



The Journal of **Gemmology**

Volume 38 / No. 8 / 2023



Colouration of
Aquamarine and
Yellow Beryl

Pyrope
from
Vietnam

Multicoloured
Quartz
from Brazil

A 42.54 ct
Historical
Alexandrite

A Notable
Roman
Sapphire Ring



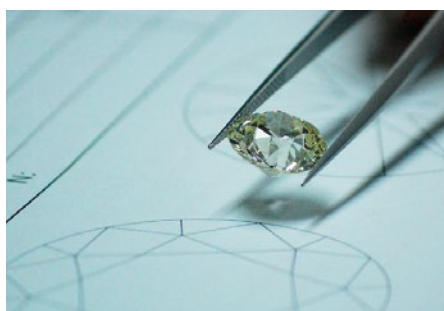
SCHWEIZERISCHES GEMMOLOGISCHES INSTITUT
SWISS GEMMOLOGICAL INSTITUTE
INSTITUT SUISSE DE GEMMOLOGIE



ORIGIN DETERMINATION · TREATMENT DETECTION

DIAMOND GRADING · PEARL TESTING

EDUCATION · RESEARCH



THE SCIENCE OF GEMSTONE TESTING™



Cover photo: The aquamarine photo on the cover accompanies a feature article on pp. 762–772 of this issue that reviews the causes of colour in blue-to-green and yellow iron-bearing beryl. The etched crystal weighs 63.31 g and the smaller faceted stones range from 2.36 to 6.15 ct (all from Zambia and/or Mozambique), while the largest gem weighs 58.57 ct and is from Santa Maria, Brazil. At top left is a 38 ct aquamarine set in an antiquarian ring with natural pearls. Courtesy of Pala International, Fallbrook, California, USA; photo by Mia Dixon.

COLUMNS

What's New

743

CIBJO 2023 Conference Reports and Videos | De Beers *Diamond Insight Report 2023* | Ethical Metalsmiths Responsible Industry Survey 2022 Report | Impact of RJC's Code of Practice on Gender Equality | JNA's *Pearl Report 2023–2024* | Jewellery Consumer Trends in China | De Beers Group Sightholder Summit 2023 Presentations | Ethical Metalsmiths International State of Practice Webinars | Kimberley International Diamond Symposium Presentations | 'Living Room Sessions' Webinars

Gem Notes

746

Blue Cat's-eye Apatite from Brazil | Star Orthoclase from Québec, Canada | Inclusion Assemblage of Lazurite, Sulphur and Bystrite in a Mogok Ruby | Topaz from Thanh Hoa, Vietnam | Traceability and Sustainability of Precious Coral in Japan | Dyed Chatoyant Quartz Misrepresented as Cats-eye Chrysoberyl in an Antique Jewel | Stabilised Aquamarine Cabochon with Unusual Colouring | Emerald Containing Residues of Green Polishing Compound | Advanced Instrumentation for Identifying Sugar-Acid-Treated Opal

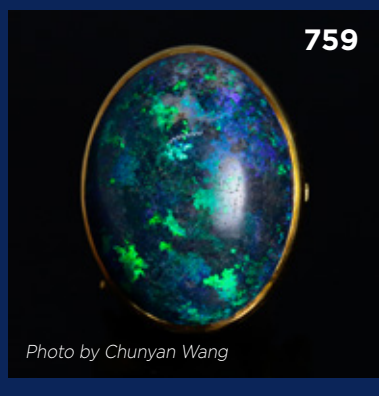


Photo by Chunyan Wang

ARTICLES

A Review of—and Proposed Explanation for—the Aquamarine (Blue to Green) and Yellow Colouration in Iron-bearing Beryl

By Lars Olov Andersson

762

Gemmological Characteristics and Origin of Basalt-related Pyrope from Southeast Vietnam

By Le Ngoc Nang, Pham Trung Hieu and Pham Minh Tien

773

Characteristics of the Colour Zones and Inclusions in Unusual Multicoloured Quartz from Brazil

By Huizhen Huang, Quanli Chen, Xianyu Liu, Yan Li, Zuwei Yin and Yanhan Wu

784

An Historical Alexandrite from the Mineralogy Museum of Paris School of Mines

By Eloïse Gaillou, Stefanos Karampelas, Ugo Hennebois, Annabelle Herreweghe, Farida Maouche, Bérengère Meslin Sainte Beuve, Didier Nectoux and Aurélien Delaunay

796

Study of a Third-Century CE Sapphire Gold Ring in the Archaeological Museum of Thessaloniki, Greece

By Maria Nikopoulou, Stefanos Karampelas, Evangelia Tsangaraki, Lambrini Papadopoulou, Christos S. Katsifas, Ioannis Nazlis, Annareta Toulountzidou, Vasilios Melfos and Nikolaos Kantiranis

804

765

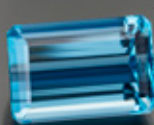


Photo by Mia Dixon

785



Photo by Zhihuoxuan Li

Conferences

20th Rendez-Vous Gemmologiques de Paris | Gem-A Conference | 37th International Gemmological Conference

810

Gem-A Notices

820

Learning Opportunities

828

New Media

831

Literature of Interest

838

The Journal is published by Gem-A in collaboration with SSEF.



The Journal of Gemmology

EDITORIAL STAFF

Editor-in-Chief
Brendan M. Laurs
brendan.laurs@
gem-a.com

Executive Editor
Alan D. Hart

Editorial Assistant
Carol M. Stockton

Editor Emeritus
Roger R. Harding

ASSOCIATE EDITORS

Ahmadjan Abduriyim
Tokyo Gem Science LLC,
Tokyo, Japan

Raquel Alonso-Perez
Harvard University,
Cambridge, Massachusetts,
USA

Edward Boehm
RareSource, Chattanooga,
Tennessee, USA

**Maggie Campbell
Pedersen**
London

Alan T. Collins
King's College London

Alessandra Costanzo
National University of
Ireland Galway

John L. Emmett
Crystal Chemistry, Brush
Prairie, Washington, USA

Emmanuel Fritsch
University of Nantes,
France

Rui Galopim de Carvalho
Gem Education Consultant,
Lisbon, Portugal

Al Gilbertson
Gemological Institute
of America, Carlsbad,
California

Lee A. Groat
University of British
Columbia, Vancouver,
Canada

Thomas Hainschwang
GGTL Laboratories,
Balzers, Liechtenstein

Henry A. Hänni
GemExpert, Basel,
Switzerland

Jeff W. Harris
University of Glasgow

Alan D. Hart
Gem-A, London

Ulrich Henn
German Gemmological
Association, Idar-Oberstein

Jaroslav Hyřl
Prague, Czech Republic

Brian Jackson
National Museums
Scotland, Edinburgh

Mary L. Johnson
Mary Johnson Consulting,
San Diego, California, USA

Stefanos Karamelas
Laboratoire Français de
Gemmologie, Paris, France

Lore Kiefert
Dr. Lore Kiefert Gemmology
Consulting, Heidelberg,
Germany

Hiroshi Kitawaki
Central Gem Laboratory,
Tokyo, Japan

Michael S. Krzemnicki
Swiss Gemmological
Institute SSEF, Basel

Shane F. McClure
Gemological Institute
of America, Carlsbad,
California

Jack M. Ogden
London

Federico Pezzotta
Mineralogical Collection
Professionals, Milan, Italy

Gérard Panczer
Claude Bernard University
Lyon 1, France

Jeffrey E. Post
Smithsonian Institution,
Washington DC, USA

George R. Rossman
California Institute of
Technology, Pasadena, USA

Karl Schmetzer
Petershausen, Germany

Dietmar Schwarz
Zmperry Gemology Lab,
Shanghai, China

Menahem Sevdemish
Gemwizard Ltd, Ramat
Gan, Israel

Andy H. Shen
China University of
Geosciences, Wuhan

Guanghai Shi
China University of
Geosciences, Beijing

James E. Shigley
Gemological Institute
of America, Carlsbad,
California

Christopher P. Smith
American Gemological
Laboratories Inc.,
New York, New York

Elisabeth Strack
Gemmologisches Institut
Hamburg, Germany

Tay Thye Sun
Far East Gemological
Laboratory, Singapore

Frederick 'Lin' Sutherland
Port Macquarie, New
South Wales, Australia

Pornsawat Wathanakul
Kasetsart University,
Bangkok, Thailand

Chris M. Welbourn
Reading, Berkshire

Bear Williams
Stone Group Laboratories
LLC, Jefferson City,
Missouri, USA

J. C. (Hanco) Zwaan
Naturalis Biodiversity
Center, Leiden,
The Netherlands



Gem-A
THE GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN

21 Ely Place
London EC1N 6TD
UK

t: +44 (0)20 7404 3334
f: +44 (0)20 7404 8843
e: information@gem-a.com
w: <https://gem-a.com>

Registered Charity No. 1109555
A company limited by guarantee and
registered in England No. 1945780
Registered office: Palladium House,
1-4 Argyll Street, London W1F 7LD

PRESIDENT

Richard Drucker

VICE PRESIDENTS

David J. Callaghan
Alan T. Collins
Nigel Israel

HONORARY FELLOWS

Gaetano Cavaliere
Terrence S. Coldham
Richard Drucker
Emmanuel Fritsch
Christopher P. Smith

HONORARY

DIAMOND MEMBER

Martin Rapaport

CHIEF EXECUTIVE OFFICER

Alan D. Hart

COUNCIL

Justine L. Carmody – Chair
Nevin Bayoumi-Stefanovic
Maggie Campbell Pedersen
Kate Flitcroft
Joanna Hardy
Philip Sadler
Pia Tonna

BRANCH CHAIRS

Midlands – Craig O'Donnell
North East – Mark W. Houghton
North West – Liz Bailey
South West – Rachael Boothroyd

COVERED BY THE FOLLOWING ABSTRACTING AND INDEXING SERVICES:

Clarivate Analytics' (formerly Thomson Reuters/ISI) Science Citation Index Expanded (in the Web of Science), Journal Citation Reports (Science Edition) and Current Contents (Physical, Chemical and Earth Sciences); Elsevier's Scopus; Australian Research Council's Excellence in Research for Australia (ERA) Journal List; China National Knowledge Infrastructure (CNKI Scholar); EBSCO's Academic Search Ultimate; ProQuest (Cambridge Scientific Abstracts); GeoRef; CrossRef; Chemical Abstracts (CA Plus); Mineralogical Abstracts; Index Copernicus ICI Journals Master List; Gale Academic OneFile; British Library Document Supply Service; and Copyright Clearance Center's RightFind application.

Science Citation Index
Expanded

Web of Science

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.

SUBSCRIPTIONS

Gem-A members receive *The Journal* as part of their membership package, full details of which are given at <https://gem-a.com/membership>. Laboratories, libraries, museums and similar institutions may become direct subscribers to *The Journal*; download the form from *The Journal's* home page.

ADVERTISING

Enquiries about advertising in *The Journal* should be directed to advertising@gem-a.com. For more information, see <https://gem-a.com/publications/media-pack>.

COPYRIGHT AND REPRINT PERMISSION

For full details of copyright and reprint permission contact the Editor-in-Chief. *The Journal of Gemmology* is published quarterly by Gem-A, The Gemmological Association of Great Britain. Any opinions expressed in *The Journal* are understood to be the views of the contributors and not necessarily of the publisher.

DESIGN & PRODUCTION

Zest Design, London. <https://www.zest-uk.com>

PRINTER

Park Communications Ltd, London.
<https://www.parkcom.co.uk>



© 2023 Gem-A (The Gemmological Association of Great Britain)
ISSN 1355-4565 (Print), ISSN 2632-1718 (Online)

What's New

NEWS AND PUBLICATIONS

CIBJO 2023 Conference Reports and Videos



The 2023 CIBJO Congress was held 3–5 October in Jaipur, India, and reports and videos from the event are available online at <https://www.cibjo.org/cibjo-news> and <https://tinyurl.com/4m6b342v>, respectively.

They cover laboratory-grown diamonds, precious coral, gem variety definitions, environmental issues of precious metal mining, pearls, international *fei cui* standards, market ‘aftershocks’ of COVID, coloured-stone mining issues, jewellery industry branding and supply-chain regulation, gemstone treatments, traceability, and more.

De Beers Diamond Insight Report 2023

Subtitled *China: The Outlook and Opportunities for Diamonds*, this year's *Diamond Insight Report* describes the evolution, structure and drivers, and opportunities for the growth of diamond demand in this important market. China is the second largest consumer of polished diamonds (after the USA), with 10% of global diamond jewellery demand. Retail buyers there spend significantly more time researching diamond purchases online, accompanied by a growth in online purchases. The report also includes global trends in the natural diamond market, with 2022 demand essentially unchanged since 2021, and 2023 demand somewhat higher than pre-pandemic levels. Global production of diamonds is still not expected to return



to pre-COVID levels in the foreseeable future. Consumer concerns about diamond origin continue to show a steady rise. Download the report at <https://www.debeersgroup.com/reports/insights/the-diamond-insight-report-2023>.

Ethical Metalsmiths Responsible Industry Survey 2022 Report



Issued in October 2022, this report from USA-based non-profit Ethical Metalsmiths summarises the findings of a 2022 survey of 114 ‘single-entity businesses’, including jewellery designers and independent jewellers mainly based in the USA, UK and Canada with annual revenues below USD100,000. The survey addressed awareness and interest in topics such as sourcing and traceability, recycled precious metals, artisanal and small-scale mining of metals and gems, ‘green’ and philanthropic practices, human rights, fair labour practices and environmental issues. Download the report at <https://ethicalmetalsmiths.org/responsible-industry-survey-2022-report>.

Impact of RJC's Code of Practice on Gender Equality

In 2022, the Responsible Jewellery Council requested members of the Sustainable Minerals Institute at the University of Queensland in Australia to investigate the outcome of the implementation of RJC's 2019 Code of Practice update on improving gender equality in the gem and jewellery industry. In August 2023, RJC released a 30-page report describing the outcomes of this study, which revealed that most surveyed member companies are committed to improving conditions and opportunities for women, but 'further engagement is needed with the RJC gender equality materials'. Download the report at <https://tinyurl.com/5n6cewa4>.



JNA's Pearl Report 2023-2024



In September 2023, JNA released its pearl report for 2023-2024. The 56-page publication includes 14 articles (in both English and Chinese) that cover the state of the international pearl trade, jewellery design and marketing trends, sustainable pearl farming, conch pearls, marketing

concepts, and profiles of specific regions and producers. Download the report at <https://news.jewellerynet.com/en/publications/supplements/Pearl-Report-2023-2024>.

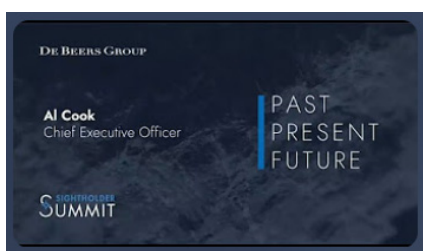
Jewellery Consumer Trends in China



In October 2023, Chow Tai Fook Jewellery Group Ltd of Hong Kong released its 2023 *Jewellery Consumer Trends Report—Shaping the Future of Jewellery Consumption in China and Beyond: Preferences and Desires of Generation Z and Millennials*. The 37-page report focuses on the jewellery buying trends among young consumers in China. Its goal is to provide information that will help guide the jewellery industry in mainland China and Hong Kong. Data were gathered from more than 5,000 consumers aged 18-40, approximately half married with children and half single. The survey showed strong preferences for traditional design elements, natural diamonds, jade and 'everyday' gold jewellery. Download the report at https://www.ctfjewellerygroup.com/file/Doc/pre231031_en.pdf.

OTHER RESOURCES

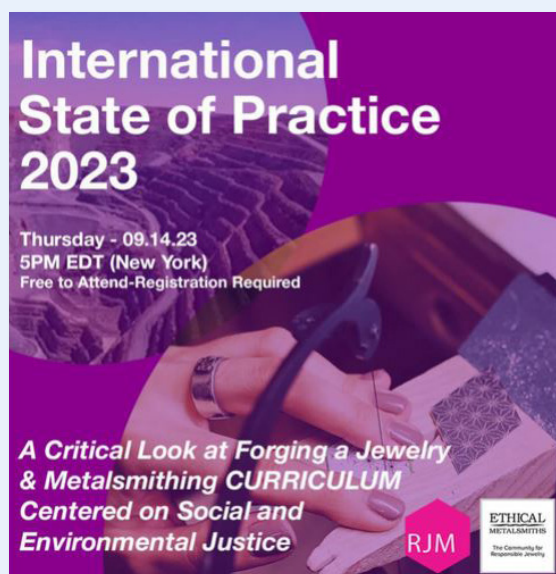
De Beers Group Sightholder Summit 2023 Presentations



Videos from the 2023 De Beers Group Sightholder Summit are now available online at <https://tinyurl.com/5hfpk2vn>. They include presentations by Al Cook (CEO of De Beers Group), Andrew Busch (economic futurist at Bering Productions Inc.), Bruce Cleaver (co-chair of De Beers Group), Paul Rowley (executive VP of Diamond Trading at De Beers Group) and Duncan Wanblad (CEO of Anglo American). The videos range from 20 to 50 minutes in length.

Ethical Metalsmiths International State of Practice Webinars

Ethical Metalsmiths held its second International State of Practice webinar in September 2023. It addressed sustainability in jewellery and metalsmithing, with a focus on the issues that are relevant to current and future educators, and provided information and examples of how educators worldwide are modifying their programs, studios and curricula to address social and environmental issues. Visit <https://ethicalmetalsmiths.org/international-state-of-practice> to watch the recorded webinar. The website also provides a link to the first webinar of this series, held in 2021 and aimed at students and new professionals, along with an accompanying list of resources as a downloadable PDF.



Kimberley International Diamond Symposium Presentations



The Kimberley International Diamond Symposium was held 23–27 August 2023, co-hosted by the Geological Society of South Africa and South African Diamond Producers Organisation. Nineteen presentations are available as PDF files at <https://sadpo.co.za/symposium> (click on the Dropbox icon to download the ZIP file). Topics include the world's largest diamonds, pink diamonds, tracing the sources of historic diamonds, methods and funding of diamond exploration and mining, various types of diamond deposits, diamondiferous xenoliths, and more.

'Living Room Sessions' Webinars

Sustainable jewellery consultant Christina T. Miller holds bimonthly virtual meetings with jewellery industry professionals. Recordings of all of these sessions, since 2020, are available at <https://www.christinatmiller.com/living-room-sessions>. Topics include supporting producer countries, precious metals recycling, legal requirements for jewellers, sustainable jewellery education and marketing, Russian diamonds, and much more. You can sign up on the same page to attend future sessions, and also access blog posts (with helpful summary 'takeaways') for each session.



What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

Gem Notes

COLOURED STONES

Blue Cat's-eye Apatite from Brazil

Gem-quality apatite shows a wide range of colours, most commonly blue and green, but also violet, yellow-orange and brown (Mauthner & Ottaway 2015). Blue colouration in apatite is thought to result from the substitution of MnO_4^{3-} for PO_4^{3-} (Ribeiro *et al.* 2005). Bright blue apatite is highly prized as a gem material because it can resemble Paraíba-type tourmaline. Some blue apatite exhibits chatoyancy, but in the authors' experience this phenomenon is more common in green or yellow material. Although chatoyant blue apatite has been documented previously (Koivula & Kammerling 1990; Kammerling *et al.* 1995; Laurs 2020), it is certainly not common.

During a past mineral show in Munich, Germany, an 11.20 ct blue cat's-eye apatite (Figure 1) was



Figure 1: This apatite cabochon (11.20 ct; 14.26 × 11.59 × 7.75 mm) displays chatoyancy, along with a blue colour not previously reported for cat's-eye material from Brazil. Photo by J. Štubňa.

purchased from a Brazilian dealer. It reportedly originated from Jacupiranga, Cajati, São Paulo, Brazil. Its spot RI values were 1.63–1.64 and its hydrostatic SG was 3.16. These data align with the typical values for apatite reported in the gemmological literature, and its identity was confirmed by Raman spectroscopy. Magnification revealed that its chatoyancy was caused by numerous parallel growth tubes (Figure 2), some of which were found to be partially filled with an unknown residue.

Apatite commonly contains rare-earth element (REE) impurities, and qualitative chemical analysis for REE in the 11.20 ct stone was performed by laser-induced breakdown spectroscopy using a Keyence EA-300 instrument. The data showed the presence of Ce, Pr, Sm and Eu, which were also found in a reference sample of blue apatite from Brazil. By comparison, the Ce content of a blue apatite from Madagascar was below the detection limit. Relatively low Ce contents in Madagascar apatite were also reported by Zhang *et al.* (2022).

Until now, mainly colourless (Laurs 2014) and

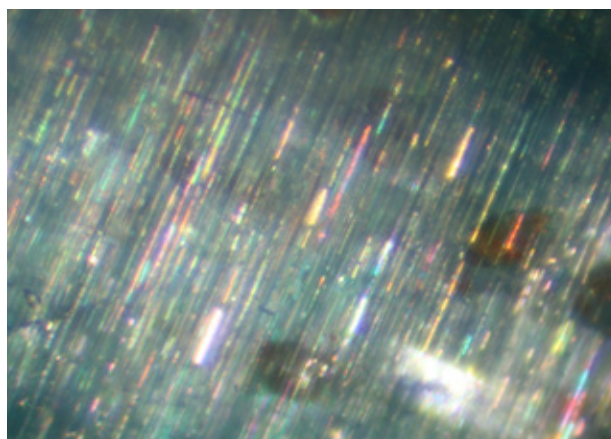


Figure 2: The chatoyancy in the Brazilian apatite is caused by parallel growth tubes. Photomicrograph by J. Štubňa; magnified 40×.

neon-blue (Hsu 2013) cat's-eye apatite has been described from Brazil. Rough blue apatite from Brazil is commonly available on the market, and when oriented correctly it may show chatoyancy after fashioning as a cabochon. Such material may be offered as tourmaline, which is even rarer.

*Dr Jana Fridrichová and Dr Peter Bačík
Comenius University
Bratislava, Slovakia*

*Dr Ján Štubňa (janstubna@gmail.com)
Gemmological Laboratory, Constantine the
Philosopher University, Nitra, Slovakia*

References

- Hsu, T. 2013. Gem News International: Blue cat's-eye apatite. *Gems & Gemology*, **49**(1), 52.
- Kammerling, R.C., Koivula, J.I., Johnson, M.L. & Fritsch, E. 1995. Gem News: Cat's-eye apatites from Madagascar. *Gems & Gemology*, **31**(3), 205–206.
- Koivula, J.I. & Kammerling, R.C. 1990. Gem News: Greenish blue cat's-eye apatite. *Gems & Gemology*, **26**(3), 230–231.
- Laurs, B.M. 2014. Gem Notes: Colourless cat's-eye apatite from Brazil. *Journal of Gemmology*, **34**(1), 8.
- Laurs, B.M. 2020. Gem Notes: Blue apatite in jasper from Brazil. *Journal of Gemmology*, **37**(3), 234–235, <https://doi.org/10.15506/JoG.2020.37.3.234a>.
- Mauthner, M. & Ottaway, T. 2015. Gem apatite localities. *Rocks & Minerals*, **90**(3), 260–269, <https://doi.org/10.1080/00357529.2015.1012957>.
- Ribeiro, H.B., Guedes, K.J., Pinheiro, M.V.B., Greulich-Weber, S. & Krambrock, K. 2005. About the blue and green colours in natural fluorapatite. *Physica Status Solidi C: Conferences*, **2**(1), 720–723, <https://doi.org/10.1002/pssc.200460274>.
- Zhang, Z.-Y., Xu, B., Yuan, P.-Y. & Wang, Z.-X. 2022. Gemological and mineralogical studies of greenish blue apatite in Madagascar. *Crystals*, **12**, article 1067, <https://doi.org/10.3390/cryst12081067>.

Microperthitic Star Orthoclase from Québec, Canada

Well-formed K-feldspar crystals occur in calcite-rich pods and dykes that are commonly known as 'calcite vein dykes' (Joyce 2006) in calc-silicate rock near Lac Tortue, ZEC Bras-Coupé-Désert, Québec, Canada. Much of the calcite has been dissolved away due to near-surface weathering, resulting in soil-filled cavities (up to $4 \times 3 \times 1.5$ m) lined with crystals of K-feldspar, black to dark green pyroxene, green apatite (sometimes of gem quality), titanite, zircon and other minerals (Joyce 2006). The K-feldspar crystals range from about 2 to 40 cm in largest dimension (Figure 3), and were recently discovered to contain a more transparent exterior zone from which cabochons (and, rarely, small faceted stones up to 1.5 ct) can be cut. The cuttable areas are up to 4 cm thick and are mostly composed of translucent colourless to light brownish yellow material. Cabochons cut from these areas weigh up to 15 ct and display weak to moderately distinct four-rayed asterism when exposed to strong point-source illumination (Figure 3, inset). They also exhibit a subtle glow in diffuse sunlight. Due to their optical phenomena, these cabochons are being used in jewellery (e.g. Figure 4). Although their asterism is difficult to capture in photographs, a video showing the effect is available in *The Journal's* online data depository.

Refractive indices of 1.522–1.527 were measured on

a translucent faceted stone, and the SG of one large representative cabochon was determined hydrostatically as 2.61. These properties are consistent with those of K-feldspar. Powder X-ray diffraction analysis was



Figure 3: This orthoclase crystal specimen (8 cm high) from Lac Tortue, Canada, is representative of material from which translucent cabochons and, rarely, transparent gems can be cut. The cabochon in the inset weighs 1.75 ct, and shows a faint four-rayed star with point-source lighting. Photos by P. Belley.



Figure 4: Cabochons of Lac Tortue orthoclase (9 × 7 mm) are mounted together with tsavorite in these 14K gold earrings. Photo courtesy of Atelier Benjamin Rembeault, Montréal, Québec, Canada.

performed on an XtaLAB Synergy-S, Dualflex, HyPix-6000HE diffractometer using $\text{CuK}\alpha$ radiation ($\lambda = 1.5406 \text{ \AA}$). The powdered sample was mounted on a nylon CryoLoop, and a series of 360° phi scans were collected over a period of 15 minutes. The data were processed with Rigaku CrysAlisPro software, and comparison to the software's feldspar reference data indicated that the feldspar consists of orthoclase.

The asterism appears to be caused by small colourless inclusions (Figure 5a) which vary in size, but are often visible to the unaided eye or with $10\times$ magnification. When these inclusions are more abundant, the intensity

of the optical effect increases, but it also tends to become more diffuse (i.e. the rays are not as sharp). Examination of a polished, carbon-coated sample using a scanning electron microscope equipped with an energy-dispersive spectrometer in backscattered-electron (BSE) mode revealed that these inclusions consist of microperthitic albite exsolution lamellae (Figure 5b). The rays of the asterism are parallel to the orthoclase parting plane $\{100\}$ and one cleavage plane ($\{010\}$ or $\{001\}$), and therefore are perpendicular to each other in well-oriented cabochons. While sub-microscopic fractures or inclusions along these planes may also contribute to the asterism, the correlation between microperthite abundance and the intensity of the asterism points to microperthite as the likely cause of the phenomenon.

Asterism or chatoyancy are uncommon in K-feldspar. Green orthoclase from granitic pegmatites in Minh Tien, Vietnam, very rarely shows chatoyancy or weak asterism caused by microperthitic plagioclase inclusions (Hanus & Štubňa 2020). Chatoyancy and four-ray asterism are also known in yellow-brown microperthitic K-feldspar from Tanzania, but the optical phenomena are caused by oriented lath-shaped hematite inclusions (Koivula & Tannous 2003; Henn *et al.* 2005).

Dr Philippe M. Belley (pbelley@mun.ca)
Memorial University of Newfoundland
St. John's, Newfoundland and Labrador, Canada

Dr Donald J. Lake
University of British Columbia
Vancouver, British Columbia, Canada

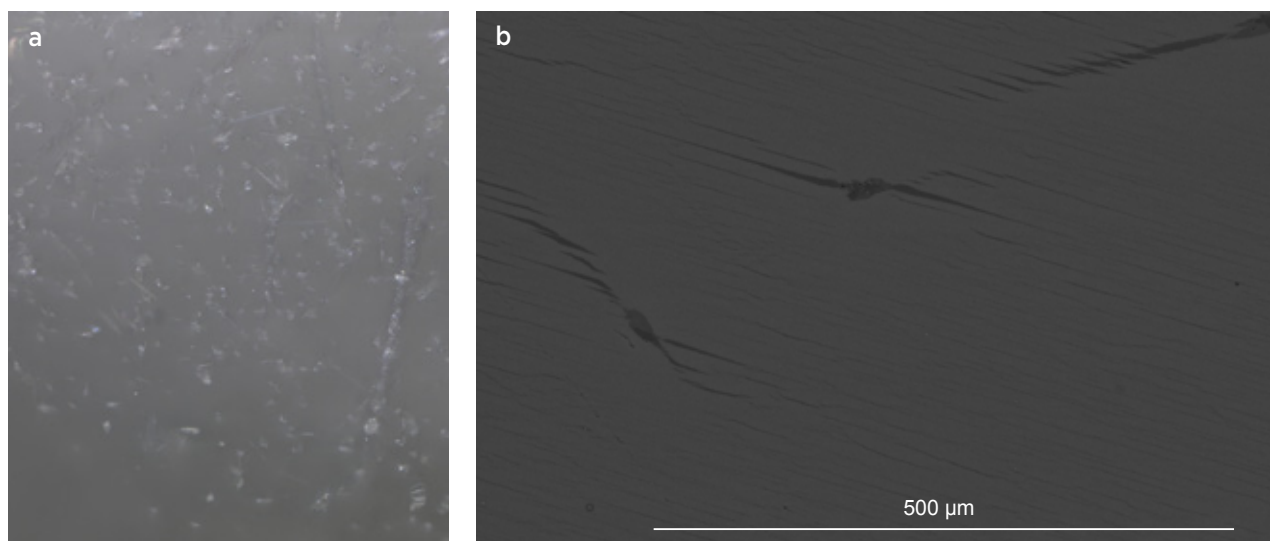


Figure 5: Microperthitic albite inclusions in Lac Tortue orthoclase are shown (a) in a reflected-light focus-stacked photomicrograph (image width 3.5 mm), and (b) in a BSE image in which lamellae of dark-appearing albite occur in lighter-appearing orthoclase. Images by P. Belley.

References

- Hanus, R. & Štubňa, J. 2020. Jewellery use of a transparent green orthoclase from Luc Yen in Vietnam. *Gemologický spravodajca*, **10**(2), 5–11.
- Henn, U., Milisenda, C.C. & Häger, T. 2005. Chatoyance und asterismus bei feldspat aus Tansania. *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **54**(1), 43–46.
- Joyce, D.K. 2006. Calcite vein-dikes of the Grenville geological province, Ontario, Canada. *Rocks & Minerals*, **81**(1), 34–42, <https://doi.org/10.3200/rmin.81.1.34-42>.
- Koivula, J.I. & Tannous, M. 2003. Gem News International: Star sunstone from Tanzania. *Gems & Gemology*, **39**(3), 235–236.

A Rare Inclusion Assemblage in a Ruby from Mogok, Myanmar: Lazurite, Sulphur and Bystrite

A 2.22 ct oval-cut ruby was recently submitted to Guild Gem Laboratories for identification (Figure 6). Fourier-transform infrared (FTIR) analysis and RIs of 1.762–1.770 confirmed the stone's identity as ruby. Trace-element analysis by energy-dispersive X-ray fluorescence revealed traces of V (120 ppmw) and Fe (60 ppmw). The chemical composition and the inclusion characteristics (described below) identified the ruby as originating from Mogok, Myanmar. However, the particular inclusion assemblage in this stone proved quite interesting.

