.

Kaadmau, as in the St Albans list, is just one of the myriad ways in which *cameo* was spelled. The most modern-looking spelling of *camaeu* is found in the 1313 inventory of Edward II (Rymer & Sanderson 1818, p. 204), and variants include *kamacu*, *kamahutus*, *camauto* and *chamah*. For the origin of the word we can probably look to the old German *gammahuia*, a term for steatite (King 1865, pp. 141–142). However, King (1865) preferred a different origin, from the Persian *chamahen* for hematite (e.g. Hammer 1818, p. 139).[20] Both seem possible, as steatite and hematite were commonly used for charms and magical amulets.

DISCUSSION

Gem knowledge in the thirteenth century can be separated into two categories that overlap to some extent. First there is the science of gems—gemmology—the skill and experience needed to recognise the gems encountered in jewellery and to list them in inventories. Then there was the lore—a familiarity with the supposed medicinal, astrological and magical attributes of gems. Most studies of medieval texts on gems have been concerned with their linguistic idiosyncrasies and etymologies, but a distinction between practical gemmology and lore has been largely ignored.

Gemmology

The St Albans *Liber Additamentorum* and other texts of the period make it clear that those who compiled such inventories thought that they were able to distinguish, for example, between ruby, *balas* and garnet. Nevertheless, there are a few admissions of uncertainty, such as a ring described in 1390 as set with 'a ruby or *balas*' (Du Cange 1886, p. 229). Matthew Paris recognised that a purple gem was not an amethyst and was wise enough not to make a guess, while one of his successors suggested that it or a similar gem might be a purplish *balas*, showing that he knew such material existed. Of the limited number of primary gems that are known today, most are mentioned in the St Albans text. Those not included are ruby, emerald and diamond, although they appear in other inventories of the period. For example, the 1204 list of jewels delivered to King John includes a rod holding 28 diamond rings (*unum baculum cum xxviii diamant*; Bayley 1830, 178 n.). This is the earliest mention of diamonds in England known to the present author and, as noted above, the same list also includes the earliest mention of *balas*.

More than 1,500 years before Paris, Theophrastus had explained that colour was the best distinguishing feature for gems, and this was probably still the case in the thirteenth century (Caley & Richards 1956, p. 49). Medieval Arab texts described how to distinguish gems in more sophisticated ways, even providing their relative specific gravity values, but the present author is not aware of any evidence that this was used for practical gem testing in medieval Europe. Besides, as with gem testing today, determination of SG is impossible with mounted stones. The principle of magnification had been known since antiquity, but there is little evidence of its practical use until a century or two after Matthew Paris's time. (For a discussion, see Ogden 2018, pp. 6–7.)

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[20] Steatite (talc or soapstone) is also known as *speckstein* in German, literally 'bacon stone'. The *gamma* in *gammahuia* relates to the English 'gammon' (bacon).

Figure 20: An instructor teaching about gems on folio 167v of the *Liber de Natura Rerum*. Courtesy of the Bibliothèque Municipale de Valenciennes.

There is no specific mention of how gem knowledge was gained or sought. Only in the sixteenth century, for example, with the creation of the inventory of the St-Denis Treasury in 1534, do we hear specifically of jewellers being brought in to help the compilers (Inglis 2016, p. 16). However, as mentioned previously, Matthew Paris might have been a trained goldsmith and that would imply at least a working acquaintance with gems. Clearly, rudimentary gem knowledge must have been taught or at least passed on in medieval monasteries. The names of the main gems and their colours could be learned from reference texts such as the lapidaries, but such knowledge was not sufficient to help distinguish *balas* from garnet from ruby—or to separate genuine stones from doublets from glass imitations. There also had to be relatively recent information available about 'new' gems such as *balas* and peridot. The former was not known in Europe in earlier centuries, and the latter were only recently called by that name. Learning had to have been at least partly practical, with gems to look at. It is intriguing to think that the magnificent *Liber Additamentorum*, penned by one of the most celebrated medieval English scholars, might have also acted as a gemmological textbook for future generations of monks, with the St Albans Abbey's precious treasures serving as a teaching collection. Figure 20 is an illustration of, in effect, a medieval gemmology instructor. It heads the chapter on gems in the *Liber de Natura Rerum* scientific encyclopaedia by Thomas de Cantimpré with additions by Albertus Magnus (*ca*. 1200–1280) preserved in the municipal library of Valenciennes, France (de Cantimpré *ca*. 1280, f. 167v).

The mention of beauty and other subjective 'quality' aspects of some gems in the *Liber Additamentorum* is also noteworthy, and presumably 'quality' would have impacted value. Certainly, the values of eight unmounted *balas* in the inventory of the St Edward shrine varied in ways not linked just to their weights (Lyte 1913, pp. 136–137), indicating that there was also some quality assessment involved. The earliest medieval English mention of the 'assessment' of gems can be found in one of the homilies of Ælfric of Eynsham, a tenth-century English Benedictine abbot who has been called 'the most erudite, prolific, and influential author writing in English before Chaucer'.[21] In his version of how Saint John the Evangelist turned sticks into gold and pebbles into gems (part of an intricate story about eschewing worldly wealth), the miraculous gems were shown to *gym-wyrhtan* (literally 'gem workers' and thus presumably lapidaries), who said they had never encountered such precious materials (Thorpe 1844, pp. 64–65).

Lore

While there were little more than a dozen differently coloured gems actually set in medieval jewellery or listed in inventories, a huge number were described in the myriad lapidaries and other texts with their supposed medicinal or magical properties.[22] The names of these were derived from classical, Arabic and other sources. The vast majority of these gems are not mentioned in any medieval inventories of royal treasuries or monasteries, and many may not have actually existed outside the pages of a lapidary. If a particular gem was believed to alleviate toothache, then no doubt you could buy what you would be assured was one, perhaps along with a saint's finger or a dragon's tooth. In few cases was a name consistently applied to a single mineral species by such purveyors. There would have been exceptions: some minerals really do have medicinal properties, and some might appear to be magical. For example, magnesite can be converted easily to magnesium hydroxide, the active ingredient in 'milk of magnesia'. A piece of pyrite clasped in a sweaty hand will produce sulphuric acid and thus a 'magical' burning sensation—just as noted in some medieval texts.

In most cases it is fruitless to ask which of the gems known today is meant by some obscure name in a medieval lapidary. An example is the *epestite*, *epetite*, *espetite*, *aspites* and *alpitistes* in medieval texts, derived from Pliny's gem *hephaestitis*. The actual identity of Pliny's gem is unknown (although pyrite has been suggested),

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[21] See the introduction to *The Digital Ælfric: Eight Catholic Homilies*, www.sd-editions.com/aelfric/intro.1.php.

[22] For a recent study of lapidary medicine, see Harris (2009).

and the name is otherwise unattested in Classical Latin texts (Eichholz 1962, book 37.57; Wyckoff 1967, p. 90). Pliny described it as red and as good as a mirror in reflecting images. If it were put in boiling water, the water would cool instantly, and it could also work as a burning glass—the sun shining through it would set fire to dry material. It came from Corycus in what is now southern Turkey, then an important port and commercial centre. If there really was such a gem, then perhaps some type of garnet was meant, which we know came from Turkey. Nevertheless, in 1934 Urban Holmes, who admitted that 'assigning modern names to the gems of the Middle Ages is complicated', suggested that *epestite* was spinel and explained that its use as a burning glass was due to it being singly refractive (Holmes 1934, p. 198). *Epestite* (and its various spellings) in medieval texts is commonly still translated as spinel (most recently by Young 2016, pp. 10 and 43, but strangely not p. 44).[23] Holmes's justification for equating *epestite* with spinel is that where Marbode originally described *espesite*, a later version of his text substituted *balas* (Holmes 1934, p. 198 n.). This does not mean that *epestite* had always been *balas*. The word *balas* first entered the European gem repertoire around 1200, a century after Marbode. One might imagine a scribe, puzzled by the lack of any mention of *balas* in Marbode's or other earlier texts, assumed that it must have been called something different. Pliny's *epestite*, as a bright red gem, conveniently fit, so it became 'balas'.

CONCLUSIONS

The *Liber Additamentorum*, dating to 1257, is a window into the state of gem knowledge in England in the thirteenth century. In addition to the clear descriptions and appealing images, it and other texts of the period demonstrate that the writers thought they could distinguish between such gems as almandine (and other garnets) and *balas*. Matthew Paris's description of a purple gem as being 'similar to amethyst' indicates both the caution and knowledge of a wise man well versed in gems (Figure 21). Similarly, one of his successors 'estimated' what was probably this same gem to be a purple *balas*—again an indication of caution combined with knowledge. Some gems, such as ruby and *balas*, had appeared in Europe only a few generations before Paris's work, suggesting they and their distinguishing features must have been assimilated rapidly into the existing information about gems. Gem knowledge seems to have been taught and, as today, this would only have been effective if there were examples of gems on hand to be seen. It seems justifiable to add 'gemmology' to the range of medieval skills that were learned at, and disseminated by, the various medieval religious houses.[24] It is also important to realise that attempting to 'identify'—in modern terms—the obscurely named gems listed in some lapidaries and other early texts is often a fruitless exercise.

Figure 21: This appealing self-portrait of Matthew Paris appears in his *Historia Anglorum*. From British Library, MS Royal 14.C.VII, f. 6r. © British Library Board.

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[23] See also the *Middle English Compendium*, https://quod.lib.umich.edu/m/middle-english-dictionary/dictionary/MED14209.

[24] For an eye-opening look at 'science' in medieval English monasteries, including much about Matthew Paris, see Falk (2020).

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The History of London's Lapidaries (Part 2)

Justin K Prim

ABSTRACT: The second and final part of this article follows developments regarding British coloured-stone cutters from the Industrial Revolution until today. London was one of the first to adopt new cutting technology in the early 19th century, and this allowed it to become an important player in the nineteenth- and twentieth-century European gem-cutting trade. The story of Hatton Garden's Chas. Mathews company provides an inside view of London gem cutting in the late nineteenth century, coinciding with the birth of modern gemmology. From that time until today, some of London's lapidaries have continued to cut using the same techniques and technology. This article also follows the rise of Britain's hobbyist lapidary community in the twentieth century, with the introduction of new cutting machines that were oriented toward the layperson.

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By the turn of the nineteenth century, the coloured-stone cutting trade in London was at least 450 years old. The first five centuries had witnessed the introduction of the hand-cranked cutting table (likely of German design) and, later, the introduction of the quadrant handpiece (probably of French design) used for precisely placing facets around a gemstone (Prim 2021). Thanks to these two pieces of technology, and to the cutting and polishing techniques that came with them, London lapidaries were held in high regard during the preceding centuries. Throughout the history of gemstone faceting, the introduction of new cutting technology directly correlated to advancements in faceting styles (e.g. Figure 1). It is this type of technological advancement which marks the next chapter of British gem cutting. Early in the nineteenth century, a new type of cutting machine—the jamb peg—made its way from Paris to London, where it transformed the lapidary trade.

Figure 1: This 21.03 ct mixed-cut synthetic sapphire was faceted in the first decade of the 2000s by the last generation of gem cutters at the Chas. Mathews company, John Taylor and Peter Rome, for a museum exhibition. The mixed-cut style epitomises the tastes of professional London cutters: the step-cut bottom saves weight and improves colour saturation, while the brilliant-cut top increases brilliancy while also following the natural shape of the rough stone. Photo by J. Prim.

JOHN MAWE AND THE BRITISH JAMB PEG (1797–1850)

Much can be said about the adventurous life of British mineralogist John Mawe (1764–1829). Hailing from Derby, in his twenties Mawe apprenticed under the

Figure 2: This illustration of a Regency-era gentleman operating a British-made portable faceting machine (Mawe 1821, facing p. 102) provides an early example of equipment designed to appeal to amateur lapidaries. It was possibly the invention of John Mawe.

well-known marble cutter Richard Brown, and in 1794 he married Brown's daughter, Sarah. In 1797, they moved to London and opened a mineral shop in Covent Garden (Torrens 1992, p. 267). Over the course of his career, he produced several books that contributed greatly to Britain's gemmological and mineralogical knowledge. Of greatest importance was *Familiar Lessons in Mineralogy and Geology*, which was first published in 1819. The book introduced the basic terms and concepts associated with mineralogy, including the study of chemistry, crystal structure and the physical properties of minerals. It was written from Mawe's practical experience (and published in 12 editions), and included basic observations on minerals, gems, geology and the lapidary craft. In the first edition, Mawe introduced readers to the world of lapidary by providing detailed instructions on how stones were cut and polished. The book includes a colour plate depicting a cutting machine that seems to have been his own invention (Figure 2). This 'portable lapidary apparatus' was offered for sale in his London shop, and Mawe stated that, 'This compact Lapidaries' Mill is contained in a small box, and may be placed on any parlour table' (Mawe 1821, p. 102). This might be the first attempt to make gem cutting appealing and available to the layperson. England was going through its first popular interest in amateur gem hunting, which may explain why Mawe's book was so successful. It spoke to a demand by hobbyist enthusiasts for mineralogical information.

In 1827, Mawe published a standalone version of his lapidary instructions, which contained an illustration of a new lapidary machine: the jamb peg (Figure 3). This drawing (which also appeared facing p. 106 of the 1828 edition of his *Familiar Lessons in Mineralogy and Geology*) is the first English-language reference to this new type of gem-cutting tool. In fact, the only previous reference to the device is in C. P. Brard's *Minéralogie Appliquée aux Arts* (1821, p. 421), which demonstrates that the jamb-peg cutting head was being used in Paris only a few years earlier. Brard described the appearance and function of the apparatus but did not give it a name. Evidently it was not yet known by the French name ascribed to it today: *évention* (a corruption of the French word *invention*). In addition to giving the device the English name of *gimp peg*, Mawe described the functions of the machine (Mawe 1827, p. 8):

> In order to cut facets…it is necessary to have a cone of wood, about eight inches high, placed perpendicular on an iron pin…. This is called a *gimp peg*: it has four or five heights of holes, about half an inch above each other…so that a line from it to the edge of the mill would form a perpendicular, and the next a very acute angle; a stick of definite length is used, and the stone that is to be cut in facets must be cemented to it.