Observation of the ruby with a gemmological microscope revealed a network of short rutile needles in one area along the girdle of the stone (Figure 7a), consistent with a Mogok origin. Also present were well-formed, colourless, transparent calcite crystals, which were partially coated by a thin, semi-transparent, bright blue layer (Figure 7b). Raman analysis revealed this blue layer to be lazurite (Figure 8). Lazurite has been reported previously in ruby and



Figure 6: This 2.22 ct (8.08 × 6.07 × 4.95 mm) ruby from Mogok, Myanmar, hosts an unusual inclusion suite. Photo by F. Hu.

spinel as isolated crystals (Renfro & Koivula 2019; Aung 2020), but this is the first time we have seen lazurite occurring as a 'sugar coating' on calcite inclusions. Also present in the calcite crystals were some

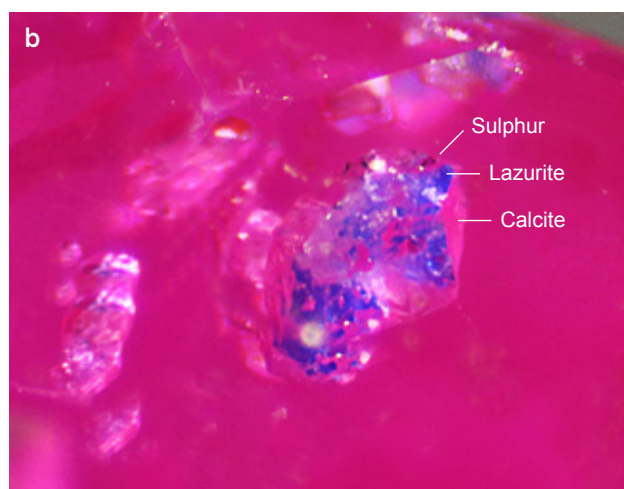
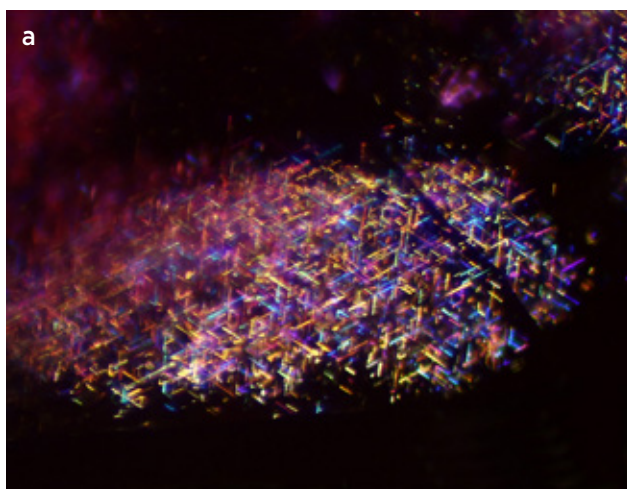


Figure 7: The ruby in Figure 6 contains (a) clusters of short rutile needles typical of Mogok, and (b) calcite crystals that are partially coated by lazurite. Also present in the calcite crystals are dark yellow sulphur inclusions. Photomicrographs by C. Y. Wang; image widths (a) 4.0 mm and (b) 1.9 mm.

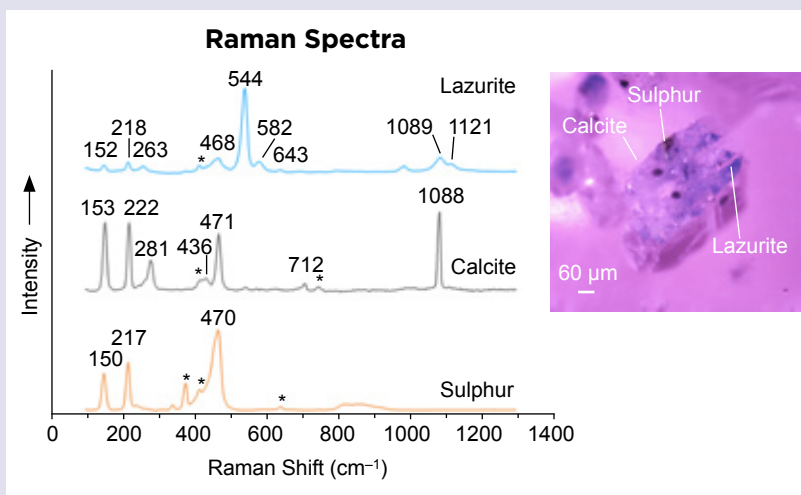


Figure 8: Raman spectra of inclusions in the ruby confirm the presence of calcite, lazurite, and sulphur. Peaks marked with an asterisk are from the ruby host. Inset photomicrograph by Z. Zhang.

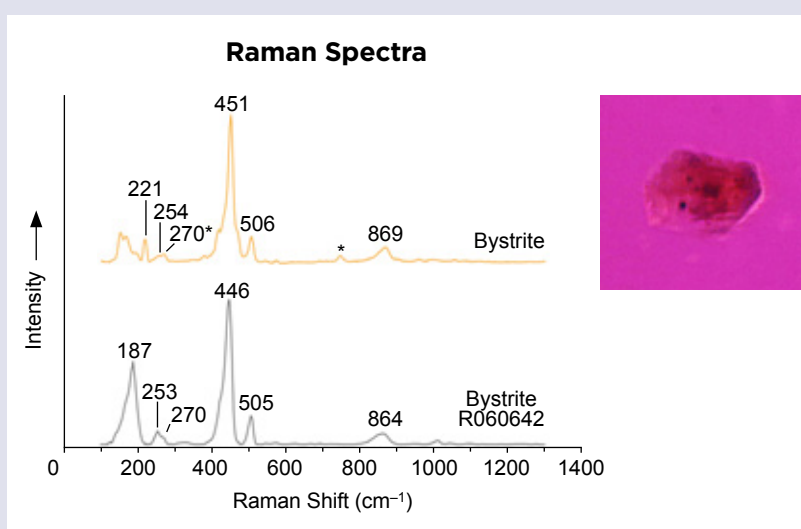


Figure 9: The Raman spectrum of an orangey yellow inclusion in the ruby matches the reference spectrum of bystrite in the RRUFF database. Peaks in the top spectrum marked with an asterisk are from the ruby host, and the 221 cm^{-1} peak is due to sulphur. Inset photomicrograph by C. Y. Wang; image width 2.87 mm.

dot-like, dark yellow inclusions, which were identified as sulphur (Figure 7b). In addition, the ruby contained a platy, hexagonal, orangey yellow crystal, for which Raman spectroscopy yielded peaks at 451, 506 and 869 cm^{-1} (Figure 9). The inclusion was identified as bystrite by comparison to a reference spectrum for this rare mineral in the RRUFF database (rruff.info; sample R060642). Sulphur inclusions were also detected within the bystrite crystal (i.e. Raman peak at 221 cm^{-1}).

Bystrite is a tectosilicate with the chemical formula $(\text{Na,K})_7\text{Ca}(\text{Al}_6\text{Si}_6\text{O}_{24})(\text{S}_5)\text{Cl}$ that belongs to the cancrinite group. It has been reported as associated with gem-quality lazurite and calcite in the Lake Baikal area of Russia (Chukanov *et al.* 2020, 2023). Until now, no other location has been

reported for bystrite.

Sulphur is integral to the composition of lazurite and bystrite. The co-occurrence of sulphur and these minerals indicates a locally S-bearing environment for the formation of ruby in the Mogok area. To our knowledge, this is the first time bystrite and sulphur have been observed together in ruby. This combination of inclusions—along with lazurite and calcite—contributes to our understanding of the formation environment of Mogok ruby.

Yujie Gao, Ziyun Zhang (zziyun@guildgemlab.com)
and Xueying Sun
Guild Gem Laboratories
Shenzhen
China

References

- Aung, T. 2020. G&G Micro-World: Uncommon inclusion of lazurite in ruby from Mogok, Myanmar. *Gems & Gemology*, **56**(4), 529.
- Chukanov, N.V., Sapozhnikov, A.N., Shendrik, R.Y., Viggasina, M.F. & Steudel, R. 2020. Spectroscopic and crystal-chemical features of sodalite-group minerals from gem lazurite deposits. *Minerals*, **10**(11), article 1042, <https://doi.org/10.3390/min10111042>.
- Chukanov, N.V., Sapozhnikov, A.N., Kaneva, E.V., Varlamov, D.A. & Viggasina, M.F. 2023. Bystrite, $\text{Na}_7\text{Ca}(\text{Al}_6\text{Si}_6\text{O}_{24})\text{S}_3^{2-}\text{Cl}^-$: Formula redefinition and relationships with other four-layer cancrinite-group minerals. *Mineralogical Magazine*, **87**(3), 455–464, <https://doi.org/10.1180/mgm.2023.29>.
- Renfro, N. & Koivula, J.I. 2019. G&G Micro-World: Lazurite in spinel. *Gems & Gemology*, **55**(1), 113.

Topaz from Thanh Hoa, Vietnam

Vietnam hosts a variety of gems including ruby, sapphire, spinel, tourmaline, chrysoberyl, zircon, garnet, aquamarine and topaz. The topaz is typically near-colourless and comes from the Thuong Xuan District of Thanh Hoa Province in north-central Vietnam, as well as Lam Dong in southern Vietnam and Yen Bai in the northern part of the country (Kane *et al.* 1991; Huong *et al.* 2012). The most important locality is the Thuong Xuan District, where the topaz is associated with aquamarine in granitic pegmatites and related secondary deposits.

Recently, there has been new production of topaz from an alluvial deposit in Thanh Hoa Province (i.e. Doi Ty mine). Gem and mineral dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained 182 pieces of rough with a total weight of 405 g while visiting Vietnam in November 2022. They consisted of smooth waterworn pebbles that ranged from colourless to light yellow to pale brown and commonly showed light iron staining (e.g. Figure 10a). Some of the pieces were quite evenly shaped and possessed an unusually smooth surface, causing Blauwet to consider selling them as natural unpolished ‘cabochons’. In July 2023, he received the first batch of faceted stones from his cutting factory, consisting of 95 pieces totalling 292.17 carats. Most of the gems were in the 2–10 ct range, and the largest weighed

20.17 ct. They were mostly colourless, although some were very light to medium-light tannish brown, and a few appeared very pale green. Blauwet noted interesting inclusions in some of the gems, and kindly loaned six faceted pieces (2.02–5.15 ct) to authors BW and CW for further examination (Figure 10b).

The samples were colourless to pale brown, and had RIs of 1.611–1.620 and hydrostatic SG values of 3.55–3.57. Microscopic examination revealed basal cleavage fractures with a feather-like appearance, often showing multicoloured thin-film iridescence (Figure 11a). Also present were multiphase inclusions (Figure 11b) and a negative crystal with an iron-stained orangey brown appearance (Figure 11c).

FTIR spectroscopy of the Vietnamese topaz revealed significant CO_2 and OH-related features, consistent with its pegmatitic origin. It showed notable differences from other formation types of topaz (Figure 12). For example, Imperial topaz from Brazil (hydrothermal origin) displays near-complete absorption in the OH-related range between 3200 and 4000 cm^{-1} . Conversely, rhyolitic topaz from Utah, USA, shows low hydroxyl content since it results from pneumatolytic growth (directly from a gas phase) at relatively high temperature and low pressure, and also lacks any primary fluid inclusions.



Figure 10: (a) Topaz from Vietnam's Thanh Hoa Province has been recently mined as waterworn pebbles such as those shown here (0.46–2.89 g). (b) These faceted samples of topaz (2.02–5.15 ct) were studied for this report. Photos by Anne Fulton/Dudley Blauwet Gems.

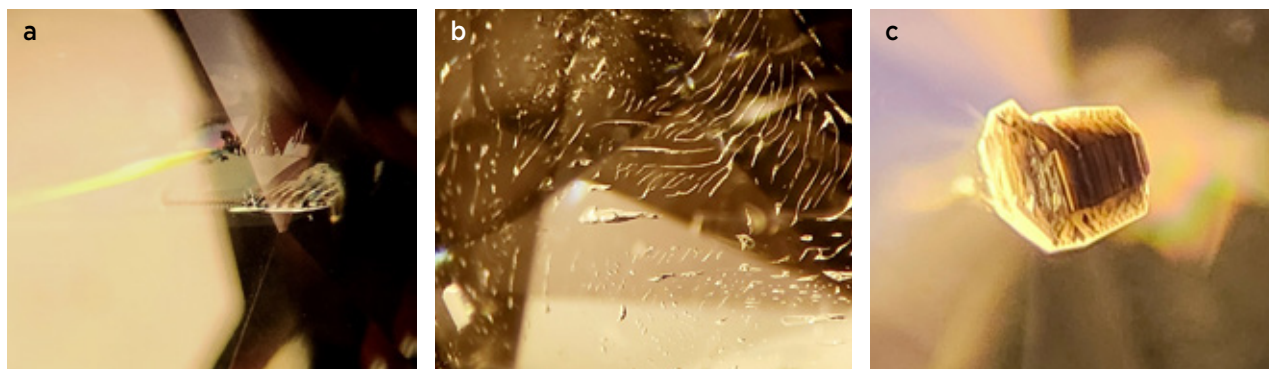


Figure 11: Internal features in the Vietnamese topaz consist of (a) cleavage fractures, (b) multiphase inclusions and (c) an iron-stained negative crystal. Photomicrographs by B. Williams; image widths (a) 2.0 mm, (b) 2.5 mm and (c) 1.5 mm.

In topaz, greater OH content (and lower F content) corresponds with higher RI values (Hoover 1992). The RIs of the Vietnamese topaz we examined correlate to an intermediate fluorine content of about 19 wt.% F, consistent with topaz formation in pegmatites and greisens (Hoover 1992).

Mining of this Vietnamese topaz has continued to take place. In October 2023, Blauwet's supplier obtained another 300 g of rough topaz from Thanh

Hoa Province, in pieces that were not as alluvially rounded and that appeared quite transparent with no iron staining.

Bear Williams FGA and Cara Williams FGA
(info@stonegrouplabs.com)
Stone Group Laboratories
Jefferson City, Missouri, USA

Brendan M. Laurs FGA

References

- Hoover, D.B. 1992. *Topaz*. Butterworth-Heinemann Ltd, Oxford, 207 pp. (see p. 46).
- Huong L.T.-T., Häger, T., Hofmeister, W., Hauzenberger, C., Schwarz, D., Van Long, P., Wehrmeister, U., Khoi, N.N. *et al.* 2012 Gemstones from Vietnam: An update. *Gems & Gemology*, **48**(3), 158–176, <https://doi.org/10.5741/gems.48.3.158>.
- Kane, R.E., McClure, S.F., Kammerling, R.C., Khoa, N.D., Mora, C., Repetto, S., Khai, N.D. & Koivula, J.I. 1991. Rubies and fancy sapphires from Vietnam. *Gems & Gemology*, **27**(3), 136–155, <https://doi.org/10.5741/gems.27.3.136>.

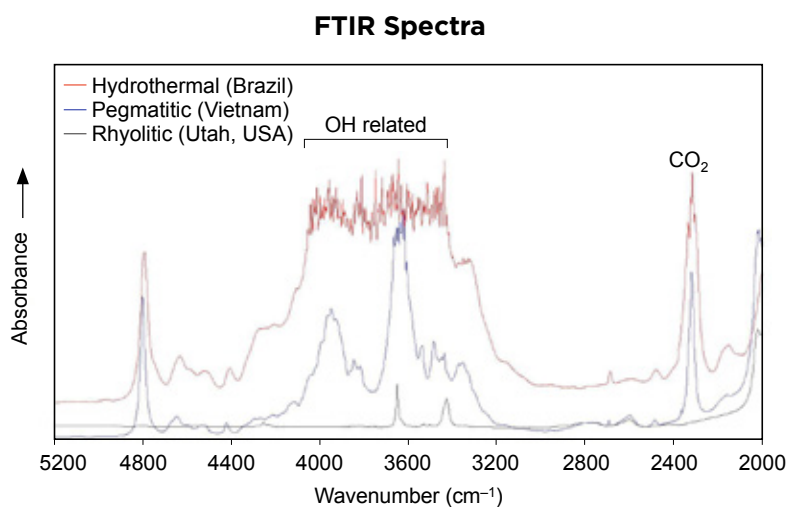


Figure 12: FTIR spectra of topaz from various deposit types show significant differences in CO₂- and OH-related features. The strongest absorption is seen for a hydrothermal-type sample (Imperial topaz) from Brazil, and the weakest features are displayed by rhyolitic topaz from Utah. Vietnamese topaz shows intermediate absorption consistent with its pegmatitic origin.

ORGANIC/BIOGENIC GEMS

Traceability and Sustainability Initiatives for Precious Corals in Japan

Kochi Prefecture is home to 80% of Japan's precious coral producers. In 1812, precious coral was discovered there by chance (entangled in a fisherman's net) off the coast of Muroto, although coral fishing actually began much later, in 1868, when it was no longer prohibited (Suzuki 1999). Fishing currently takes place in Kochi, Wakayama, Nagasaki and Tokyo prefectures. The three main types of precious coral caught in Japan, at depths of approximately 80–350 m, are Aka (*Corallium japonicum*), Momo (*Pleurocorallium elatius*) and Shiro (*Pleurocorallium konojoi*; Figure 13). These three species are listed in CITES Appendix III, and a certificate of origin is required for their export.

Japanese stakeholders are committed to establishing traceability and greater transparency for coral harvesting and trading. The fishermen sort the corals by type, and a fishery cooperative weighs the corals in the presence of a third-party observer, takes photographs of the corals along with a catch report, and submits them to the prefectural authorities. 'Certificates of catches sold' are issued by the fisheries cooperative to certify that the coral was not caught illegally. All of the harvested Japanese

precious coral is collected and sold to processors and dealers through bidding events, which are held four times a year in February, May, August and December. They are organised by the Japan Coral Association (JCA; <https://www.japan-coral.net>) and are open to about 80 members. JCA issues 'traceability slips' (e.g. Figure 14) to the processors and dealers who win bids. These are then attached to the products when they are sold to a retailer, so that their customers are informed accordingly.

Since 2016, there have been two projects in Japan geared towards the sustainability of precious corals, carried out by the Precious Coral Protection and Development Association of Japan (<https://www.coral-npo.jp>) with the support of JCA. The first project involves transplanting coral branches of *C. japonicum* and *P. konojoi* so they can be regenerated on the seabed. Branch tips of low commercial value supplied by fishermen are raised in special aquariums, where both the water temperature (18°C) and the lighting are adjusted to simulate an environment approximating the 100 m depth of a seabed. The size of each coral fragment is recorded before release, and periodic surveys are carried out to measure

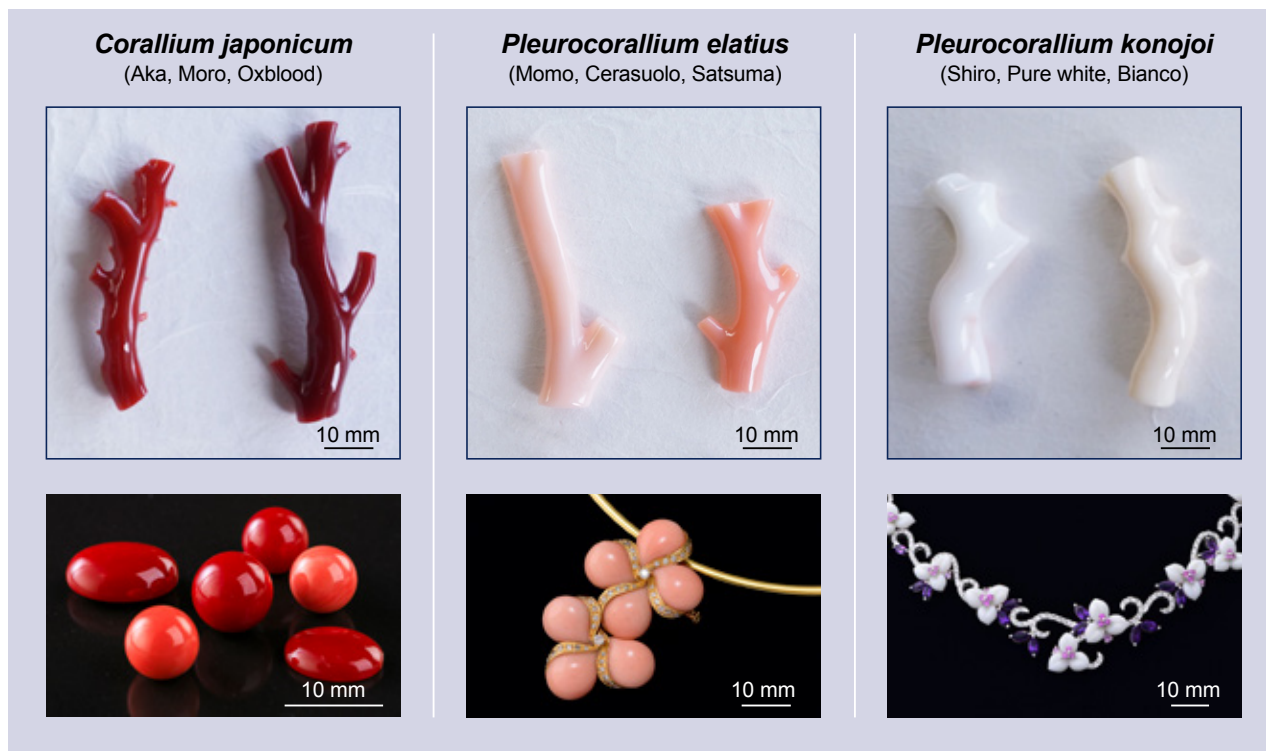


Figure 13: Three main types of precious corals are harvested in Japan: Aka (*Corallium japonicum*), Momo (*Pleurocorallium elatius*) and Shiro (*Pleurocorallium konojoi*). Illustration courtesy of Masaki Coral Inc.

No. 2022 / 12 / 14			
No. 22120467			
産地	高知 (東・西)	東京	和歌山
	長崎	鹿児島	沖縄
品種	赤桃白	種別	生 枯
重さ	119 匁	備考	

日本珊瑚商工協同組合
高知県高知市本町1-3-20
カーニープレイス高知本町5F
TEL 088-826-1050 FAX 088-826-1054
mail:jca35@nifty.com

Figure 14: The traceability slip provided with each coral sale at a JCA bidding event contains the date of sale, identification number, place of catch, species, type and weight (in momme). Photo by C. Sasajima.

their survival rates and growth. In a 2016–2020 study (Koido *et al.* 2022), 99.1% of the fragments survived, of which 97.2% showed polyp formation or thickening and elongation of the coenenchyme (the colony tissue between the polyps), while 71.6% showed branch elongation or new branch formation. The project is conducted within a prohibited fishing area in Kochi Prefecture,

References

- Iwasaki, N. 2010. *A Biohistory of Precious Corals—Scientific, Cultural and Historical Perspectives*. Tokai University Press, Hadano-shi, Kanagawa, Japan, 286 pp.
- Koido, T., Toshino, S., Kumon, F., Nakachi, S., Yoshimoto, N. & Mezaki, T. 2022. Transplantation tests of precious coral fragments using small-sized artificial substratum.

which provides good conditions for the growth of the corals and, thus, a high success rate.

The second project is a study of *C. japonicum* aiming to breed the coral in aquariums and then transfer the seedlings to the sea. In recent years, long-term breeding in aquariums has become possible, and the previously unknown life cycle of precious red corals is gradually being understood.

Based on existing studies (e.g. Iwasaki 2010), the growth rate of Japanese precious corals is very slow: 0.3 mm per year in the direction orthogonal to the branch axis. They are estimated to take 50 years to grow large enough to harvest. This slow growth is one more reason to continue the culture of precious corals, while also maintaining existing corals as a sustainable resource by restricting fishing, bolstering traceability, and continuing research on their growth and protection.

Acknowledgements: Thanks to T. Masaki and the staff members of Masaki Coral Inc. (Kochi, Japan) for the photos in Figure 13 and for allowing the author to visit their company.

Chiemi Sasajima FGA DGA (info@gemschiemies.com)
Gemmological Institute of Liguria
Rome, Italy

Zoological Studies, **61**, article 46, <https://doi.org/10.6620/ZS.2022.61-46>.

Suzuki, K. 1999. Sango [Coral]. *Cultural History of Tools and Human Beings*, No. 91. University of Housei Press, Tokyo, Japan, 362 pp. (in Japanese).

SYNTHETICS AND SIMULANTS

Dyed Chatoyant Quartz Misrepresented as Cats-eye Chrysoberyl in an Antique Jewel

The authors recently acquired a rose-gold pin mounted with small diamonds and a chatoyant cabochon represented as cat's-eye chrysoberyl (Figure 15) from an

antique jewellery dealer on Etsy.com. The piece was declared as being from the 1920s, and nothing about the metalwork appeared to contradict this claim.



Figure 15: This rose-gold pin (8 cm long) set with diamonds and a gem represented as cat's-eye chrysoberyl was acquired from an online seller. The piece was claimed to be antique, but the use of chatoyant chrysoberyl in such jewellery would be highly unusual. Photo by T. Hainschwang.

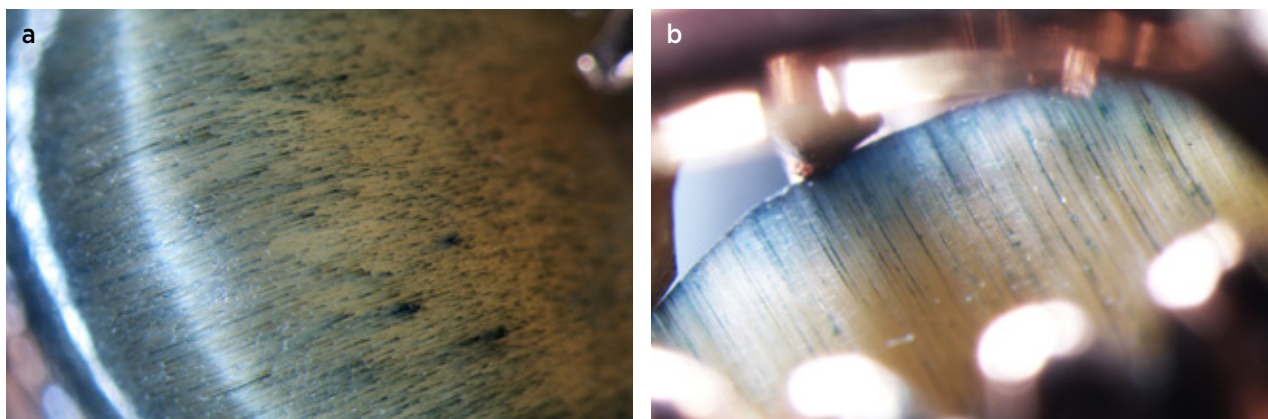


Figure 16: Parallel fibres and/or hollow growth channels responsible for the stone's chatoyancy are seen with magnification on both (a) the dome and (b) the flat base of the cabochon. Blue dye is visible in all the hollow channels. Photomicrographs by T. Hainschwang; image widths (a) 4.5 mm and (b) 3.5 mm.

Chatoyant and asteriated gems are uncommon in antique jewellery, so the piece appeared to be quite unusual.

The cabochon exhibited an unusual brownish yellow-green colour, which resembled cat's-eye alexandrite more than regular chrysoberyl. Therefore, the stone was observed under both incandescent and daylight illumination to see whether it exhibited a colour change, which it did not. Since cat's-eye chrysoberyl rarely exhibits such colouration, and since chatoyant gems are so rare in antique jewellery, suspicion arose that the stone might be treated or not chrysoberyl at all.

Microscopic examination showed that two of the four diamonds were modern full-cut brilliants, which suggests either a time well after the 1920s or that the original diamonds—which should exhibit an older cutting style—had been replaced. The usual practice is to replace such stones with equally antique diamonds, so the presence of modern-cut diamonds made us suspect that the entire piece might be a forgery.

The cat's-eye cabochon contained distinct fibrous and tubular parallel inclusions, which were obviously responsible for the cat's-eye effect. To our surprise, blue colour concentrations were apparent within the fibres/tubes, while the body colour of the gem was brownish yellow (Figure 16). The combination of these hues apparently resulted in the unusual colour appearance of this cabochon.

Reflectance infrared (IR) spectroscopy showed that the stone was not chrysoberyl, but rather quartz, a much more common and cheaper material (Figure 17a). Cat's-eye quartz can make a very convincing imitation of chatoyant chrysoberyl, particularly in finer qualities (Webster 1994). IR spectroscopy taken with the beam transmitted through the stone revealed distinct hydrocarbon peaks at 2958, 2926 and 2853 cm^{-1} (Figure 17b),

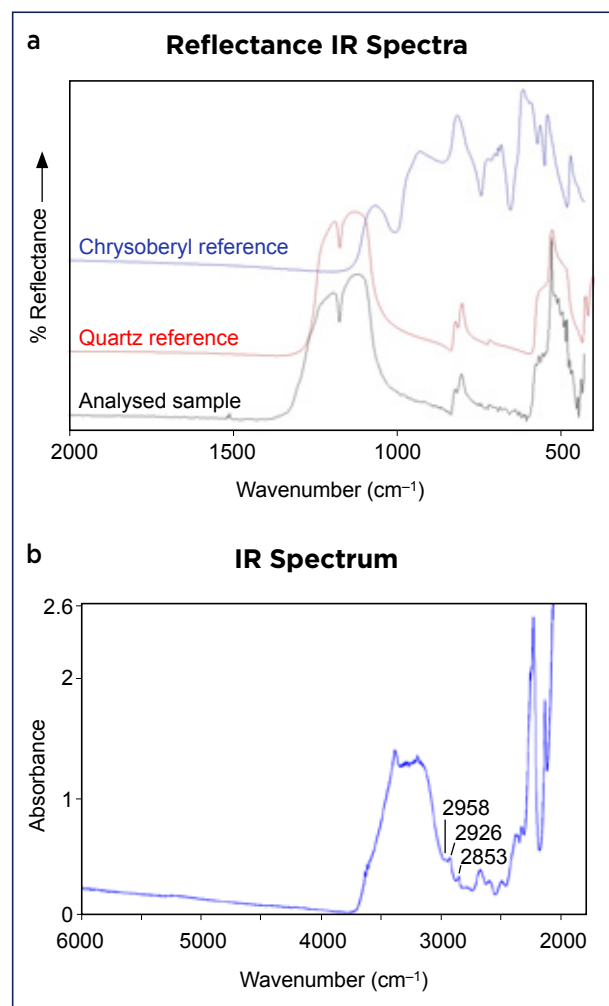


Figure 17: (a) The specular reflectance IR spectrum of the chatoyant gem compared with reference spectra from the authors' database clearly identifies the alleged chrysoberyl as quartz. The spectra are offset vertically for clarity. (b) The IR spectrum of the stone recorded in transmission shows typical OH absorption features in the 3700–3000 cm^{-1} range, overlain by C–H absorptions at 2958, 2926 and 2853 cm^{-1} from the coloured oil used to dye the quartz.

which are caused by oils (Guillen & Cabo 1997). This indicates that the blue dye in the fibres/tubes was introduced via an oil.

When the seller was informed about the true identity of the piece, he refused its return, claiming that the stones had been switched by the authors. Fortunately, the authors had fully characterised the piece and matched it to the details and images that were used by the seller online, so a refund was provided by the financial institution used for the transaction. A quick online search for similar pieces revealed that the same seller had previously sold another pin with a very similar-looking yellow-green chatoyant cabochon declared as cat's-eye chrysoberyl.

This case—not an isolated event—demonstrates how important it is to verify your purchases, no matter how authentic they look. Camouflaging gem scams in antique jewellery (the metalwork appeared authentic) can be an effective means for getting away with such dishonest transactions. It is important to remember that not only can stones be remounted in antique jewellery

in order to deceive, but also that glass and dyed gems have been used since antiquity, and various synthetics have been in circulation since the late nineteenth and early twentieth centuries.

Dr Thomas Hainschwang *FGA*
(thomas.hainschwang@ggtl-lab.org)
and Gianna Hainschwang
GGTL Laboratories Liechtenstein
Balzers, Liechtenstein

References

- Guillen, M.D. & Cabo, N. 1997. Infrared spectroscopy in the study of edible oils and fats. *Journal of the Science of Food and Agriculture*, **75**(1), 1–11, [https://doi.org/10.1002/\(sici\)1097-0010\(199709\)75:1%3C1::aid-jsfa842%3E3.0.co;2-r](https://doi.org/10.1002/(sici)1097-0010(199709)75:1%3C1::aid-jsfa842%3E3.0.co;2-r).
- Webster, R. 1994. *Gems: Their Sources, Descriptions and Identification*, 5th edn., revised by P.G. Read. Butterworth-Heinemann, Oxford, p. 230.

TREATMENTS

Stabilised Aquamarine Cabochon with Unusual Colouring

Recently, the authors examined a 17.20 ct greenish blue oval cabochon that exhibited a noticeably blurry, uneven colour distribution (Figure 18). It had a spot RI of 1.57, as measured with a standard gemmological refractometer, and a hydrostatic SG of 2.60. Ultraviolet-visible-near infrared spectra obtained with a GL Gem Spectrometer were consistent with that of natural beryl, specifically aquamarine. Its identity as beryl was further confirmed

by Raman spectroscopy (using a Magilabs GemmoRaman spectrometer with a 532 nm laser), but the reason for the unusual blurry colour distribution required further testing.

Examination with a standard gemmological microscope revealed clearly visible blue, pink and yellow flash effects, as well as gas bubbles, along the fissures throughout the stone (Figure 19). Testing with long-wave (356 nm) and

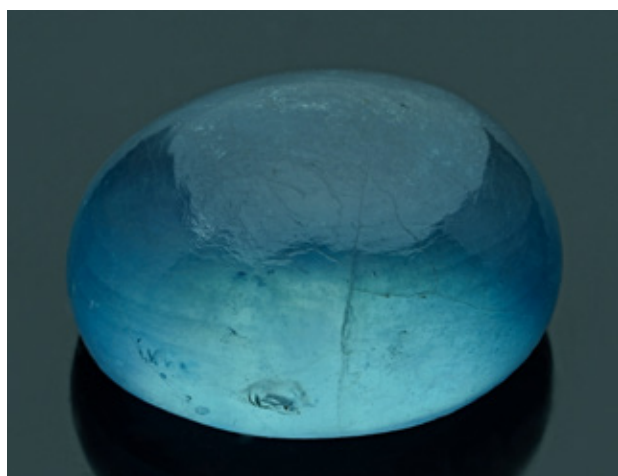


Figure 18: This 17.20 ct aquamarine cabochon displays an atypically blurred colour distribution due to a significant amount of fracture filling with resin. Photo by Q. Wang.