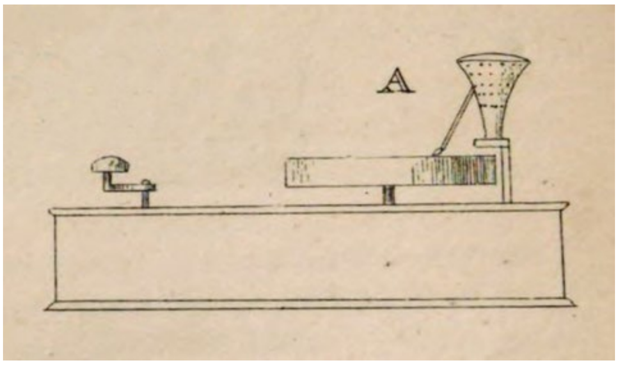

Figure 3: The drawing shows the first representation of a jamb-peg faceting device to appear in English-language literature (Mawe 1827, plate A, facing p. 9). This type of machine would forever change the cutting traditions of London's lapidaries.

Regarding the name *gimp peg* (today known as jamb peg), Mawe's use of *gimp* was likely a mispronunciation of the French word *jambe*, which means *leg*. The word *peg* equates to the word *notch* (as in the idiom 'take one down a peg' vs 'take one down a notch'). It refers to an indentation or incision on an edge or surface, which is appropriate for describing this apparatus: a wooden cone with a series of notches cut for a tapered wooden 'leg' to sit in.

Mawe also provided an interesting piece of lapidary history. He mentioned that before the invention of the gimp peg, 'The ancient mode of cutting stones was with a quadrant having a moveable index, to which the stone was cemented, and placed at any angle desired. This mode, though mathematically exact, is now discontinued, and the workman depends more on habit in placing his stick at a proper angle, and on his eye, in forming facets' (Mawe 1827, p. 10 n.). Thus, the quadrant handpiece, which had been in use since the early 1600s, began to be replaced by the new jamb-peg device in the 1820s. Although cutters lost the mathematical precision of the quadrant, they gained speed and, with practise, their cutting accuracy was just as good if not better than that of the old quadrant cutters.

Over the next 70 years, the jamb-peg device appeared in numerous books. In 1850, for example, Charles Holtzapffel's six-volume *Turning and Mechanical Manipulation* series featured various images of the jamb-peg table (e.g. Holtzapffel 1850, p. 1324; see Figure 4). Volume 3 of the series contains detailed information about how the gem cutters of the mid-nineteenth century worked, including a discussion of the types of polishing abrasives used on the machine (Holtzapffel 1850, pp. 1307–1308):

> Notwithstanding the apparent expence [*sic*] of the diamond powder, it is very generally employed…and although for this and some of the softer stones, emery, or in some cases even sand, might be successfully employed, the diamond powder is almost exclusively used, as it is found to be the most economical, when the time occupied in the cutting is taken into account.

Holtzapffel distinguished between the machines used by professionals and those used by amateurs (Holtzapffel 1850, pp. 1341–1347), reinforcing Mawe's idea that lapidary work was becoming a popular hobby at the time. Before 1800, there were almost no amateur lapidaries—only professionals who had painstakingly learned the cutting and polishing techniques of previous generations through the apprenticeship system.

Beginning with Mawe's generation, a new favourite pastime arose: people throughout Victorian Britain began to polish locally collected gems (Crawford 2008, p. 67). Adaptations to the cutting bench were made for those lacking the experience needed to become proficient at the jamb peg. An 1833 article included instructions for how to build an 'amateur lapidary's apparatus' (Reed 1833)—essentially duplicating the machine illustrated in

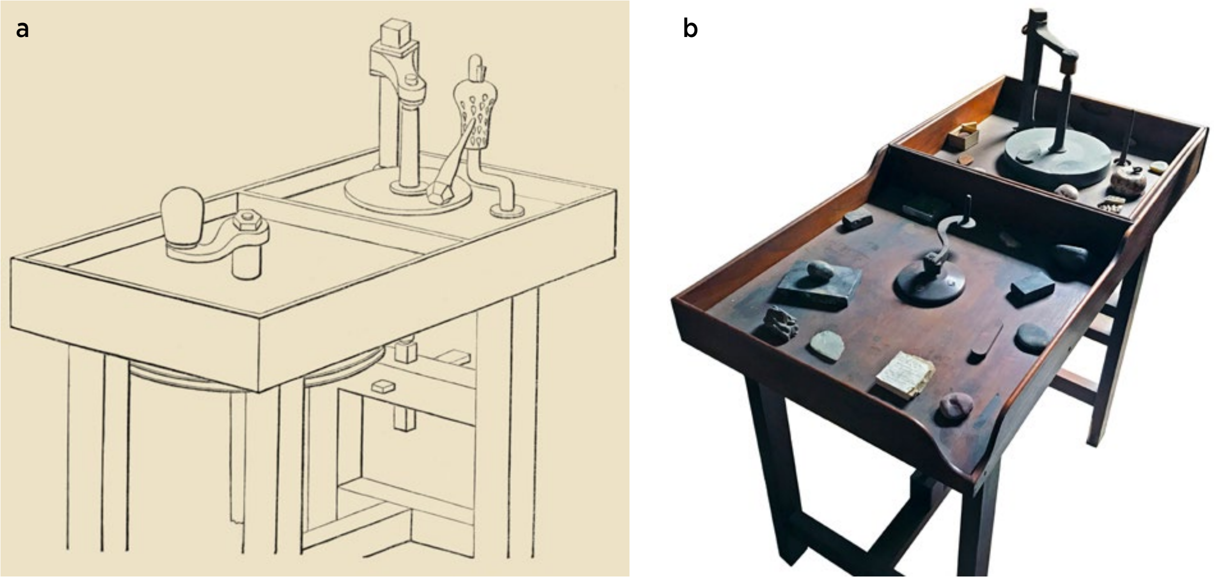

Figure 4: (**a**) This drawing by Charles Holtzapffel (1850, p. 1324) is essentially identical to (**b**) the last surviving Victorian lapidary table, which now resides at Calke Abbey (Ellis 2021). The Calke Abbey table is missing the jamb-peg head, although the metal post that it attaches to can be seen. Photo by J. Prim.

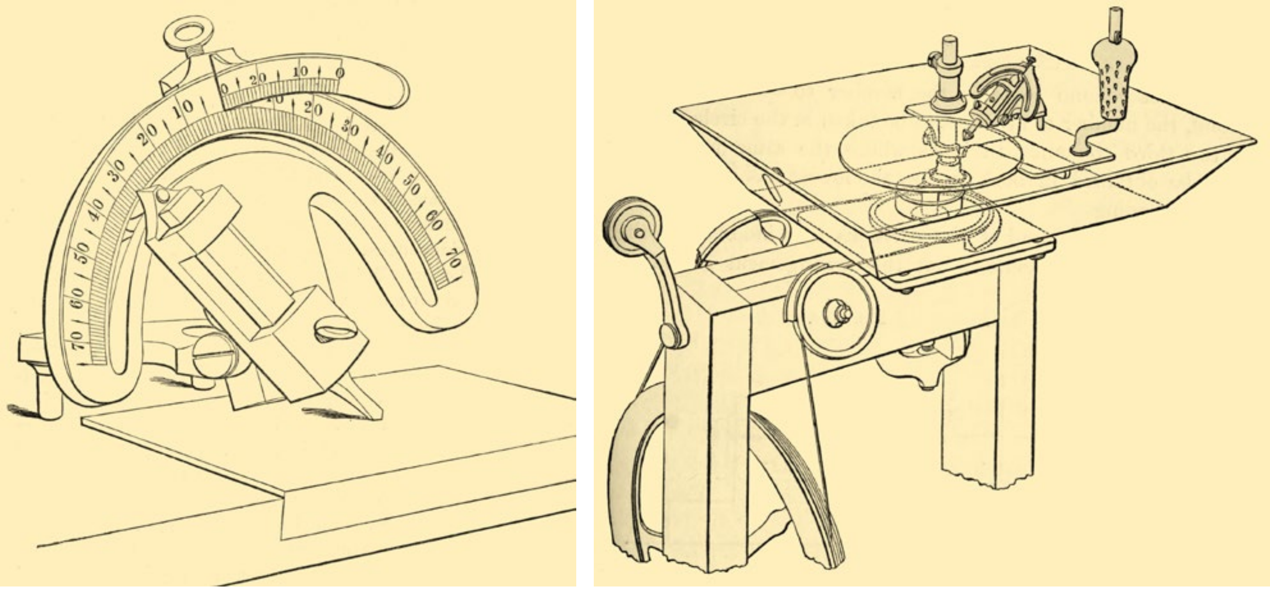

Figure 5: In 1850, Charles Holtzapffel took a device used for lathe-turning (which he later called a *goniostat*) and converted it for cutting gemstones. By modifying the device with a rotating gear, the goniostat—with its adjustable angles and removable dop stick—helped amateur cutters easily facet gemstones without the years of training needed to master the jamb-peg cutting technique. Drawings from Holtzapffel (1850), p. 1165 (left) and p. 1344 (right).

de Boodt's 1609 *Gemmarum et Lapidum Historia*—with a hand-crank table and a quadrant handpiece. It was accompanied by an anecdote about the fine 'pebbles' that could be found on the coast near Scarborough.

Holtzapffel's work also records another adaptation for amateurs: the use of a goniostat (Figure 5), normally employed for lathe turning, but modified for cutting facets. In Holtzapffel's 1850 book he simply referred to it as 'the instrument' (p. 1164), but in a later edition he named it a *goniostat* (Holtzapffel 1864, p. 1159). He remarked that this device, with its mechanically controlled angles and indices, would make it much easier for the amateur to cut a perfect facet arrangement (Holtzapffel 1850, p. 1344), foreshadowing the progression of twentieth-century faceting technology.

CHAS. MATHEWS LAPIDARIES, LONDON'S OLDEST GEM-CUTTING WORKSHOP (1894–1930s)

The Chas. Mathews company was founded in 1894, when Charles Mathews (Figure 6) was only 21 years old (Anonymous 1932b), presumably right after his apprenticeship ended. He soon built a reputation as one of the foremost gem experts in Hatton Garden. Not only was he a gem cutter, but he was also a gemmologist. Like Mawe, Mathews travelled the world looking for gem materials and brought them back to London to be cut and sold. His office was on the main street of Hatton

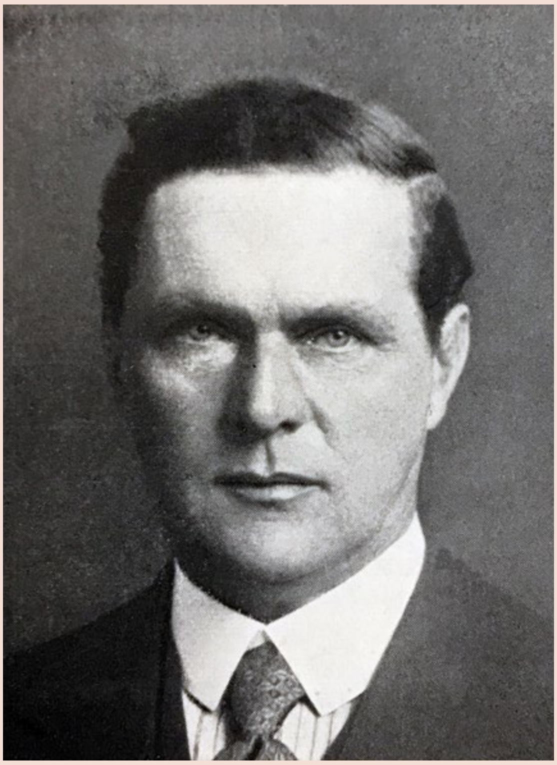

Figure 6: Charles Mathews has been described as 'Hatton Garden's best known lapidary' (Anonymous 1932b) and 'a great gemmologist' (Anonymous 1941). He founded his Hatton Garden-based gem and lapidary company in 1894. The Chas. Mathews company still exists today.

Garden; 127 years and three offices later, the studio is still located on the same road.

By the time the company was founded, the jamb-peg machine had been in use for approximately seven decades and was standard for London lapidaries. Stones were cut on hand-cranked laps made of copper, gunmetal, pewter or lead, with carborundum (silicon carbide) or diamond powder used as the cutting abrasive (Smith 1913, p. 105). Polishing was then done on hand-cranked wheels made of copper, tin, pewter or sometimes wood topped with cloth or leather. The polishing agents used were diamond powder, ruby powder, tripoli, putty powder, pumice or rouge, in all cases mixed with oil or water (Smith 1913, p. 106; Ken Harrington, pers. comm. September 2021). Stones were 'stuck up' on a dop with a cement made of shellac and plaster of paris. As a general rule, the harder the stone, the greater the speed of the lap.

Holtzapffel (1850) illustrated examples of faceting styles of the period (Figure 7) which, in turn, laid the foundations for the cuts seen in jewellery stores today. By the turn of the twentieth century, stones from all over the world were being sent to London for recutting (Streeter 1898, p. 41).

The London cutting facility described in Leopold Claremont's 1906 book *The Gem-Cutter's Craft* was likely identical to Chas. Mathews' studio (Claremont 1906, p. 39–40):

> What strikes a casual visitor most forcibly upon entering a modern lapidary's workshop is the *extreme simplicity* and almost primitiveness of the tools and instruments in use. This is the key-note to the art of cutting and polishing precious stones, for the work is essentially a matter of skill and judgment.

Some of the most notable and precious stones made their way through London, arriving as rough material or crudely cut stones that were recut to perfection by London's lapidaries (Ward 1933, p. 187). Their continued use of hand-crank faceting tables (Figure 8a), even after the availability of electricity, provided a considerable degree of accuracy due to the fine control of the lap speed, along with the delicate touch that was necessary for their jamb-peg work (Figure 8b).