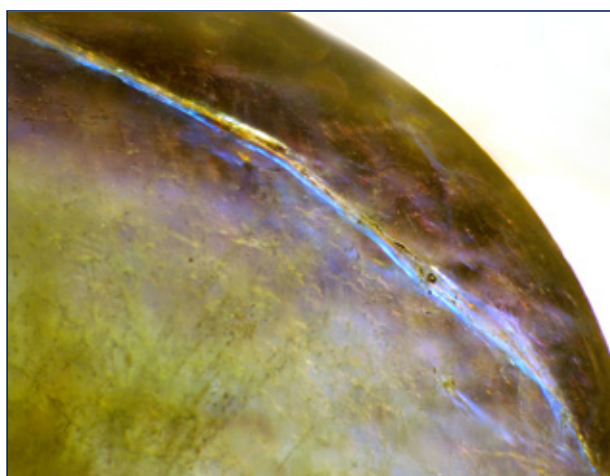


Figure 19: Resin-filled fissures in the aquamarine show characteristic blue, pink and yellow flash effects, as well as a gas bubble. Photomicrograph by Q. Wang; magnified 32x.

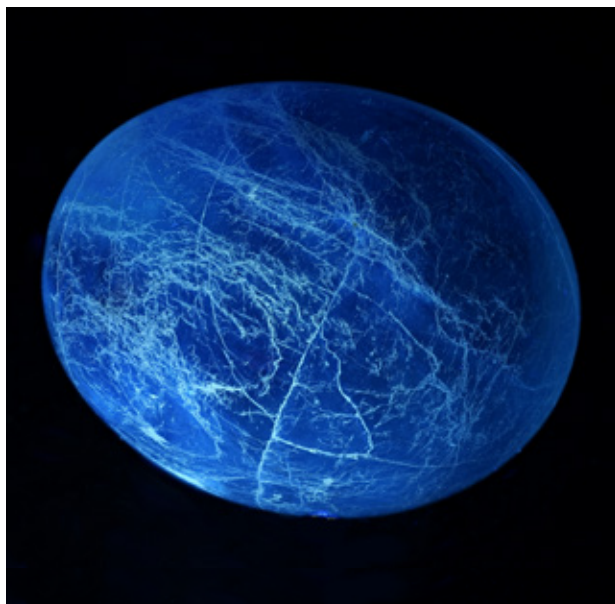


Figure 20: The 17.20 ct aquamarine cabochon displays web-like bluish white fluorescence patterns corresponding to the resin-filled fissures when viewed with long-wave UV radiation. Photos by Q. Wang.

short-wave (254 nm) UV radiation revealed a distinct web-like bluish white fluorescence along the fissures throughout the stone, with stronger luminescence to long-wave UV (Figure 20). These properties are diagnostic of clarity enhancement (e.g. Stephan *et al.* 2019).

The stone's relatively low SG of 2.60 (compared with the typical value for aquamarine of approximately 2.70) is another indication of fissure-filling with some kind of polymer (Stephan *et al.* 2019; Cao *et al.* 2023). Raman spectroscopy on predominantly fissured areas of the sample confirmed the presence of an artificial resin (Figure 21). Similar resin-filled aquamarines have been described previously (e.g. Li *et al.* 2009; Stephan 2019; Stephan *et al.* 2019; Jia *et al.* 2021). The unusual colour

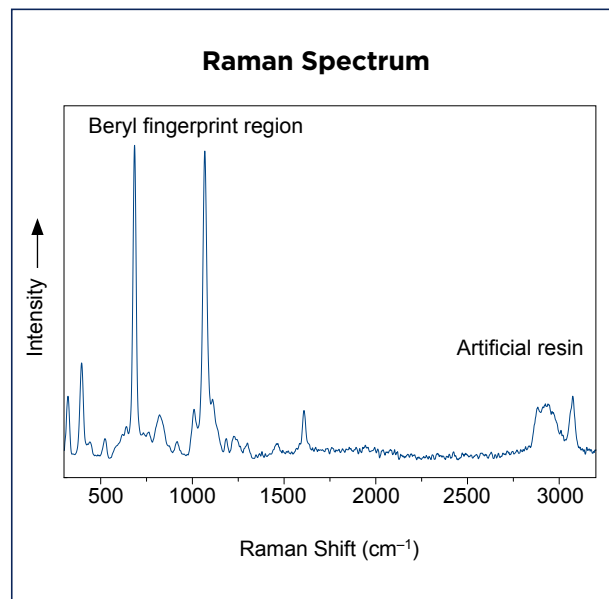


Figure 21: The Raman spectrum of a fractured area of the aquamarine cabochon shows typical beryl peaks (the 'fingerprint region'), as well as features due to artificial resin between 2800 and 3100 cm^{-1} .

appearance of the present stone is due to the strong flash effects combined with the blue body colour of the aquamarine.

Due to the amount of artificial resin in this aquamarine cabochon, it should, in the authors' opinion, correctly be described as 'stabilised', or in accordance with the Laboratory Manual Harmonisation Committee's recommendations (LMHC 2023) as 'aquamarine with resin'.

Christine Matter (c.matter@dgemg.com) and Qi Wang
German Gemmological Association
Idar-Oberstein
Germany

References

- Cao, N., Chen, T., Zheng, J., Chen, X., Zhuang, Y. & Wang, Z. 2023. Identification method of glue-filled aquamarine. *Journal of Gems & Gemmology*, **25**(1), 45–51 (in Chinese with English abstract).
- Jia, Q., Li, G., Li, X., Xiao, Y., Wang, H. & Luo, J. 2021. Characteristic and identification of bleached and filled aquamarine. *Journal of Gems & Gemmology*, **23**(5), 43–50, <https://doi.org/10.15964/j.cnki.027jgg.2021.05.005> (in Chinese with English abstract).
- Li, J., Sun, Y., Hao, W., Luo, H., Cheng, Y., Liu, H., Liu, Y., Ye, H. *et al.* 2009. Polymer-filled aquamarine. *Gems & Gemology*, **45**(3), 197–199, <https://doi.org/10.5741/gems.45.3.197>.
- LMHC 2023. LMHC Information Sheet # 12: Organic Fillers (Oil, Resin, Wax) in Gemstones. Version 5, January, https://www.lmhc-gemmology.org/wp-content/uploads/2023/06/LMHC-Information-Sheet_12_V5_2023.pdf, accessed 3 November 2023.
- Stephan, M. 2019. Lab Notes: Resin-coated and clarity-enhanced aquamarine pendant. *Gems & Gemology*, **55**(2), 246–247.
- Stephan, T., Milisenda, C., Müller, S. & Huaysan, B. 2019. Uncommon treatments – Stabilized aquamarines and dyed feldspars. *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **68**(3/4), 61–64 (in German with English abstract).

Emerald Containing Residues of Green Polishing Compound

Emeralds are commonly treated with organic fillers to reduce the visibility of fissures and thus improve their clarity (McClure *et al.* 1999), and in some cases green oil is also used to enhance their colour (Ringsrud 1983; Jang-Green 2016). Recently, while examining a parcel of emeralds submitted for identification, the authors encountered one stone containing organic as well as inorganic material in its fractures.

The green colour of the 2.38 ct gem showed a moderate to high saturation (Figure 22). Its gemmological features identified it as emerald, with RIs of 1.560–1.568 and a typical FTIR spectrum for beryl. Microscopic observation revealed fluid and mineral inclusions, as well as some distinct areas containing filler in fissures. Transmission FTIR spectroscopy revealed peaks at 2850, 2920 and 2955 cm^{-1} , indicating the presence of an organic filler (i.e. oil; Zwaan *et al.* 2005). In addition, a green substance in some of the fissures caught our attention (Figure 23a). At first glance, we thought that its greenish appearance was caused by light reflecting off the gem host. However, as we rotated the sample, the substance still appeared green. In addition, it filled several hollow tubes in the emerald (Figure 23b).

Raman spectroscopy of the green substance identified it as chromium oxide (Cr_2O_3), with peaks at 305, 349, 545 and 608 cm^{-1} (Beattie & Gilson 1970). Chromium oxide is commonly used by gem cutters, usually as a polishing compound or abrasive paste, so we obtained samples of both these materials from the local market in Shenzhen to analyse for comparison (Figure 24). Their Raman spectra agreed well with that of the green substance in the emerald (Figure 25).



Figure 22: This 2.38 ct emerald exhibits an attractive green body colour, but inorganic green material is also visible along fractures (circled). Photo by H. X. Zhao.

The green residues in the fissures of this emerald seem to contribute little to the gem's colour appearance. Considering the stone's inherently attractive colour, it is unlikely that the chromium oxide was intentionally introduced in an effort to improve its appearance. The gem cutter may have been using the polishing compound with other gem materials and paid no attention to its

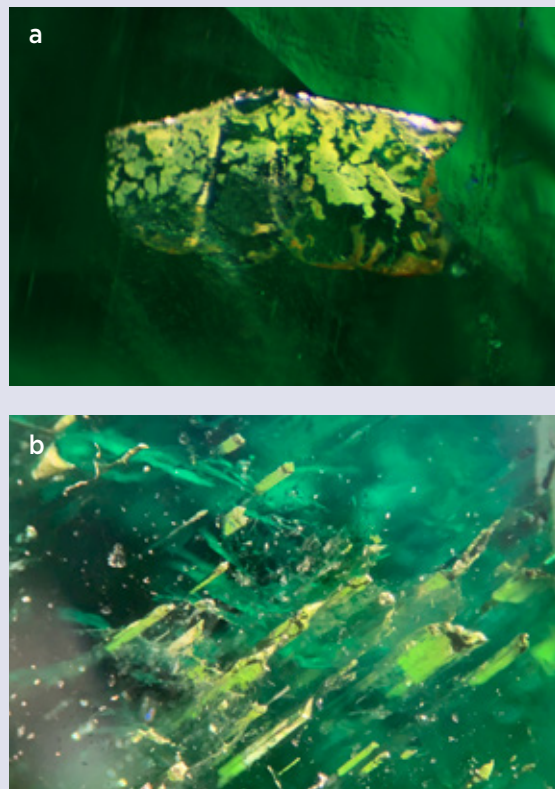


Figure 23: Closer views of the green substance in the emerald are shown (a) in a fissure and (b) in hollow tubes. Photomicrographs by H. X. Zhao; image widths (a) 2.7 mm and (b) 2.2 mm.



Figure 24: Chromium oxide polishing compound (left) and abrasive paste (right) were obtained for comparison with the green substance in the emerald's fissures. Photo by H. X. Zhao.

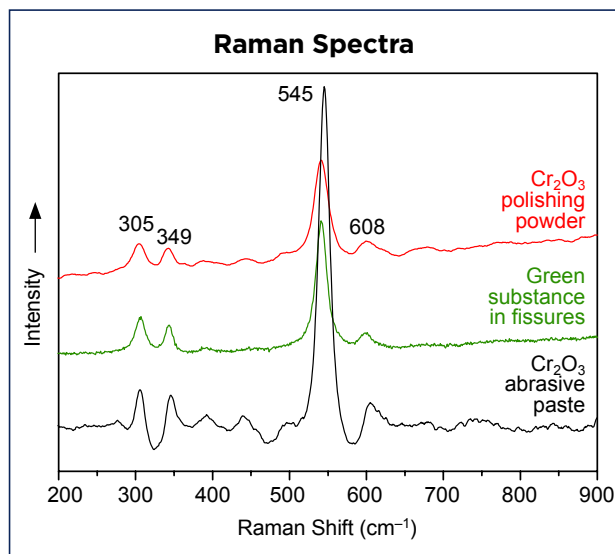


Figure 25: Raman spectra of the green material in the emerald's fissures and the two polishing compounds in Figure 24 all display peaks at 305, 349, 545 and 608 cm^{-1} , consistent with chromium oxide.

References

- Beattie, I.R. & Gilson, T.R. 1970. The single-crystal Raman spectra of nearly opaque materials. Iron(III) oxide and chromium(III) oxide. *Journal of the Chemical Society A: Inorganic, Physical, Theoretical*, 980–986, <https://doi.org/10.1039/j19700000980>.
- Jang-Green, H. 2016. Lab Notes: Dyed green beryl. *Gems & Gemology*, **52**(4), 410.
- McClure, S.F., Moses, T.M., Tannous, M. & Koivula, J.I. 1999. Classifying emerald clarity enhancement at the GIA Gem Trade Laboratory. *Gems & Gemology*, **35**(4), 176–185, <https://doi.org/10.5741/gems.35.4.176>.
- Ringsrud, R. 1983. The oil treatment of emeralds in Bogotá, Colombia. *Gems & Gemology*, **19**(3), 149–156, <https://doi.org/10.5741/gems.19.3.149>.
- Zwaan, J.C., Seifert, A.V., Vrána, S., Laurs, B.M., Anckar, B., Simmons, W.B. *et al.* 2005. Emeralds from the Kafubu area, Zambia. *Gems & Gemology*, **41**(2), 116–148, <https://doi.org/10.5741/gems.41.2.116>.

green colour when subsequently cutting the emerald. Although such residues are typically removed by cleaning the stone in acid, sometimes they remain in fissures (see, e.g., figure 8 in Ringsrud 1983).

In our view, chromium oxide can be difficult to remove and such a substance in emerald should be disclosed to a client, since it is not intrinsic to the gem and may modify its colour to some extent. A similar situation exists with the presence of green polishing compound within filled fractures and cavities in jadeite. It is possible that not requiring such disclosure may promote the intentional use of green polishing abrasive residues to imitate the appearance of green minerals in jadeite, which play an important role in its pricing.

Dan Ju, Yujie Gao (peter.gao@guildgemlab.com)
and Xueying Sun
Guild Gem Laboratories
Shenzhen, China

Advanced Instrumentation for Identifying Sugar-Acid-Treated Opal

Black opal is commonly more highly valued than white opal because the dark background makes the play-of-colour appear more prominent. Therefore, sugar-acid and smoke treatments have been applied to darken the body colour of light-coloured opal. In addition to its use on white opal, sugar-acid treatment is most commonly done to more porous material such as matrix opal from Andamooka, Australia (Brown 1991; Hsu & Kennedy 2022) and hydrophane opal from Ethiopia (Rondeau *et al.* 2011). The opal is soaked in a hot sugar solution followed by a hot acid bath, resulting in the deposition of dark carbon material in its porous structure (Brown 1991).

Recently, Guild Gem Laboratory was asked to re-check a 14.30 ct opal mounted in a pendant (Figure 26), since its poor lustre and relatively weak play-of-colour raised

Figure 26: A 14.30 ct opal mounted in a pendant shows a rather strange appearance, including poor lustre. Photo by Chunyan Wang.



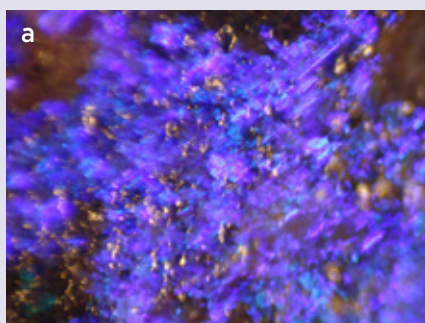


Figure 27: (a) Patches of play-of-colour in the opal are broken by the black background. (b) Distinct cavities are visible on the surface of the opal in reflected light. Photos by Chunyan Wang; image widths (a) 2.81 mm and (b) 2.65 mm.

concern about an accompanying gemmological report's claim the stone was untreated opal. The stone's FTIR spectrum yielded prominent bands at 1115, 782 and 476 cm^{-1} , consistent with opal and ruling out hydrophane, which usually has a main band located at 1095 cm^{-1} (Hu *et al.* 2013). Viewed with a gemmological microscope, the pattern of play-of-colour appeared as if it was embedded within a black background (Figure 27a), and reflected light revealed abundant cavities on the surface (Figure 27b). Furthermore, as the stone was tilted, the edges of the play-of-colour pattern did not move as expected.

Identification of sugar-acid-treated opal usually involves FTIR spectroscopy and magnification (Brown 1991; Rondeau *et al.* 2011), but in this case these techniques were not sufficient to confirm whether or not it had been sugar-acid treated, so we applied advanced techniques. The SYNTHdetect instrument was developed for testing diamonds (<https://institute.debeers.com/en-gb/instruments/synthdetect>), but it has also been used to obtain images of short-lived phosphorescence of other gem materials (e.g. Gao & Sun 2023). In this case, fluorescence imaging of a reference sample of untreated black opal using a SYNTHdetect unit showed a patchy appearance (Figure 28a), while the opal in the pendant exhibited blue luminescence overall except that

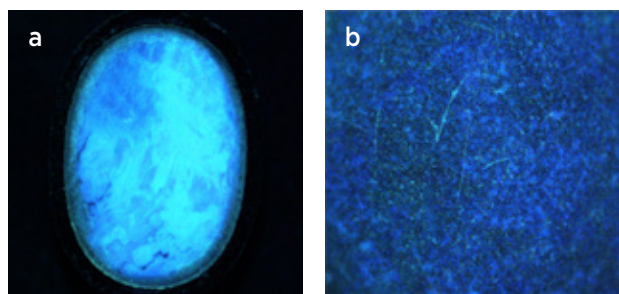


Figure 28: Viewed with a SYNTHdetect instrument, the fluorescence pattern (a) of a 0.67 ct untreated opal appears patchy, whereas (b) the opal in the pendant exhibits overall blue fluorescence with granular-like inert areas corresponding to the dark areas of the stone, indicative of sugar-acid treatment (image width 18 mm). Photos by Wenjing Xu.

the black areas were inert (Figure 28b), as expected for carbon material deposited by sugar-acid treatment. This phenomenon could also be seen using a standard UV lamp.

A Raman spectrum obtained from the dark spots revealed two prominent peaks at 1330 and 1571 cm^{-1} (Figure 29), which agree with the characteristic spectral features of amorphous carbon (Beyssac *et al.* 2002). More than ten additional Raman analyses of such dark areas all indicated amorphous carbon; no graphite was detected. The detection of amorphous carbon with Raman micro-spectroscopy provides another means to identify sugar-acid-treated opal.

SYNTHdetect combined with Raman micro-spectroscopy was found to be an effective and efficient way to identify sugar-acid-treated opal, and can supplement the usual techniques of FTIR spectroscopy and microscopic observation.

✓ Huang

Tiantian Huang, Yujie Gao
(peter.gao@guildgemlab.com) and Chunyan Wang
Guild Gem Laboratories
Shenzhen, China

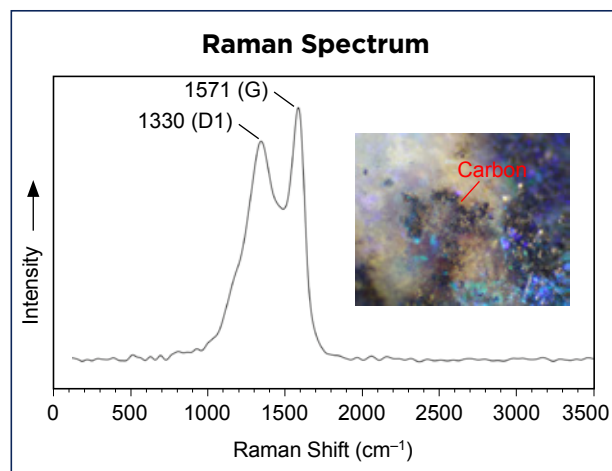


Figure 29: The Raman spectrum of dark spots on the opal shows two prominent peaks at 1330 cm^{-1} (D1 band) and 1571 cm^{-1} (G band), which are typical of amorphous carbon. The inset photo (by Chunyan Wang) shows one of the areas analysed.

References

- Beyssac, O., Goffé, B., Chopin, C. & Rouzaud, J.N. 2002. Raman spectra of carbonaceous material in metasediments: A new geothermometer. *Journal of Metamorphic Geology*, **20**(9), 859–871, <https://doi.org/10.1046/j.1525-1314.2002.00408.x>.
- Brown, G. 1991. Treated Andamooka matrix opal. *Gems & Gemology*, **27**(2), 100–106, <https://doi.org/10.5741/gems.27.2.100>.
- Gao, Y. & Sun, X. 2023. Gem Notes: Photochromism and phosphorescence of tugtupite. *Journal of Gemmology*, **38**(5), 429–431, <https://doi.org/10.15506/JoG.2023.38.5.429>.
- Hsu, T. & Kennedy, L. 2022. Gem News International: Sugar/heat-treated opal. *Gems & Gemology*, **58**(1), 107–108.
- Hu, Y., Fan, L. & Xue, Q. 2013. Study on filling treatment and identification characteristics of opal from Ethiopian [sic]. *Journal of Gems & Gemmology*, **15**(2), 32–37.
- Rondeau, B., Fritsch, E., Mazzero, F. & Gauthier, J.-P. 2011. Gem News International: Sugar-acid treatment of opal from Wollo, Ethiopia. *Gems & Gemology*, **47**(4), 333–334.

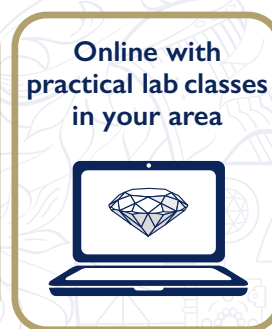
ERRATUM

In the Gem Note titled 'Tourmaline from Calabar, Nigeria' (see *The Journal*, Vol. 38, No. 7, 2023, pp. 657–658), the byline for author Brendan M. Laurs FGA was inadvertently omitted.

Gem-A: over **110** years of experience in gemmology education

Our FGA and DGA Members are located around the world –
join them by studying with Gem-A

**STUDY
IN ONE
OF THREE
WAYS**



Find out more by contacting: education@gem-a.com

Creating gemmologists since 1908



A Review of—and Proposed Explanation for—the Aquamarine (Blue to Green) and Yellow Colouration in Iron-bearing Beryl

Lars Olov Andersson

ABSTRACT: The aquamarine (blue to green) and yellow colours of beryl are due to iron ions, but past studies disagree on the locations of these ions in the crystal structure. A recent suggestion is that the substitution of Fe^{2+} for Be^{2+} does not occur at the Be site, but rather in an adjacent, normally empty tetrahedron (T3) that is larger than the Be tetrahedron. Irradiation of Fe^{2+} located at this site creates tetrahedral Fe^{3+} , which gives beryl its yellow colour. When only one of two neighbouring Fe^{2+} ions is oxidised during irradiation, an $\text{Fe}^{2+}/\text{Fe}^{3+}$ pair is created, which produces blue colouration. This may not be the only explanation for these colours, but it can describe the changes in colour observed when beryl crystals are heated and irradiated. It can also explain how the colours of yellow and blue-to-green beryls (other than emerald) are created by natural radiation. Conversely, the colour of dark blue beryl is due to a different $\text{Fe}^{2+}/\text{Fe}^{3+}$ pair (with Fe^{3+} at the 6g site).

The Journal of Gemmology, 38(8), 2023, pp. 762–772, <https://doi.org/10.15506/JoG.2023.38.8.762>

© 2023 Gem-A (The Gemmological Association of Great Britain)

Beryl has several colour varieties, and many of them are caused by impurity ions substituting at the octahedral Al^{3+} site, such as Cr^{3+} in emerald, Mn^{3+} in red beryl and Mn^{2+} in morganite. Iron ions are responsible for the yellow (Figure 1a) and blue (Figure 1b) varieties of beryl. Over the past several decades, various suggestions have been made about the locations of the chromophoric iron ions in the beryl structure. This article reviews these proposals and shows how the appropriate location of these iron ions can explain the natural origins of the aquamarine and yellow beryl colours, and their changes upon heating and irradiation.

The ideal formula of beryl is $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. Its structure consists of six-membered silicate rings stacked upon each other so that their empty centres form channels along the *c*-axis direction (Figure 2; Bragg & West 1926; Morosin 1972). The Al^{3+} ion is

hosted by an octahedral arrangement of oxygen ions, and the Be^{2+} ion is located in a tetrahedron of oxygen

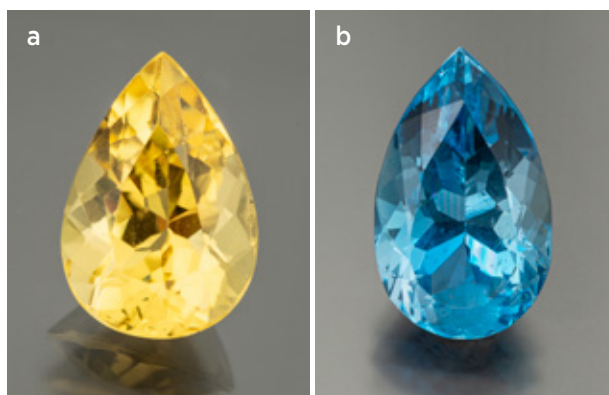


Figure 1: (a) Yellow beryl (1.69 ct, locality unknown) and (b) blue beryl (7.26 ct, from East Africa) owe their colours to iron ions of different valences, but the locations of these ions in the beryl crystal structure have been the subject of debate. Courtesy of Pala International; photos by Mia Dixon.

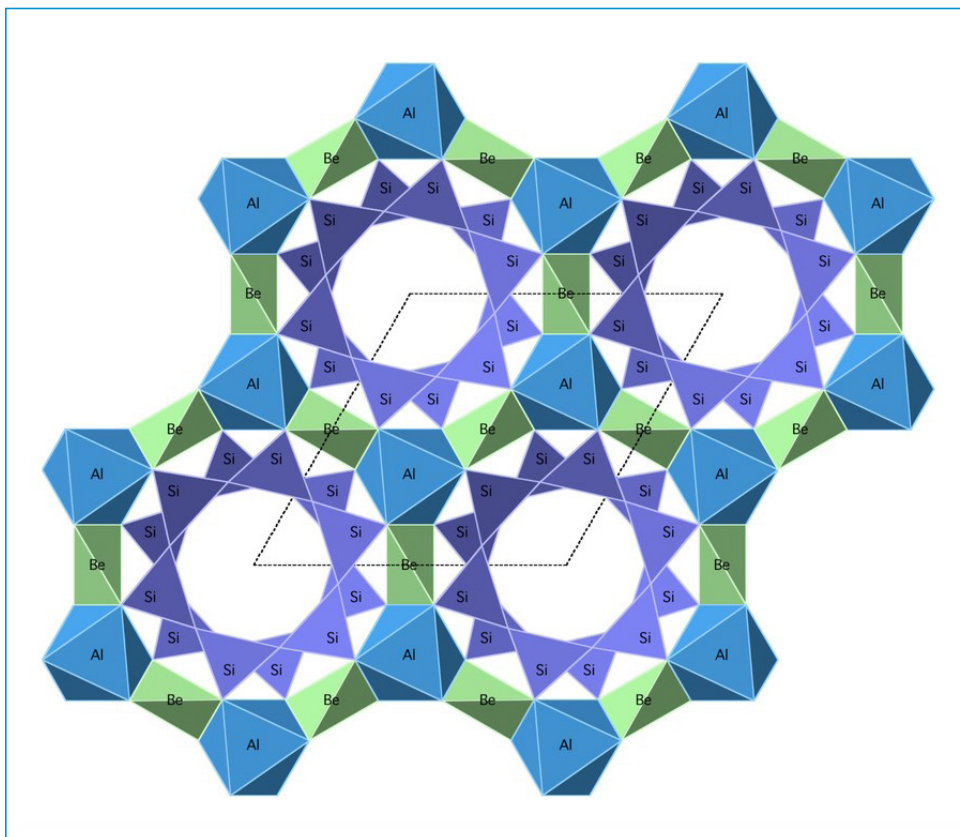


Figure 2: The structure of beryl ($\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$, here viewed down the c -axis) consists of six-membered rings of Si tetrahedra stacked so their empty centres form channels along the c -axis direction. Al^{3+} ions occupy surrounding octahedral sites in the structure, and Be^{2+} ions are located at tetrahedral sites. Various ions (some contributing to colour) can occupy the channels or substitute for Al^{3+} or Be^{2+} ions. Image from Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Beryl_Crystal_Structure.png).

ions. During the formation of a beryl crystal, Fe^{3+} can substitute for Al^{3+} at the octahedral site, and Fe^{2+} can substitute for Be^{2+} at a tetrahedral site. Fe^{2+} can also be incorporated at the octahedral site if Na^+ ions are present in the beryl channel as charge compensators.

One method to investigate the positions of impurity ions in the beryl structure is optical absorption spectroscopy. The absorptions associated with the different iron ions in beryl are shown in Figure 3. Price *et al.* (1976) concluded that an absorption at 810 nm (and 1000 nm) in the π -polarised spectrum (extraordinary ray; $E||c$) is due to Fe^{2+} at an octahedral site. They also concluded that an absorption band at 810 nm in the σ -polarised spectrum (ordinary ray; $E\perp c$) is due to Fe^{2+} at a tetrahedral site. (Other investigators may locate these absorptions at 820 or 830 nm.) Goldman *et al.* (1978) thought that the Be and Si tetrahedra are too small to accommodate the large iron ions; they suggested that the Fe^{2+} ion that gives rise to the 820 nm $E\perp c$ absorption is located in a channel site. This channel position was re-assigned to a tetrahedral site by Taran and Rossman (2001). They investigated absorptions by Fe^{2+} ions in beryl in more detail, and inferred that tetrahedral Fe^{2+} substitutes for Be^{2+} in a strongly distorted tetrahedron.

Loeffler and Burns (1976) described the different mechanisms responsible for the absorption of light in

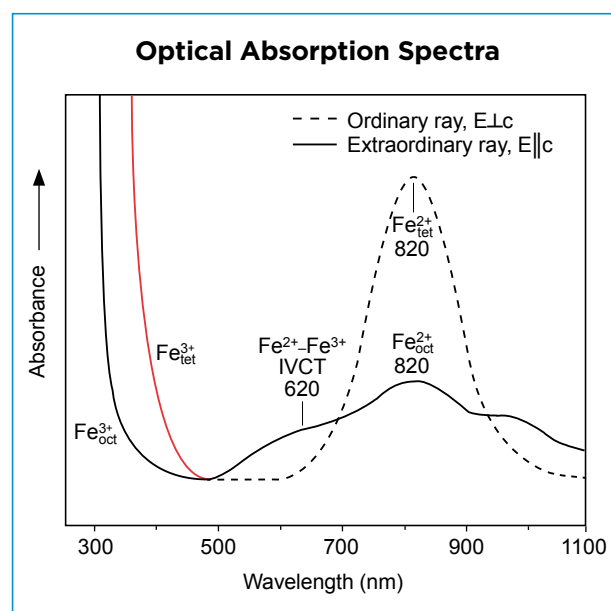


Figure 3: Idealised polarised optical absorption spectra show the features associated with the different iron ions in blue beryl. The charge-transfer absorption by the Fe^{3+} ions is many times stronger than the crystal-field absorption by the Fe^{2+} ions. The tail of the octahedral Fe^{3+} band in blue beryl is observed as an absorption edge in the spectra for both polarisations. In yellow beryl, intense charge-transfer absorption by tetrahedral Fe^{3+} is responsible for the absorption edge shown in red. Fe^{2+} - Fe^{3+} intervalence charge transfer (IVCT) absorption is also very strong, but since such ion pairs are rare in beryl, the total amplitude of its absorption band is not as large.

the visible region of the optical spectrum (approximately 380–740 nm), giving rise to the colours of gem materials. The 820 nm absorption bands in beryl are outside the visible range, which means that the Fe^{2+} ion cannot be a chromophore. Absorption bands of Fe^{3+} ions reach their maxima between 250 and 300 nm, and are also outside the visible range. The discussion below shows how tetrahedral Fe^{3+} ions can still be the source of yellow colour, and that pairs of Fe^{2+} and Fe^{3+} ions produce blue colouration in beryl.

BLUE COLOURATION IN BERYL

The first extensive study of the optical absorption spectra of differently coloured beryl crystals was performed by Wood and Nassau (1968). They attributed the blue colour to an absorption at 620 nm, which is only observed in the $E||c$ spectrum (see Figure 3). Their interpretation was that this absorption is caused by Fe^{2+} ions in the beryl channels. Samoilovich *et al.* (1971), however, proposed that the 620 nm absorption is caused by IVCT between octahedral Fe^{2+} and tetrahedral Fe^{3+} ions located close to one another. Loeffler and Burns (1976) also ascribed the 620 nm absorption to IVCT. They suggested that both iron ions substitute for Al^{3+} at neighbouring octahedral sites, with a distance between the Fe^{2+} and Fe^{3+} ions of 4.60 Å in the c -axis direction. Absorption due to IVCT is strong in the direction between the ions and almost absent in the perpendicular direction. This is consistent with the strong pleochroism of the blue colour in aquamarine.

Platonov *et al.* (1978) stated that, in addition to a 610 nm absorption, there is an absorption at 690–700 nm for the extraordinary ray in aquamarine, which is caused by IVCT between an octahedral Fe^{2+} ion and an Fe^{3+} ion located at an interstitial site halfway between the Al sites. Goldman *et al.* (1978) suggested that the 620 nm shoulder is actually an absorption band at 700 nm caused by Fe^{2+} – Fe^{3+} IVCT involving the same interstitial Fe^{3+} ion. Its distance to the octahedral Fe^{2+} ion is 2.30 Å, which agrees better with the reported distance between IVCT ions in other minerals (Loeffler & Burns 1976). Because of overlap with the 820 nm absorption, it has been difficult to determine the position of the IVCT feature. Taran *et al.* (1989) separated the overlapping absorptions in the $E||c$ polarisation direction and found that the IVCT absorption maximum is at 620–630 nm.

Groat *et al.* (2010) thoroughly investigated dark



Figure 4: Dark blue beryl, such as these stones from Canada (0.06–0.82 ct), owes its colour to an IVCT pair different from that in aquamarine. From Rohtert *et al.* (2003); courtesy of True North Gems Inc.; photo by Maha Tannous, © GIA.

blue beryl from Canada (Figure 4). They found that the only possible location of the IVCT ions is the one previously suggested with Fe^{2+} at an Al site and Fe^{3+} at the site halfway between two Al sites, which has the crystallographic notation 6g. They excluded the corresponding site between two Be sites. However, efforts to experimentally detect the iron ion at 6g were not successful.

Andersson (2019) proposed that there exists another IVCT pair of Fe^{2+} and Fe^{3+} ions in beryl, which gives rise to the light blue aquamarine colour. This will be discussed in detail in the following section. The intensity of this IVCT absorption is less than that of the dark beryl IVCT absorption, and it has not been possible to exactly determine its position.

Taran *et al.* (2018) as well as Taran and Vyshnevskiy (2019) suggested that there are two mechanisms for producing blue colouration in beryl: (1) the tail of the 820 nm absorption in the $E||c$ polarisation direction from octahedral Fe^{2+} extends into the visible region, thus causing light blue colouration, and (2) octahedral Fe^{2+} – Fe^{3+} IVCT absorption produces dark blue colour. Spinolo *et al.* (2007) also suggested that the tail of the 820 nm absorption contributes to the light blue colouration. However, the absorption in the tail is probably too weak to result in a visible colour. Figure 8 in Wood and Nassau (1968) shows a spectrum where the tails of the Fe^{2+} absorptions in both polarisation directions extend below 700 nm. However, this spectrum was obtained from a colourless beryl.

Recently, Chen *et al.* (2024) suggested that the blue colour of aquamarine is due to interaction between octahedral Fe^{2+} and oxygen vacancies.

The unstable deep blue colour of Maxixe and Maxixe-type beryl is not due to iron impurities. Their chromophores are NO_3 and CO_3^- radicals, respectively, in the beryl channels (Andersson 1979).

THE AQUAMARINE AND DARK BLUE CHROMOPHORES

Aquamarine is the name originally used to refer to light-to-medium blue beryl. Today it is also used for darker blue beryl. This article makes a clear distinction between *aquamarine* and *dark blue beryl*:

- *Aquamarine* here refers to light- or pale-coloured blue beryl (e.g. Figure 5a).
- *Dark blue beryl* here refers to deeply coloured blue beryl, which is sometimes called ‘Santa Maria’, ‘Santa Maria Africana’ or ‘double blue’ aquamarine in the trade, although these terms are not defined consistently (e.g. Figure 5b).

These two types of blue beryl have different chromophores, which give rise to their different colours. The chromophores have different configurations of iron ions, which do not respond in the same way to heating and irradiation. These treatments therefore change the colour of the two types of blue beryl in different ways, as described below.

The *dark blue chromophore* consists of an $\text{Fe}^{2+}/\text{Fe}^{3+}$ ion pair with the Fe^{3+} ion at the 6g site halfway between two Al^{3+} ions and with the Fe^{2+} ion at the site of one of these Al^{3+} ions (i.e. isomorphic substitution), as mentioned above (Groat *et al.* 2010). One problem with this configuration is the charge compensation of the additional Fe^{3+} ion. Taran and Rossman (2001) suggested that three Al^{3+} ions are substituted by three Fe^{2+} ions to compensate for the charge of the 6g Fe^{3+} ion. An alternative explanation could be that the 6g Fe^{3+} ion substitutes for the second Al^{3+} ion, leaving the Al site empty (i.e. non-isomorphic substitution).

The very dark blue colour of the beryl from Canada studied by Groat *et al.* (2010; see Figure 4) is due to

the large number of dark blue chromophores corresponding to the extremely high Fe concentration in this material. At lower Fe concentrations, the dark blue colour from this chromophore would be expected to resemble that shown in Figure 5b.

The *aquamarine chromophore* is an $\text{Fe}^{2+}/\text{Fe}^{3+}$ ion pair with the iron ions located at tetrahedral sites. It has been commonly assumed that iron ions in beryl substitute isomorphically for Be^{2+} at the tetrahedral Be site, even if the iron ions are much larger than the Be^{2+} ion: the ionic radius of Be^{2+} in tetrahedral coordination is 0.27 Å, while the ionic radius of Fe^{3+} is 0.49 Å and that of Fe^{2+} is 0.63 Å (Shannon 1976). Bačík and Fridrichová (2019) performed bond-length calculations for impurity ions at different sites in beryl, and found that it is unlikely that the Fe^{2+} ion can be located at the Be^{2+} site. Andersson (2019) suggested that the Fe^{2+} ion is instead located in the T3 tetrahedron (Figure 6), which shares one side with the Be tetrahedron. The distance of the oxygen ions to the centre of the T3 tetrahedron is 1.84 Å (Andersson 2006), while the distance between Be and its surrounding oxygens is 1.65 Å. In the ideal beryl structure, the T3 tetrahedron is empty and can only accommodate an iron ion if the Be site is empty (non-isomorphic substitution).

The T3 tetrahedron shares one oxygen ion with another T3 tetrahedron mirrored in the plane containing this oxygen ion, as shown in Figure 6. The distance between the centres of these two T3 tetrahedra is 3.07 Å, and the direction of the line between the centres is parallel to the crystal’s *c*-axis. Andersson (2019) proposed that the aquamarine chromophore is an IVCT pair of Fe^{2+} and Fe^{3+} ions located in this mirror-pair of T3 tetrahedra.



Figure 5: (a) Aquamarine (7.32 ct, locality unknown) and (b) dark blue beryl (18.96 ct, from Brazil) are coloured by different $\text{Fe}^{2+}/\text{Fe}^{3+}$ iron pairs. Photos by (a) Orasa Weldon and (b) Mia Dixon (courtesy of Pala International).

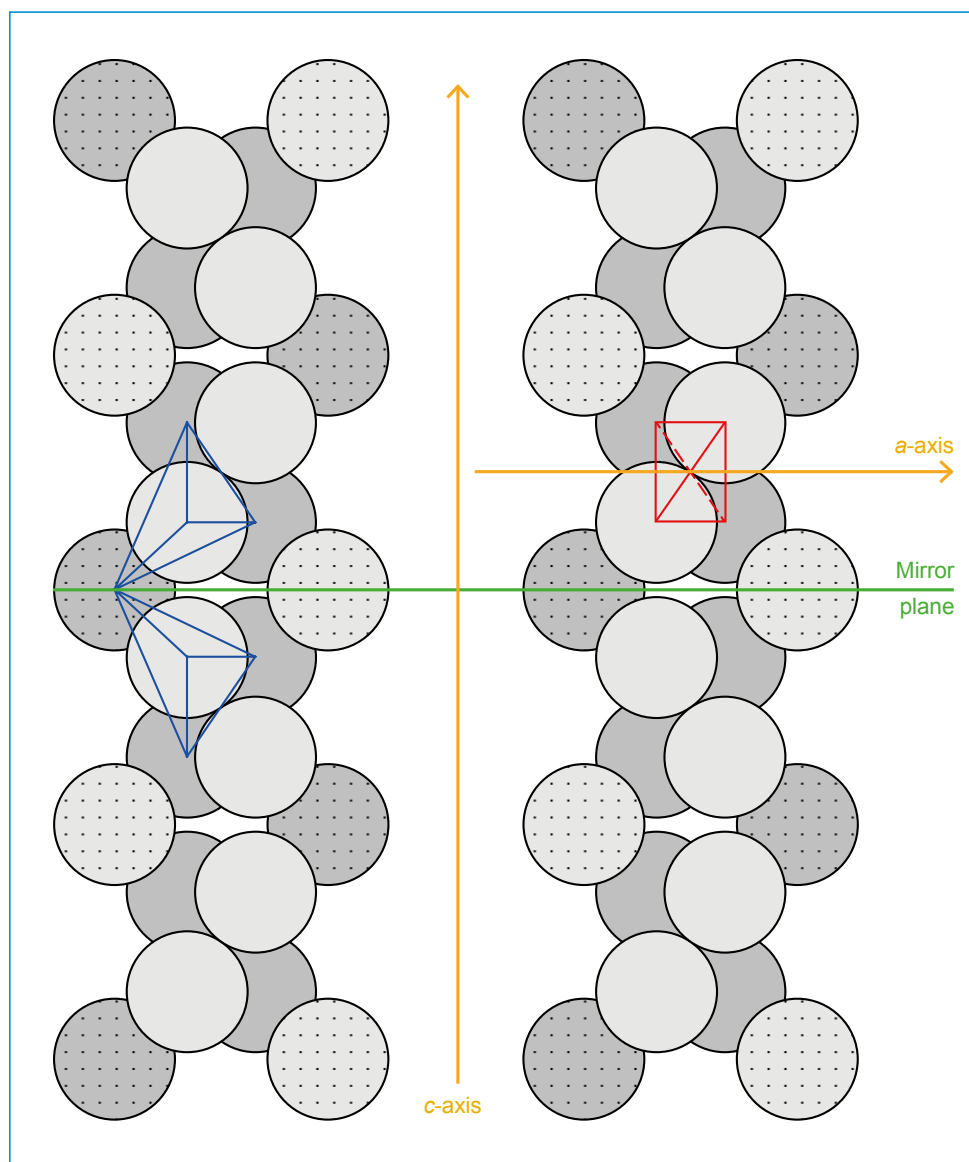


Figure 6: The beryl crystal structure is viewed here parallel to the plane containing the *c*-axis and the *a*-axis of the unit cell (only the oxygen atoms are shown, while the smaller Si, Be and Al atoms are not depicted). Light grey circles represent oxygen ions above this plane, and the dark grey circles indicate oxygen ions below the plane. Stippled circles refer to oxygen ions connected only to Si ions and lie in the plane of the Si ions. This plane is perpendicular to the *c*-axis, and is a mirror plane in the beryl crystal structure. The Al ions and the Be ions lie in a plane halfway between two Si planes. One tetrahedron with a Be ion at its centre is shown in red. One mirror pair of T3 tetrahedra is shown in blue. The aquamarine chromophore is proposed to be due to IVCT between Fe^{2+} and Fe^{3+} ions located in such a pair of T3 tetrahedra.

THE YELLOW CHROMOPHORE

Wood and Nassau (1968) studied a golden beryl and found that the absorption edge changed position from around 410 nm to around 320 nm after the crystal's yellow colour disappeared upon heating. Absorption up to 410 nm covers the violet part of the visible range and gives rise to the yellow colour. Wood and Nassau (1968) reported that the most likely site of the Fe^{3+} ion causing this absorption is that of the octahedral Al^{3+} ion, but they also stated that their evidence was not conclusive. Still, the assumption that octahedral Fe^{3+} is the yellow chromophore in beryl has survived for decades in numerous publications, textbooks and review articles, including that of Loeffler and Burns (1976).

Octahedral Fe^{3+} has a typical five-line signal in electron paramagnetic resonance spectra. Andersson (2013) found this signal in beryl samples of various

colours—as well as in colourless beryl, which shows that octahedral Fe^{3+} is not a chromophore. Andersson (2013) suggested instead that tetrahedral Fe^{3+} is the yellow chromophore.

The same explanation was also proposed earlier. Samoilovich *et al.* (1971) noted that the yellow colour disappears upon heating because the absorption band from tetrahedral Fe^{3+} vanishes. Simultaneously, the 820 nm band due to tetrahedral Fe^{2+} appears. Goldman *et al.* (1978) found that this 820 nm band (purportedly due to Fe^{2+} in the channels of the beryl structure) began to strengthen with heating above 200°C, while the absorption tail at about 400 nm began to recede. From this, they interpreted that the absorption tail responsible for the yellow colour arises from Fe^{3+} in the channels (rather than, as is now known, Fe^{3+} at the tetrahedral site).

Channel-hosted Fe^{3+} was also proposed as causing the green colour of beryl (Blak *et al.* 1982). However, Bačík

and Fridrichová (2019) showed that there are no stable positions for iron ions in the beryl channels.

The Fe^{3+} absorption is due to charge-transfer transition between the iron ion and the surrounding oxygen ions. This is a very strong absorption: it can be two to three orders of magnitude stronger than the crystal-field absorption at 820 nm by the same number of iron ions (Samoilovich *et al.* 1971). Observations of the maxima of Fe^{3+} absorptions are rare, and their positions are not well established because they are often overlapped by other absorptions. Spinolo *et al.* (2007) and Isotani *et al.* (2010) recorded an absorption around $37,000\text{ cm}^{-1}$ (270 nm) that can be correlated to octahedral Fe^{3+} .

The number of Fe^{3+} ions at the tetrahedral site is often too small to form an absorption edge at 410 nm (as in figure 9 in Wood & Nassau 1968). In this case, the tetrahedral Fe^{3+} absorption is seen as a slope stretching from the absorption edge of octahedral Fe^{3+} to about 500 nm (cf. figure 6 in Wood & Nassau 1968).

Yellow beryl occurs in different shades. Platonov *et al.* (2016) proposed two different types of yellow beryl, which they referred to as *heliodor* and *golden beryl* (inferred as yellow and orangey yellow, respectively; e.g. Figure 7). They suggested that the chromophore of golden beryl is Fe^{3+} at the Be site, while the colour of heliodor is due to octahedral Fe^{3+} . Most yellow beryls contain mixtures of the two chromophores, giving rise to the different shades.

Andersson (2019) suggested that Fe^{3+} gives rise to the yellow colour in beryl when it occupies the T3 tetrahedron described above in the section on blue chromophores. The mirror pair of the normally empty T3 tetrahedra can contain one or two Fe^{3+} ions, which in both cases results in yellow colouration.

GREEN BERYL

The best-known green beryl is emerald, which obtains its colour from Cr and/or V ions. However, a different green colour can be obtained from mixtures of the yellow and blue beryl chromophores described above.

When yellow and aquamarine chromophores are simultaneously present, the colour becomes light green. Depending on the relative concentrations of the two chromophores, the colour can vary from light yellow-green to light blue-green (e.g. Figure 8a). Shang *et al.* (2022) classified the colours of beryls containing these chromophores into five groups, from yellow to light blue.

The colour of the blue-green beryl shown in Figure 8b could occur when the yellow and dark blue beryl chromophores are simultaneously present. It has not yet been definitely established whether these two chromophores can coexist, but this possibility can be confirmed by a test suggested in the Discussion section below. (The colour of the greenish blue beryl in Figure 8b could also occur when there is some Cr present.)

CHANGES TO COLOUR DUE TO HEATING AND IRRADIATION

Some colours of beryl change upon heating or irradiation. These colour modifications are related to changes of the valence state of the iron ions. Mathew *et al.* (2000) irradiated a colourless beryl crystal (goshenite) which became yellow. Heating this crystal to 400°C caused the colour to change from yellow to blue. Further heating above 500°C caused the beryl to lose its colour and again become colourless. Another example of a change

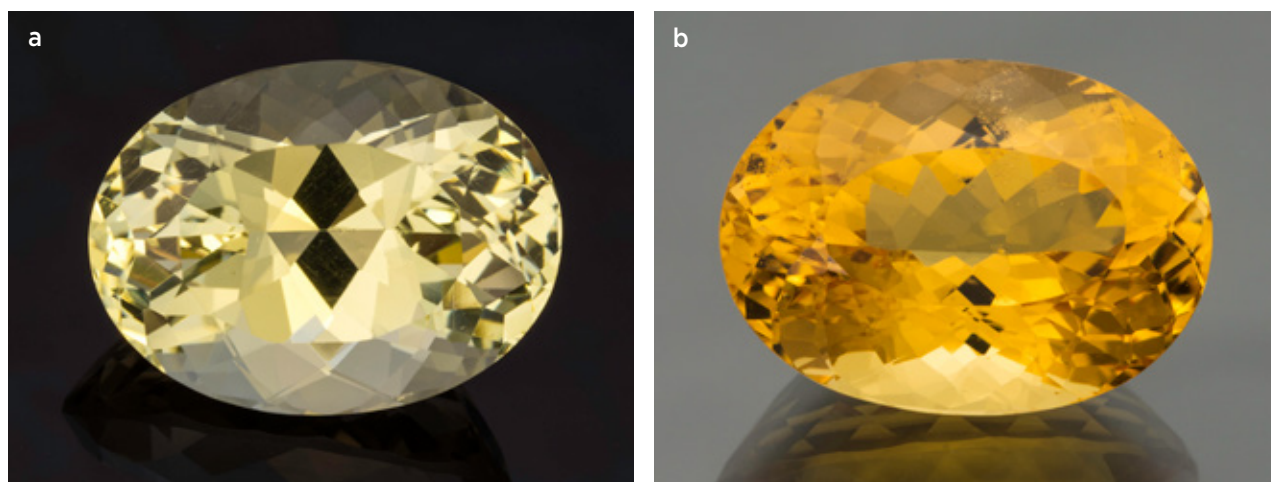


Figure 7: Some researchers have proposed two types of yellow beryl representing two different chromophores, referring to them as **(a)** heliodor, such as this 25.37 ct yellow stone from an unspecified locality, and **(b)** golden beryl, such as this 11.05 ct orangey yellow gem from Brazil. Courtesy of Pala International; photos by Mia Dixon.

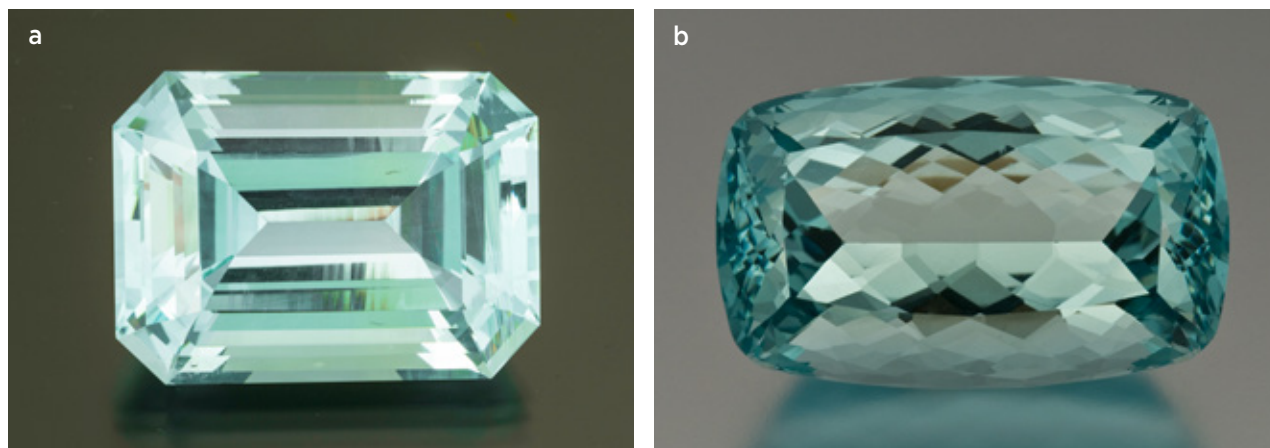


Figure 8: (a) The colour of green beryl (116.20 ct, from Sri Lanka) results from a mixture of aquamarine and yellow beryl chromophores. (b) Blue-green beryl (33.58 ct, from Mozambique) may result from a mixture of dark blue and yellow beryl chromophores. Courtesy of Pala International; photos by Mia Dixon.

from yellow beryl to aquamarine due to heat treatment was given by Ruzeng *et al.* (2007). A similar change of colour is illustrated in Figure 9.

Fridrichová *et al.* (2015) heated crystals of deeply coloured aquamarine and yellow beryl to different temperatures. After heating one of the yellow crystals to 300°C it was still yellow. Heating of additional yellow beryl samples to 500°C and 700°C in each case resulted in light blue aquamarine colouration.

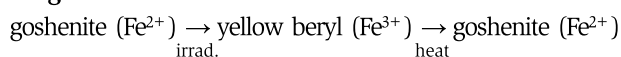


Figure 9: The aquamarine colour at the top (123.69 g) was obtained by heating greenish yellow beryl from Ukraine, such as those samples shown at the bottom of the photo (50.02 g and 68.87 g). The top sample turned blue after heating at 400°C for 30 minutes. Photo by George R. Rossman.

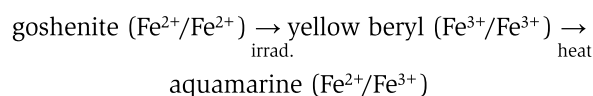
Another yellow crystal heated to 900°C lost almost all its colour. However, the dark blue crystals remained blue after heating to all these temperatures, which shows that the dark blue chromophore does not change upon heating.

The changes in colour of crystals displaying the aquamarine chromophore can be explained if the iron ions occupy the T3 tetrahedra. The following transformations involve one or two tetrahedral iron ions—starting with Fe^{2+} alone or $\text{Fe}^{2+}/\text{Fe}^{2+}$ —in the T3 mirror pair. All these transformations have been described in detail by Andersson (2019) with literature references to the experimental observations.

Single ion:

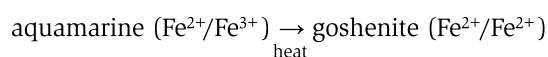


Two ions:

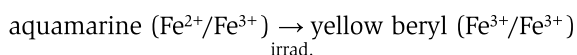


Iron-free goshenite and goshenite containing Fe^{2+} ions only at the octahedral site remain colourless upon irradiation. Only goshenite with Fe^{2+} ions at a tetrahedral site turns yellow.

Upon further heating, the aquamarine loses its colour:



Irradiation of the aquamarine causes it to return to yellow beryl:



This shows how the aquamarine chromophore (tetrahedral $\text{Fe}^{2+}/\text{Fe}^{3+}$) changes with irradiation to become

the yellow chromophore (tetrahedral $\text{Fe}^{3+}/\text{Fe}^{3+}$). Heating reverses the change. The electron ejected from Fe^{2+} by irradiation is trapped somewhere in the crystal and is released from the trap upon heating, reducing Fe^{3+} to Fe^{2+} .

The temperature at which a change in colour is observed can vary depending on the characteristics of the samples (number, type and depth of the occupied electron traps) and on the experimental setup (number of steps, rapidity and duration of the heating). The type, intensity and duration of irradiation can also give varying results.

NATURAL RADIATION

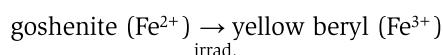
Mathew *et al.* (2000) inferred that natural yellow, blue and green colours in beryls containing Fe impurities are due to prolonged natural irradiation.

Reinitz and Rossman (1988) studied the role of natural radiation in tourmaline colouration. They found that the pink colour obtained after laboratory irradiation of colourless elbaite is the same as that of natural pink elbaite. They concluded that the natural elbaite was colourless at the high temperature of crystallisation and that the pink colour subsequently arose in the cooled crystal by gamma rays emitted from K-feldspar in the surrounding pegmatite. The pink colour is due to the valence change of Mn ions (i.e. $\text{Mn}^{2+} \rightarrow \text{Mn}^{3+}$) both in the natural- and the laboratory-irradiated crystal. They calculated that the concentration of ^{40}K in pegmatitic feldspar is sufficient to produce a visible pink colour by irradiation due to the decay of these radioactive nuclei over geological time.

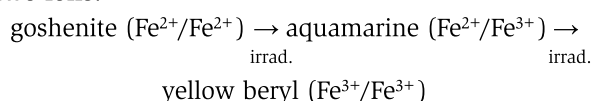
Irradiation from the ^{40}K nuclei in the surrounding pegmatitic K-feldspar can likewise eject electrons from the tetrahedral Fe^{2+} ions in beryl, creating the tetrahedral chromophores. After many millions of years, the amount of these chromophores becomes sufficient to produce visible colouration in beryl. K^+ is a common impurity ion in the beryl channels and could be an additional source of radiation.

The following transformations show the effects of natural irradiation:

Single ion:



Two ions:



The intermediate aquamarine stage has not been reported from laboratory irradiation experiments,

probably because the radiation dose has been too strong. It should certainly appear during the slower transformation due to natural irradiation.

When the transformation to yellow beryl is only partly completed, a mixture of aquamarine and yellow chromophores is present, so the colour appears green. Depending on the progress of the transformation, the colour can vary from blue-green to yellow-green.

Irradiation from other radioactive nuclei in the surrounding rock, such as uranium or thorium, can also create colouration in beryl. Wise (2005) described a 40-cm-long beryl crystal that was blue-green at one end and yellow at the other end where it was located near an area rich in uraninite. Another example is provided by the beryl crystal in Figure 10, which shows a darker orangey yellow colouration at the end that was inferred to be closer to a uranium source (Wise 2005).

DISCUSSION

Wu *et al.* (2023) reviewed the site occupancy and colouration mechanisms of iron ions in beryl, citing a large number of investigations. They came to the conclusion that further research is needed to definitively determine the colour-causing effects of iron ions and the locations



Figure 10: This yellow beryl from the Orchard pit in Maine, USA (approximately 7 cm tall), is inferred to have formed close to a uranium source, which caused the deeper colour at the bottom of the crystal. Photo by G. Freeman.

of these ions in the beryl structure. Their review includes a drawing showing the position of the T3 tetrahedron in the beryl crystal lattice.

The explanations given in the present article assume that the tetrahedral iron ions occupy the T3 tetrahedra (again, see Figure 6). There may be other explanations that could account for the colouration of yellow, green and aquamarine beryls, as well as the transformations in colour due to heating and irradiation. One explanation could be that the iron ions involved in IVCT are located at the Al and Be sites. The dark blue beryl colour could then be simply explained by IVCT between iron ions at the Al sites, as suggested by Loeffler and Burns (1976). IVCT between iron ions located at the Be sites could explain the aquamarine colour, while valence changes of the iron ions at the Be sites could give rise to the colour changes caused by heating and irradiation. However, the 4.60 Å distance between the Al and the Be sites in the *c*-axis direction is probably too large for effective IVCT (Groat *et al.* 2010).

One difficulty with the present proposal is how to explain the stability of the intermediate aquamarine stage in the colour transformations. When yellow beryl is heated to about 400°C, only one of the Fe³⁺ ions in the mirror pair of T3 tetrahedra is reduced, so the aquamarine colour appears. It is not clear why a higher temperature is needed to reduce the second Fe³⁺ ion to make the crystal colourless. Perhaps the rapid exchange between Fe²⁺/Fe³⁺ and Fe³⁺/Fe²⁺ in the IVCT pair makes it difficult to convert the second ion. Mathew *et al.* (2000) observed that too-rapid heating made the crystal colourless without first becoming aquamarine blue. Similarly, irradiation would be expected to first oxidise only one of the Fe²⁺ ions in goshenite, creating the IVCT pair to produce aquamarine. Further irradiation also oxidises the second Fe²⁺ ion, so the crystal becomes yellow. As mentioned earlier, the too-strong irradiation in laboratory experiments has not allowed the observation of the intermediate aquamarine stage.

During beryl crystallisation, the temperature is so high that all tetrahedral iron ions are present as Fe²⁺. Stable tetrahedral Fe³⁺ ions can be created by irradiation only after the temperature has cooled down. The radiation from the surrounding rock is typically weak, and it will take many millions of years until there are enough Fe³⁺ ions to make the aquamarine, green or yellow colour visible. The colouration depends on the distribution of iron as single ions and as Fe pairs in the mirror pairs of T3 tetrahedra. The introduction of the (large) iron ion into the (small) tetrahedron causes a local distortion of the crystal structure. This distortion

may make it easier for a second iron ion to enter the other tetrahedron of the T3 pair, which may explain a large concentration of such pairs. The colour also depends on subsequent natural heating after the beryl crystallises. A temperature above only 200°C is sufficient to reduce the tetrahedral Fe³⁺ ion (Goldman *et al.* 1978), making the yellow colour disappear. When the system has cooled down, the crystal can again become yellow from continued irradiation by the surrounding rock.

It is possible that the aquamarine chromophore can exist together with the dark blue beryl chromophore in the same crystal. This could be tested by irradiating a piece of blue beryl: (1) aquamarine becomes yellow upon irradiation (Samoilovich *et al.* 1971), (2) dark blue beryl remains blue (with less intensity), and (3) a mixture would become green (because of the remaining dark blue beryl chromophores).

When the Fe³⁺ ion in a dark blue chromophore is oxidised to Fe³⁺ by irradiation, the IVCT pair disappears. Fewer IVCT pairs leads to a weaker colour, as in case (2) above. Upon extended irradiation, as occurs in pegmatites containing K-feldspar, the Fe²⁺ ions in all dark blue chromophores are oxidised. Therefore, dark blue beryl should not occur in pegmatites containing K-feldspar. (This assumption could be verified by strong irradiation of a dark blue beryl, which should become colourless.) Synthetic iron-containing beryls are dark blue (Adamo *et al.* 2008), and are created under irradiation-free conditions. It would be interesting to establish under which conditions dark blue beryl forms in nature.

Schmetzer *et al.* (1975) reported that blue beryl becomes green upon irradiation. As in case (3) above, this indicates that the dark blue chromophore can coexist with the aquamarine chromophore (before irradiation) and with the yellow chromophore (after irradiation). However, it is unlikely that the yellow chromophore, which is created by irradiation, and the dark blue chromophore, which is probably destroyed by irradiation, can exist together in the same crystal. Further research is needed to clarify this situation.

It is possible that two different yellow chromophores exist, as suggested by Platonov *et al.* (2016). As an alternative to their explanation, the difference between heliodor and golden beryl could be that heliodor has a single Fe³⁺ ion and golden beryl has two Fe³⁺ ions in the T3 mirror pair. This would explain why heliodor loses colour and golden beryl turns blue upon heating, as noted by Platonov *et al.* (2016). In addition, the orientation of the Fe³⁺ ion pair parallel to the crystal *c*-axis

may cause the strong pleochroism that they reported for golden beryl.

CONCLUSION

The aquamarine, yellow and green colours of Fe-containing beryl are created by exposure to natural irradiation from the surrounding rock. The colours result when the radiation creates Fe^{3+} ions by displacing an electron from the Fe^{2+} ions that reportedly substitute for Be^{2+} during the growth of the beryl crystal. No other impurity ion besides the tetrahedral Fe^{3+} ion influences these colours. The interpretation described in this article proposes that

the substituting Fe^{2+} ion is located not at the Be^{2+} site, but in an adjacent T3 tetrahedron that is normally empty in the beryl structure.

The aquamarine chromophore is a pair of Fe^{2+} and Fe^{3+} ions located in a mirror pair of T3 tetrahedra (whereas the dark blue beryl colour is due to a different $\text{Fe}^{2+}/\text{Fe}^{3+}$ pair, with Fe^{3+} at the normally empty interstitial 6g site). One yellow chromophore is due to a pair of Fe^{3+} ions in the same T3 tetrahedra, but a single Fe^{3+} ion in a T3 tetrahedron can also be a yellow chromophore. The green colour of (non-emerald) beryl results when both the aquamarine and yellow chromophores are present simultaneously.