Chas. Mathews started training apprentices early on. In 1903, James Arthur Cummings started his apprenticeship and ended up staying with the company for 40 years (Anonymous 1962). Starting in 1931, Mathews penned occasional gemmological articles for the newly launched magazine, *The Gemmologist*. He wrote about emeralds,

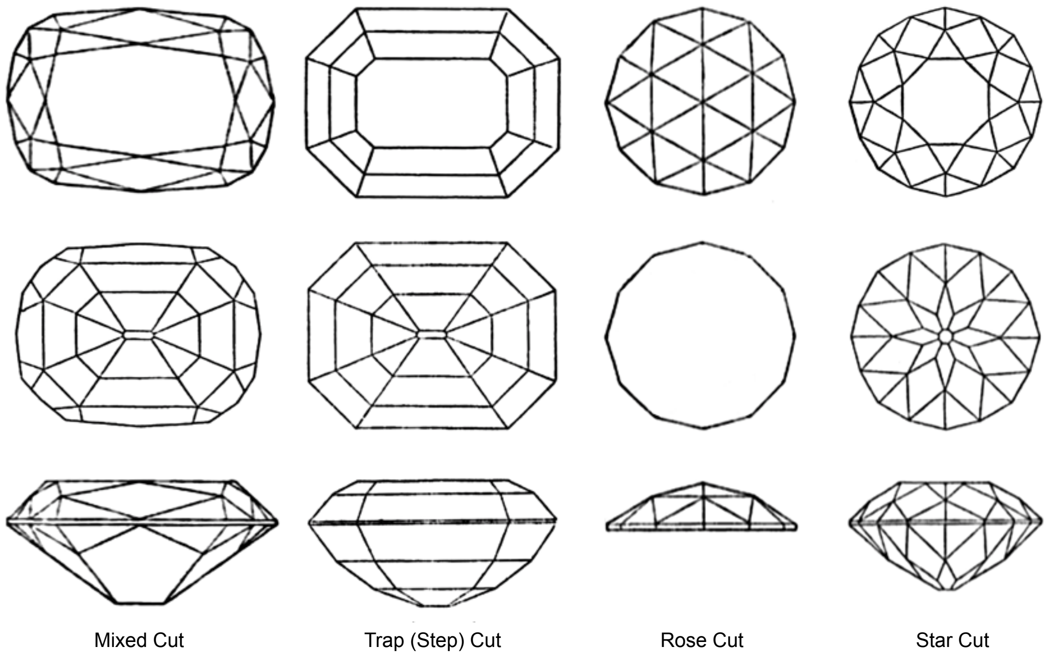

Figure 7: Gem cutting styles used in London in the mid-nineteenth century included the mixed cut, step cut, rose cut and star cut (composite illustration from Holtzapffel 1850, pp. 1325–1335). Only 23 years after Mawe's 1827 publication introduced the jamb peg, Holtzapffel (1850, p. 1337) reported, 'All the different forms of facetting are usually cut by practical lapidaries, without any other guide than the gim [*sic*] peg, and cement stick'.

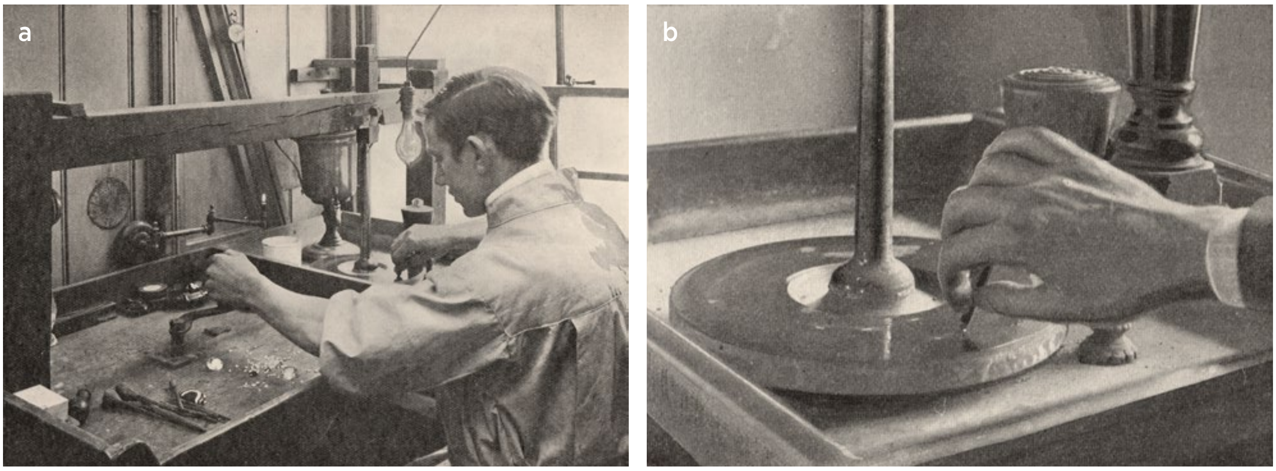

Figure 8: These 1906 photos show London lapidary Leopold Claremont hand-cranking his machine (**a**), as well as a close-up of cutting a gemstone (**b**). From Claremont's *The Gem-Cutter's Craft*, pp. 55 and 57.

rubies and sapphires (staples of the Chas. Mathews lapidary studio), as well as how to test for synthetics (Mathews 1931a–d, 1932). He gave a first-hand account of gem hunting in Ceylon (Sri Lanka; Mathews 1932), and also mentioned visits to Siam (Thailand) and Burma (Myanmar; Mathews 1935). During the 1930s, he travelled to South Africa to give expert advice on newly discovered emeralds in the Transvaal (Anonymous 1941).

Articles of this period stressed that London cutting was much better than the work of local cutters in South-East Asia because, in part, British gem cutters had the science of gemmology to aid them (Ward 1931). This is consistent with the presence of one of the first gemmology schools in the world—the Gemmological Association of Great Britain (now Gem-A)—which opened in London in 1931, less than 5 km from Hatton Garden (Gem-A n.d.). In the mid-nineteenth century, cutters already knew that correctly cutting facets on gems could 'improve their brilliancy, by multiplying the number of reflecting surfaces, in order that the play of light may be proportionally increased' (Holtzapffel 1850, p. 1321). However, after a further 80 years of gemmological discoveries, London lapidaries with a background in gemmology, such as Mathews, were cutting with an understanding of how light interacts with different types of gem materials.

Early records show that Charles Mathews donated rough gem materials to Gem-A and was involved with several committees and societies through which he would have been acquainted with some of Gem-A's founders, as well as local gemmology lecturers (Anonymous 1932c, p. 3). Mathews seems to have attended such lectures as early as 1893, when he was still an apprentice (Anonymous 1937). These educational pursuits made Mathews an early 'gemmologist gem cutter', who used his scientific knowledge of crystal systems, optics and cleavage to pursue the best colour and shape for his gemstones.

By the 1930s, however, the London lapidary trade had waned. Factories that once had 24 cutters were scaled down to workshops of only a dozen (One of them 1932, p. 249). Despite the public interest in gem cutting—as seen at the Streeters jewellery shop on Bond Street, where Leopold Claremont and his lapidary mill were positioned in the window (Anonymous 1932a)—it seemed that London's lapidary trade was losing work to cutters in other countries. This was likely due to the French modification of the jamb-peg technique to include a 'mechanical stick', which gave French lapidaries a competitive edge by cutting at much faster speeds (Prim 2017). Large-scale cutting factories were constructed in France, and in 1920 the Jura region housed around 8,000 lapidaries, a number that London never came close to. However, when the Great Depression made its way to France in the 1930s, many lapidary factories went out of business (Prim 2017).

THE SPLIT: PROFESSIONAL LAPIDARIES vs HOBBYIST CUTTERS (1935–1945)

The idea of the hobbyist cutter had been building in popularity since the early nineteenth century, but the most powerful wave of amateur cutting began in 1935 with the publication of the *Handbook for the Amateur Lapidary* (Howard 1935, reviewed by Anderson 1935). The book was filled with instructions and photos written by amateur cutters for amateur cutters. It was an immediate hit in the United States (where it was written) and in the United Kingdom, where it was offered for sale at the London offices of *The Gemmologist* magazine.

Over the next 40 years, several other books were written for the amateur lapidary, first in the United States and then in the UK and Australia. They followed the premise of Howard's original book: amateur gem cutters teaching amateur gem cutters. Thus began a movement that has continued until the present day and, through exponential growth, would eventually surpass the lineage of professional cutters. The number of hobbyist cutters in the United States, the UK and Australia grew dramatically, while the number of new apprentices in the professional London cutting trade declined to almost none.

Along with the dissemination of cutting techniques came new technology designed for use by amateur gem cutters. The jamb-peg machine, which had been the specialty tool of London cutters for more than 100 years, was too difficult for hobbyist cutters to use. American engineer-cutters, building upon the concepts utilised by Holtzapffel's goniostat, began to develop a new type of gem-cutting device as early as the 1890s (Passmore 1892), which eventually became popularly available in the 1940s: the 'mast-style' faceting machine.

One of the first mass-produced mast-style devices was manufactured by the American company M. D. Taylor around 1938 (Taylor 1938) and also exported to Britain (Figure 9). Instead of employing a jamb-peg head and rosewood dop stick, cutting was done with a metal 'faceting head' and 'dop arm' (Anonymous 1948). While the jamb peg used a series of holes to determine the angles of facets, the new mast-style machines featured an extremely accurate vernier scale to determine specific angles for cutting facets, a feature also found on Holtzapffel's goniostat (Figure 5, left). With the jamb-peg technique, facets were placed by manually rotating a stone, using the cutter's eye and experienced touch. The newer machines allowed a stone to be accurately and easily rotated using an index gear containing 64 or 96 teeth.

This new technology meant that a gemstone could be faceted relatively quickly and easily with accurate angles and meetpoints. Theoretically, a lengthy lapidary apprenticeship was no longer needed. There was virtually no crossover between the methodologies employed by the amateur cutters with their mast-style machines and the professional cutters with their jamb-peg devices, so amateur cutters never came to know many of the tricks and techniques used by professional cutters. In addition, a distinctive cutting aesthetic developed in hobbyist cutting circles: an obsession with brilliance and the brilliant cut (Vargas & Vargas 1975, p. vi). This contrasted with the traditional aesthetic tastes of professional London cutters, who used cuts that emphasised colour while saving weight (e.g. the step cut). A 1938 article by a London-based gem cutter heralded this transition (Roberts 1938, p. 59):

> To-day we live at a very high speed.... We have to try and get the facetted stone brilliant and bright. Years back, people loved the softly blue sapphire, but it takes a little while to find the hidden beauty. There is no time to look to-day. We have to make our effects striking.... The London lapidary could seldom afford to reduce weight, sometimes necessary when facetting in order to make a fine gem. He had to save weight instead and could seldom cut a stone as he desired.

In 1941, shortly after the newest phase of the amateur-cutting movement began, Charles Mathews died at the age of 68 (Anonymous 1941). Reginald Mathews, Charles's son, who had joined the company in 1934 (Anonymous 1934), took over and focused on running the gem-trading side of the business. He hired a new manager to run the lapidary studio: George Bull-Diamond (Figure 10).

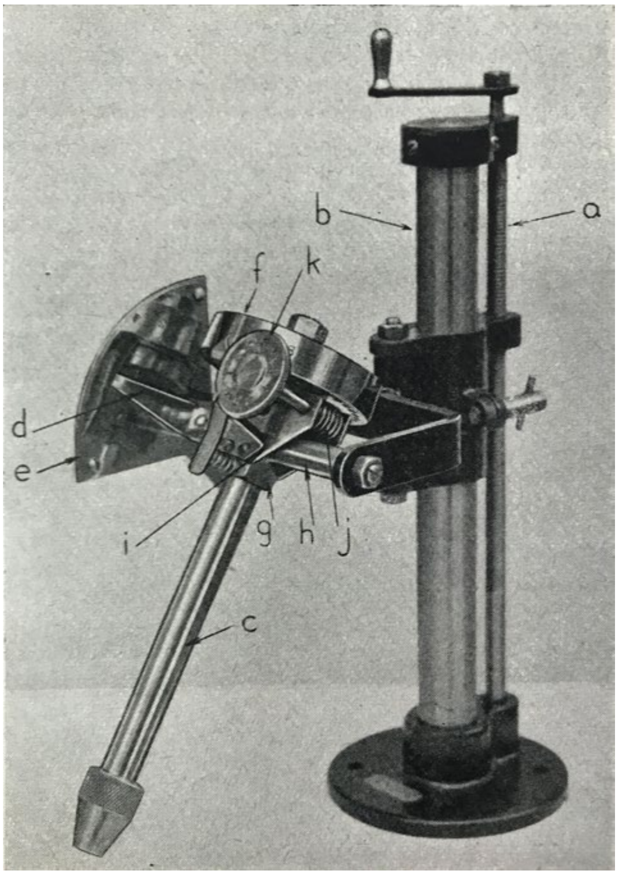

Figure 9: The Taylor faceting head was one of the first new 'mast-style' faceting machines to enter the British hobbyist community from the United States. This image of the device appeared in a 1948 article in *The Gemmologist* magazine (Anonymous 1948, p. 101).

Figure 10: George Bull-Diamond, manager of Chas. Mathews (Lapidaries) Ltd from the 1940s to the 1980s, is shown cutting a stone on a jamb-peg bench in this illustration from Webster's *Gems* (1975, p. 434). Reproduced with permission.

Starting in 1947, the company formally split and incorporated into two different entities (Figure 11): Chas. Mathews (Lapidaries) Ltd, which was responsible for cutting stones, and C. Mathews & Son, which bought and sold gems (Mathews 1947). While Chas. Mathews (Lapidaries) Ltd was managed by Bull-Diamond, C. Mathews & Son was managed by Reginald, who had never taken up his father's interest in gem cutting (John Taylor, pers. comm. May 2019).

World War II began two years before Charles Mathews died. One-third of London was destroyed between 1941 and 1945, and Hatton Garden took a huge hit. More people died in Hatton Garden's encompassing district of Holborn than in any other part of the country (Lichtenstein 2013, p. 239). During both world wars, Chas. Mathews halted production to aid the war effort (John Taylor, pers. comm. May 2019). The cutters worked on government-mandated projects such as carving marble parts for airplane fuel injectors, fabricating agate wedges for balance scales and manufacturing engine bearings made of tourmaline (Ken Harrington, pers. comm. September 2020). Some cutters, such as James Cummings, departed for the battlefront. After World War II, Cummings rejoined the firm and helped Charles Mathews start the British Gemcutting Company, which retrained disabled veterans as lapidaries to help them reintegrate into civilian life (Gilbertson & Prim 2019).

HATTON GARDEN GETS A FACELIFT (1950s)

The 1666 Great Fire of London changed the old jewellery quarter of Cheapside forever, and the same can be said about World War II and Hatton Garden. After the war, as the neighbourhood was rebuilt, it began to transform from an insular manufacturing district into a shopping centre that would attract tourists and customers worldwide. Before the 1950s, there were no public jewellery shops in Hatton Garden. Soon, new retail outlets started to open, and workshops were pushed to upper floors as street-level storefronts were needed to attract customers (John Taylor, pers. comm. May 2019).

Precious Stone Merchants

GEMS
DIRECT FROM
THE MINES

14
HATTON
GARDEN
LONDON
E·C·1

C·MATHEWS & SON
EST. 1894 Telephone Holborn 5103

CHAS·MATHEWS
(LAPIDARIES) LTD.
Phone: Holborn 7333 'Grams: Lapidary, London

Cutters of Precious Stones

WE SPECIALISE
IN RECUTTING
FOR THE TRADE

Figure 11: This advertisement for both of the Mathews companies appeared in *The Gemmologist* in 1950. Variations of this ad ran in the same publication from 1947 to 1952 and in *The Journal of Gemmology* from 1947 to 1951.