REFERENCES

- Adamo, I., Pavese, A., Prosperi, L., Diella, V., Ajo, D., Gatta, G.D. & Smith, C.P. 2008. Aquamarine, Maxixe-type beryl, and hydrothermal synthetic blue beryl: Analysis and identification. *Gems & Gemology*, **44**(3), 214–226, <https://doi.org/10.5741/gems.44.3.214>.
- Andersson, L.O. 1979. The difference between Maxixe beryl and Maxixe-type beryl: An electron paramagnetic resonance investigation. *Journal of Gemmology*, **16**(5), 313–317, <https://doi.org/10.15506/JoG.1979.16.5.313>.
- Andersson, L.O. 2006. The positions of H^+ , Li^+ and Na^+ impurities in beryl. *Physics and Chemistry of Minerals*, **33**(6), 403–416, <https://doi.org/10.1007/s00269-006-0086-x>.
- Andersson, L.O. 2013. The yellow color center and trapped electrons in beryl. *Canadian Mineralogist*, **51**(1), 15–25, <https://doi.org/10.3749/canmin.51.1.15>.
- Andersson, L.O. 2019. Comments on beryl colors and on other observations regarding iron-containing beryls. *Canadian Mineralogist*, **57**(4), 551–566, <https://doi.org/10.3749/canmin.1900021>.
- Bačík, P. & Fridrichová, J. 2019. The site occupancy assessment in beryl based on bond-length constraints. *Minerals*, **9**(10), article 641, <https://doi.org/10.3390/min9100641>.
- Blak, A.R., Isotani, S. & Watanabe, S. 1982. Optical absorption and electron spin resonance in blue and green natural beryl. *Physics and Chemistry of Minerals*, **8**(4), 161–166, <https://doi.org/10.1007/bf00308238>.
- Bragg, W.L. & West, J. 1926. The structure of beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$. *Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character*, **111**(759), 691–714, <https://doi.org/10.1098/rspa.1926.0088>.
- Chen, Y., Wang, Y. & Shu, J. 2024. The effect of oxygen vacancies on the color formation of aquamarine. *Journal of Solid State Chemistry*, **329**, article 124400, <http://doi.org/10.1016/j.jssc.2023.124400>.
- Fridrichová, J., Bačík, P., Rusinová, P., Antal, P., Škoda, R., Bizovská, V. & Miglierini, M. 2015. Optical and crystal-chemical changes in aquamarines and yellow beryls from Thanh Hoa Province, Vietnam induced by heat treatment. *Physics and Chemistry of Minerals*, **42**(4), 287–302, <https://doi.org/10.1007/s00269-014-0719-4>.
- Goldman, D.S., Rossman, G.R. & Parkin, K.M. 1978. Channel constituents in beryl. *Physics and Chemistry of Minerals*, **3**(3), 225–235, <https://doi.org/10.1007/bf00633572>.
- Groat, L.A., Rossman, G.R., Dyar, M.D., Turner, D., Piccoli, P.M.B., Schultz, A.J. & Ottolini, L. 2010. Crystal chemistry of dark blue aquamarine from the True Blue showing, Yukon Territory, Canada. *Canadian Mineralogist*, **48**(3), 597–613, <https://doi.org/10.3749/canmin.48.3.597>.
- Isotani, S., Blak, A.R. & Watanabe, S. 2010. UV optical absorption spectra analysis of beryl crystals from Brazil. *Physica B: Condensed Matter*, **405**(6), 1501–1508, <https://doi.org/10.1016/j.physb.2009.12.029>.
- Loeffler, B.M. & Burns, R.G. 1976. Shedding light on the color of gems and minerals. *American Scientist*, **64**(6), 636–647, <https://www.jstor.org/stable/27847555>.
- Mathew, G., Karanth, R.V., Gundu Rao, T.K. & Deshpande, R.S. 2000. Colouration in natural beryls: A spectroscopic investigation. *Journal of Geological Society of India*, **56**(3), 285–303.
- Morosin, B. 1972. Structure and thermal expansion of beryl. *Acta Crystallographica*, **B28**(6), 1899–1903, <https://doi.org/10.1107/s0567740872005199>.

- Platonov, A.N., Taran, M.N., Minko, O.E. & Polshyn, E.V. 1978. Optical absorption spectra and nature of color of iron-containing beryls. *Physics and Chemistry of Minerals*, **3**(1), 87–88, <https://doi.org/10.1007/bf00357447>.
- Platonov, A., Khomenko, V. & Taran, M. 2016. Crystal chemistry, optical spectra and color of beryl. I. Heliodor and golden beryl — Two varieties of natural yellow beryl. *Mineralogical Journal*, **38**(2), 3–14, <https://doi.org/10.15407/mineraljournal.38.02.003> (in Russian with English abstract).
- Price, D.C., Vance, E.R., Smith, G., Edgar, A. & Dickson, B.L. 1976. Mössbauer effect studies of beryl. *Journal de Physique Colloques*, **37**(C6), 811–817, <https://doi.org/10.1051/jphyscol:19766171>.
- Reinitz, I.M. & Rossman, G.R. 1988. Role of natural radiation in tourmaline coloration. *American Mineralogist*, **73**(7–8), 822–825.
- Rohtert, W.R., Quinn, E.P., Groat, L.A. & Rossman, G.R. 2003. Gem News International: Blue beryl discovery in Canada. *Gems & Gemology*, **39**(4), 327–329.
- Ruzeng, Y., Hongyi, X. & Minjie, L. 2007. The effect of heat treatment on colour, quality and inclusions of aquamarine from China. *Journal of Gemmology*, **30**(5–6), 297–301, <https://doi.org/10.15506/JoG.2007.30.5.297>.
- Samoilovich, M.I., Tsinober, L.I. & Dunin-Barkovskii, R.L. 1971. Nature of the coloring in iron-containing beryl. *Soviet Physics, Crystallography*, **16**, 147–150 (in Russian).
- Schmetzer, K., Berdinski, W. & Bank, H. 1975. Farbveränderungen von Edelsteinen der Beryllgruppe [Color changes of gemstones of the beryl group]. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **24**(2), 81–87.
- Shang, Y., Guo, Y. & Tang, J. 2022. Spectroscopy and chromaticity characterization of yellow to light-blue iron-containing beryl. *Scientific Reports*, **12**(1), article 10765, <https://doi.org/10.1038/s41598-022-11916-z>.
- Shannon, R.D. 1976. Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. *Acta Crystallographica Section A*, **32**(5), 751–767, <https://doi.org/10.1107/s0567739476001551>.
- Spinolo, G., Fontana, I. & Galli, A. 2007. Optical absorption spectra of Fe²⁺ and Fe³⁺ in beryl crystals. *Physica Status Solidi (B)*, **244**(12), 4660–4668, <https://doi.org/10.1002/pssb.200743102>.
- Taran, M.N. & Rossman, G.R. 2001. Optical spectroscopic study of tihualite and a re-examination of the beryl, cordierite, and osumilite spectra. *American Mineralogist*, **86**(9), 973–980, <https://doi.org/10.2138/am-2001-8-903>.
- Taran, M.N. & Vyshnevskiy, O.A. 2019. Be, Fe²⁺-substitution in natural beryl: An optical absorption spectroscopy study. *Physics and Chemistry of Minerals*, **46**, 795–806, <https://doi.org/10.1007/s00269-019-01040-2>.
- Taran, M.N., Klyakhin, V.A., Platonov, A.N., Pol'shin, E.V. & Indutnyi, V.V. 1989. Optical spectra of natural and artificial iron-containing beryls at 77–297 K. *Soviet Physics, Crystallography*, **34**(6), 882–884 (in Russian).
- Taran, M.N., Dyar, M.D. & Khomenko, V.M. 2018. Spectroscopic study of synthetic hydrothermal Fe³⁺-bearing beryl. *Physics and Chemistry of Minerals*, **45**(5), 489–496, <https://doi.org/10.1007/s00269-017-0936-8>.
- Wise, M. 2005. Mellow yellow: Heliodor and golden beryl. In: Simmons, W.S., Staebler, G., Wilson, T. & Wise, M. (eds) *Beryl and Its Color Varieties*. extraLapis English Mineral Monograph No. 7, Lapis International LLC, East Hampton, Connecticut, USA, 58–60.
- Wood, D.L. & Nassau, K. 1968. The characterization of beryl and emerald by visible and infrared absorption spectroscopy. *American Mineralogist*, **53**(5–6), 777–800.
- Wu, X., Han, X., Feng, X. & Guo, S. 2023. Site occupancy and coloring mechanisms of iron ions in beryl. *Acta Petrologica et Mineralogica*, **42**(4), 577–590 (in Chinese with English abstract).

The Author

Dr Lars Olov Andersson

Riedikerstrasse 25, CH-8610 Uster, Switzerland
Email: loandersson@bluewin.ch

Acknowledgements

Bill Larson and Mia Dixon of Pala International (Fallbrook, California, USA) are thanked for supplying numerous photos to illustrate this article. The author also thanks Gary Freeman (Coromoto Minerals LLC, South Paris, Maine, USA), the Gemological Institute of America (Carlsbad, California, USA), Dr George R. Rossman (California Institute of Technology, Pasadena, California) and Orasa Weldon (OW Design, Carlsbad) for providing additional images.

Gemmological Characteristics and Origin of Basalt-related Pyrope from Southeast Vietnam

Le Ngoc Nang, Pham Trung Hieu and Pham Minh Tien

ABSTRACT: Basalt-related pyrope from Southeast Vietnam occurs as both xenocrysts and xenoliths, and is collected from secondary deposits. The garnet is transparent deep orange to light red when observed with transmitted light. The gemmological characteristics, as well as Raman and FTIR spectra, confirm it is pyrope. The chemical composition yields molar percentages of $\text{Py}_{72.0-75.3}\text{Al}_{14.8-18.3}\text{Gr}_{9.2-9.9}$ (where Py = pyrope, Al = almandine and Gr = Grossular) and an average chemical formula of $(\text{Mg}_{2.15}\text{Fe}_{0.42}^{2+}\text{Ca}_{0.27}\text{Mn}_{0.01})_{2.85}\text{Al}_{2.14}(\text{Si}_{2.99}\text{O}_{12})$. The surfaces of the pyrope exhibit resorption that occurred during transport to the surface in basaltic magma. Examination of coronae (kelyphitic texture) surrounding the xenolithic garnets with a petrographic microscope, combined with FTIR spectroscopy, shows that the pyrope originated from a deep garnet peridotite source.

The Journal of Gemmology, 38(8), 2023, pp. 773–783, <https://doi.org/10.15506/JoG.2023.38.8.773>
© 2023 Gem-A (The Gemmological Association of Great Britain)

Recently, various gems related to Cenozoic alkali basalt have been discovered and exploited in Southeast Vietnam, including sapphire, zircon, garnet, feldspar, augite and peridot (Nang *et al.* 2023a, b). Among these, pyrope is potentially one of the most commercially significant species for the gem and jewellery trade (Figure 1). Local people refer to these gems as ‘red stones’, and they are commonly gathered in areas underlain by Cenozoic basalt (Figure 2).

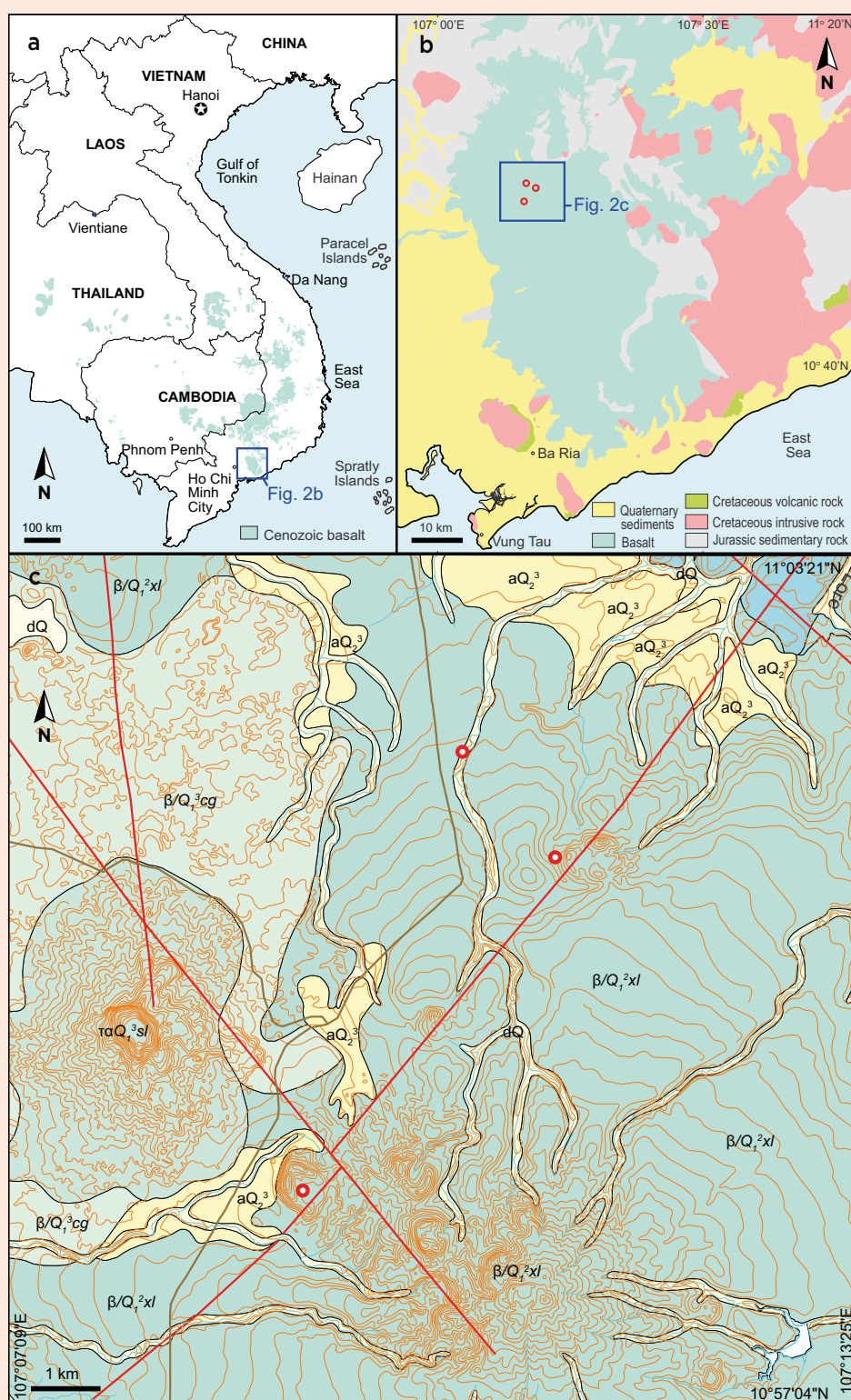
Pyrope is the Mg-rich end member of the garnet group and is sometimes encountered as a gem material. Relatively pure gem-quality pyrope is rather uncommon, with only a few commercially significant localities, such as Italy (Guastoni *et al.* 2001) and the Czech Republic (Duraj *et al.* 2015). Although pyrope mainly forms in metamorphic rocks (e.g. Kawabata & Takafuji 2005), it also occurs in basaltic rocks as xenocrysts (i.e. crystals introduced into igneous rock from an external source) and xenoliths (i.e. rock fragments entrained in igneous rock; Keankeo *et al.* 2000; Aydar & Gourgaud 2002; Scully *et al.* 2004). Most studies have pointed out that,

although pyrope is found in association with basalt, it did not crystallise from the basaltic magma, but rather formed in a different geological environment and was then transported to the surface in the basalt.

After it crystallises, pyrope may subsequently become unstable with changing geological conditions—such as



Figure 1: Gem-quality pyrope xenocrysts from Southeast Vietnam sometimes occur in attractive shapes that are suitable for mounting in jewellery without the need for cutting or polishing, as shown by this pendant (sample PG-12, 1.6 g) and ring (sample PG-8, 0.2 g). Photos by Le Ngoc Nang.



when the garnet is transported towards the surface by basaltic magma—resulting in a corona-like alteration product called *kelyphite* (Ezad *et al.* 2022). Kelyphitic texture is shown by xenolithic garnet that is rimmed by a fine-grained, fibrous intergrowth of multiple phases

such as pyroxene, spinel and amphibole (Obata 2011). The specific composition of the kelyphite assemblage is related to the original formation environment of the garnet. For example, pyrope from garnet peridotite (an ultramafic rock consisting mainly of olivine that

formed in the upper mantle) has kelyphite consisting of orthopyroxene, clinopyroxene, spinel and varying amounts of phlogopite, amphibole and carbonate, while garnet from eclogite (a metamorphic rock comprised of pyrope-almandine in a matrix of Na-rich pyroxene) has kelyphite comprising phlogopite, amphibole, spinel, chlorite, plagioclase and glass (Garvie & Robinson 1984). For this article, we used the differences between peridotitic and eclogitic kelyphites to determine the primary origin of pyrope from Southeast Vietnam. In addition, we describe the gemmological characteristics of these garnets.

GEOLOGICAL SETTING

The Indochina block hosts numerous occurrences of Late Cenozoic basalts, divided into six eruption periods, which include two types: alkali basalt and basanite (e.g. Barr & Macdonald 1981; Hoang *et al.* 1996; Hoang & Flower 1998; Hoang *et al.* 2018). Of these, alkali basalt is more important for hosting gem materials (e.g. Nang *et al.* 2023a, b). Basaltic plateaus in Indochina cover an area of about 70,000 km² in Vietnam, Cambodia, Laos and Thailand (Barr & Macdonald 1981; Hoang *et al.* 1996). In Vietnam, the basaltic plateaus form layered units up to 450 m thick, and crop out in several areas in the Central Highlands, such as Buon Me Thuot, Pleiku, Dak Mil, Duy Linh–Bao Loc, Phuoc Long–Loc Ninh–Bu Dang and in portions of Southeast Vietnam such as Xuan Loc (Dong Nai) and Binh Phuoc (Barr & Macdonald 1981; Hoang *et al.* 1996; An *et al.* 2017; Hoang *et al.*

2018). The Cenozoic basalt sits atop Cretaceous igneous rock and Jurassic sedimentary layers, and is overlain by Quaternary sediments (again, see Figure 2).

Gem materials are commonly associated with the Cenozoic basaltic plateaus in Vietnam's Dong Nai Province. Augite, feldspar, sapphire, zircon, garnet and peridot are thought to be xenocrystic megacrysts that were transported to the surface in alkali basalt (Nang *et al.* 2023a, b). The gems are distributed on diluvial slopes and are mainly deposited in small stream beds. Most of the gem areas are located near basaltic eruption craters (Tri & Khuc 2011). The gems are recovered artisanally in limited quantities by the locals on their land. According to information provided by stone dealers, the estimated quantity of gem-quality pyrope gathered from Vietnam's Southeast Region in 2022 was 750–800 g of xenocrysts (measuring 5–45 mm) and 9–12 kg of xenoliths.

MATERIALS AND METHODS

A total of more than 50 garnet samples were collected by author LNN during two field trips in August 2020 and October 2021. For this study, we selected 15 xenocrysts of various shapes, consisting of three pieces embedded in weathered basaltic rock (e.g. Figure 3) and 12 specimens found loose in basaltic soil on hillslopes (e.g. Figure 4). We also studied nine xenoliths showing different ratios of garnet to rock matrix (e.g. Figure 5). From these specimens, ten gemstones (Figure 6) were faceted by Nguyen Tri Duc, a gem cutter associated with LIULAB: eight from xenocrysts (samples PG-1 to

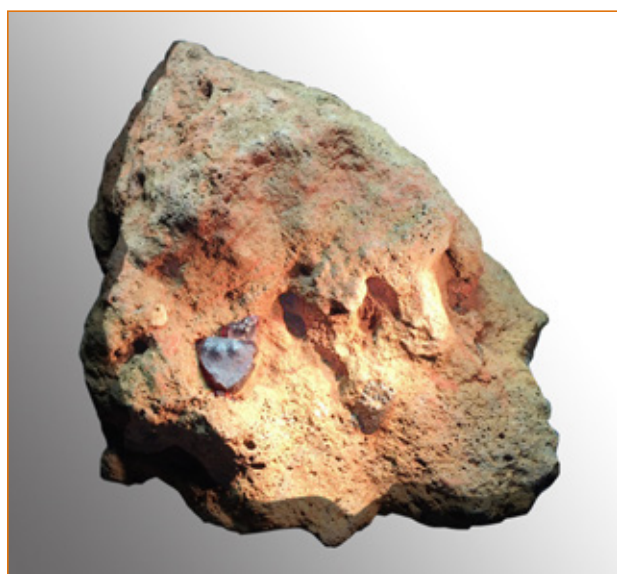


Figure 3: Two pyrope xenocrysts are embedded together in weathered basalt in this sample from Southeast Vietnam. The larger garnet measures 1.5 × 1.2 cm. Photo by Le Ngoc Nang.

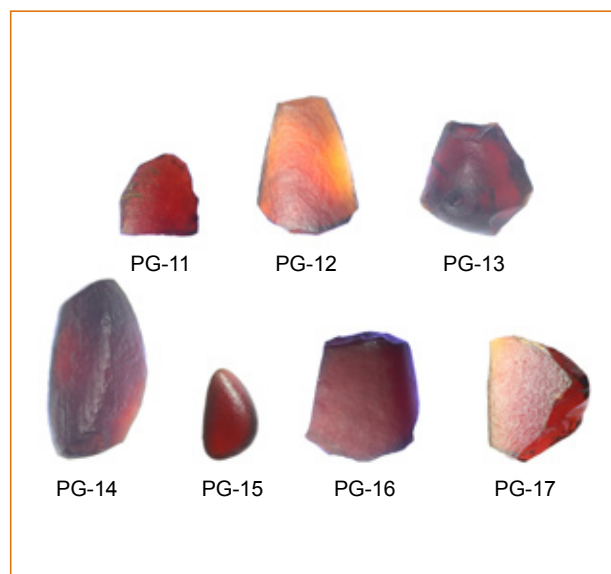


Figure 4: Pyrope xenocrysts (0.87–3.53 g) from Southeast Vietnam have various shapes and are naturally etched and weathered to varying degrees. Photo by Pham Minh Tien.

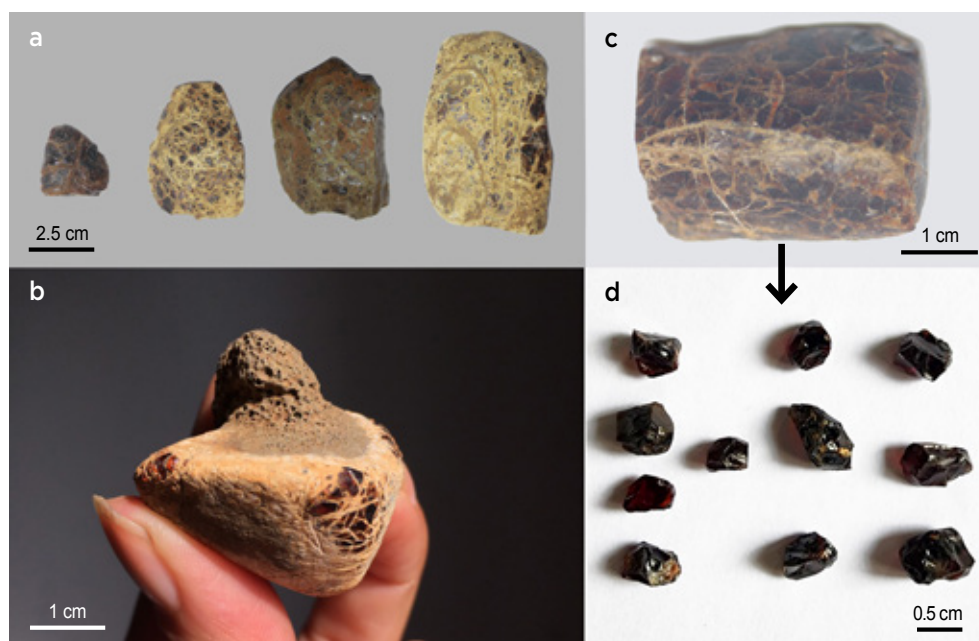


Figure 5: (a) These xenoliths from Southeast Vietnam consist of pyrope and matrix rock (deeply altered) in which it formed. (b) In this specimen, a garnet-bearing xenolith (bottom) is attached to weathered basalt (top). (c, d) A single piece of xenolithic garnet can produce several gem-quality pyrope fragments. Photos by Pham Minh Tien.

PG-8) and two from xenoliths (PG-9 and PG-10). Two additional xenolith samples were sliced and polished into thin sections (0.03 mm thickness) and examined with an Olympus CH-2 petrographic microscope with 100×–400× magnification. The remaining seven xenocrysts (Figure 4) and five xenolith samples were retained in their original condition.

Standard gemmological properties were collected at LIULAB. The colour appearance of the garnets was observed with a 60 W GLS LED daylight lamp (5000–6000K) using transmitted light. Refractive index was measured on all ten faceted stones using a refractometer with a sodium light source and an RI liquid consisting of a mixture of methylene iodide and tetraiodoethylene (RI = 1.81). Additional gem properties—including hydrostatic SG, polariscope reaction, and fluorescence to long-wave (365 nm) and short-wave (254 nm) UV radiation—were collected for the faceted stones and

five rough samples (PG-11 to PG-15). The microscopic features in all of these specimens were observed with a Carton SPZV-50 stereo-zoom microscope with 7×–50× magnification.

Quantitative chemical data were obtained by energy-dispersive X-ray fluorescence analysis (EDXRF) at the Center of Analytical Services and Experimentation in Ho Chi Minh City, Vietnam. Five faceted samples (from xenocrysts PG-2, PG-3, PG-4 and PG-8, and xenolith PG-9) were analysed using a Shimadzu EDX-8100 instrument operated with a voltage of 30 kV and a beam current of 10 mA. Limits of detection were Si and Al = 10 ppm; Ti, Fe, Mn, Ca and K = 1 ppm; and Mg and Na = 100 ppm. Analytical standards consisted of quartz (Si), corundum (Al), titanium dioxide (Ti), manganosite (Mn), periclase (Mg), fayalite (Fe), jadeite (Na), wollastonite (Ca), potassium titanium phosphate (K) and eskolaite (C).



Figure 6: These faceted pyropes (1.09–12.15 ct) were cut from xenocrysts (PG-1 to PG-8) and xenoliths (PG-9 and PG-10), and show relatively uniform colour. Composite photo by Le Ngoc Nang.

Raman spectroscopy of the garnets was performed at the Institute of Chemical Technology, Ho Chi Minh City. Three faceted stones were analysed—two from xenocrysts (PG-1 and PG-2) and one from a xenolith (PG-9)—using a Horiba Scientific XploRA ONE Raman microscope in the range of 100–3750 cm^{-1} with the following parameters: 50 $\times$ objective, 15 s acquisition time, two accumulations, 532 nm laser, 900 grooves/mm grating, 50% filter and a spectral resolution of 5 cm^{-1} .

Fourier-transform infrared (FTIR) spectroscopy of three faceted garnets (xenocrystic samples PG-1 and PG-2 and xenolithic specimen PG-9) was performed at LIULAB using an Agilent Cary 630 spectrometer with the attenuated total reflectance (ATR) sampling technique. The resolution was < 2 cm^{-1} and scanning time was 3 s in the range of 400–1200 cm^{-1} . FTIR spectra were also taken (in the 400–4000 cm^{-1} range) from three powdered kelyphite samples obtained by scraping the rough samples with a scalpel.

RESULTS AND DISCUSSION

General Appearance

Xenocrystic Pyrope. The xenocrystic garnet samples were mostly irregular in shape (again, see Figure 4). The more pleasing forms of xenocrystic pyrope can be used in their natural state to make jewellery (e.g. Figure 1). Their surfaces were etched, creating textures that showed various dendritic, rippled, or rough patterns (Figure

7a–d). The degree of corrosion varied from sample to sample, indicating that the pyrope had undergone different episodes of breakage followed by chemical etching and weathering processes.

Xenolithic Pyrope. The xenolithic garnet samples formed fractured masses with round or oblong shapes (Figure 5a). They ranged in size from a few centimetres to more than 10 cm. Most of the garnet material was transparent between fractures, while the matrix was weathered and opaque. The proportion of garnet to matrix in each xenolith varied greatly, from a few tiny garnets to nearly 80% garnet. Occasionally, the xenoliths were found attached to the host basalt (Figure 5b). All of the xenolithic samples contained kelyphitic material in association with the pyrope.

Transparent pieces of garnet could be extracted from some of the xenoliths for faceting (Figure 5c, d). The garnet surfaces showed etching and weathering textures (Figure 7e–h) that were similar to those seen on the xenocrysts. This morphological resemblance leads to a hypothesis that both xenocrystic and xenolithic garnets underwent the same conditions of formation and weathering.

Gemmological Characteristics

Both the xenocrystic and xenolithic pyrope samples exhibited similar colouration, appearing dark brownish

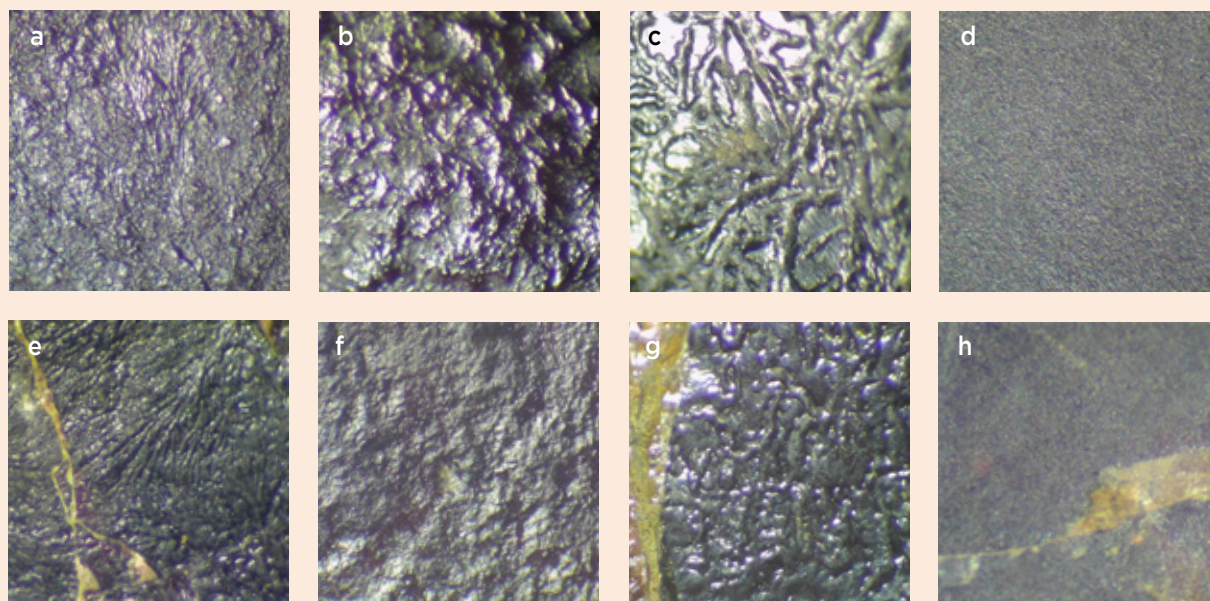


Figure 7: Photomicrographs depict surface etching and weathering features for xenocrystic (a–d) and xenolithic (e–h) pyrope samples. The most common patterns are dendritic forms (a, c, e, g), ripple-like features (b, f) and rough surfaces (d, h). The similarity of the patterns on the xenolithic and xenocrystic garnets suggests that they both share the same geological history. Photomicrographs by Le Ngoc Nang; magnified 30 $\times$ (a, e), 40 $\times$ (b, f) and 50 $\times$ (c, d, g, h).

red in daylight and ranging from deep orange to medium red in transmitted light. The faceted stones showed good transparency and a vitreous lustre.

There were no differences in the gemmological properties of the xenocrystic and xenolithic garnets. The RIs of the ten faceted samples (PG-1 to PG-10) ranged from 1.740 to 1.742, with an average of 1.741. Hydrostatic SG values were 3.70–3.75, with an average of 3.74. Viewed with the polariscope, all samples were optically isotropic without anomalous extinction. Also, all of them were inert to long- and short-wave UV radiation. These properties are consistent with those of gem-quality pyrope (Liddicoat 1993).

All the faceted samples were of high clarity with few internal features, so we examined near-surface inclusions in the rough samples. These most commonly consisted of feathers, channels and solid inclusions surrounded by tension fractures (Figure 8). Some of the surface-reaching feathers were partially or completely filled with secondary material (Figure 8a, c). Bundles of parallel channels were seen in both xenocrystic and xenolithic pyrope samples, and were typically filled with a brown material (Figure 8b). Their thickness became narrower (i.e. tapering inward) with increasing distance from the surface. The appearance of these channels suggests that they are dissolved dislocations that formed from preferential chemical etching along defects such as screw dislocations (Philippe & Fritsch 2019). The solid inclusions surrounded by haloes (Figure 8d) were seen only in the xenocrystic garnets, and probably resulted from differential expansion of the inclusions during basaltic transport to the surface.

Chemical Composition

The chemical compositions of five pyrope samples from Southeast Vietnam are shown in Table I and compared to gem-quality pyrope from other localities reported in the literature. The amounts of Si, Mg and Fe measured in this study are similar to those of pyrope from the Kolin area of the Czech Republic (Vrána 2008), while Ca and Cr are lower. The molar percentages of the end members, $\text{Py}_{72.0-75.3}\text{Al}_{14.8-18.3}\text{Gr}_{9.2-9.9}$, indicate that the garnets from Southeast Vietnam consist mainly of pyrope, with some almandine and grossular (and very little spessartine). An average chemical formula of the garnet, assuming 12 oxygens and all iron as Fe^{2+} , is $(\text{Mg}_{2.15}\text{Fe}_{0.42}^{2+}\text{Ca}_{0.27}\text{Mn}_{0.01})_{2.85}\text{Al}_{2.14}(\text{Si}_{2.99}\text{O}_{12})$, thus showing significant Fe^{2+} and some Ca replacing Mg at the bivalent position, thereby lowering the amount of Mg and resulting in a mixture of pyrope, almandine and grossular.

The content of major oxides MgO, FeO, CaO and MnO varies significantly in pyrope from the different localities shown in Table I. In particular, the MgO contents of pyrope from Vietnam, the Czech Republic and Tanzania were lower than that in material from Italy. In addition, the FeO and CaO contents of pyrope from Vietnam were much higher than in those from Tanzania and Italy. Also, the MnO content of the pyrope from Tanzania was notably higher than in material from the other localities.

Raman and FTIR Spectra

The Raman and FTIR spectra illustrate essentially the same spectral features for the xenocrystic (PG-1 and PG-2) and xenolithic (PG-9) garnets. The Raman spectra

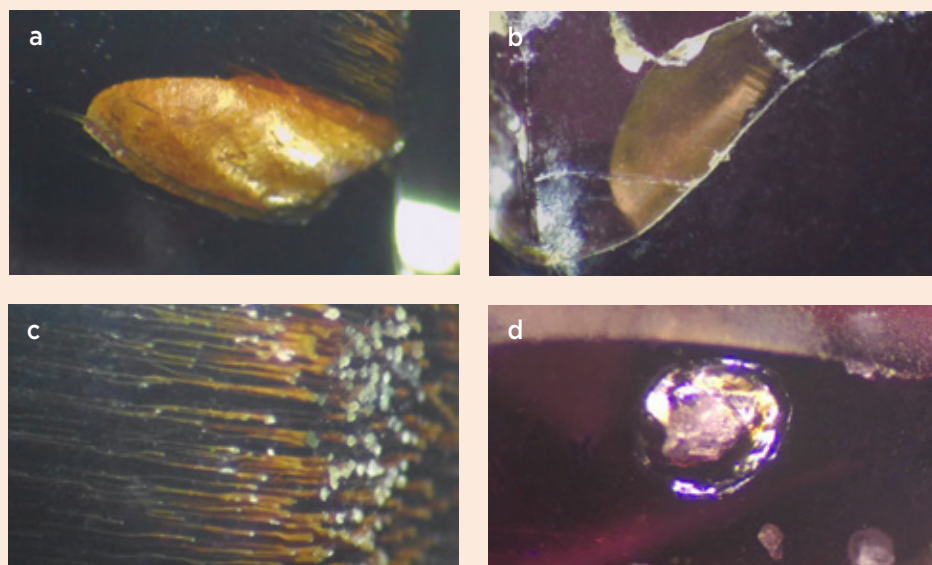


Figure 8: Internal features in pyrope from Southeast Vietnam include (a, b) open feathers filled with secondary material, (c) parallel tapered channels and (d) solid inclusions with tension fractures. Photomicrographs by Le Ngoc Nang; magnified 50× (a, b and c) and 30× (d).

Table 1: Chemical composition of pyrope from Southeast Vietnam and elsewhere for comparison.*

Locality and reference	Southeast Vietnam (this study)					Czech Republic (Vrána <i>et al.</i> 2008)	Italy (Anthony <i>et al.</i> 2008)	Tanzania (Sun <i>et al.</i> 2015)
	PG-2	PG-3	PG-4	PG-8	PG-9			
Oxides (wt.%)								
SiO ₂	42.36	40.99	42.46	41.80	42.60	42.32–42.67	45.21	40.86–42.14
TiO ₂	0.30	0.29	0.26	0.27	0.26	0.05–0.50	nr	0.03–0.06
Al ₂ O ₃	25.74	25.25	25.70	25.61	25.54	20.91–22.34	25.55	24.19–25.70
Cr ₂ O ₃	0.08	0.05	bdl	0.12	0.12	0.90–3.37	nr	0.07–0.13
FeO	7.14	9.20	7.65	7.69	7.14	6.67–9.39	0.91	4.04–5.30
MnO	0.20	0.27	0.22	0.22	0.21	0.25–0.32	0.02	5.42–7.45
MgO	20.41	20.27	19.73	20.61	20.42	18.92–20.29	28.83	19.40–20.73
CaO	3.60	3.59	3.67	3.63	3.64	4.50–5.53	0.28	2.10–2.69
Ions based on 12 oxygens								
Si	2.988	2.902	3.011	2.949	2.988	3.033–3.067	3.030	2.930–2.992
Ti	0.016	0.015	0.014	0.014	0.014	0.003–0.027	nr	0.002–0.003
Al	2.140	2.107	2.143	2.127	2.140	1.769–1.897	2.018	2.024–2.170
Fe ²⁺	0.421	0.490	0.454	0.453	0.421	0.400–0.567	0.051	0.200–0.316
Mn	0.012	0.016	0.013	0.013	0.012	0.015–0.020	0.001	0.328–0.452
Mg	2.146	2.139	2.085	2.165	2.146	2.038–2.149	2.880	2.070–2.194
Ca	0.272	0.272	0.276	0.276	0.272	0.352–0.425	0.020	0.159–0.206
Mol.% end members								
Pyrope	75.27	71.95	73.66	74.52	75.18	67.9–71.6	97.55	68.92–72.90
Almandine	14.77	18.32	16.02	15.60	14.75	13.3–18.9	1.73	6.56–10.14
Grossular	9.47	9.18	9.85	9.43	9.36	2.0–5.9	0.68	4.48–5.61
Spessartine	0.42	0.54	0.47	0.45	0.44	0.5–0.7	0.04	9.55–15.08

* Abbreviations: bdl = below detection limit; nr = not reported.

in the 100–1100 cm⁻¹ range (Figure 9a) show peaks at 203, 359, 492, 551, 635, 858, 914 and 1050 cm⁻¹. The 203 cm⁻¹ peak is attributed to T(SiO₄)⁴⁻ (where T = internal bending and stretching vibrations of the SiO₄ tetrahedra); the 359 cm⁻¹ peak corresponds to rotational

vibrations of (SiO₄)⁴⁻; the 551 cm⁻¹ peak is associated with Si–O bending vibrations; and the 858 and 914 cm⁻¹ peaks are attributed to Si–O stretching vibrations (Mernagh & Liu 1990; Gillet *et al.* 1992; Kolesov & Geiger 1998; Li *et al.* 2022). No Raman spectral features were

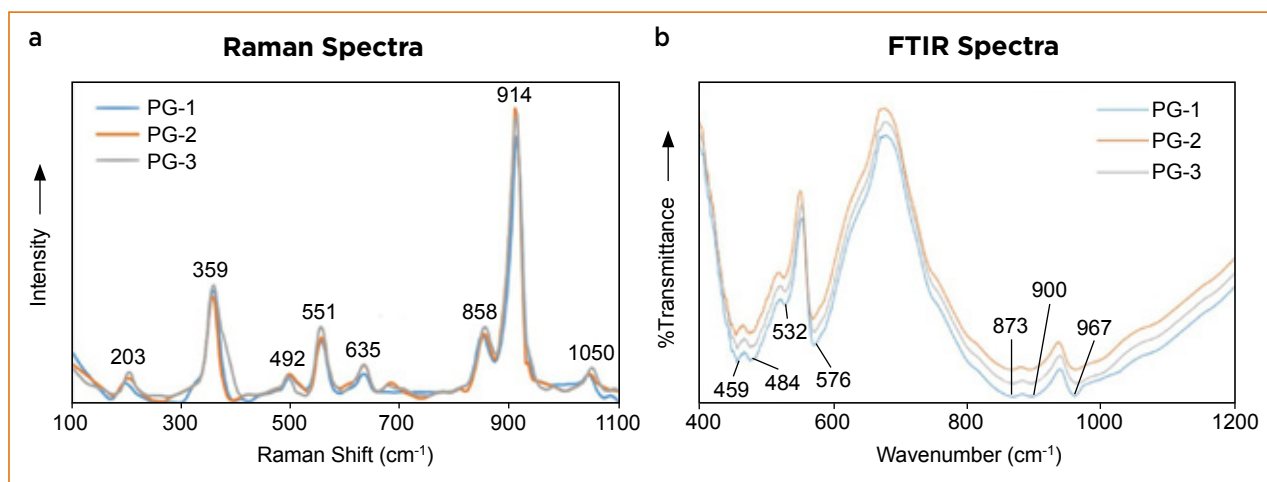


Figure 9: (a) The Raman spectra of three pyrope samples from Southeast Vietnam show peaks at 203, 359, 492, 551, 635, 858, 914 and 1050 cm⁻¹. (b) FTIR spectra for the same three samples show bands at 459, 484, 532, 576, 873, 900 and 967 cm⁻¹. In combination, Raman and FTIR features in the 800–1000 cm⁻¹ range indicate that the samples mainly consist of pyrope.

found in the 1200–3750 cm^{-1} range.

FTIR spectroscopy in the 400–1200 cm^{-1} range showed bands at 459, 484, 532, 576, 873, 900 and 967 cm^{-1} (Figure 9b). The band at 459 cm^{-1} is due to asymmetrical bending vibrations of Si–O, the band at 484 cm^{-1} is related to lattice vibrations, the bands at 532 and 576 cm^{-1} are due to symmetric bending vibrations of Si–O, and the bands at 873, 900 and 967 cm^{-1} are attributed to asymmetric stretching vibrations of Si–O (Li *et al.* 2022).

Raman and FTIR spectra individually cannot distinguish between garnet species, but consideration of the combination of their features in the 800–1000 cm^{-1} range can help determine the species present (Li *et al.* 2022). Accordingly, the Raman peaks at 858 and 914 cm^{-1} , and the FTIR bands at 873, 900 and 967 cm^{-1} , provide confirmation of the pyrope-rich composition of these garnets from Southeast Vietnam.

Kelyphite Texture and the Origin of the Garnet Xenoliths

The morphological characteristics, gemmological properties, chemical composition and spectroscopic features

of the pyrope samples in this study indicate that both the xenocrystic and xenolithic garnets derived from the same primary source. Although the xenolithic garnets are included within fragments of their primary host rock, the associated minerals are so deeply altered that they are no longer recognisable. Nevertheless, information about the original primary crystallisation environment of the pyrope can be gleaned by studying their kelyphitic rims.

Our observations of petrographic thin sections from two of the garnet xenoliths revealed clear boundaries between the garnets and their kelyphitic rims, and an overall strong degree of kelyphitic alteration (Figure 10). The kelyphite contained pyroxene and spinel, consistent with the assemblage expected for garnet peridotite (Garvie & Robinson 1984; Keankeo *et al.* 2000; Obata 2011).

FTIR spectra of powdered kelyphite taken from three xenolithic garnet samples revealed bands at 896 and 1008 cm^{-1} related to silicate (Si–O–Si) vibrations, while bands at 1647 and 3390 cm^{-1} correspond to H–O–H and O–H bonds, respectively (Figure 11; Keankeo *et al.* 2000). In addition, a band at 3650 cm^{-1} indicates the presence of free O–H in the structure. These FTIR features resemble

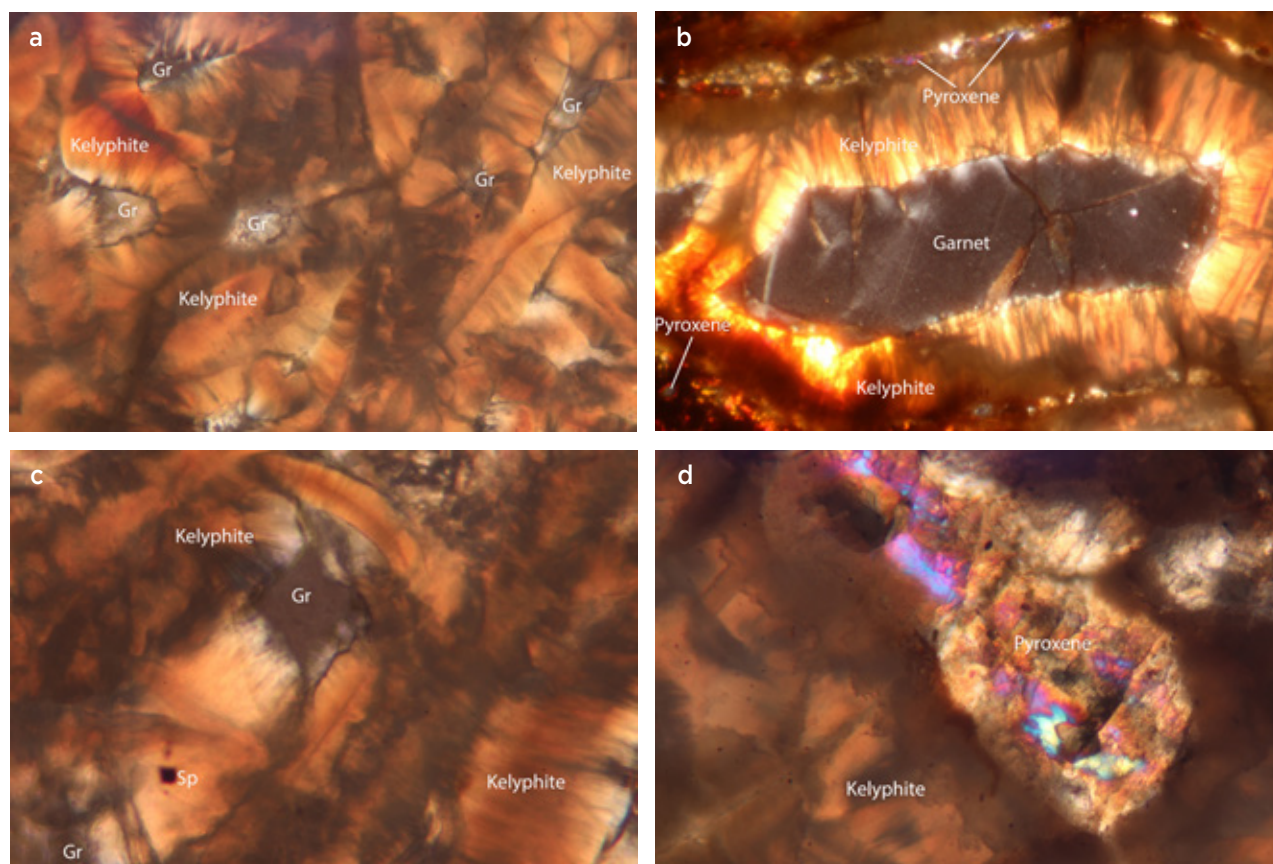


Figure 10: The kelyphitic texture of garnet (Gr) from Southeast Vietnam is shown here in petrographic thin sections of pyrope-bearing xenoliths in cross-polarised light. (a) The garnet grains are separated and surrounded by fibrous coronas of kelyphite. (b) Small pyroxene crystals are distributed along the kelyphite boundaries. (c) A euhedral spinel (Sp) crystal is present in the kelyphite. (d) A large pyroxene crystal is characterised by strong interference colours surrounded by kelyphite coronas. Photomicrographs by Le Ngoc Nang; image widths 1.8 mm (a), 1.2 mm (b and c) and 0.7 mm (d).

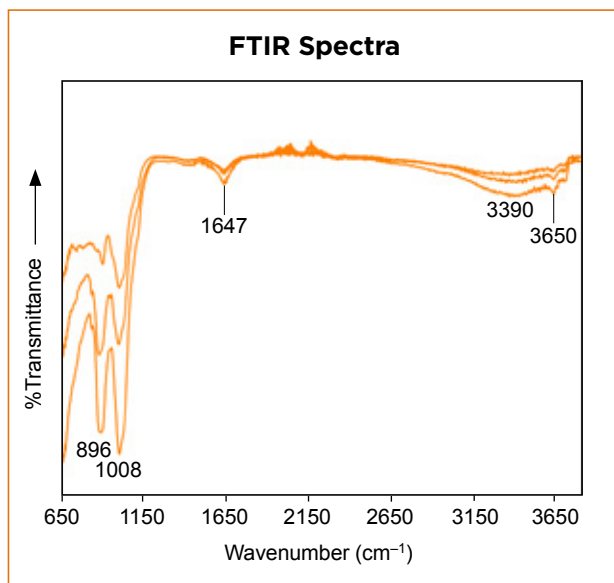


Figure 11: FTIR spectra of powdered kelyphite taken from three xenoliths show features consistent with the formation of the pyrope in garnet peridotite.

those of garnet peridotite kelyphite from Australia, which contains assemblages of enstatite, spinel and other unidentified components (Keankeo *et al.* 2000). These minerals may be a weathering or hydrothermal alteration product of the kelyphite itself. In any case, a different FTIR spectral signature would be expected for kelyphite from garnet crystallised in an eclogitic environment.

According to the geological history of southern Vietnam, granite and granosyenite were generated in the Triassic and Cretaceous periods during the orogeny formed by the Yangtze plate colliding with the Paleo-Tethys plate

(Nakano *et al.* 2008; Trĩ & Khuc 2011). More recently, Late Cenozoic alkali basaltic magma was generated under high pressure and temperature conditions (< 4 GPa and about 1,470°C; Hoang & Flower 1998). Pyrope that originally formed in garnet peridotite was incorporated into alkali basaltic magma as xenocrysts and xenoliths, and subsequently the kelyphitic texture locally developed around the garnets in the xenoliths before being erupted in basaltic lava flows.

CONCLUSIONS

Gem-quality pyrope from Southeast Vietnam is an attractive gem material (e.g. Figure 12) that is recovered from secondary deposits associated with alkali basalt. The stones appear deep orange to light red in transmitted light, and their gemmological features are consistent with those of pyrope. Chemical analysis yielded a compositional range of $\text{Py}_{72.0-75.3}\text{Al}_{14.8-18.3}\text{Gr}_{9.2-9.9}$. Raman and FTIR spectra show features in the 800–1000 cm^{-1} range that are also indicative of a pyrope-dominant composition. Mineralogical and FTIR spectroscopic characteristics of the kelyphite associated with the xenolithic pyrope indicates formation in a garnet peridotite. The pyrope was subsequently transported to the surface as xenocrysts and xenoliths in basaltic magma. The stones are found over a wide area due to the abundant basaltic volcanism in the region and subsequent weathering of the lava flows. Pyrope from Southeast Vietnam shows good potential to be used in jewellery as both faceted and rough material.



Figure 12: Pyrope from Southeast Vietnam is featured in these jewellery items: (a) a 14K gold pendant with a 12.15 ct cushion-cut stone accented by synthetic moissanite and (b) a 14K gold ring mounted with a 7.54 ct oval brilliant. Courtesy of Truong Cong Hau; photos by Le Ngoc Nang.

REFERENCES

- An, A.R., Choi, S.H., Yu, Y. & Lee, D.C. (eds) 2017. Petrogenesis of Late Cenozoic basaltic rocks from southern Vietnam. *Lithos*, **272–273**, 192–204, <https://doi.org/10.1016/j.lithos.2016.12.008>.
- Anthony, J.W., Bideaux, R.A., Bladh, K.W. & Nichols, M.C. (eds) 2021. Pyrope. *Handbook of Mineralogy*, Mineralogical Society of America, Chantilly, Virginia, USA, <https://www.handbookofmineralogy.org/pdfs/Pyrope.pdf>, accessed 7 October 2023.
- Aydar, E. & Gourgaud, A. 2002. Garnet-bearing basalts: An example from Mt. Hasan, Central Anatolia, Turkey. *Mineralogy and Petrology*, **75**(3–4), 185–201, <https://doi.org/10.1007/s007100200023>.
- Barr, S.M. & Macdonald, A.S. 1981. Geochemistry and geochronology of Late Cenozoic basalts of Southeast Asia. *GSA Bulletin*, **92**(8, Part II), 1069–1142, <https://doi.org/10.1130/gsab-p2-92-1069>.
- DGM 1999. *Geology and Mineral Resources Map, Da Lat-Cam Ranh Sheet, Scale 1:200,000*. Department of Geology and Minerals of Viet Nam, Hanoi, Vietnam.
- Duraj, M., Marschalko, M., Duda, R., Sitányiová, D. & Masarovičová, S. 2015. The history of pyrope extraction and processing in the Czech Republic and its significance for geotourism. *Procedia Earth and Planetary Science*, **15**, 663–668, <https://doi.org/10.1016/j.proeps.2015.08.079>.
- Ezad, I.S., Dobson, D.P., Thomson, A.R., Jennings, E.S., Hunt, S.A. & Brodholt, J.P. 2022. Kelyphite textures experimentally reproduced through garnet breakdown in the presence of a melt phase. *Journal of Petrology*, **63**(11), article egac110, <https://doi.org/10.1093/petrology/egac110>.
- Garvie, O.G. & Robinson, D.N. 1984. The formation of kelyphite and associated sub-kelyphitic and sculptured surfaces on pyrope from kimberlite. In: Kornprobst, J. (ed) *Kimberlites – I: Kimberlites and Related Rocks*. Elsevier, Amsterdam, The Netherlands, **11**(Part A), 371–382, <https://doi.org/10.1016/b978-0-444-42273-6.50031-6>.
- Gillet, P., Fiquet, G., Malézieux, J.M. & Geiger, C.A. 1992. High-pressure and high-temperature Raman spectroscopy of end-member garnets: Pyrope, grossular and andradite. *European Journal of Mineralogy*, **4**(4), 651–664, <https://doi.org/10.1127/ejm/4/4/0651>.
- Guastoni, A., Pezzotta, F., Superchi, M. & Demartin, F. 2001. Pyrope from the Dora Maira massif, Italy. *Gems & Gemology*, **37**(3), 198–204, <https://doi.org/10.5741/gems.37.3.198>.
- Hoang, N. & Flower, M. 1998. Petrogenesis of Cenozoic basalts from Vietnam: Implication for origins of a ‘diffuse igneous province’. *Journal of Petrology*, **39**(3), 369–395, <https://doi.org/10.1093/ptro/39.3.369>.
- Hoang, N., Flower, M.F.J. & Carlson, R.W. 1996. Major, trace element, and isotopic compositions of Vietnamese basalts: Interaction of hydrous EM1-rich asthenosphere with thinned Eurasian lithosphere. *Geochimica et Cosmochimica Acta*, **60**(22), 4329–4351, [https://doi.org/10.1016/s0016-7037\(96\)00247-5](https://doi.org/10.1016/s0016-7037(96)00247-5).
- Hoang, T.H.A., Choi, S.H., Yu, Y., Pham, T.H., Nguyen, K.H. & Ryu, J.S. 2018. Geochemical constraints on the spatial distribution of recycled oceanic crust in the mantle source of Late Cenozoic basalts, Vietnam. *Lithos*, **296–299**, 382–395, <https://doi.org/10.1016/j.lithos.2017.11.020>.
- Kawabata, H. & Takafuji, N. 2005. Origin of garnet crystals in calc-alkaline volcanic rocks from the Setouchi volcanic belt, Japan. *Mineralogical Magazine*, **69**(6), 951–971, <https://doi.org/10.1180/0026461056960301>.
- Keankeo, W., Taylor, W.R. & FitzGerald, J.D. 2000. Clinoferrosilite-bearing kelyphite: A breakdown product of xenolithic garnet, Delegate breccia pipes, New South Wales, Australia. *Mineralogical Magazine*, **64**(3), 469–479, <https://doi.org/10.1180/002646100549364>.
- Kolesov, B.A. & Geiger, C.A. 1998. Raman spectra of silicate garnets. *Physics and Chemistry of Minerals*, **25**(2), 142–151, <https://doi.org/10.1007/s002690050097>.
- Li, W., Zheng, J., Pei, J., Xu, X. & Chen, T. 2022. Correlations between garnet species and vibration spectroscopy: Isomorphous substitution implications. *Crystals*, **12**(1), article 104, <https://doi.org/10.3390/cryst12010104>.
- Liddicoat, R.T. Jr 1993. *Handbook of Gem Identification*. Gemological Institute of America, Santa Monica, California, USA, 364 pp.
- Mernagh, T.P. & Liu, L.G. 1990. Pressure dependence of Raman spectra from the garnet end-members pyrope, grossularite and almandite. *Journal of Raman Spectroscopy*, **21**(5), 305–309, <https://doi.org/10.1002/jrs.1250210506>.
- Nakano, N., Osanai, Y., Minh, N.T., Miyamoto, T., Hayasaka, Y. & Owada, M. 2008. Discovery of high-pressure granulite-facies metamorphism in northern Vietnam: Constraints on the Permo-Triassic Indochinese continental collision tectonics. *Comptes Rendus Geoscience*, **340**(2–3), 127–138, <https://doi.org/10.1016/j.crte.2007.10.013>.
- Nang, L.N., Phat, L.V., Tien, P.M., Hieu, P.T., Kawaguchi, K. & Minh, P. 2023a. Gem-quality augite from Dong Nai, Vietnam. *Gems & Gemology*, **59**(2), 182–194, <https://doi.org/10.5741/gems.59.2.182>.

- Nang, L.N., Tien, P.M. & Tri Man, H.N., 2023b. Gem News International: Mining basalt-related gems in Southeast Vietnam. *Gems & Gemology*, **59**(3), 399–401.
- Obata, M. 2011. Kelyphite and symplectite: Textural and mineralogical diversities and universality, and a new dynamic view of their structural formation. In: Sharkov, E. (ed) *New Frontiers in Tectonic Research – General Problems, Sedimentary Basins and Island Arcs*. IntechOpen, London, 93–122.
- Philippe, M. & Fritsch, E. 2019. Dissolved dislocations in gems: An overview. *36th International Gemmological Conference*, Nantes, France, 28–31 August, 189–191.
- Scully, K.R., Canil, D. & Schulze, D.J. 2004. The lithospheric mantle of the Archean Superior Province as imaged by garnet xenocryst geochemistry. *Chemical Geology*, **207**(3–4), 189–221, <https://doi.org/10.1016/j.chemgeo.2004.03.001>.
- Sun, Z., Palke, A.C. & Renfro, N. 2015. Vanadium- and chromium-bearing pink pyrope garnet: Characterization and quantitative colorimetric analysis. *Gems & Gemology*, **51**(4), 348–369, <https://doi.org/10.5741/gems.51.4.348>.
- Trị, V.T. & Khuc, V. (eds) 2011. *Geology and Earth Resources of Việt Nam*. Publishing House for Science and Technology, Hanoi, Vietnam, 634 pp.
- Vrána, S. 2008. Mineral inclusions in pyrope from garnet peridotites, Kolín area, central Czech Republic. *Journal of Geosciences*, **53**(1), 17–30, <https://doi.org/10.3190/jgeosci.018>.

The Authors

Le Ngoc Nang^{1,2,3*}, Dr Pham Trung Hieu^{1,2} and Pham Minh Tien³

¹ Faculty of Geology, University of Science, Ho Chi Minh City, Vietnam

² Vietnam National University, Ho Chi Minh City, Vietnam

³ Liu Gemological Research and Application Center (LIULAB), 572B/5 Tran Hung Dao Street, Ward 2, District 5, Ho Chi Minh City 700000, Vietnam

* Email: nang@liulab.edu.vn

Acknowledgements

This research was funded by Vietnam National University, Ho Chi Minh City (VNU-HCM), under grant number B2023-18-11. We would also like to express our deep gratitude to Tran Ngoc Vien, who guided us during our field research.



Gem-A
INSTRUMENTS



**OVER 100
PRODUCTS
AVAILABLE**

**Buy Gem-A
Instruments online!**



View the full collection at:
shop.gem-a.com

GEM-A MEMBERS!

Log in to the Gem-A Instruments website and gain instant access to discounted rates.

Username is your Gem-A membership number.

Password is your surname with a capitalised first letter.

You must log in before adding products to your basket.

We recommend changing your password in the account settings.

Characteristics of the Colour Zones and Inclusions in Unusual Multicoloured Quartz from Brazil

Huizhen Huang, Quanli Chen, Xianyu Liu, Yan Li, Zuowei Yin and Yanhan Wu

ABSTRACT: An unusual type of quartz from Brazil that is currently on the market displays multi-coloured zoning along the *c*-axis. From bottom to top, these zones are purple, orangey red, grey and purple, and each one is accompanied by a distinctive inclusion assemblage. Four representative samples were analysed with standard gemmological instruments, as well as Raman spectroscopy, electron probe microanalysis and ultraviolet-visible spectroscopy. The colour of both purple zones (amethyst) is due to charge-transfer between O^{2-} and Fe^{4+} , while the orangey red zone is coloured by numerous hematite various inclusion assemblages within the host amethyst, and the grey zone consists of colourless quartz that contains abundant dark grey FeS_2 (pyrite and/or marcasite) inclusions. The colours of the host quartz and its various inclusion assemblages reflect changes in iron valence, which shows a progression during crystal growth from oxidising (inner purple and orangey red zones, dominated by Fe^{3+}) to reducing (grey zone, dominated by Fe^{2+}) and back to oxidising conditions (outer purple zone, dominated by Fe^{3+}).

The Journal of Gemmology, 38(8), 2023, pp. 784–794, <https://doi.org/10.15506/JoG.2023.38.8.784>
© 2023 Gem-A (The Gemmological Association of Great Britain)

Quartz has a long history of use as a gemmological material (Beer 2023). Amethyst, citrine, rose quartz and smoky quartz are the most common colour varieties, typically exhibiting a single hue. Bicoloured amethyst-citrine, or *ametrine*, is also a popular type of quartz. However, multicoloured quartz is rather rare and does not have a fixed variety name such as ametrine. Krzemnicki (2000) reported on ametrine with layers of smoky quartz from the Yuruty mine in Bolivia, showing purple, yellow and dark brown in the same crystal. Later, Hyršl (2017) described another type of quartz with multicoloured zones accompanied by various inclusions from Bahia, Brazil. It was thought to form due to changes in the type and abundance of iron present during different stages of growth. In addition, Laurs and Renfro (2017) described yet another type of multicoloured quartz from Minas Gerais, Brazil. Its colour variations were ascribed to

probable inclusions of hematite, goethite and chlorite that grew on rhombohedral faces of the quartz during its crystallisation.

Recently, a similar type of multicoloured quartz—commonly traded as ‘Auralite 23’ quartz and said to originate from Brazil—appeared on the gem and jewellery market in Donghai County, China. This quartz had been sold in many countries, especially through various online merchants. It typically exhibits four regular colour zones along the *c*-axis: purple, orangey red, grey and purple (Figure 1). The outer purple zone usually contains some golden, V-shaped inclusions that are visible to the unaided eye. When these inclusions are abundant, an additional orangey yellow colour zone is seen at the crystal termination.

In this study, we used a combination of techniques to characterise each zone in this multicoloured quartz to determine its colour origin and infer its formation conditions.



Figure 1: (a) From left to right, these quartz specimens consist of two crystals and a polished specimen that measure approximately 7.5×6.5 cm, 9.2×6.6 cm and $8.2 \times 5.5 \times 3.7$ cm. Although not part of this study, they are representative of the multicoloured material examined by the authors. (b) The polished crystal has a golden band in the outer purple zone formed by numerous V-shaped clusters of goethite inclusions. (c) Similar V-shaped inclusions are also present in the inner purple zone of the same sample, oriented more-or-less perpendicular to the adjacent boundary with the orangey red zone. Photos by Zhuoxuan Li; image widths (b) 6.5 cm and (c) 2.4 cm.

MATERIALS AND METHODS

Five multicoloured quartz samples (Qz1–Qz5; Figure 2) were selected for this study that were obtained from the Donghai crystal, gem and jewellery market near Lianyungang in China's Jiangsu Province. Some of the samples showed a well-developed rhombohedral termination on one end and an uneven tapered shape with parallel striations on the other end (e.g. Figure 3). Specimens Qz1–Qz4 were selected for detailed examination, and were sliced and polished parallel to the *c*-axis; Qz5 was retained intact as a representative crystal. In addition, we prepared thin sections (0.04–0.05 mm thick) from samples Qz1–Qz3 to expose the solid inclusions for chemical and spectroscopic analysis. Also, a doubly polished optical wafer (2 mm thick) was made from sample Qz4 to study the fluid inclusions and collect absorption spectra from each colour zone.

Standard gemmological testing of all four samples Qz1–Qz4 was performed at the Gemological Institute, China University of Geosciences (Wuhan). Refractive index and birefringence were measured using a Fable FGR-003A gemmological refractometer. Specific gravity was obtained by the hydrostatic weighing method. Fluorescence was observed with a Fable FUV-4 unit equipped with long-wave (365 nm) and short-wave (254

nm) UV lamps. Solid inclusions were photographed with a Leica M205 A microscope with a maximum magnification of $256\times$, and fluid inclusions were photographed with a Zeiss Axio Imager 2 microscope with $50\times$ – $500\times$ magnification.

Raman spectroscopy of the host quartz and its inclusions in all four samples was done in confocal mode. Solid inclusions were analysed at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan) with a Horiba LabRAM HR Evolution Raman microscope. The instrument was equipped with a 532 nm laser (20 mW energy), a grating containing 600 grooves/mm and a blaze wavelength of 500 nm, and a $50\times$ objective lens. The spectra were collected in the range of 100 – 1600 cm^{-1} with a resolution of 6.4 cm^{-1} (scanning twice with 30 s of integration time). The Raman shift was calibrated using the 521 cm^{-1} peak of monocrystalline silicon. Fluid inclusions were analysed at the Gemological Institute, China University of Geosciences (Wuhan) with a Jasco NRS-7500 Raman spectrometer. The instrument used a 532 nm laser (4.8 mW energy), a grating containing 600 grooves/mm and a blaze wavelength of 500 nm, and a $50\times$ objective lens. The spectra were collected in the range of 100 – 4000 cm^{-1} with a resolution of 9.6 cm^{-1} (scanning twice with 30 s of integration time).