Despite this change, the cutting studios of Hatton Garden persevered. In January 1952, two gem cutters from Chas. Mathews gave a talk at the Gemmological Association of Great Britain about the methods used in gem cutting (Tremayne 1952). Their presentation indicated how little the cutting technology had evolved since the time of Mawe and Holtzapffel. Cutters were still faceting stones with carborundum powder on copper laps and polishing them using tripoli, diamond powder and ruby powder on copper laps for hard stones, and on lead and pewter laps for softer stones. The only modern innovation they mentioned was that the polishing mills had become motorised, running at 400 rpm. This fact was also briefly mentioned by London cutter Leopold Claremont in *The Gem-Cutter's Craft* (1906, p. 59), so we can assume that motorised polishing laps became standard at the very beginning of the twentieth century, when electricity became commonplace in London.

Another aspect they emphasised was the specialisation of roles in London cutting studios. Each stone had to go through two sets of hands and across two benches—one for cutting and one for polishing. Since the laps of large lapidary machines cannot easily be changed, it was necessary to have one bench for the cutting abrasive and lap, and another for the polishing abrasive and lap. Each tradesman was specialised only in his particular role—either cutting the facets or polishing them—which was not the case in other jamb-peg cutting centres such as Paris and Idar-Oberstein (Sébastien Hourrègue and Gerhard Hörnlein, pers. comm. September 2021).

New tastes and cutting styles were being developed in other parts of the world (Howard 1946, pp. 128–139), but the London lapidaries still followed nineteenth-century traditions, such as continuing to use the hand-cranked cutting machines. These cutters scoffed at new brilliant styles as 'synthetic looking' (Peter Rome, pers. comm. May 2019), an opinion that had been promulgated since the earliest days of their apprenticeships, and was partially due to the fact that they were trained to cut expensive material that would lose too much weight and value if faceted in a modern and more brilliant style (Roberts 1938, p. 59).

By the 1950s, London had developed a reputation for the beautiful stones that were being produced in Hatton Garden and exported to other parts of the UK, across continental Europe and to America. Merchants from other countries sent their poorly-cut stones to Hatton Garden to have them recut to perfection. London studios also obtained rough material from mines worldwide. For example, Reginald Mathews received monthly shipments of Burmese ruby and sapphire due to his friendship with a mine manager in Mogok, and the company also regularly obtained parcels of emerald from Colombia, as well as shipments of the highest-quality sapphires from Kashmir (Peter Rome, pers. comm. May 2019).

During this time, Chas. Mathews trained its last generation of cutters. Ken Harrington started his apprenticeship in 1960. A few years later, Patrick Aldridge (who later formed the Jewel House cutting studio) started, and finally Peter Rome and John Taylor joined the company, and ended up being the last two Chas. Mathews apprentices to become professional cutters (Ken Harrington, pers. comm. November 2019).

THE END OF AN ERA (1970s–1980s)

The London gem-cutting industry changed drastically when the value-added tax (VAT) was introduced to the UK in 1973. Internationally sourced rough material was then subject to import tax, which significantly increased the cost of business for London cutters and merchants. Other than De Beers, all the major dealers left London, with many going to Geneva. Simultaneously, Asia started to become a major player in the world's gem-cutting industry, and this shifted even more business away from London (Peter Rome, pers. comm. May 2019). Many London gem merchants and cutters simply retired.

As more retail shopping outlets opened in Hatton Garden, rents increased, and this pushed many people out of the neighbourhood. New shops meant new merchants, but this generation of retail jewellers was no longer interested in patronising local gem cutters for custom-cut stones; it was easier to buy gems directly from large manufacturers who imported them (often cheaply and crudely cut) from elsewhere, which severely curtailed London's cutting trade (Peter Rome, pers. comm. May 2019). Clerkenwell, which had helped push immigrant cutters and traders into Hatton Garden a century before, now took on gem cutters who needed a cheaper hub to work from. During the 1970s, most of the buildings in Hatton Garden were torn down as the neighbourhood was modernised.

The Chas. Mathews company circumvented the VAT, thanks to an aggressively worded letter written to Prime Minister Margaret Thatcher in which they expressed, 'If they couldn't export their skills, they may be forced to export themselves'. Chas. Mathews became the first company in the UK to be awarded the special VAT exemption called 'Inward Processing Relief' (Peter Rome, pers. comm. May 2019).

The Chas. Mathews studio transferred ownership to its current generation in the 1980s. Cutter Peter Rome and polisher John Taylor (Figure 12) took over the company from George Bull-Diamond when he retired, and the studio that once had up to a dozen cutters was reduced to only two (Peter Rome, pers. comm. May 2019). Very little rough material was coming into London, likely because most was going to Bangkok, Hong Kong and India, where it could be processed cheaply (Patrick Aldridge, pers. comm. October 2019). London's lapidary industry all but disappeared due to the exodus caused by the VAT, and the gem market there eventually crashed due to a recession.

Since the late 1970s, recutting became the main

Figure 12: London's last traditional gem cutters, John Taylor and Peter Rome (left and right, respectively), pose in their studio in 2018 with hand-cranked jamb-peg machines. Photo by J. Prim.

activity for the remainder of London's lapidaries, whose customers in Hatton Garden are mostly second-hand and antique dealers (Peter Rome, pers. comm. May 2019). Rome and Taylor, who apprenticed during the beginning of the unstable market period, excelled at recutting fine material. The Chas. Mathews company had always avoided treated stones, and unheated sapphires and rubies had become one of their specialties. In today's market, customers for high-end untreated stones are typically the only ones who can afford the hourly rate of London's top cutters.

Over the years, many companies closed, but new ones occasionally replaced them. One of these is R. Holt & Co., which was established in 1948 and opened a cutting workshop in 1970 (Holts Lapidary 2021). Since then, they have rebranded as Holts Lapidary and have become one of the major lapidary shops in Hatton Garden, among only a handful of others. In the 1970s, there were at least five medium-size lapidary studios in Hatton Garden: Chas. Mathews, F. Dennis and Co., Art and Fowler, Benjamin Roberts, and Holts; only two of these remain today (John Taylor, pers. comm. May 2019).

INTO THE 21ST CENTURY

Today in Hatton Garden there is a new generation of merchants working on a vastly transformed high street, but inside the Chas. Mathews lapidary studio little has changed in the 127 years since it opened. Although it is smaller nowadays, the techniques and technology have stayed the same. Rome and Taylor cut and recut fine sapphires, rubies and emeralds on their traditional lapidary benches. The machine that Rome uses is from the 1940s, when Reginald Mathews was still in charge of the company. The crank is a repurposed bicycle pedal arm, and the large gear that turns underneath is from an old-fashioned mangle washing machine. They have been using the same copper laps since their apprenticeships (Peter Rome, pers. comm. May 2019). They still cut the old-fashioned way and prefer the same classic designs that were popular in the 1900s, based on those from centuries before. To them, only the step cut and the mixed cut (see Figure 1) bring out beauty and colour while also saving weight. They use the same grit of diamond powder (0.5–3 μm) for polishing as the masters they learned from. (They prefer powder made of natural diamond, and specifically avoid synthetic diamond powder because they think that it does not 'feel the same'.) The dops are English-made rosewood, and they still use dop wax from Germany (Gilbertson & Prim 2019), as they have always done.

In London, the days of the cutting factory or even small studio are over. Lapidaries in Hatton Garden now mostly work in single-cutter studios. As of 2021, six gem cutters were actively working, aside from those at Chas. Mathews and Holts: Roger Duncan from England, Muhammad Ishaq (Gem Craft Lapidary Ltd) and Shabbir Khan (Khan Gems & Jewellery) from Pakistan, Kaneel Mathurata (Crystal Myths International) from Sri Lanka, Duncan McLauchlan (McLauchlan Gems) from Australia, and Bruno Zoppolato from Italy.

MODERN APPRENTICESHIPS AND THE FUTURE OF BRITISH GEM CUTTING

The apprenticing of new lapidaries in London has always been tricky. Unlike goldsmiths, who have been trained under the watchful eyes of the Goldsmiths' Company since its inception in the fourteenth century, the apprenticeship of a gem cutter depends heavily on who is doing the training. Not all master cutters are of the same skill level, so not all apprentices are prepared to reach the same heights.

Fortunately for Ken Harrington, John Taylor and Peter Rome, who apprenticed with Chas. Mathews, they learned from some of the best cutters in London (Patrick Aldridge, pers. comm. October 2019). A novice traditionally started an apprenticeship at age 14 and was bound for seven years. The master was only responsible for training and a modest wage, unlike masters in earlier centuries who were required to feed and house their apprentices together with a lower wage (Cowman 2014). When Ken Harrington started his apprenticeship in 1960, the wage was GBP2.15 per week (Ken Harrington, pers. comm. November 2019).

In those days, it took six weeks just to learn how to dop a stone. The apprentice learned by sitting next to a master cutter or polisher and watching how they worked through each step of the process. The apprentice would typically learn either cutting or polishing, depending on what the studio needed. Slowly, the master would give the apprentice more work and responsibilities, and eventually the apprentice would become specialised, such as in cutting large sapphires or polishing emeralds (Ken Harrington, pers. comm. November 2019).

After seven years, during which time a vast amount of accumulated technique had successfully been transferred, the apprentice became a specialist. Typically, the apprentice would continue to work for the same company and the wage would be raised to the salary of a full-time employee. Often, a cutter and a polisher who had apprenticed or worked together would form a partnership and friendship that would last until their retirement (Ken Harrington, pers. comm. November 2019).

Nowadays, the old jamb-peg cutting techniques have almost died out in London, and so has the tradition of training apprentices. As early as the 1930s, requests were made to the British government to start a training centre for cutters (One of them 1932; A lapidary 1934), but this never occurred. Rome and Taylor have had a few apprentices over the years, but none stayed long enough to finish their training. Fortunately, there is still hope that new cutters will emerge. Two shops have taken on the training of lapidaries, and they each follow a different approach: one uses traditional methods with jamb-peg machines, while the other uses modern techniques with mast-style machines.

Figure 13: At Holts Academy (now the British Academy of Jewellery) in Hatton Garden, apprentice Yasmin St Pierre learns the art of lapidary. Image used with permission of Holt Gems (2011).

In 2000, Holts Lapidary set up Holts Academy (which later evolved into the British Academy of Jewellery) to train the next generation of lapidaries and jewellery craftspeople (Holts Lapidary 2021; BAJ n.d.a). The school had six cabbing wheels and an American mast-style Ultra Tec faceting machine on the ground level of Holts' shop in Hatton Garden (BAJ n.d.b). Headed by Roger Dunkin and supported by Holts lapidaries Claire Westenhofer, Jan Hugye and Emma Barne, 70 people were trained in the art of gem cutting and design in the school's first year (BAJ n.d.b).

In recent years, only one apprentice lapidary has completed their training in London. Yasmin St Pierre started training at the Holts Academy in September 2016 (Figure 13; Holts Lapidary 2021). Aside from her apprenticeship there, she was also part of a new Goldsmiths' Centre apprenticeship scheme to ensure familiarity with all aspects of the jewellery trade (Helen Dobson, pers. comm. June 2019). Through her Holts apprenticeship, St Pierre learned how to cut and carve a wide variety of gem materials, from coral, turquoise and carnelian to agate, amethyst and topaz. She has won two awards for her work (Keim 2019; The Goldsmiths' Centre 2021).

The traditional British lapidary methods have not been lost either. In 2011, Ken Harrington, a former polisher at Chas. Mathews, founded Salamander Gems, a full-service jewellery company based in Ipswich, Suffolk. The facility combines a retail outlet with an extensive workshop of lapidaries and gemmologists. Over the

Figure 14: Ryan Kiddle, the UK's latest professional lapidary apprentice, is shown working at Salamander Gems in 2019. Photo by J. Prim.

past 10 years, the facility has evolved from a one-man jamb-peg studio to a facility housing six cutters, including their newest apprentice, Ryan Kiddle (Figure 14; Ken Harrington, pers. comm. November 2019). Harrington is therefore continuing the lineage of British gem cutting that he inherited through his apprenticeship in the Chas. Mathews studio in the 1970s. He has continued the ancient tradition of the British jamb peg and is passing it on to the team at Salamander Gems. In Harrington's apprentices lie the hope for the future of the lineage of traditional British lapidaries, going back to the invention of the jamb peg in the mid-1800s, to the quadrant cutters of the mid-1700s, to the Cheapside Hoard in the mid-1600s and to William Wytlesey's ring in 1374 (see Prim 2021).

THE RISE OF HOBBYIST LAPIDARIES IN BRITAIN

Interest in the amateur art of lapidary has been growing in the UK. The first lapidary club, The Kensington Lapidary Society, was founded in 1964 in Hull by Kenneth Parkinson (Wainwright 1971, p. I). By 1969, the club had 150 members, and clubs had been formed in other parts of the country, such as North Yorkshire and Hampshire. As in the United States and Australia, 'rock hounding' was an expanding hobby (Jerrard 1969).

Being an amateur cutter in the UK was initially somewhat challenging due to a lack of resources. Not only did the UK have a limited number of clubs, but they also had few locally made machines (Figure 15), so most faceting devices had to be imported. In 1973, one source reported that almost all such machines came from the United States, although Japanese cutting benches (likely Imahashi) had also been imported at the time (Fairfield 1973). A new amateur cutter could expect to spend GBP300 (GBP3,780 by today's value) to equip their studio with a faceting machine and all the needed accessories (Fairfield 1973, p. 86). Hobbyist cutters were aware that other methods of cutting were used in professional workshops, but they did not want to spend years learning to cut stones with a jamb peg when the newer mast-style machines were so easy to use.

The number of British lapidary clubs has grown, and today this community continues to provide a way for hobbyist cutters to learn the art of faceting gemstones. In 1994, many of the clubs consolidated under the umbrella of the UK Facet Cutters Guild (UKFCG 2021). Only a few of them have lapidary workshops, the most notable ones being the Scottish Mineral & Lapidary Club in Edinburgh, The Bristol Lapidary Club, The Leith Lapidary Club in Edinburgh, the NE1 Faceters group in Blaydon and the Sidcup Lapidary & Mineral Society in Kent. The lapidary club network remains one of the best ways for the layperson to become an amateur gem cutter in Britain today.