The Raman shift was calibrated with the 520.5 cm^{-1} peak of monocrystalline silicon. The solid inclusions in specimens Qz1–Qz3 were chemically analysed at

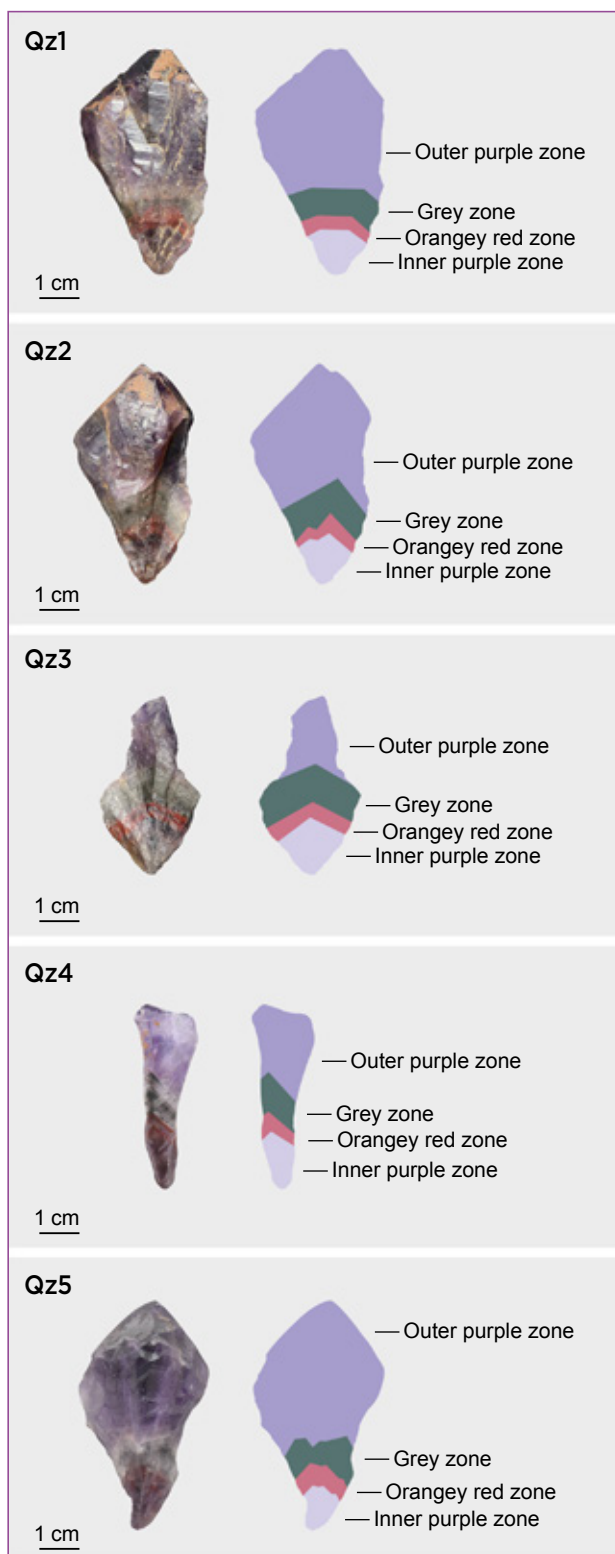


Figure 2: All of the multicoloured quartz samples obtained for this study show a consistent sequence of four colour zones. The samples (Qz1–Qz5) weigh 26.36 g, 29.73 g, 15.63 g, 6.01 g and 31.27 g, respectively. Photos by H. Huang.

Wuhan Sample Solution Analytical Technology Co. Ltd with a JEOL JXA-8230 electron probe micro-analyser (EPMA). Operating conditions were set at 15 kV accelerating voltage and 10 nA beam current, with a spot size of $5\text{ }\mu\text{m}$. Two different measurement times were used: major elements were analysed using 10 s for peak counts and 5 s for the background, and elements with concentrations less than 1,000 ppm were measured using 30 s for peak counts and 15 s for the background. Standard materials obtained from SPI Supplies (West Chester, Pennsylvania, USA) were used for calibration, including zinc (Zn), chalcopyrite (Cu), arsenopyrite (As), pyrope (Mg), pyrite (Fe and S), cobalt (Co), pentlandite (Ni) and galena (Pb). Data processing was performed using the ZAF correction of JEOL Ltd. Minor- and trace-element mapping of selected inclusions was carried out using the instrument's energy-dispersive X-ray spectrometer (EDS). In addition, backscattered-electron (BSE) images provided details about the internal features.

Ultraviolet-visible (UV-Vis) spectra were obtained from the optical wafer of sample Qz4 at the Gemological Institute, China University of Geosciences (Wuhan), using a PerkinElmer Lambda 650 S spectrophotometer. The instrument was equipped with an integrating sphere and a standard D65 light source. The spectra were collected in transmission mode in the 380–780 nm range. The spectral interval was set at 1 nm with air as the background test.

RESULTS

Gemmological Characteristics

The gemmological properties of the four samples were typical of quartz. The RI of the polished samples was 1.544–1.553 (birefringence 0.009) and SG ranged from 2.63 to 2.65. All zones in the specimens were inert to long- and short-wave UV radiation.

The various colour zones had significant differences in their solid inclusions. Within the inner purple zone, we observed no characteristic solid inclusions in samples Qz1–Qz3, but there was a small amount of reddish brown and brassy yellow needle-like inclusions in Qz4 (Figure 4a).

Relatively more solid inclusions were present in the orangey red zone. Numerous orangey red platelets formed 'phantoms' along the rhombohedral faces (Figure 4b) and were responsible for the colour appearance of this zone. In addition, reddish brown needle-like inclusions were often present that were oriented perpendicular to the concentrations of the orangey red platelets

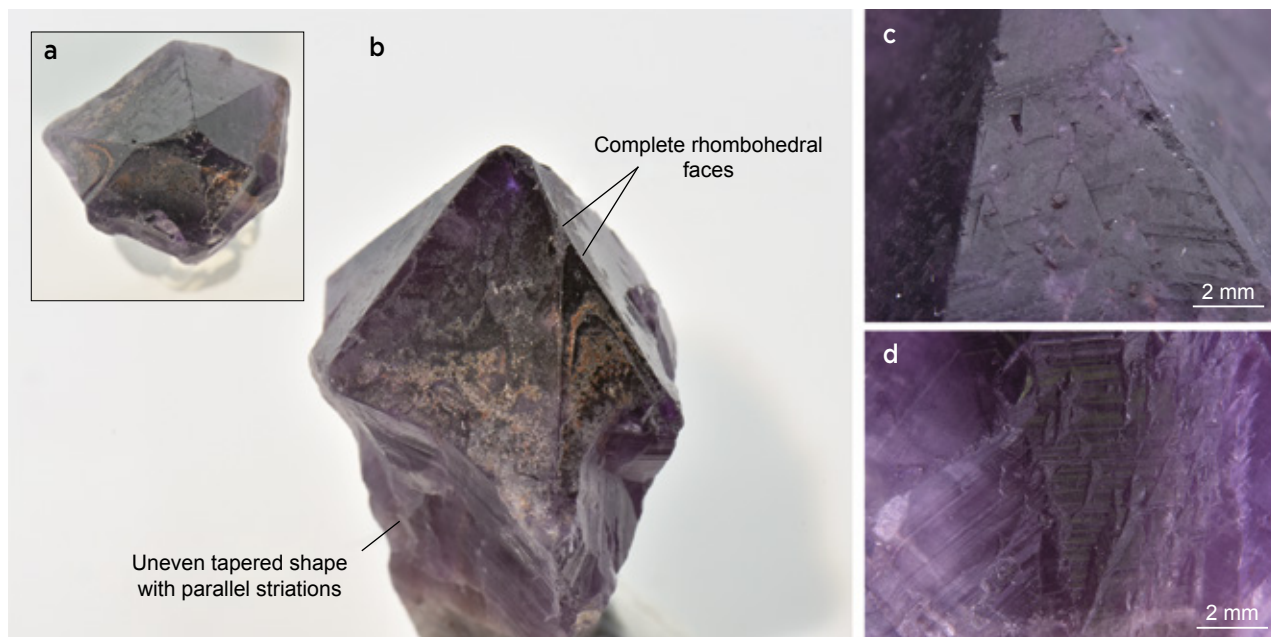


Figure 3: Quartz sample Qz5 (6.3 × 3.7 cm) is shown here as an example of (a) well-developed rhombohedral faces and (b) uneven tapered sides. (c) Some triangular growth marks and (d) parallel striations are present on the rhombohedra and sides of the crystal, respectively. Photos by H. Huang.

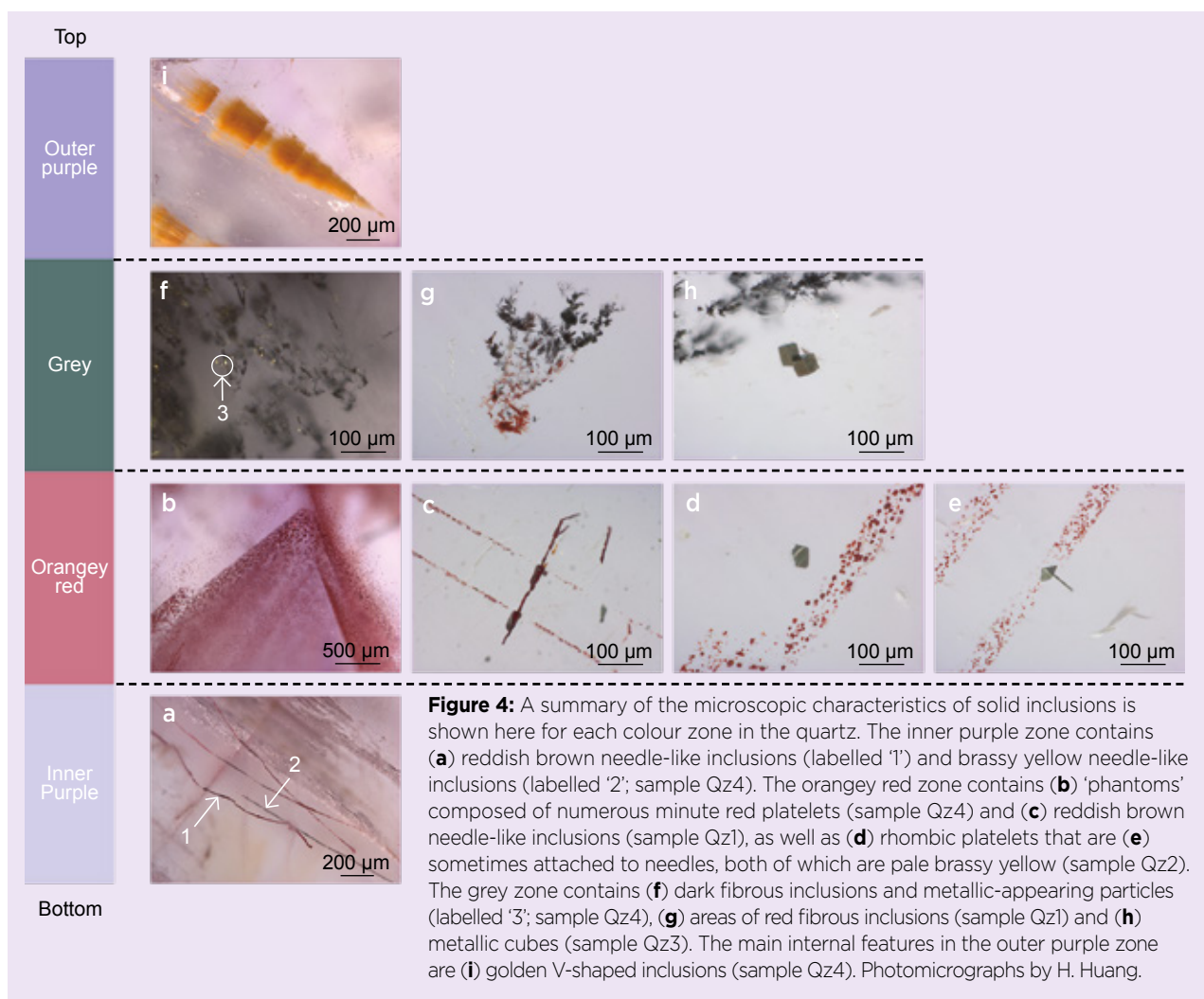


Figure 4: A summary of the microscopic characteristics of solid inclusions is shown here for each colour zone in the quartz. The inner purple zone contains (a) reddish brown needle-like inclusions (labelled '1') and brassy yellow needle-like inclusions (labelled '2'; sample Qz4). The orangey red zone contains (b) 'phantoms' composed of numerous minute red platelets (sample Qz4) and (c) reddish brown needle-like inclusions (sample Qz1), as well as (d) rhombic platelets that are (e) sometimes attached to needles, both of which are pale brassy yellow (sample Qz2). The grey zone contains (f) dark fibrous inclusions and metallic-appearing particles (labelled '3'; sample Qz4), (g) areas of red fibrous inclusions (sample Qz1) and (h) metallic cubes (sample Qz3). The main internal features in the outer purple zone are (i) golden V-shaped inclusions (sample Qz4). Photomicrographs by H. Huang.

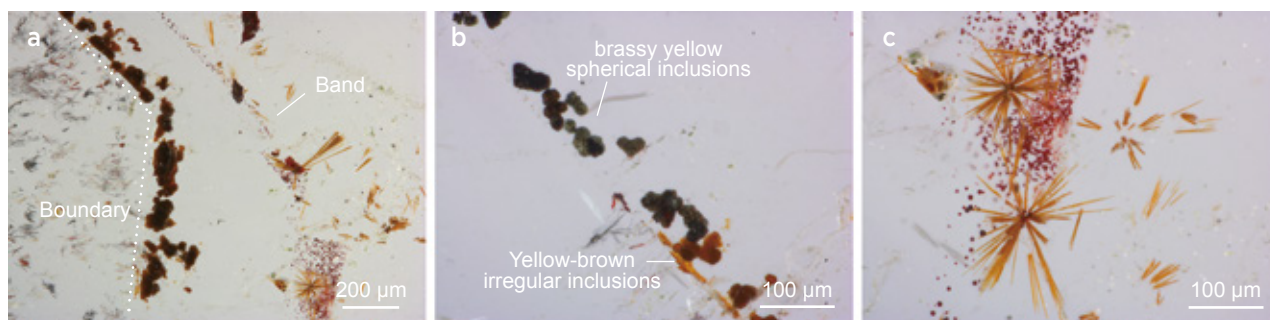


Figure 5: (a) The well-defined boundary between the grey zone and the outer purple zone in quartz sample Qz1 is emphasised by the presence of numerous solid inclusions. (b) These include yellow-brown irregular goethite and brassy yellow spherical pyrite. (c) Orangey red hematite platelets and golden radiating goethite needles are distributed in a band within the outer purple zone that is parallel to the boundary with the grey zone. Photomicrographs by H. Huang.

(Figure 4c). A few brassy yellow inclusions were also observed in this zone (i.e. in the thin sections of samples Qz1–Qz3; Figure 4d, e). They showed various morphologies, including rhombic platelets with striations and some that were pyramid-shaped on one end and needle-like on the other end.

The grey quartz zone was coloured by numerous dark fibrous inclusions. With magnification and reflected light, they showed brassy yellow reflections in places (Figure 4f). The morphological features of these inclusions were revealed more clearly in thin sections, where the dark fibres had plumose or spider-like forms (Figure 4g). Some of the fibres were orangey red. This zone also contained a few metallic-looking cubes (Figure 4h).

A well-defined boundary separated the grey zone from the outer purple zone. This was particularly evident in sample Qz1 (Figure 5), where the boundary was marked by

concentrations of orangey brown and brassy yellow inclusions with spherical to irregular forms. In addition, a band of orangey red platelets associated with golden radiating needles occurred in the outer purple zone close to this boundary. Also present in this zone were prominent golden fibrous tufts that formed V-shaped inclusions (see Figure 4i). They varied in size from 1 to 3 μm , were oriented perpendicular to the rhombohedral faces and were mainly distributed near the outer margin of the quartz crystals. In addition, these inclusions may be present in the inner purple zone (see Figure 1c), although they were not in any of the four samples characterised for this study.

By comparison, fluid inclusions showed small differences between the various colour zones. The most common types were partially healed fractures and irregular or flat monophase fluid inclusions (Figure 6a, b). Two-phase inclusions were extremely rare, and were seen

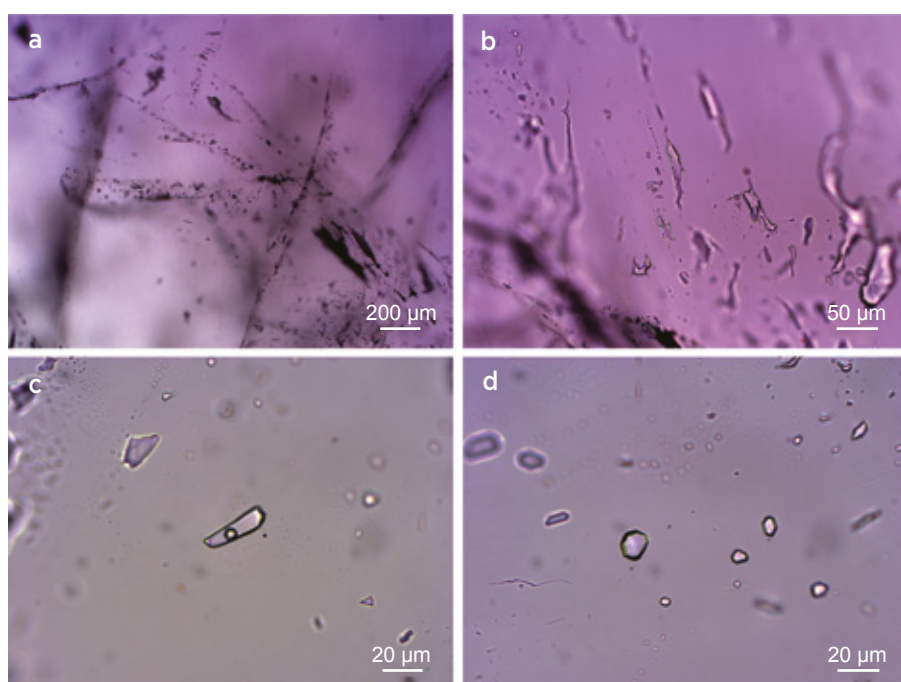


Figure 6: Characteristic fluid inclusions in the quartz, shown here in sample Qz4, consist of (a) partially healed fractures and (b) monophase fluid inclusions. This sample alone contains (c) a rare two-phase fluid inclusion and (d) negative crystals. Photomicrographs by H. Huang.

only in the inner purple zone of the Qz4 optical wafer, accompanied by negative crystals in the same zone (Figure 6c, d).

Raman Spectroscopy

Host Quartz. Raman spectra of the host quartz (samples Qz1–Qz4) were obtained to identify quartz peaks that might be included in the spectra of various inclusions. Quartz peaks were observed at 127, 206, 262, 354, 393, 464, 695 and 1160 cm^{-1} (cf. Krishnan 1945; Krishnamurti 1958).

Solid Inclusions. The reddish brown needle-like inclusions in the inner purple zone and the orangey red zone—and the orangey red platelets in the orangey red zone—all yielded Raman peaks at about 223, 242, 292, 407, 497, 608 and 1314 cm^{-1} , identifying them as hematite (Bersani *et al.* 1999; Shim & Duffy 2002; Pérez León *et al.* 2004; Zoppi *et al.* 2005). The main Raman signals of the golden V-shaped inclusions, golden radiating needles and orangey brown irregular inclusions (all in the outer purple zone) showed peaks at about 204, 241, 297, 389, 415, 464, 547, 681 and 996 cm^{-1} , which match goethite (Abrashv *et al.* 2020). Raman spectra of the brassy yellow rhombic platelets and the pyramid-shaped inclusions in the orangey red zone were characterised by a strong peak around 320 cm^{-1} and a weak peak around 384 cm^{-1} , which are characteristic of marcasite (Lutz & Müller 1991; An *et al.* 2014). The brassy yellow needle-like inclusions in the inner purple and orangey red zones showed only a strong peak at about 320 cm^{-1} , probably representative of the lower crystallinity of marcasite. The brassy yellow spherical

inclusions located along the boundary between the grey zone and the outer purple zone yielded three distinct peaks at 345, 381 and 435 cm^{-1} , which are attributed to pyrite (Bryant *et al.* 2018). Similar Raman peaks were obtained for the metallic cubes in the grey zone, also identifying them as pyrite. Interestingly, the dark fibrous inclusions in the grey zone yielded mixed results, with characteristic spectra for both pyrite (peaks at 338, 374 and 423 cm^{-1}) and marcasite (peak at 327 cm^{-1} ; Lutz & Müller 1991; An *et al.* 2014; Zhang *et al.* 2022). Thus, the solid inclusions in the quartz were identified as iron oxides, iron hydroxides and sulphides.

Fluid Inclusions. The Raman spectra of all the fluid inclusions tested showed a broad band extending up to 4000 cm^{-1} . Specifically, the Raman band at 3000–3800 cm^{-1} indicates the presence of H_2O , which is characteristic of the vibration of a temporal C_{2v} tetrahedral-like structure around an oxygen atom (Tominaga *et al.* 1998). In the two-phase inclusions, no gases were detected in the bubbles. The liquid in these inclusions may consist of ‘gas-free’ aqueous salt solutions (Gilg *et al.* 2014).

Chemical Composition of the Dark Fibrous Inclusions

BSE imaging of the dark fibrous inclusions in the grey zone revealed numerous crystal particles with mostly square to rectangular cross-sections (Figure 7). Four different locations on these inclusions were selected for EPMA chemical analysis (Table I), which revealed the main components as Fe (average 45.64 wt.%) and S (average 53.51 wt.%), yielding a molar ratio of Fe to S of approximately 1:2 (i.e. FeS_2). Traces of Zn, Cu, As, Mg, Co, Ni and Pb were also detected. Both pyrite and marcasite are FeS_2 minerals, but these inclusions are more likely to be pyrite given their morphology (Zhao 2017). The presence of pyrite is consistent with the brassy yellow reflections in reflected light that we observed from some particles in the dark fibrous inclusions.

Given the combination of results from the Raman and EPMA analyses, we concluded that the dark fibrous inclusions consist of two types of FeS_2 : particles of well-crystallised FeS_2 , such as pyrite, with poorly crystallised FeS_2 , such as marcasite, exhibiting a more fibrous morphology.

BSE imaging also revealed some tiny fibrous inclusions that were too narrow to be analysed by EPMA, so EDS mapping scanning analysis was carried out. The images revealed that they were enriched in Fe and S as the main components. Some of these inclusions showed

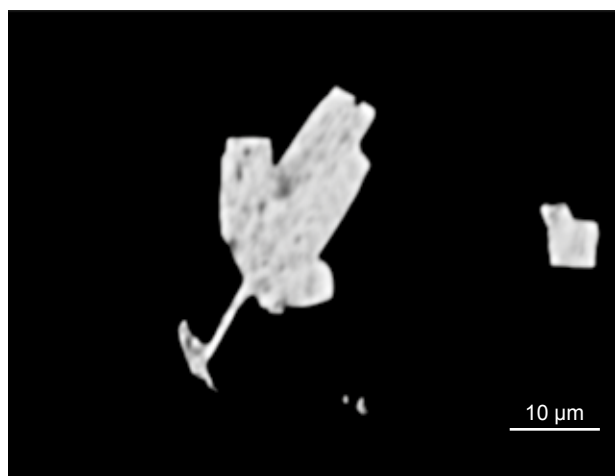


Figure 7: At high magnification, the dark fibrous inclusions in the grey zone of the quartz show square to rectangular cross-sections, as seen in this BSE image. Image by H. Huang.

Table 1: Chemical composition of the dark fibrous inclusions in the grey quartz zone measured by EPMA.

Element (wt.%)	Analysis location			
	1	2	3	4
Fe	45.51	45.60	45.69	45.66
S	52.25	53.14	54.16	53.96
Zn	0.049	0.027	bdl	0.007
Cu	bdl*	0.012	0.002	bdl
As	bdl	bdl	0.014	bdl
Mg	bdl	bdl	0.003	0.014
Co	0.066	0.077	0.072	0.076
Ni	bdl	0.003	0.011	0.001
Pb	0.503	0.183	0.122	0.252
Total	98.38	99.05	100.08	99.97

* Abbreviation: bdl = below detection limit.

brighter grey areas, where the heavier element Pb was also detected.

UV-Vis Spectroscopy

UV-Vis spectroscopy was performed on each colour zone of the optical wafer of sample Qz4. Visual examination showed that the body colour of the quartz in these zones was either purple or colourless.

Both purple zones and the orangey red zone yielded a broad absorption band centred at about 540 nm (Figure 8) commonly associated with $O^{2+} \rightarrow Fe^{4+}$ charge transfer (Lehmann & Bambauer 1973; Cohen & Hassan 1974; Cox 1977), which is typical of amethyst. The strength of the band was about the same for the inner purple zone and the orangey red zone, while it was stronger for the outer purple zone. The UV-Vis spectrum obtained from the grey zone did not show any absorption features, consistent with the colourless appearance of the host quartz in this zone.

DISCUSSION

Our examination of the four zones in this Brazilian multi-coloured quartz focused on the solid inclusions and the body colour of the host quartz. In the absence of specific geological background information, the results of our study enable us to characterise the Fe-bearing phases and infer the formation conditions for this zoned quartz. Each colour zone represents a particular growth stage. As summarised in Figure 9, the quartz initially crystallised as light purple amethyst (stages 1 and 2), then abruptly became colourless (stage 3), and then changed to a more intense purple amethyst (stage 4). In addition, the types and amounts of solid inclusions showed distinctive characteristics in each zone, from a small amount of hematite

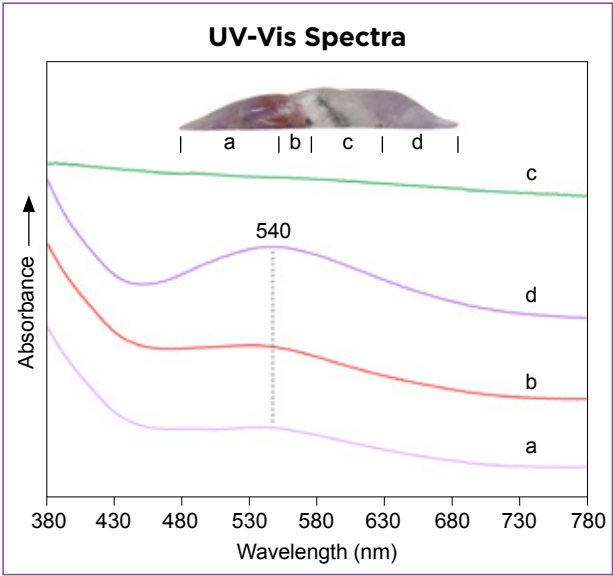


Figure 8: Absorption spectra are shown for each zone of the multicoloured quartz. The inner purple zone (a), orangey red zone (b) and the outer purple zone (d) all show a broad absorption band centred at about 540 nm associated with $O^{2+} \rightarrow Fe^{4+}$ charge transfer that is typical for amethyst. No features are present in the spectrum of the grey zone (c), where the host quartz is essentially colourless. The spectra are offset vertically for clarity.

(Fe_2O_3) and marcasite (FeS_2) in stage 1, to a substantial quantity of hematite and very little marcasite in stage 2, followed by abundant FeS_2 fibrous inclusions in stage 3 and, finally, to varying amounts of goethite ($\alpha-FeO(OH)$) V-shaped inclusions in stage 4.

During crystallisation of the first growth stage, the presence of amethyst colouration indicates that traces of Fe were incorporated into the quartz. The iron initially entered the quartz lattice as Fe^{3+} and then oxidised to Fe^{4+} by exposure to naturally occurring radiation (Cox 1977), causing absorption in the yellow-green range of the visible spectrum (from $O^{2+} \rightarrow Fe^{4+}$ charge transfer) and resulting in purple colouration (Fritsch & Rossman 1988). The presence of Fe^{3+} indicates oxidising conditions during the first growth stage.

The second growth stage was accompanied by a greater amount of Fe^{3+} , as shown by the presence of numerous inclusions of hematite and the continued amethyst colouration of the host quartz. Hematite provides evidence for a high-oxygen fugacity, low-pH environment (Cai & Yu 1999; Zhang *et al.* 2008), indicating a change towards more oxidising conditions. The quartz-forming solution of both stages 1 and 2 may have also contained very small amounts of Fe^{2+} , based on the presence of some Fe^{2+} -containing (marcasite) inclusions.

The third growth stage is represented by the grey

zone, which owes its colour to the presence of fibrous FeS_2 inclusions within colourless quartz. The sulphide inclusions show that iron was present as Fe^{2+} , thus

indicating reducing conditions (Gilg *et al.* 2014; Li *et al.* 2021). This is also supported by the fact that the quartz in this zone is colourless, rather than purple. The distinct

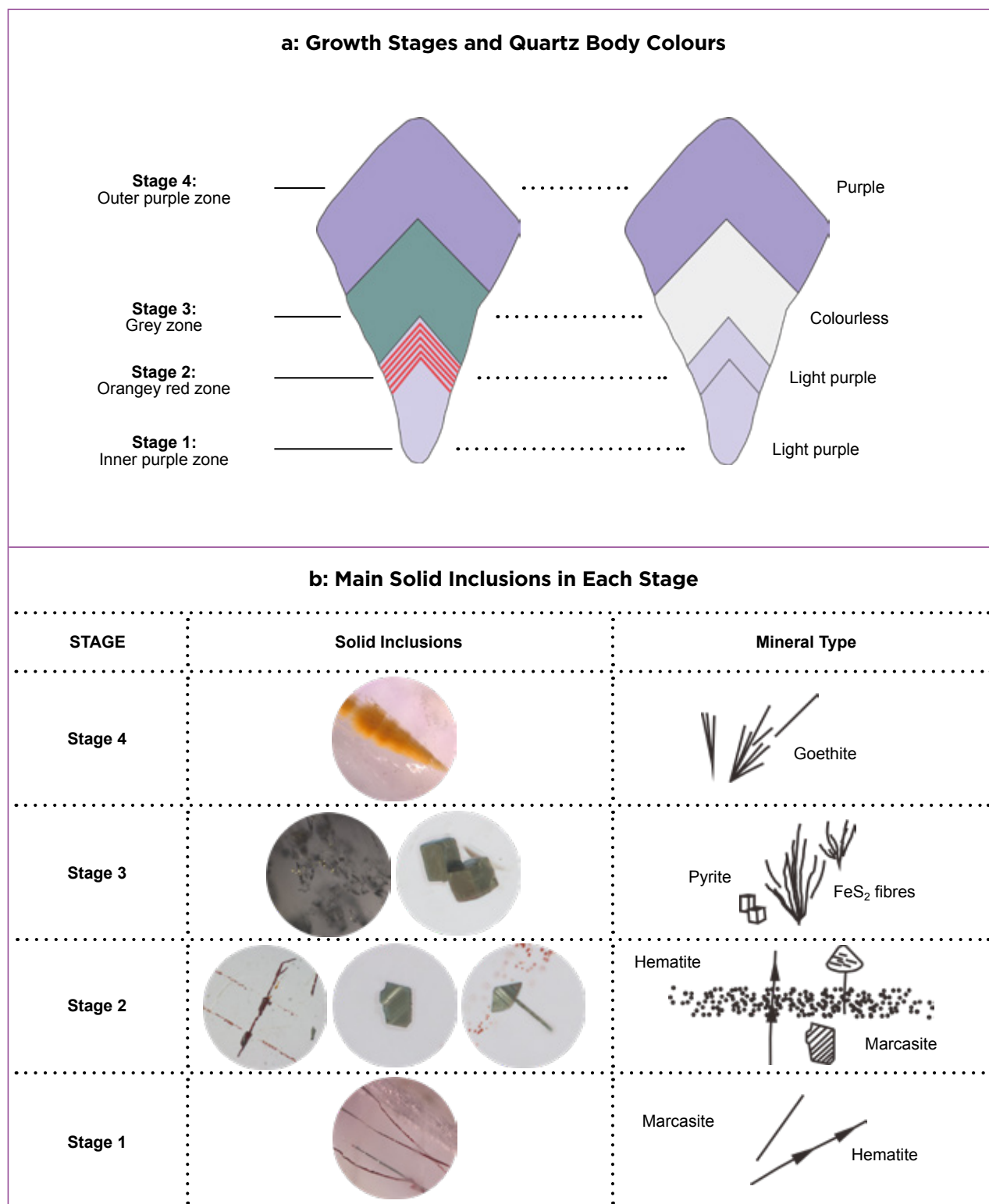


Figure 9: This schematic diagram summarises the (a) growth stages and quartz body colours, and (b) solid inclusions in the multicoloured quartz. Stage 1 is the inner amethyst zone with hematite and marcasite inclusions. Stage 2 is also amethyst, but it appears orangey red due to abundant hematite inclusions. Stage 3 is colourless quartz with abundant FeS_2 inclusions (pyrite and/or marcasite) that cause a grey appearance, along with cubes of pyrite. Stage 4 consists of amethyst with a more intense purple colour, locally accompanied with golden V-shaped fibrous goethite inclusions (especially in the outermost layer of this zone).