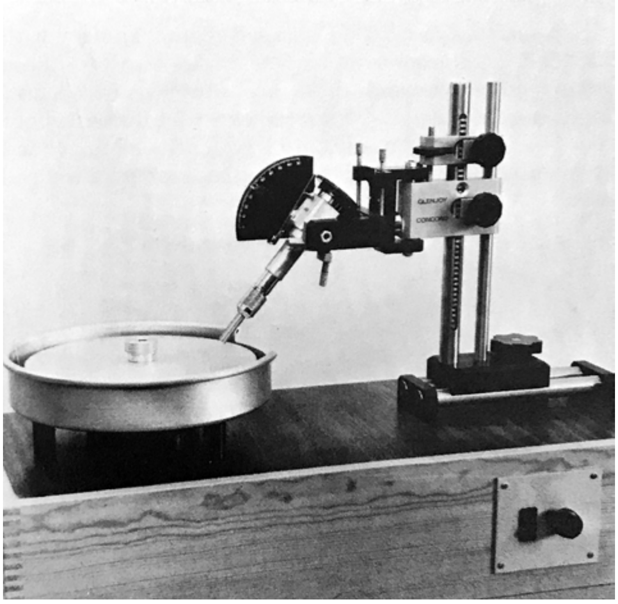

Figure 15: This photo shows a rare British-made faceting machine, the Glenjoy 'Concord' from Wakefield, England (from Scarfe 1979, p. 73). Reproduced with permission.

CONCLUSION

The story of British lapidary is intrinsically linked to gem cutting all over Europe, from the quadrant handpieces of France to the hand-cranked polishing tables that originated in Germany along with the methods of Jewish Portuguese cutters. The techniques used by professional European cutters, while not British innovations, became the traditions of British cutters through transmission from master to apprentice. However, the traditions of London lapidaries have evolved differently from those in neighbouring European cutting centres. Today, London is the only major city in the world where you can find a professional lapidary cutting a gemstone on a hand-cranked machine using a wooden jamb peg with just the cutter's expertise to place the facets.

Without support from the government and the local trade, it is likely that commercial British gem cutting will cease to exist, as it has in some other European countries. The fact that British apprentices are currently learning the art of gem cutting gives hope, but the lapidary trade needs more young people to realise that gem cutting is a learned profession that can provide employment.

Those wishing to see a representation of classic British gem cutting can view numerous stones cut by the Chas. Mathews company at the Natural History Museum in London (Figure 16). The collection was donated by Reginald Mathews in 1992 and is on permanent display in the Earth's Treasury gallery of the museum.

Figure 16: These gems are part of a collection of 268 stones cut by the Chas. Mathews company and donated by Reginald Mathews in 1992 to the Natural History Museum in London. A selection of stones from the collection is on permanent display at the museum. The box shown here measures 20 cm wide. Courtesy of NHM London, © The Trustees of the Natural History Museum, London.

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ERRATUM

In the *Journal* article by J. K Prim titled 'The History of London's Lapidaries (Part 1)' (Vol. 37, No. 7, 2021, pp. 688–701), the first two lines on p. 696 should have read: 'appeared as early as 1550 in German manuscripts such as Eucharius Roeslin's *Kreuterbůch*….' On p. 701, the reference to this manuscript should have also indicated the year as 1550. In addition, in Figure 3 the appearance of the step cut should have been given as the late 14th century.

Conferences

3RD INTERNATIONAL CONFERENCE ON TOURMALINE

The 3rd International Conference on Tourmaline (TUR2021) took place 9–11 September 2021 in Portoferraio on Elba Island, Italy, and also online for those who could not attend in person (Figure 1). The event was organised by **Drs Ferdinando Bosi** (Sapienza University of Rome, Italy), **Federico Pezzotta** (Museo Civico di Storia Naturale di Milano, Italy) and **Giovanni B. Andreozzi** (Sapienza University of Rome). It was attended by 78 participants (51 in person and 27 online) from 12 countries (e.g. Figure 2). This report summarises those presentations of greatest interest to the gemmological community. The full abstracts volume and field trip guidebook are freely available to download at www.tur2021.com.

The conference included several interesting overview presentations on tourmaline. **Drs Darrell J. Henry** and **Barbara L. Dutrow** (Louisiana State University, Baton Rouge, Louisiana, USA) reviewed tourmaline crystallography, crystal chemistry and nomenclature, as well as trends in tourmaline research. This is an active and evolving area, as shown by a sustained large number of tourmaline articles being published over the years, as well as an increase in the number of tourmaline species characterised. Currently, there are 38 species in the tourmaline supergroup and additional species are forthcoming. In another presentation, Drs Dutrow and Henry examined the origin and petrogenetic utility of magnesian tourmaline (e.g. dravite and uvite). Of note for gemmologists were the descriptions of gem-quality yellow and green tourmalines from Tanzania. Yellow tourmaline from the Arusha Region consists of dravite that formed in volcanic breccias, whereas green V-Cr-bearing 'chrome' tourmaline is typically found in a metacarbonate matrix (white calcite marble). **Paul Rustemeyer** (Gundelfingen, Germany) gave an inspirational pre-recorded presentation and 35-minute video on the inner structures of tourmaline crystals and the aesthetics of tourmaline slices. Over the past 25 years he has cut around 30,000 tourmaline slices, mostly oriented perpendicular to the *c*-axis of black specimens, which display beautiful coloured patterns (mainly as a

Figure 1: During the opening session of the TUR2021 conference, Dr Federico Pezzotta introduces Prof. Francesco Princivalle (current president of the Italian Society of Mineralogy and Petrology, the principal TUR2021 sponsor), who delivered an online lecture via Zoom. Photo by B. M. Laurs.

Figure 2: Most of the in-person TUR2021 participants gather in the courtyard of the De Laugier Cultural Centre in Portoferraio, where the conference took place. Photo courtesy of Federico Pezzotta.

result of sector zoning and concentric growth zoning) when the thin slices are viewed with transmitted light. Various growth structures and healing phenomena have been systematically and aesthetically documented in sequences of these slices, as seen in his books and in a special exhibition that is currently travelling to various museums (see What's New section in this issue, p. 760). **This author** gave an overview of tourmaline as a gem, including its species/varieties, origin determination of Cu-bearing Paraíba-type material, treatments (heating, irradiation and fracture filling), internal features and future challenges for gem-testing laboratories.

Various aspects pertaining to the chemical composition of tourmaline were examined. **Marko Bermanec** (University of Zagreb, Croatia) and co-authors described the creation of a comprehensive standardised dataset of tourmaline geochemical analyses. Data from the literature and online databases are being digitally integrated with locality and petrogenetic information, and this compilation will eventually be freely available online. **Ziyin Sun** (Gemological Institute of America, Carlsbad, California, USA) and co-authors (delivered by **Dr Aaron C. Palke**) presented a simplified species classification procedure for gem-quality tourmaline using LA-ICP-MS analyses. Details are provided in an article by Z. Sun *et al.* ('A new method for determining gem tourmaline species by LA-ICP-MS', *Gems & Gemology*, **55**(1), 2019, 2–17, https://doi.org/10.5741/GEMS.55.1.2).

As would be expected, various presentations focused on tourmaline from Elba Island. **Dr Federico Pezzotta** delivered an evening plenary lecture titled 'Elba tourmalines, over two centuries of collecting and scientific research' in a beautiful outdoor setting in the village of San Piero in Campo. He chronicled the history of Elba's gem-bearing pegmatites, including mining and research efforts from the end of the 18th century to the present, the miners and scientists involved, some famous specimens produced and their acquisition by various museums in Italy. **Dr Vanni Moggi Cecchi** and co-authors (Università degli Studi di Firenze, Italy) described the scope of the 'Elbana' mineralogical collection of the Natural History Museum at the University of Florence, Italy. In the collection are 11 holotypes (i.e. minerals first identified) from Elba, including the elbaite species of tourmaline, which was discovered in 1825. **Alessandra Altieri** (Sapienza University of Rome) and co-authors described colour anomalies at the termination of gem tourmaline crystals from Elba Island. She proposed that late-stage enrichments in Mn and Fe (associated with the dark-coloured caps on these crystals) are due to fluids that were influenced by chemical alteration of pre-existing spessartine and biotite in the host pegmatites; these fluids were introduced during so-called 'pocket rupture' events towards the end of the crystallisation of the gem-bearing cavities.

Other tourmaline localities were covered in additional presentations. **Monika Kubernátová** and **Dr Jan Cempírek** (Masaryk University, Brno, Czech Republic) studied Pb-rich tourmaline from various deposits, including gem-quality material from Minh Tien, Vietnam, which was previously documented to contain up to 17.5 wt.% PbO. The highest Pb contents in their samples were measured in the latest generations of tourmaline to crystallise, and they ascribed this Pb enrichment to the alteration of amazonite in the host pegmatite. **Matthew C. Taylor** (Vista, California, USA) discussed the origin of gem-tourmaline-bearing granitic pegmatites of the Peninsular Ranges Batholith in Southern California, USA. He proposed that the pegmatite magmas were derived from parent granites (monzogranites adjacent to tonalite bodies) during shearing events, and then the melts intruded fractures in the surrounding rocks and underwent process-driven (rather than chemically driven) crystallisation from volatile-rich gel-like media. **Alexander U. Falster** and co-authors (Maine Mineral & Gem Museum, Bethel, Maine, USA) documented the occurrence and chemical composition of gem-quality fluor-elbaite from the Emmons pegmatite in Oxford County, Maine. During the 1990s, five pockets were found in the lower part of the pegmatite that ranged up to 40 cm in dimension and contained tourmaline (pink, blue, green and colour zoned), lepidolite, microcline and albite feldspars, quartz, muscovite and cookeite. The largest tourmaline was 26 cm long but had been broken into several segments by natural forces. **Dr Lee A. Groat** (University of British Columbia, Vancouver, Canada) reviewed gem-deposit research in Canada and implications for future exploration activities. Of particular interest to tourmaline aficionados is the occurrence of gem-quality elbaite in the O'Grady batholith, Northwest Territories.

Experimental studies on tourmaline were documented in several presentations, and three of them were noteworthy for gemmologists. **Dr Andreas Ertl** (University of Vienna, Austria) examined the interesting question, 'Why was it not possible to synthesise Li-rich tourmaline?' He emphasised that most lithium tourmalines in nature consist of fluor-elbaite rather than elbaite, and that synthesis efforts should focus on growing this species at moderate pressures and temperatures of >550°C, with relatively high amounts of Li and F in the starting material. **Dr Tatiana Setkova** (D. S. Korzhinskii Institute of Experimental Mineralogy, Chernogolovka, Russia) and co-authors described efforts to produce Ga- and Ge-rich synthetic tourmaline. So far, the experiments have not been successful at growing single-crystal material, but only overgrowths (up to 1.2 mm) on tourmaline seeds. **Beatrice Celata** (Sapienza University of Rome) and co-authors performed laboratory experiments to investigate the conditions under which tourmaline breaks down in nature. In one experiment, heating of a gem-quality sample of Mn-bearing purplish red elbaite from Madagascar initially caused a decrease in the *a* cell parameter at 750°C due to the oxidation of Mn^{2+} to Mn^{3+}, followed by tourmaline breakdown (i.e. formation of B-bearing mullite, an aluminium silicate) at 825°C.

The oral presentations closed with a thought-provoking lecture by **Dr Michele Macrì** (Museo Universitario di Scienze della Terra, Sapienza University of Rome), who discussed 'Gemmology vs mineralogy: Problems, solutions and opportunities'. The two disciplines share much in common, but nomenclature issues arise from the different backgrounds and approaches (commercial vs scientific) that are often taken by gemmologists and mineralogists. Dr Macrì proposed that greater cross-linking between the disciplines could come from organising joint workshops and conferences, offering university-taught gemmology courses (e.g. field studies and advanced analytical techniques), and fostering greater collaboration between the gem industry and academia.

The poster session included two presentations of interest to gemmologists. **Drs Aaron J. Lussier** (Canadian Museum of Nature, Ottawa, Ontario, Canada) and **Frank C. Hawthorne** (University of Manitoba, Winnipeg, Canada) documented trace-element patterns determined by LA-ICP-MS in oscillatory-zoned liddicoatite from Anjanabonoina, Madagascar. The incorporation of trace elements into this complexly patterned tourmaline is affected by subtle differences in the ionic and crystallographic characteristics of the growth system. **Petra Kardošová** (Comenius University, Bratislava, Slovakia) and co-authors performed heat-treatment experiments on three Mg-dominant tourmalines: (1) brown dravite from Yunnan, China, (2) black schorl-dravite from Rubeho Mountains, Tanzania, and (3) black Cr-bearing fluor-uvite from Merelani Hills, Tanzania. No visual changes were observed in the tourmalines after heat treatment.

Alessandra Altieri received an award for the best presentation given by a young female scientist at the conference. During one evening, conference attendees visited the MUM–Mineralogical Museum 'Luigi Celleri' in San Piero in Campo, where they saw an impressive exhibition of mineral specimens and cut gemstones from Elba Island. In addition, a post-conference field trip took participants to visit some classic localities for Elba tourmaline, including several famous pegmatites and the type localities for various tourmaline species.

The 4th International Conference on Tourmaline is scheduled to take place in 2025 at a location to be determined.

Brendan M. Laurs FGA

Gem-A Notices

MESSAGE FROM GEM-A CEO ALAN HART

It has been a busy quarter here at Gem-A, with both our conference and graduation ceremony taking place in early November 2021. For those of you who attended our first-ever online conference, we would like to extend our sincerest thanks for joining the various sessions that ran throughout the day. An encouraging 98% of our Members told us that they found the talks engaging and relevant, and we have our knowledgeable speakers to thank for being so generous with their time and expertise—I am sure you will join me in offering them a huge 'well done'!

Similarly, our graduation ceremony—which this year took place at Church House in Westminster—was a resounding success. Meeting and awarding our enthusiastic graduates is always one of the genuine highlights of my year, and doing so for both this years' graduates and those who achieved their diplomas despite the turbulence of 2020, was no exception. I would also like to take this opportunity to offer personal thanks to Gem-A alumnus and jewellery specialist Kate Flitcroft FGA. Kate delivered a rousing and inspirational graduation speech that illuminated the many possibilities open to our talented graduates—congratulations once again to everyone involved!

Although the year may be drawing to a close, Gem-A is thrilled to announce that soon we will launch our first-ever introductory course, *GemIntro*. This interactive online course is intended to give those starting off or considering a career in gems or jewellery an insight into the basics of our trade, and a taste of what to expect should they pursue their passion in gemmology. Look out for more details soon.

Speaking of the new, we have also now opened the window on membership renewals for 2022. You should have already received an email inviting you to renew. What's more, if you renew before 31 December, you can also take advantage of our early-bird discounted fee. We look forward to your continued support, and hope you enjoy the many benefits of being a Gem-A Member.

Looking ahead to next year, we have begun preparing for the Tucson gem shows in February. This time, we are teaming up with both CGA and AGA to deliver our Gem-A Bash, which will take place on 1 February 2022 at the Tucson Marriott University Park hotel. I look forward to catching up with many of you then!

All that remains is for me to wish you a very happy Holiday Season from all of us at Gem-A, whatever this festive time of year holds in store for you, and we look forward to seeing you in 2022.

GEM-A CONFERENCE, GRADUATION AND PRESENTATION OF AWARDS

In the first week of November 2021, Gem-A hosted two significant events for its Members and Students, signalling a return to some in-person events and the continuation of Gem-A's annual conference tradition.

The Gem-A Online Conference 2021 took place on Sunday 7 November, and included a line-up of 10 speakers covering historic diamonds, international royal collections, jewellery design, and the gemmological properties of beryl and tourmaline. The conference also focused on a range of 'trending' topics in the UK and international gem trade, including issues of responsible and sustainable sourcing, and the screening of laboratory-grown diamonds using portable instruments. More than 300 Members registered to attend, and engagement was high across the talks. Members also actively participated in asking questions, which helped to foster a sense of community among those who logged in. We will be making select sessions available on Gem-A's YouTube channel, and you can receive alerts by subscribing at www.youtube.com/gemaofficialchannel.

The conference was followed by the Gem-A Graduation Ceremony and Presentation of Awards on the evening of Monday 8 November, hosted at Church House in London, where participants enjoyed balcony views across Westminster Abbey. It was accompanied by a drinks reception for Graduates and guests in Hoare Memorial Hall, where Winston Churchill delivered historic announcements during his premiership.

Gem-A has long reserved the first weekend in November to host its most anticipated annual events, including the Gem-A Conference, field trips to the Natural History Museum and Tower of London, and its annual Graduation Ceremony and Presentation of Awards. These in-person events have been well-attended by international delegates, speakers and students.

'COVID-19 restrictions did force us to make changes in our annual in-person events, but we are reintroducing the Gem-A Conference and Graduation Ceremony in ways that are safe, effective and for the benefit of our Members and Students,' explained Alan Hart FGA DGA, chief executive officer of Gem-A. He continued, 'This year's Gem-A Online Conference included a fantastic line-up of speakers, and our Graduation Ceremony was once again a fitting tribute to our Students, many of whom achieved their Gemmology Foundation, Gemmology Diploma and Diamond Diploma qualifications in 2020. It was important to all of us at Gem-A that we recognise the achievements of all of our students who have tackled our courses in unusual and challenging global circumstances.'

Participants at Gem-A's combined 2020–2021 graduation ceremony. Photo by Tempest Photography.

GEMMOLOGY DIPLOMA PASSES

Kuerbanjiang Adilai, P.R. China
Kimberly Ahonen, Singapore
Husna Alderazi, Bahrain
Raphaël Amacker, Switzerland
Gamitha Hasanga Amarasena, Sri Lanka
Edgar Attie, Monaco
Wing See Au Yeung, Hong Kong (S.A.R.)
Chika Baba, Japan
Tinatin Baikoff, France
Frédérique Bello Cortes, France
Dr Carolyn Browne, The Netherlands
Alexia Iris Bryson, Canada
Tharcisse Byaje, Madagascar
Yosef Caldaron, United States of America
Ying Cao, P.R. China
Kok Lam Chan, Hong Kong (S.A.R.)
Wai In Chao, P.R. China
Jiajing Chen, P.R. China
Jingwen Chen, P.R. China
Mingcan Chen, P.R. China

Mingxue Chen, P.R. China
Siying Chen, P.R. China
Wan Chen, P.R. China
Wanting Chen, P.R. China
Xiaoran Chen, P.R. China
Yifang Chen, P.R. China
Yulin Chen, P.R. China
Yumeng Chen, P.R. China
Yuying Chen, P.R. China
Man Kuen Kannus Cheng, Hong Kong (S.A.R.)
Si-Xing Season Cheng, United Kingdom
Chun Kit Keith Chow, P.R. China
Shichen Chu, P.R. China
Hei Tung Chui, Hong Kong (S.A.R.)
Tina Cole, United Kingdom
Boyang Cui, P.R. China
Qi Dai, P.R. China
Shangzhan Dai, P.R. China
Agnieszka Deja, France
Guanqiong Deng, P.R. China
Brice Diffon, Switzerland
Yihang Ding, P.R. China
Lan Dong, P.R. China
Linling Dong, P.R. China
Shuxin Dong, P.R. China
Zeping Dong, P.R. China
Mingjun Du, P.R. China
Delphine du Breuil, France
M. Benoît Du Fayet De La Tour, France
Qiqi Duan, P.R. China
Reina Endo, Japan
Jessica Ann Fall, United Kingdom
Lanxi Fan, P.R. China
Mengxiao Fan, P.R. China
Xiaowen Fan, P.R. China
Thomas William Plant Forrester, United Kingdom
Lei Ngar Isabella Fu, Hong Kong (S.A.R.)
Eri Fuchino, Japan
Fukiko Fukumoto, Japan
Marie Galgani, France
Lixuan Gao, P.R. China
Luer Gao, P.R. China
Xin Gao, P.R. China
Yang Gao, P.R. China
Yuekai Gao, P.R. China
Valaya Gaudet, United States of America
Enzo Fenohasina Georget, Madagascar
Patience Mtinkeni Gondwe, The Netherlands
Charlotte Reedtz Grierson, United Kingdom
Xue Gu, P.R. China
Ying Gu, P.R. China
FangFang Guo, P.R. China
Yi Guo, P.R. China
Yuming Guo, P.R. China
Dong Guyuan, P.R. China
Wenjing Han, P.R. China
Yue Hao, P.R. China
Lifang He, P.R. China
Samantha Homes, United Kingdom
Yanan Hong, P.R. China
Yiqiu Hong, P.R. China
Dan Hu, P.R. China
Hsiang Yun Hu, Taiwan (R.O.C.)
Xiaoyun Martina Hu, P.R. China
Yangcheng Hu, P.R. China
Wei Hua, P.R. China
Jing Huang, P.R. China
Wanlin Huang, P.R. China
Xuren Huang, P.R. China
Yuanjing Huang, P.R. China
Leyla Ismail, United Kingdom
Jeroen Adrianus Wilhelmus Janssen, The Netherlands
Peng Ji, P.R. China
Lu Lu Jia, P.R. China
Hanyi Jiang, P.R. China
Shuzhen Jiang, P.R. China
Xin Yu Jiang, P.R. China
Yuqian Jiang, P.R. China
Leng Jianhui, P.R. China
Yang Jie, P.R. China

Michelle Marco Jirkovsky, United States of America
Simon Johnson, United Kingdom
Nichola Elizabeth Jones, United Kingdom
Tzu-Ting Kao, Taiwan (R.O.C.)
Noémie Keuleyan, France
Ziad H. Khaled, Bahrain
Yurika Kimura, Japan
Lok Ting Ko, P.R. China
Ayaka Koda, Japan
Wu-Chiang Kuo, Taiwan (R.O.C.)
Zoe Tung Kwok, Hong Kong (S.A.R.)
Fung Chi Charlie Lai, Hong Kong (S.A.R.)
Hiu Ching Francesca Lam, Hong Kong (S.A.R.)
Jianghai Lan, P.R. China
Shuai Lan, P.R. China
Nicolas Langerock, France
Changling Lao, P.R. China
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Nannan Le, P.R. China
Sarah Lee, United Kingdom
Tsz Ching Lee, P.R. China
Yuan-Chi Lee, Taiwan (R.O.C.)
Melissa Lee-Patrick, United Kingdom
Ka Yee Leung, Hong Kong (S.A.R.)
Claire Leydier-Durieux, France
Bohao Li, P.R. China
Coco JingWen Li, P.R. China
Fengyi Li, P.R. China
Heshan Li, P.R. China
Huiqiong Li, P.R. China
Jiayao Li, P.R. China
Li Li, P.R. China
Lin Ye Li, P.R. China
Mingli Li, P.R. China
Xinyang Li, P.R. China
Xinyi Li, P.R. China
Yixiu Li, P.R. China
Yuanjing Li, P.R. China
Yumei Li, P.R. China
ShiYao Liang, P.R. China
Xiaochun Lin, P.R. China
Que Liping, Singapore
Chen Liu, P.R. China
Junyu Liu, P.R. China
Qi Liu, P.R. China
Qian Liu, P.R. China
Qianyu Liu, P.R. China
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Wei Liu, P.R. China
Xiaoyu Liu, P.R. China
Xueli Liu, P.R. China
Yitong Liu, P.R. China
Yixuan Liu, P.R. China
Yu Liu, P.R. China
Yuchen Liu, P.R. China
Yuting Liu, P.R. China
Qi Lu, P.R. China
Siyu Lu, P.R. China
Zengqi Lu, P.R. China
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Kwan Lui Man, P.R. China
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Di Ma, P.R. China
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Julien Martineau-Fabre, France
Honda Megumi, Japan
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Mihaja Liantsoa Loren Randriamahefa, Madagascar
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Megan Christina Shepherd, United Kingdom
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Yutong Shi, P.R. China
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Moemi Sugimura, Japan
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Qiman Sun, P.R. China
Xiaowan Sun, P.R. China
Yizhan Sun, P.R. China
Miyoshi Suzuki, Japan
Yu Suzuki, Japan
Huei-Ting Tang, Taiwan (R.O.C.)
Ting Tang, P.R. China
Yeling Tang, P.R. China
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Zhang Tiantian, P.R. China
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Ling Wang, P.R. China
Lu Wang, P.R. China
Shasha Wang, P.R. China
Shuqi Wang, P.R. China
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Wei Wang, P.R. China
Xinyi Wang, P.R. China
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Peiqi Wu, P.R. China
Ting Kai Wu, Taiwan (R.O.C.)
Yizhen Wu, P.R. China
Ling Xiang, P.R. China
Jing Xiao, P.R. China

Qirun Xiao, P.R. China
Xinye Xiao, P.R. China
Xuejuan Xie, P.R. China
Guanghui Xu, P.R. China
Na Xu, P.R. China
Qian Xu, P.R. China
Xiaofeibai Xu, P.R. China
Yi Xu, P.R. China
Liu Xudong, P.R. China
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Jingqi Yang, P.R. China
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Weikun Yin, P.R. China
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Hongwei Yu, P.R. China
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Fang Yu, P.R. China
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Fuheng Zhang, P.R. China
Hangyu Zhang, P.R. China
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Jing Zhang, P.R. China
Letian Zhang, P.R. China
Lin Zhang, P.R. China
Na Zhang, P.R. China
Nina Zhang, P.R. China
Ningning Zhang, P.R. China
Xiaojuan Zhang, P.R. China
Yafan Zhang, P.R. China
Yanglin Zhang, P.R. China
Yaoyao Zhang, P.R. China
Yijun Zhang, P.R. China
Ying Zhang, P.R. China
Yue Zhang, P.R. China
Ziqi Zhang, P.R. China
Chang Zhao, P.R. China
Jiazheng Zhao, P.R. China
Rui Zhao, P.R. China
Fusheng Zhong, P.R. China
Chen (Isabelle) Zhou, P.R. China
Hang Zhou, P.R. China
Mengyuan Zhou, P.R. China
Yijun (Delia) Zhou, P.R. China
Luxiao Zhu, P.R. China
Yanli Zhu, P.R. China
Ji Hong Zou, P.R. China
Yang Zou, P.R. China

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Dalila Falato, United Kingdom
Yan Fang, P.R. China
Wenyi Fei, P.R. China
Derek Jackson, Canada
Zoe Kerridge-Biosse Duplan, United Kingdom
Na Li, P.R. China
Ning Li, P.R. China
Sachiko Mori, Japan
Sophie Charlotte Padfield, United Kingdom
Tomoko Sasaoka, Japan

Tianyi Shen, P.R. China
Florie Sou, France
Kuniko Takahashi, Japan
Emi Uematsu, Japan
Jingxuan Wang, P.R. China
So-Mei Vivian Wong, Hong Kong (S.A.R.)
Yufei Zhou, P.R. China

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He Li, P.R. China
Ci Lu, P.R. China
Aurore Mélienne Colette Mathys, United Kingdom
Rebecca Matthews, United States of America
Yan Wang, P.R. China

DIAMOND DIPLOMA PASSES

Anouska Banks, United Kingdom
Chi-Lan Chang, Taiwan (R.O.C.)
Un-Man Chao, Taiwan (R.O.C.)
Huang-Ju Chen, Taiwan (R.O.C.)
Jack Cherry, United Kingdom
Chak Wa Cheung, P.R. China
Chun Him Cheung, Hong Kong (S.A.R.)
Ka Ming Cheung, P.R. China
Wai Man Cheung, Hong Kong (S.A.R.)
Siu Wai Cho, Hong Kong (S.A.R.)
Hei Yuen Destin Chow, Hong Kong (S.A.R.)
Lok Man Chow, Hong Kong (S.A.R.)
David A. Clark, United Kingdom
Simone Dunlop, United Kingdom
Will Ellin, United Kingdom
Xue Gao, P.R. China
Zuleika Gerrish, United Kingdom
Claire Haywood-Dunn, United Kingdom
Sarah Joanne Howson, United Kingdom
Shih-Han Huang, United Kingdom
Yayu Huang, United Kingdom
Timofey Ignatov, United Kingdom
Jie Jiang, Hong Kong (S.A.R.)
Kerri Louise Keeling, United Kingdom
Jane Marie Kharade, United Kingdom
Yan Kit Ingrid Law, Hong Kong (S.A.R.)
Sin Ying Lee, Hong Kong (S.A.R.)
Yim Ping Leung, P.R. China
Geng Li, P.R. China
Yingxin Liu, P.R. China
Qi Lu, P.R. China
Sui Ting Mak, Hong Kong (S.A.R.)
Ka Kei Ng, Hong Kong (S.A.R.)
Yuk Ting Ng, Hong Kong (S.A.R.)
Aileen Poon, Hong Kong (S.A.R.)
Wai-In Ruby Sam, Taiwan (R.O.C.)
Peter Sandberg, Sweden
Kin Mei Siu, Hong Kong (S.A.R.)
Jo-Jie Shih, Taiwan (R.O.C.)
Ming Chu Sze, P.R. China
Maya Aisun Taylor-West, United Kingdom
Pui Ki Tsang, Hong Kong (S.A.R.)
Lung Shing William Wai, P.R. China
Jiaxin Wang, P.R. China
Oliver Webb, United Kingdom
Man Ting Wong, Hong Kong (S.A.R.)
Shiu Ting Wu, Hong Kong (S.A.R.)
On Ting Alice Yang, Hong Kong (S.A.R.)
Yachu Yang, United Kingdom
Jiahui Ye, Hong Kong (S.A.R.)
Wing Ling Yeung, Hong Kong (S.A.R.)
Yanyi Flora Zhou, Hong Kong (S.A.R.)

DIAMOND DIPLOMA PASSES WITH MERIT

Sophia Christina Ericsdotter Akerlund, Sweden
Mei Chin Wai Chung, P.R. China
Sophie Evans, United Kingdom
Nicole Summer Flavell-Avery, United Kingdom
Nancy Anne Herdman, United Kingdom
Anna Kerr, United Kingdom
Baoming Li, France
Francesca Lockton, United Kingdom
Asha Nayak, United Kingdom
Jonathan Stokes, United Kingdom
Rachel Elizabeth Weekes, United Kingdom

DIAMOND DIPLOMA PASSES WITH DISTINCTION

Dalila Falato, United Kingdom
Dr Juliette Hibou, United Kingdom
Harishkumar Lodhia, United Kingdom
Patricia Negus, United Kingdom
Floriane Van Den Brande, United Kingdom
Ilona Aurelia Walentynowicz, United Kingdom

PRIZE AND MEDAL WINNERS

Awards and prizes are presented to the best candidates of the year, selected from our students worldwide.

GEMMOLOGY FOUNDATION CERTIFICATE

Anderson Medal

Awarded to the candidates submitting the best papers of the year in the Gemmology Foundation examination.

This medal was established in 1981 in honour of Basil W. Anderson FGA*, former Director of the Gem Testing Laboratory, London.*

2021 Winners: Daria Mironova, a student from L'École des Gemmes, Bourg La Reine, France and Vishesh Vassantray, a student from the Bureau de Géologie et de Gemmologie de Madagascar.

GEMMOLOGY DIPLOMA

Anderson Bank Prize

Awarded to the candidates submitting the best theory papers of the year for the Gemmology Diploma examination.

Established in 1981 and named after Basil W. Anderson FGA *and Prof. Dr Hermann Bank* FGA*, former director of the German Gemmological Association in Idar-Oberstein, Germany.*

2021 Winner: So Mei Vivian Wong, a student from the Asian Gemmological Institute and Laboratory Ltd, Hong Kong.

Christie's Prize for Gemmology

Awarded to the candidates submitting the best papers of the year for the Gemmology Diploma examination.

This prize was established in 1954 as the Rayner Prize, renamed the Diploma Trade Prize in 1991, replaced and sponsored from 2001 by Christie's London.

2021 Winners: Rebecca Matthews, a student from Jewelry Television (JTV), USA and Aurore Mathys, a student from Gem-A, London.

The Read Practical Prize

Awarded to the candidate submitting the best practical papers of the year for the Gemmology Diploma examination.

First awarded in 2009 and named in memory of Peter Read FGA*, author and former tutor for Gem-A. In 2021, the prize was sponsored by Richard Drucker* FGA (Hons) *of Gemworld International.*

2021 Winner: Shi Qiao, a student from China University of Geosciences, Wuhan (Beijing Branch), China.

DIAMOND DIPLOMA

Bruton Medal

Awarded to the overall best candidate of the year in the Diamond Diploma examination.

This silver medal was established in 1996 in honour of Eric Bruton FGA to recognise his work in the field of diamonds.

2021 Winner: Dr Juliette Hibou, an online distance learning student from the UK.

Gem-A would like to congratulate all of our students who achieved such fantastic results!

MEMBERSHIP RENEWAL NOTICE

The renewal window for 2022 is now open to Members. As we continue to adjust and recover from the impact of the COVID pandemic, we have tried to make it easier for you to renew your membership, and we wish to assure you that our Association remains resilient and will continue to flourish during these uncertain times. Renew your membership before 31 December 2021 and take advantage of our early bird discount! Pay now for just £110* and get your post-nominals, access to eight publication issues a year—including the prestigious *Journal of Gemmology* and insightful *Gems&Jewellery*—and a discount on all GI instruments and equipment. Check your email for your invitation to renew.

*Membership fee increases to £135 after 31 December 2021.

GIFTS TO THE ASSOCIATION

Gem-A is most grateful to our generous donors, who support continued research and teaching:

Michal Kosior, Amber Experts, Poland, for some specimens of Polish amber and images of the mine they came from.

Sherril Dixon, Windy Gemstones, United Kingdom, for a set of lustre comparison stones, a set of Mohs hardness minerals and a set of geological samples.

James Evans, Lustre Gemmology Ltd, United Kingdom, for a Sheffield Red Compensator and two copies of his book titled *The History of Synthetic Ruby*.

A WEBINAR WITH THE EDITOR

Go behind the scenes at *The Journal of Gemmology* by tuning in to our ongoing webinar series with Editor-in-Chief Brendan Laurs FGA, on 19 January 2022 at 17:00 GMT. Join us as we hear Brendan discuss the current issue of *The Journal* with Gem-A's CEO Alan Hart FGA DGA, explaining how the issue was developed and focusing in greater detail on some of the fascinating feature articles and Gem Notes. To register your place, head to: https://linktr.ee/gemaofgb. Did you miss our last session of Gem-A Live with Brendan? Head to Gem-A's YouTube Channel and watch it now: www.youtube.com/c/GemAOfficialChannel.

Learning Opportunities

Note: Event dates and formats are subject to change depending on the COVID-19 situation.

CONFERENCES AND SEMINARS

23rd Federation for European Education in Gemmology (FEEG) Symposium
29 January 2022
Paris, France
www.feeg-education.com/symposium

NAJA 57th ACEit© Winter Conference
30–31 January 2022
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
1–6 February 2022
Tucson, Arizona, USA
https://agta.org/agta-gem-fair-tucson/seminars
Note: Includes a seminar programme

AGA Tucson Conference
2 February 2022
Tucson, Arizona, USA (and online)
https://accreditedgemologists.org/currevent.php

7th International Gem & Jewelry Conference (GIT 2021)
2–3 February 2022
Chanthaburi, Thailand (and online)
https://gitconference2021.com

Tucson Gem and Mineral Show
10–13 February 2022
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
11–14 February 2022
Munich, Germany (and online)
www.inhorgenta.com/en
Note: Includes a seminar programme

Hong Kong International Jewellery Show
3–7 March 2022
Hong Kong
https://event.hktdc.com/fair/hkjewellery-en/HKTDC-Hong-Kong-International-Jewellery-Show
Note: Includes a seminar programme

Hasselt Diamond Workshop 2022 (SBDD XXVI)
9–11 March 2022
Hasselt, Belgium
www.uhasselt.be/SBDD

American Gem Society Conclave
25–27 April 2022
Oklahoma City, Oklahoma, USA
www.americangemsociety.org/conclave-2022

Scottish Gemmological Association Conference
29 April–2 May 2022
Cumbernauld, Scotland
www.scottishgemmology.org/hotelandtransport

Association for the Study of Jewelry and Related Arts (ASJRA) Conference
21–22 May 2022
Online
www.jewelryconference.com

34th Santa Fe Symposium
22–25 May 2022
Albuquerque, New Mexico, USA
www.santafesymposium.org

JCK Las Vegas
10–13 June 2022
Las Vegas, Nevada, USA
https://lasvegas.jckonline.com
Note: Includes a seminar programme

5th International Conference on Innovation in Art Research and Technology (inArt 2022)
28 June–1 July 2022
Paris, France
https://inart2022.sciencesconf.org
Note: Mobile instrumentation will be among the topics covered

Sainte-Marie-aux-Mines Mineral & Gem Show
23–26 June 2022
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a workshop on emerald

Goldschmidt2022
10–15 July 2022
Honolulu, Hawaii, USA (and online)
https://2022.goldschmidt.info
Session of interest: Gems and Gem Minerals as Precious Indicators of Diverse Earth Processes

NAJA 58th Annual Mid-Year Education Conference
13–14 August 2022
Online
www.najaappraisers.com/html/conferences.html

32nd International Conference on Diamond and Carbon Materials
4–8 September 2022
Lisbon, Portugal
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

Maine Pegmatite Workshop
7–12 September 2022
Bethel, Maine, USA
www.maine-pegmatite-workshop.com

International Colored Gemstone Association (ICA) Congress
September 2022 (exact dates TBA)
Shenzhen, China
www.gemstone.org/ica-congresses

13th Annual Portland Jewelry Symposium
2–3 October 2022
Portland, Oregon, USA
https://portlandjewelrysymposium.com

OTHER EDUCATIONAL OPPORTUNITIES

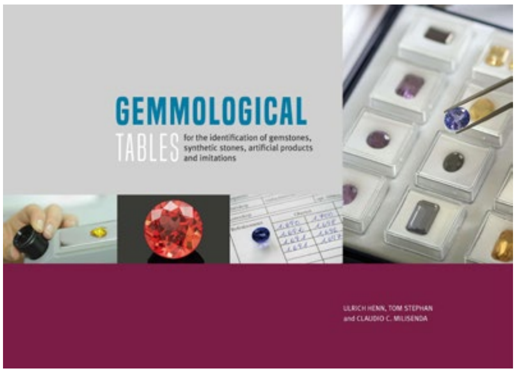
Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Gemstone Safari to Tanzania
12–29 January 2022 and 6–23 July 2022
www.free-form.ch/tanzania/gemstonesafari.html

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Tim Schroder—Jewels at the Court of Henry VIII
  25 January 2022
- Rebecca Roberts—Jewellery and Power in Iron Age Kazakhstan
  22 February 2022
- Natasha Awais-Dean—Jewels Captured in Perpetuity: The Jewellery Book of Anne of Bavaria
  22 March 2022
- Gonçalo de Vasconcelos e Sousa—An Aspect of Portuguese Jewellery
  24 May 2022
- Karl Schmetzer—The Late 14th-Century Royal Crown of Blanche of Lancaster
  28 June 2022
- Maria Filomena Guerra—Fresh Scientific Insights in Ancient Egyptian Gold Technology
  27 September 2022
- Usha Balakrishnan—The Jewellery of the Nizam of Hyderabad
  22 November 2022

New Media



Gemmological Tables for the Identification of Gemstones, Synthetic Stones, Artificial Products and Imitations/ Gemmologische Tabellen zur Bestimmung von Edelsteinen, Synthesen, künstlichen Produkten und Imitationen, 4th edn.

By Ulrich Henn, Tom Stephan and Claudio C. Milisenda, 2020. Deutsche Gemmologische Gesellschaft e.V. and German Gemmological Association, Idar-Oberstein, Germany, 42 pages, illus., ISBN 978-3000648564 (English) or ISBN 978-3000648557 (German). EUR25.00 softcover.

Compiling and updating gemmological tables is a monumental task that challenges even the best gemmologists. The team of Drs Ulrich Henn, Tom Stephan and Claudio Milisenda at the DSEF German Gem Lab have managed to provide a set of the most comprehensive tables of gemmological properties to date. These tables cover natural and synthetic gem materials, organic substances, artificial products and imitations. The layout features 11 columns of properties, starting with a column of ascending RI values conveniently located on the far left of each page. This is followed by birefringence, optic character, density (or SG), colour, transparency, pleochroism, hardness/cleavage, the gem material's name and chemical composition (along with crystal system) and, finally, notes on additional characteristics such as structure, fluorescence, inclusions, absorption spectrum features, reaction to hydrochloric acid, etc. All nomenclature corresponds to CIBJO recommendations, and the commercially more important gems appear in bold type. The tables are organised in a calendar-like spiral-bound format that makes it easy to flip through when searching for a gem in question.

Some of the more unusual materials included in the tables are preobrazhenskite, zektzerite, goyazite, shomiokite (actually shomiokite-(Y) according to current International Mineralogical Association guidelines), väyrynenite and bahianite. While a gemmologist is not likely to see these materials in everyday settings, their presence in the tables is nonetheless appreciated since they are cuttable and therefore could show up for sale as a loose collector gem or in a finished piece of jewellery.

Towards the end of the publication is a handy table of stone densities organised in ascending order and which includes the corresponding page where the other properties of that gem can be found. These are followed by two pages featuring 22 of the more important characteristic absorption spectra, as seen in colour through a diffraction-grating spectroscope. These visible-spectrum images are quite useful because they allow one to compare the entire characteristic spectral scene with the individually listed absorption lines and bands provided in the corresponding (11th) column of the tables. Mastering these spectral characteristics using a portable diffraction-grating spectroscope is one of the most difficult—but also most helpful—techniques for any gemmologist wishing to make accurate determinations in the field. (The lightweight portability of *Gemmological Tables* also makes this publication a useful tool for the travelling gemmologist or buyer.) Finally, the last three pages contain an alphabetical index of 485 cuttable materials that have been observed by the authors to date.

This reviewer consulted several publications (Wigglesworth 1948; Günther 1988; GIA 1992; Lazzarelli 2010) to randomly compare previous data with those listed in this new set of tables, and found no errors or inconsistencies. One very minor note is that 'Tourmaline' and 'Tourmaline cat's eye' appear on page 16, rather than on page 15 as listed in the index.

I highly recommend these *Gemmological Tables* to students, young professionals and seasoned experts looking for a comprehensive yet easy-to-use listing of gem properties.

Edward Boehm FGA
RareSource, Chattanooga, Tennessee, USA

References

GIA 1992. *Gem Property Chart A and Gem Property Chart B*. Gemological Institute of America, Santa Monica, California, USA.

Günther, B. 1988. *Tables of Gemstone Identification*, 2nd edn. Vlerlagsbuchhandlung Elizabeth Lenzen, Kirschweiler, Germany, 162 pp.

Lazzarelli, H.N. 2010. *Gemstones Identification: Blue Chart*. Self-published, 18 pp.

Wigglesworth, E. 1948. *Properties of Gem Varieties of Minerals*. Gemological Institute of America, Los Angeles, California, USA, 62 pp.

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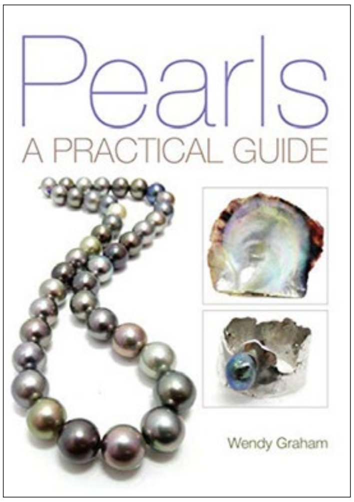

Pearls: A Practical Guide

By Wendy Graham, 2021. The Crowood Press, Marlborough, Wiltshire, www.crowood.com/products/pearls-by-wendy-graham, 96 pages, illus., ISBN 978-1785008122 or e-ISBN 978-1785008139. GBP12.99 softcover or GBP9.99 eBook.

This book includes a mixture of basic information for the interested consumer as well as some slightly more technical information for the hobbyist. It also chronicles the author's own experiences working in the pearl industry.

From a technical standpoint, the information covered in the first chapter, titled 'Pearl Basics', is in some cases confusing and leaves quite a bit to be desired. Calcite is hexagonal, but here it is described as amorphous. And the mention of hexagonal aragonite platelets infers that aragonite is hexagonal, when actually aragonite is orthorhombic and should be described as 'pseudo-hexagonal'. The simplified diagram of a generic bivalve mollusc is interesting, but the key to the specific parts of the mollusc is in such small print as to be unreadable. Many of the photographs appear slightly out of focus, without the sharpness one would expect in a well-produced book. A very generalised pearl-grading system is presented, with cautions that it is not absolute. Descriptions of pearl shapes are helpful, but not all shapes mentioned are depicted.

Chapter 2, 'From Farm to Customer', is a bit more straightforward and offers a glimpse into how oysters are stocked and raised in a pearl farm. Raising the molluscs and selecting mantle-tissue donors are described, as is the implantation process. Sorting and grading of the pearls is typically done at a site away from the actual farm.

The Maeshori treatment is mentioned as a commonly performed process involving heating and then cooling to enhance lustre, but the process may make the nacre more brittle. Silicone polymer or lacquer coatings can also be used on inexpensive cultured pearls to enhance their lustre, and the author mentions that they may also be applied in thick layers that are then faceted. This reviewer is not aware of such a practice, and by comparison true faceted pearls are high-quality products with surfaces that are faceted to show off the natural lustre of the nacre. This would have been a good place to discuss the 'peeling' of pearls, where surface layers of nacre are removed to eliminate dark spots and blemishes, but unfortunately this practice is not mentioned. Bleaching and the addition of dyes are described, with descriptions of some of the more common attempts to deceive.

After undergoing any treatments, pearls are then sized, sorted and graded to be matched into strands or, if they are of particularly good quality, sold individually. This difference in how they are sold is repeated several times throughout the book. Trade shows in Hong Kong and Tucson (Arizona, USA) are mentioned as venues where pearls are sold to the retailer for final sale to the end consumer. A box at the end of this chapter discusses the effects of global warming on pearl farms and their production rates. Increased warming, salinity, acidification and contamination affect the ocean water itself, and rising seas are impinging upon existing atolls used for pearl farming, forcing farmers to face expensive relocations.

The third chapter, titled 'Buying Pearls', suggests various outlets and considerations for purchasing pearls, including summaries of roundness, lustre, colour and size, as mentioned in the previous chapter. The question of whether the merchandise being offered is genuine or imitation is addressed, with tips on how to spot the latter products. Online purchases are also covered, with the usual caveats about not being able to inspect merchandise before buying. A box briefly highlights Kokichi Mikimoto and his journey to create and market cultured pearls. Also discussed is the purchase of pearls from wholesalers for those in the business, although it would seem that, for professionals, this basic information would be common knowledge.

The following chapters focus on drilling, setting and stringing pearls, which seem most useful to the hobbyist. Information on equipment and materials needed to perform basic tasks such as drills, bits and stringing supplies is helpful for those just starting on their pearl journey. Tips for the placement of drill holes and the setting of pearls are useful. A series of photos help instruct how to string pearls. Also covered are considerations such as silk (string) colour, loose nuclei, partial insertion of the stringing needle and proper techniques for making three-strand necklaces.

The remainder of the book focuses on the different types of cultured pearls, including South Seas, Tahitian, akoya, freshwater and their sub-classes. Some of the information is a repeat from previous chapters and seems redundant, including oyster farming and pearl grading. The chapter on akoya products mentions that their popularity has been low for several years because freshwater cultured pearls now provide a superior product in that market niche. The description of freshwater cultured pearls begins with the 'Rice Krispie' shapes seen in the 1970s, and ends with the perfectly round product, generally with very good to excellent lustre, that has emerged in the last several years. Nearly all freshwater cultured pearl production is from China. Hybrid-species mussels are employed to produce up to 30 cultured pearls per mollusc. Freshwater cultured pearls were initially grown without nuclei, but in the past decade farmers have developed a bead-nucleation technique that generally yields fewer cultured pearls but of higher quality. Non-nucleated cultured pearls are becoming increasingly rare. Japanese Biwa and Kasumi cultured pearls are discussed in a separate box. Other types of freshwater cultured pearls covered are soufflé, Edison, Ming and bead-nucleated 'tadpole' varieties. Treatments mentioned include silver nitrate, gamma irradiation and various dyes.

The book concludes with a separate chapter on unusual and non-nacreous pearls, including natural pearls from the UK and those from various molluscs (abalone, clam, conch and Melo). Regulations associated with collecting the species that produce pearls are provided in separate boxes.

In summary, this book shows promise in part due to its practical organisation. With judicious proofreading and editing, as well as improvement in images, this book could prove more useful as an introduction to prospective pearl buyers and hobbyists.

Jo Ellen Cole
Cole Appraisal Services
Los Angeles, California, USA

The Smithsonian National Gem Collection—Unearthed: Surprising Stories Behind the Jewels

By Jeffrey Edward Post, 2021. Abrams, New York, New York, USA, www.abramsbooks.com/product/smithsonian-national-gem-collectionunearthed_9781419745805, 192 pages, illus., ISBN 978-1419745805 or e-ISBN 978-1683359401. USD29.99 softcover or USD23.32 eBook.

Dr Jeffrey Post has been curator of the Smithsonian's National Gem and Mineral Collection for more than 25 years, so he is the perfect person to relate the fascinating background stories about how various notable pieces came to the collection.

The first section, 'The Story of a Gem', provides a short four-page introduction that describes what a gem is, along with a brief history of how Englishman James Smithson created the Smithsonian Institution in 1834.

The second section, 'A Storied Collection', occupies almost half of the book. It covers 41 individually named gems and jewels, as well as the people who were involved with them and the story behind each of these named items in the National Gem and Mineral Collection. Almost every page of the book has wonderful photos—both historic and modern—that illustrate the pieces and the owners who donated them. Consider, for example, the 75.57 ct Hooker emerald. Four pages with five photos cover how this historic piece, originally owned by Sultan Abdul Hamid and incorporated into a belt buckle, was subsequently acquired at auction by Tiffany & Co. and sold to Janet Annenberg Hooker, who wore it from 1955 until she donated it to the Smithsonian in 1977. Also chronicled is the 48 kg flawless Warner Crystal Ball—one of the museum's most popular exhibits—and how it was saved by Mr and Mrs Warner. And one story I'm personally familiar with is how Gene Meieran helped save two giant topaz crystals from being sliced for monochromators.

In the third section, 'A Dozen Notable Gems', 12 gemstones were selected to represent the diversity of the collection. Many are among the finest examples known, including a superb 11.24 ct Russian demantoid that is better than any I have seen throughout my extensive travels.

The fourth section, 'Gem Families', showcases the rich breadth of the collection, from diamond, emerald and sapphire to quartz, tourmaline and six other minerals. Again, many of these rank among the finest of their kind, and each has a story behind it. One of my favourites is the supersize, superb 1,377 ct Brazilian morganite faceted by Buzz Gray. Another, on page 140, is the tourmaline specimen named 'The Candelabra', which my father and I dug out of the Tourmaline Queen mine in Pala, California, at midnight 50 years ago.

The fifth section, 'The Hope Diamond', describes the most famous gem of the collection—and possibly in the world. Each day thousands of people visit the Hope gallery to gaze at the famous blue stone. This final chapter has 17 intriguing pages that cover the Hope diamond's history, from Jean-Baptiste Tavernier, King Louis XIV, the theft of the French Crown Jewels, and Henry Hope, through various hands to Cartier, Evalyn Walsh McLean and, finally, Harry Winston. In 1958 Harry Winston donated the diamond and its necklace to the Smithsonian.

The book finishes with a glossary, photo credits, an index and acknowledgements.

Anyone who is interested in gems or the Smithsonian's National Gem and Mineral Collection should consider acquiring this very reasonably priced book. The photographs and stories will please most everyone.

Bill Larson FGA
Pala International
Fallbrook, California, USA

Other Book Titles

COLOURED STONES

Sapphire: A Celebration of Colour
By Joanna Hardy, 2021. Thames & Hudson, New York, New York, USA, 328 pages, ISBN 978-0500024775. USD125.00 hardcover.

CULTURAL HERITAGE

The Art of Medieval Jewelry: An Illustrated History
By T.N. Pollio, 2021. McFarland & Co. Inc., Jefferson, North Carolina, USA, 191 pages, ISBN 978-1476681757 or e-ISBN 978-1476640471. USD55.00 softcover or USD24.99 Kindle edn.

Marmor, Gold und Edelstein: Materialimitation in der Buchmalerei vom Hof Karls des Großen [Marble, Gold, and Gemstone. Imitation of Materials in Carolingian Book Illumination]
By Ilka Mestemacher, 2021. De Gruyter GmbH, Berlin, Germany, Natur Bilder/Images of Nature, Vol. 11, 448 pages, ISBN 978-3110710779 or e-ISBN 978-3110730166, https://doi.org/10.1515/9783110730166. EUR79.95 hardcover or EUR79.95 eBook (in German).

DIAMOND

Blood, Sweat and Earth: The Struggle for Control Over the World's Diamonds Throughout History
By Tijl Vanneste, 2021. Reaktion Books, London, 432 pages, ISBN 978-1789144352. GBP25.00 hardcover.

Diamonds: Diamond Stories
By Anders Christian Madsen, 2021. Assouline Publishing, New York, New York, USA, and Only Natural Diamonds, 260 pages, ISBN 978-1649800114. USD95.00 hardcover.

Diamonds from the Arkhangelsk Province, NW Russia
By Victor Garanin, Konstantin Garanin, Galina Kriulina and George Samosorov, 2021. Springer Mineralogy, Cham, Switzerland, 265 pages, ISBN 978-3030357160 or e-ISBN 978-3030357177, https://doi.org/10.1007/978-3-030-35717-7. EUR124.78 hardcover or EUR96.29 eBook.

Diamonds – Natural, Treated & Laboratory-Grown
By Branko Deljanin with Alan Collins, Alexander Zaitsev, Taijin Lu, Viktor Vins, John Chapman and Thomas Hainschwang, 2021. Gemmological Research Industries Inc., Vancouver, British Columbia, Canada, 184 pages, ISBN 978-1777369224 (hardcover) or ISBN 978-1777369231 (softcover). USD119.95 hardcover or USD79.95 softcover.

Diamonds: Their History, Sources, Qualities and Benefits
By Renée Newman, 2021. Firefly Books Ltd, Richmond Hill, Ontario, Canada, 272 pages, ISBN 978-0228103318. USD49.95 hardcover.

GEM LOCALITIES

Indian Placer Deposits
Ed. by R. Dhana Raju, 2021. Cambridge Scholars Publishing, Newcastle upon Tyne, 655 pages, ISBN 978-1527569331. GBP95.99 hardcover.

The Mineralogy of Bisbee, Arizona: Volume 1—Geology & Mineralogy
By Richard W. Graeme III, Richard W. Graeme IV and Douglas Graeme, 2020. Copper Czar Publishing, Bisbee, Arizona, USA, 256 pages, ISBN 978-0578748979. USD34.00 softcover.

The Mineralogy of Bisbee, Arizona: Volume 2—Descriptive Mineralogy
By Richard W. Graeme III, Richard W. Graeme IV and Douglas Graeme, 2020. Copper Czar Publishing, Bisbee, Arizona, USA, 294 pages, ISBN 978-0578638393. USD11.00 softcover.

GENERAL REFERENCE

Jewelry Appraisal Handbook, 10th edn.
By American Society of Appraisers, 2021. ASA, Reston, Virginia, USA, 182 pages, no ISBN. USD175.00 three-ring binder, USD145.00 PDF file or USD249.00 for both.

INSTRUMENTATION

Modern Techniques of Spectroscopy: Basics, Instrumentation, and Applications
Ed. by Dheeraj Kumar Singh, Manik Pradhan and Arnulf Materny, 2021. Progress in Optical Science and Photonics, Vol. 13, Springer Nature Singapore Pte Ltd, Singapore, ISBN 978-9813360839 or e-ISBN 978-9813360846, https://doi.org/10.1007/978-981-33-6084-6. EUR135.19 hardcover or EUR106.99 eBook.

JEWELLERY HISTORY

Collecting Inspiration: Edward C. Moore at Tiffany & Co.
Ed. by Medill Harvey, 2021. The Metropolitan Museum of Art, New York, New York, USA, 304 pages, ISBN 978-1588396907. USD65.00 hardcover.

Edle Steine für Tabatieren: Die Schmuckstein-sammlung des Herzogs Anton Ulrich von Sachsen-Meiningen (1687–1763) [Precious Stones for Snuffing: The Gemstone Collection of Duke Anton Ulrich von Sachsen-Meiningen (1687–1763)]
By Ralf Schmidt, 2020. Naturhistorisches Museum Schloss Bertholdsburg, Schleusingen, Germany, 280 pages, ISBN 978-3000650840 (in German). EUR25.00 hardcover.

The Native American Silver Jewelry Renaissance 1938–1948
By Bille Hougart, 2021. Bille Hougart Books, Washington DC, USA, 206 pages, no ISBN. USD69.99 hardcover.

JEWELLERY AND *OBJETS D'ART*

Le Bijou Dessiné/Designing Jewels
By Guillaume Glorieux, Michaël Decrossas and Stéphanie Desvaux, 2021. Editions Norma and L'École School of Jewelry Arts, Paris, France, 192 pages, ISBN 978-2376660453 (in English and French). EUR39.00 hardcover.

Bulgari Magnifica: The Power Women Hold
Ed. by Tina Leung, 2021. Rizzoli, New York, New York, USA, 208 pages, ISBN 978-8891832962. USD95.00 hardcover.

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The following individuals served as guest reviewers during the past publication year. A special thanks is extended to each one of them for lending their expertise to reviewing manuscripts submitted to *The Journal*. Together with the Associate Editors, these individuals have enhanced the quality of *The Journal* through their knowledge and professionalism.

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