Figure 10: The multicoloured quartz from Brazil is available as various objects such as bracelets, tablets and polished crystals. These items were recently obtained at the Donghai crystal, gem and jewellery market. Photo by Qingfeng Wu.

boundary between the grey zone and the outer purple zone suggests an abrupt change in the quartz's formation environment.

During the fourth growth stage, the conditions then changed back to oxidising, dominated by Fe^{3+} , resulting in the outer amethyst zone. The presence of an iron hydroxide phase (goethite) predominantly in the outer margin of this zone suggests a potentially more H_2O -rich environment for this final growth stage.

CONCLUSIONS

Based on our study of the characteristics and composition of the colour zones in the multicoloured quartz from Brazil, we conclude the following:

1. This quartz shows four colour zones from inner purple to intermediate orangey red and grey, and finally an outer purple zone. The quartz body colours of the four zones are light purple, light purple, colourless and more intense purple, respectively. The colouration of the purple zones is due to $\text{O}^{2-} \rightarrow \text{Fe}^{4+}$ charge transfer, while the colour appearances of the orangey red and grey zones are due to the presence of abundant inclusions of hematite and dark FeS_2 fibrous inclusions, respectively.

2. Significant differences in the solid inclusions are seen in the various zones. Hematite and marcasite are present in small amounts in the inner purple zone, followed by abundant hematite and scarce marcasite in the orangey red zone. The grey zone contains numerous fibrous FeS_2 inclusions, and the outer purple zone hosts varying amounts of goethite inclusions. The fluid inclusions within each colour zone are primarily composed of partially healed fractures and monophasic fluid inclusions.

3. During the multi-stage crystallisation of the quartz, the Fe ions in the growth environment were influenced by redox conditions. The inner purple zone and the adjacent orangey red zone formed in an oxidising environment (predominantly Fe^{3+}), while the grey zone experienced reducing conditions (predominantly Fe^{2+}) and, finally, the outer purple zone crystallised in an oxidising environment (predominantly Fe^{3+}).

This multicoloured quartz presents colour characteristics that are both unusual and beautiful (e.g. Figure 10), which has led to increased interest in collecting this attractive material and using it for ornamental and gem purposes.

REFERENCES

- Abrashev, M.V., Ivanov, V.G., Stefanov, B.S., Todorov, N.D., Rosell, J. & Skumryev, V. 2020. Raman spectroscopy of alpha-FeOOH (goethite) near antiferromagnetic to paramagnetic phase transition. *Journal of Applied Physics*, **127**(20), article 205108, <https://doi.org/10.1063/5.0006352>.
- An, Y., Zhong, L. & Jiang, D. 2014. Micro-Raman spectral characteristics and implication of FeS₂ of augen granites in western Guangdong. *Spectroscopy and Spectral Analysis*, **34**(9), 2439–2443, [https://doi.org/10.3964/j.issn.1000-0593\(2014\)09-2439-05](https://doi.org/10.3964/j.issn.1000-0593(2014)09-2439-05) (in Chinese with English abstract).
- Beer, M. 2023. *Magic Rock Crystal*. Hirmer Verlag GmbH, Munich, Germany, 448 pages.
- Bersani, D., Lottici, P.P. & Montenero, A. 1999. Micro-Raman investigation of iron oxide films and powders produced by sol-gel syntheses. *Journal of Raman Spectroscopy*, **30**(5), 355–360, [https://doi.org/10.1002/\(SICI\)1097-4555\(199905\)30:5<3C355::AID-JRS398%3E3.0.CO;2-C](https://doi.org/10.1002/(SICI)1097-4555(199905)30:5<3C355::AID-JRS398%3E3.0.CO;2-C).
- Bryant, R.N., Pasteris, J.D. & Fike, D.A. 2018. Variability in the Raman spectrum of unpolished growth and fracture surfaces of pyrite due to laser heating and crystal orientation. *Applied Spectroscopy*, **72**(1), 37–47, <https://doi.org/10.1177/0003702817736516>.
- Cai, X. & Yu, W. 1999. Artificial synthesis of hematite in red granite and in rocks. *Journal of Rock Mineralogy*, **18**(2), 134–140, <https://doi.org/10.3969/j.issn.1000-6524.1999.02.005> (in Chinese with English abstract).
- Cohen, A.J. & Hassan, F. 1974. Ferrous and ferric ions in synthetic α -quartz and natural amethyst. *American Mineralogist*, **59**(7–8), 719–728.
- Cox, R.T. 1977. Optical absorption of the d⁴ ion Fe⁴⁺ in pleochroic amethyst quartz. *Journal of Physics C: Solid State Physics*, **10**(22), 4631–4643, <https://doi.org/10.1088/0022-3719/10/22/032>.
- Dumańska-Słowik, M., Toboła, T., Jarmołowicz-Szulc, K., Naglik, B., Dyląg, J. & Szczerba, J. 2017. Inclusion study of hourglass amethyst from Boudi (Morocco) by Raman microspectroscopy and microthermometric measurements. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **187**, 156–162, <https://doi.org/10.1016/j.saa.2017.06.053>.
- Fritsch, E. & Rossman, G.R. 1988. An update on color in gems. Part 2: Colors involving multiple atoms and color centers. *Gems & Gemology*, **24**(1), 3–15, <https://doi.org/10.5741/gems.24.1.3>.
- Gilg, H.A., Krüger, Y., Taubald, H., van den Kerkhof, A.M., Frenz, M. & Morteani, G. 2014. Mineralisation of amethyst-bearing geodes in Ametista do Sul (Brazil) from low-temperature sedimentary brines: Evidence from monophase liquid inclusions and stable isotopes. *Mineralium Deposita*, **49**(7), 861–877, <https://doi.org/10.1007/s00126-014-0522-7>.
- Heinis Dias, C., de Sá Carneiro Chaves, M.L., Figueiredo e Silva, R.C. & Dutra Gomes, S. 2021. Fluid inclusions in amethyst quartz of different geological environments from Brazil. *Mineralogical Magazine*, **85**(3), 332–347, <https://doi.org/10.1180/mgm.2021.38>.
- Hyršl, J. 2017. Gem News International: Multi-color-zoned quartz from Brazil. *Gems & Gemology*, **53**(3), 380.
- Krishnamurti, D. 1958. Raman spectrum of quartz and its interpretation. *Proceedings of the Indian Academy of Sciences – Section A*, **47**, 276–291, <https://doi.org/10.1007/BF03052811>.
- Krishnan, R.S. 1945. Raman spectrum of quartz. *Nature*, **155**, 452, <https://doi.org/10.1038/155452a0>.
- Krzemnicki, M.S. 2000. Gem News International: Ametrine with layers of smoky quartz. *Gems & Gemology*, **36**(2), 163.
- Laurs, B.M. & Renfro, N.D. 2017. Gem Notes: Amethyst from Brazil with interesting inclusion patterns. *Journal of Gemmology*, **35**(6), 468–469.
- Lehmann, G. & Bambauer, H.U. 1973. Quartz crystals and their colors. *Angewandte Chemie International Edition*, **12**(4), 283–291, <https://doi.org/10.1002/anie.197302831>.
- Li, Y.L., Xue, Q.F., Li, L.P., Chen, M.H. & Yin, Z.W. 2017. *The Gemmology Course*, 3rd edn. China University of Geosciences Press, Wuhan, China, 247 pp. (in Chinese).
- Li, S.R., Shen, J.F., Dong, G.C. et al. 2021. *Genetic Mineralogy: Principle · Methodology · Application*. China Science Publishing & Media Ltd, Beijing, China, 133 pp. (in Chinese).
- Lutz, H.D. & Müller, B. 1991. Lattice vibration spectra. LXVIII. Single-crystal Raman spectra of marcasite-type iron chalcogenides and pnictides, FeX₂ (X=S, Se, Te; P, As, Sb). *Physics and Chemistry of Minerals*, **18**(4), 265–268, <https://doi.org/10.1007/bf00202579>.
- Pérez León, C., Kador, L., Zhang, M. & Müller, A.H.E. 2004. *In situ* laser-induced formation of α -Fe₂O₃ from Fe³⁺ ions in a cylindrical core-shell polymer brush. *Journal of Raman Spectroscopy*, **35**(2), 165–169, <https://doi.org/10.1002/jrs.1125>.
- Shim, S.-H. & Duffy, T.S. 2002. Raman spectroscopy of Fe₂O₃ to 62 GPa. *American Mineralogist*, **87**(2–3), 318–326, <https://doi.org/10.2138/am-2002-2-314>.
- Tominaga, Y., Fujiwara, A. & Amo, Y. 1998. Dynamical structure of water by Raman spectroscopy. *Fluid Phase Equilibria*, **144**(1–2), 323–330, [https://doi.org/10.1016/s0378-3812\(97\)00276-8](https://doi.org/10.1016/s0378-3812(97)00276-8).

Zhang, H., Qian, G., Cai, Y., Gibson, C. & Pring, A. 2022. Crystal chemistry of arsenian pyrites: A Raman spectroscopic study. *American Mineralogist*, **107**(2), 274–281, <https://doi.org/10.2138/am-2021-7806>.

Zhang, L., Rao, C., Zhang, C., Ruan, Q., Lei, W., Liao, B. & He, T. 2008. Morphology, structure and origin of spherulite and tubular iron oxide inclusions in rock crystals. *Geological Review*, **54**(6), 786–792, <https://doi.org/10.3321/j.issn:0371-5736.2008.06.007> (in Chinese with English abstract).

Zhao, S.R. 2017. *Crystallography and Mineralogy*, 3rd edn. Higher Education Press, Beijing, China, 302 pp. (in Chinese).

Zoppi, A., Lofrumento, C., Castellucci, E.M. & Migliorini, M.G. 2005. The Raman spectrum of hematite: Possible indicator for a compositional or firing distinction among *Terra Sigillata* wares. *Annali di Chimica*, **95**(3–4), 239–246, <https://doi.org/10.1002/adich.200590026>.

The Authors

**Huizhen Huang^{1,2}, Dr Quanli Chen^{1,3,*},
Dr Xianyu Liu⁴, Dr Yan Li¹, Dr Zuowei Yin¹
and Yanhan Wu¹**

¹ Gemological Institute, China University of Geosciences, No. 388 Lumo Rd., 430074 Wuhan, China

² Hubei Gems and Jewellery Engineering Technology Research Centre, No. 388 Lumo Road, 430074 Wuhan, China

³ School of Jewelry, West Yunnan University of Applied Sciences, No. 1 Ruixing Road, 679100 Tengchong, China

⁴ School of Jewelry, Shanghai Jianqiao University, No. 111 Huchenghuan Road, 201306 Shanghai, China

* Email: chenquanli@cug.edu.cn

Acknowledgements

This work was funded by the Hubei Gems and Jewellery Engineering Technology Research Centre (grant/award no. CIGTXM-04-S202203); the Fundamental Research Funds for National University, China University of Geosciences, Wuhan (grant/award no. CUGDCJJ202221); the Philosophy and Social Science Foundation of Hubei Province (grant/award no. 21G007); the National Natural Science Foundation of China (grant/award no. 41874105) and support from a Yunnan Undergraduate Education Teaching and Reform Research Project Grant (no. JG2023143).

The authors thank Zhuoxuan Li and Qingfeng Wu for supplying the photos in Figures 1 and 10, respectively. We also thank the reviewers for their constructive comments, which have greatly helped improve the article.



Gem-A

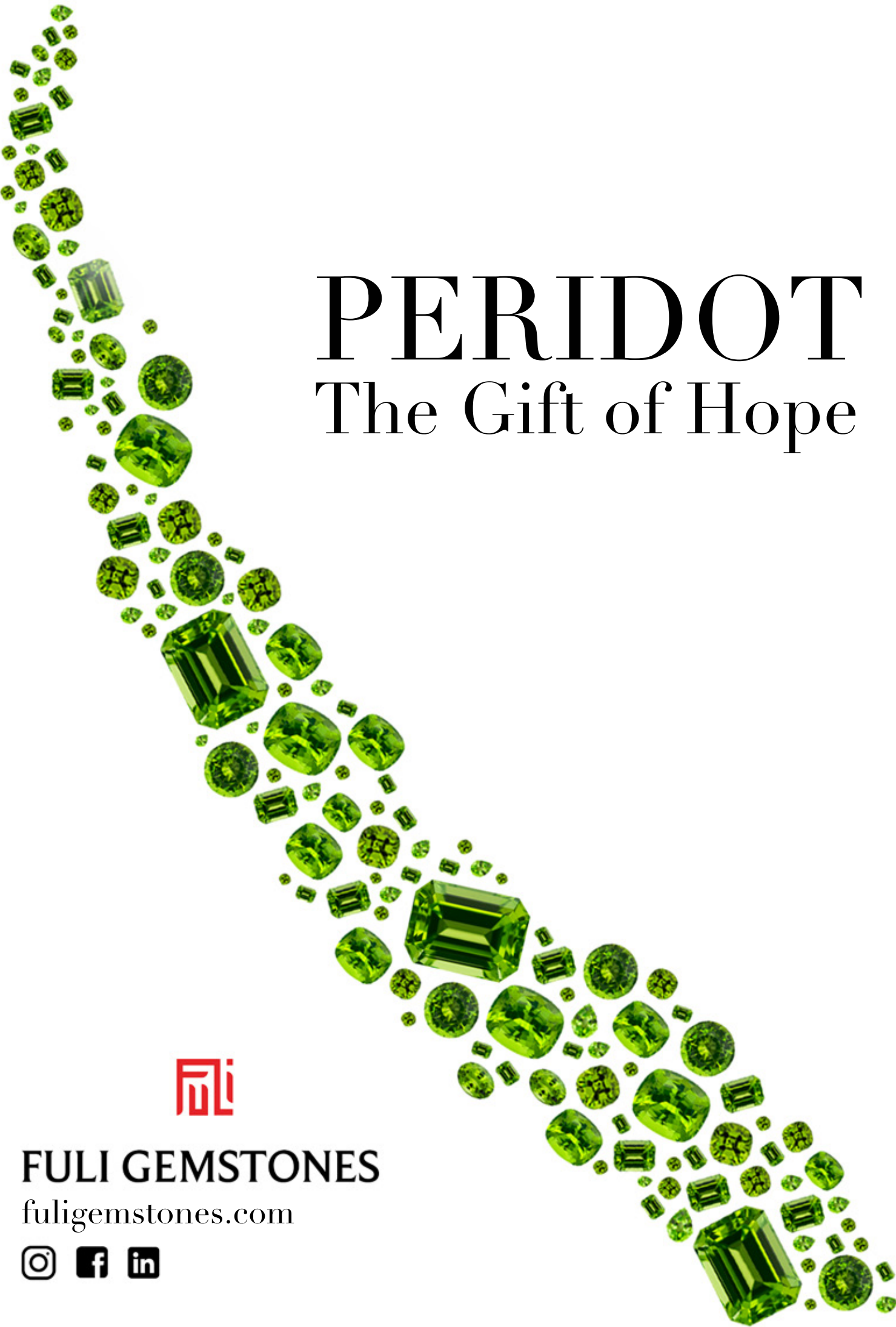
THE GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN

Study gemmology online!

- Online class groups
- Virtual learning
- Interactive quizzes
- Start your journey to FGA Membership with online learning by leading provider, Gem-A



Contact education@gem-a.com for more information



PERIDOT

The Gift of Hope



FULI GEMSTONES

fuligemstones.com



An Historical Alexandrite from the Mineralogy Museum of Paris School of Mines

Eloïse Gaillou, Stefanos Karampelas, Ugo Hennebois, Annabelle Herreweghe, Farida Maouche, Bérangère Meslin Sainte Beuve, Didier Nectoux and Aurélien Delaunay

ABSTRACT: A spectacular 42.54 ct faceted alexandrite belonging to the collection of the Mineralogy Museum of Paris School of Mines was non-destructively characterised for this report. This historical gem was exhibited in at least one exposition in Paris during the late 1870s and/or in 1880 before it was donated to the museum by lapidary Henri Garreaud in 1882. However, its geographic origin was not stated, and its gemmological properties have not been examined until now. Our study reveals that the gem's microscopic, chemical and spectroscopic characteristics are similar to those of alexandrite from Sri Lanka.

The Journal of Gemmology, 38(8), 2023, pp. 796–803, <https://doi.org/10.15506/JoG.2023.38.8.796>
© 2023 Gem-A (The Gemmological Association of Great Britain)

A 42.54 ct alexandrite belonging to the Mineralogy Museum of Paris School of Mines (Mines Paris – PSL; Figure 1) is exceptional in several ways: it is historical, very rare, shows a distinct change of colour and is quite large for its species (particularly with this colouration). The only larger faceted alexandrites that we know of in other museums are two stones in the collection of the Smithsonian Institution (Washington DC, USA) weighing 48.20 and 65.70 ct, and a 43.18 ct alexandrite in the Natural History Museum, London. All three of these gems are reportedly from Sri Lanka. To the best of our knowledge, no scientific studies have been published on any of them.

Until recently, the 42.54 ct stone that is the subject of this article was stored in the vault at Mines Paris – PSL since its donation in 1882, but it is now on public display in a temporary exhibit titled 'Collectible Minerals' (6 September 2023–9 March 2024; see *The Journal*, Vol. 38, No. 7, 2023, p. 644). For this occasion, Mines Paris – PSL partnered with the Laboratoire Français de Gemmologie

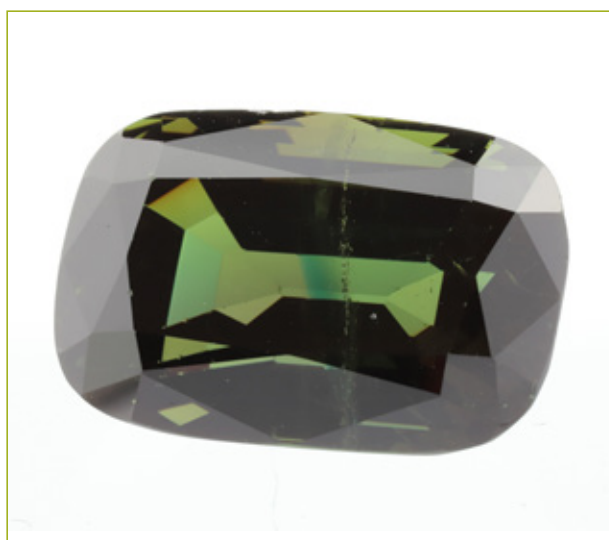


Figure 1: This 42.54 ct alexandrite (23.15 × 15.95 × 12.31 mm) belongs to the collection of Paris School of Mines (Mines Paris – PSL). It was donated in 1882 by French lapidary Henri Garreaud, with the only note of its origin being the 'Indies'. It is shown here under 5500 K illumination. Photo by E. Gaillou; © Mineralogy Museum, Mines Paris – PSL (sample no. ENSMP 69873).

(LFG) to conduct a scientific examination of the stone (Gaillou *et al.* 2022; Karampelas *et al.* 2023). This article chronicles its history and describes its gemmological and chemical properties in order to infer its probable geographical origin.

HISTORICAL BACKGROUND

Although the museum has owned the alexandrite for approximately 140 years, until now very little was known about it, other than what was written in the museum's catalogue (Figure 2). The gem was reported to be a faceted alexandrite, also known as *cymophane*, weighing 41½ ct and presenting a distinctive internal pattern, as illustrated in a sketch of the stone in the catalogue (again, see Figure 2). The catalogue entry mentions that it was donated in 1882 by H. Garreaud, a lapidary and expert for the French government. The catalogue also states that Emile Bertrand, a mineralogist and former student of the School of Mines, suggested that the alexandrite came from the 'Indies'.

The donation of this alexandrite to the museum was important enough to be reported in several press articles (e.g. Weiss 1883). We were able to trace the donor back to Henri Garreaud, who died in Paris in 1892. Garreaud had a boutique of gemstones and *objets d'art* made of gem materials. He exhibited on several occasions at national and international world fairs. For example, he won a gold medal for his gemstone display at the 1878 Exposition Universelle in Paris (Gonse & de Lostalot 1890, p. 444), and in 1876 and 1880 he received silver

medals at the Exposition des Beaux-Arts appliqués à l'Industrie. It is most likely that the 1880 fair is the one mentioned in the 'Observations' column of the museum's catalogue, as it was the last one to take place before Garreaud donated the stone in 1882.

The reason Garreaud gave the stone to the School of Mines is not known. However, it is interesting to note that the organisers of the 1878 Exposition Universelle decided to unite the Fine Arts and the Industrial Arts sections under the same exhibit, in which the School of Mines played a role. Indeed, the School of Mines encouraged its professors and engineers to participate in these international fairs as organisers, jury members or exhibitors, and acquired many of the samples presented at the fairs for its collection. A meeting between Garreaud and School of Mines personnel was likely, possibly leading to the donation.

Garreaud's name and skills were forgotten after he died in 1892, leaving his entire shop of gems and lapidary *objets d'art* to be sold at auction (Anonymous 1893). No other French museums seem to have acquired any of Garreaud's other pieces.

METHODS

For this study, Mines Paris – PSL provided the alexandrite to LFG on a very short-term loan (eight hours) for scientific characterisation by strictly non-destructive methods. It was examined with a Zeiss Stemi 508 binocular microscope equipped with crossed polarisers, and also with a Chelsea Colour Filter. Its RIs

NUMÉRO DE L'ÉCHANTILLON	DESCRIPTION DÉTAILLÉE DE L'ÉCHANTILLON NATURE – LOCALITÉ, etc.	DÉTERMINATION D'INVENTAIRE	LOCALITÉ	PAYS	REVENIR DES ANCIENS CATALOGUES	OBSERVATIONS
4410	Alexandrite taillée La pierre a un défaut 41 ½ carats	Cymophane n. 7 Cymophane no. 7	Indes (d'après M. Bertrand)	Indes (according to Mr Bertrand)		(au coffre fort 15 juin 1921 assuré) d. p. M. H. Garreaud lapidaire Expert du Gouvernement Hors concours à l'Exposition des Beaux-Arts appliqués à l'Industrie 67. rue de Richelieu Paris (in the vault June 15 1921 insured) Donated by Mr H. Garreaud lapidary Government Expert Standout at the Exhibition of Fine Arts applied to Industry 67. rue de Richelieu Paris

Figure 2: The alexandrite was documented in entry no. 4410 of the museum's catalogue. Photo by E. Gaillou; © Mineralogy Museum, Mines Paris – PSL.

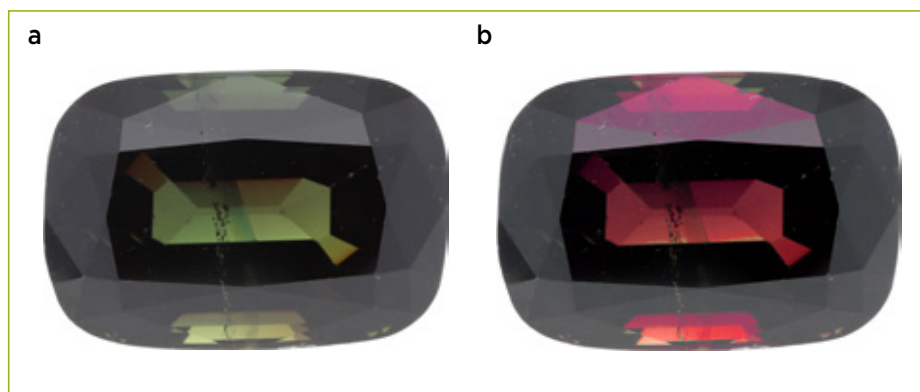


Figure 3: The 42.54 ct alexandrite appears (a) brownish green in daylight-equivalent light (6500 K) and (b) brownish-reddish purple in incandescent light (2856 K). Photos by Thiala Magalhaes/LFG; © Mineralogy Museum, Mines Paris – PSL.

were measured with a refractometer and its SG was determined hydrostatically. The stone's luminescence was tested with a 6 W UV lamp (Vilber Lourmat VL-6, LC) equipped with long-wave (365 nm) and short-wave (254 nm) radiation, in a Vilber CN-6 darkroom with a distance of 10 cm between the sample and the lamp.

Raman and photoluminescence (PL) spectra were acquired using a GemmoRaman-532SG spectrometer with 532 nm laser excitation and a spectral resolution of 11 cm^{-1} . Raman spectra were collected in the $200\text{--}2000\text{ cm}^{-1}$ range (1 s exposure time and four accumulations), and PL spectra were obtained in the $540\text{--}760\text{ nm}$ range (0.3–0.4 s exposure time and 30 accumulations). Raman and PL spectra were also acquired for the gem—as well as its inclusions—with a Renishaw inVia spectrometer coupled with an optical microscope and 514 nm excitation from a diode-pumped solid-state laser. Raman spectra covered the range of $250\text{--}1250\text{ cm}^{-1}$ (30 s exposure time and ten accumulations); the laser power on the sample was 40 mW and the spectral resolution was about 2 cm^{-1} . PL spectra spanned $500\text{--}900\text{ nm}$ (10 s exposure time and one accumulation) with a laser power of 0.1 mW. Both spectrometers were calibrated using the 1331.8 cm^{-1} Raman peak of diamond.

Fourier-transform infrared (FTIR) spectra were obtained in the range of $400\text{--}8000\text{ cm}^{-1}$ using a Nicolet iS5 spectrophotometer with 4 cm^{-1} resolution and 500 scans. Ultraviolet-visible-near infrared (UV-Vis-NIR) spectra were acquired over $365\text{--}1000\text{ nm}$ using a GemmoSphere spectrometer (0.05–0.10 s acquisition time and 50 accumulations) equipped with an integrating sphere. In addition, UV-Vis spectra were obtained using a Jasco V-630 spectrophotometer from 250 to 850 nm, with a data interval and spectral bandwidth of 2 nm and a scan rate of 210 nm/min. All of the acquired spectra were unpolarised.

Chemical analysis was performed using a Thermo Scientific ARL Quant'X energy-dispersive X-ray fluorescence (EDXRF) spectrometer with an aperture of 5 mm diameter. Specific sets of parameters for filters and

voltages were optimised for the most accurate analysis of chrysoberyl (no filter/4 kV, cellulose/8 kV, aluminium/12 kV, thin palladium/16 kV, medium palladium/20 kV, thick palladium/28 kV and thick copper/50 kV), with an acquisition time of about 20 minutes for each measurement. Measured iron was calculated as FeO, and BeO was fixed at 18.7%.

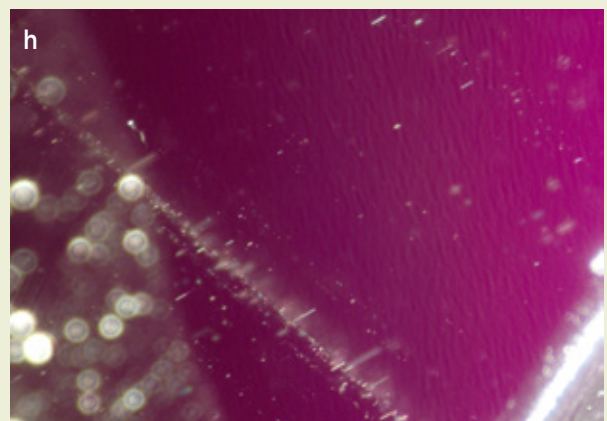
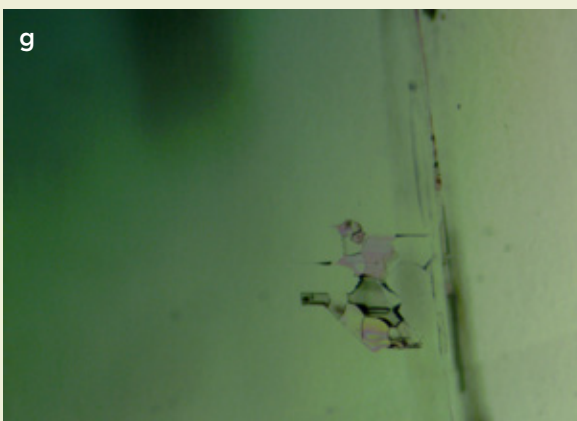
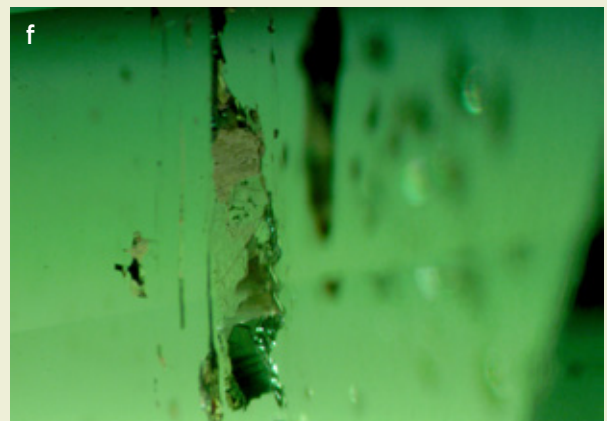
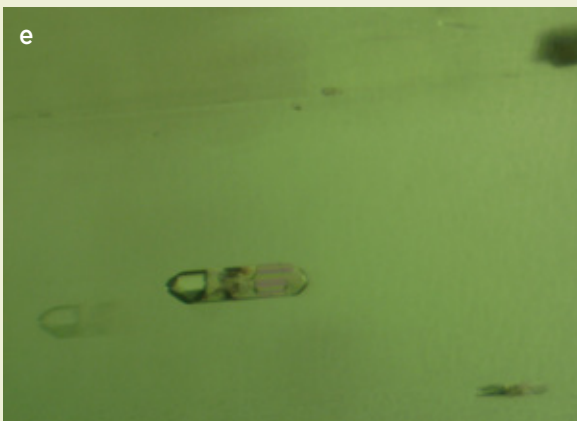
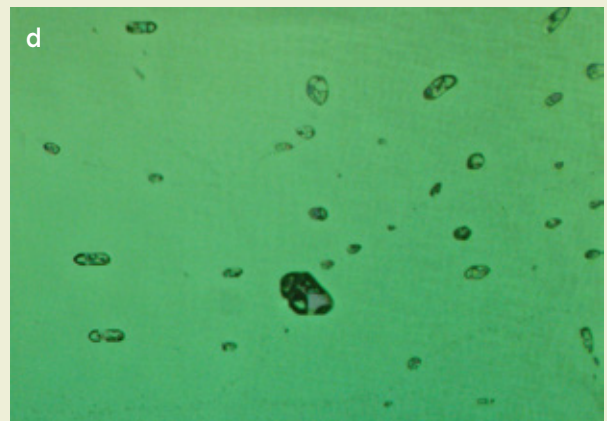
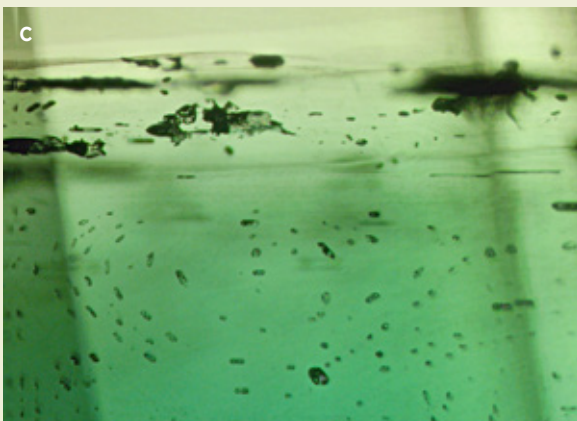
RESULTS AND DISCUSSION

Gemmological and Chemical Characteristics

The alexandrite was faceted as a cushion-shaped mixed-cut gemstone that measured $23.15 \times 15.95 \times 12.31\text{ mm}$ and weighed 42.54 ct (vs $41\frac{1}{2}$ ct recorded in the museum catalogue). The gem displayed a pronounced colour change, from brownish green in daylight-equivalent light (6500 K; Figure 3a) to brownish-reddish purple in incandescent light (2856 K; Figure 3b). The RIs were 1.745–1.755 and the SG value was 3.72. The stone showed strong pleochroism from yellow to green to purple (Figure 4). It appeared red with the Chelsea filter, and was inert to long- and short-wave UV radiation. These characteristics are consistent with the typical properties of alexandrite (cf. Webster & Anderson 1983).

The stone contained an eye-visible twin plane through its centre (Figures 1, 3 and 4a, b)—which

Figure 4: (a, b) A twin plane in the alexandrite appears more distinct when viewed with different orientations of the polariser in transmitted light. The sample's strong pleochroism is also evident in these images. (c–h) Several types of internal features are present within the linear array of inclusions that is seen crossing the stone in Figures 1 and 3, including multiphase inclusions of various shapes and sizes (c–g)—some with rounded outlines—as well as fingerprints and feathers (f–g), and also particles and short needles (h). Photomicrographs by U. Hennebois/LFG; © Mineralogy Museum, Mines Paris – PSL; image widths (a, b, d, e) 1.4 mm, (c, g) 2.2 mm, (f) 4.5 mm and (h) 3.5 mm.



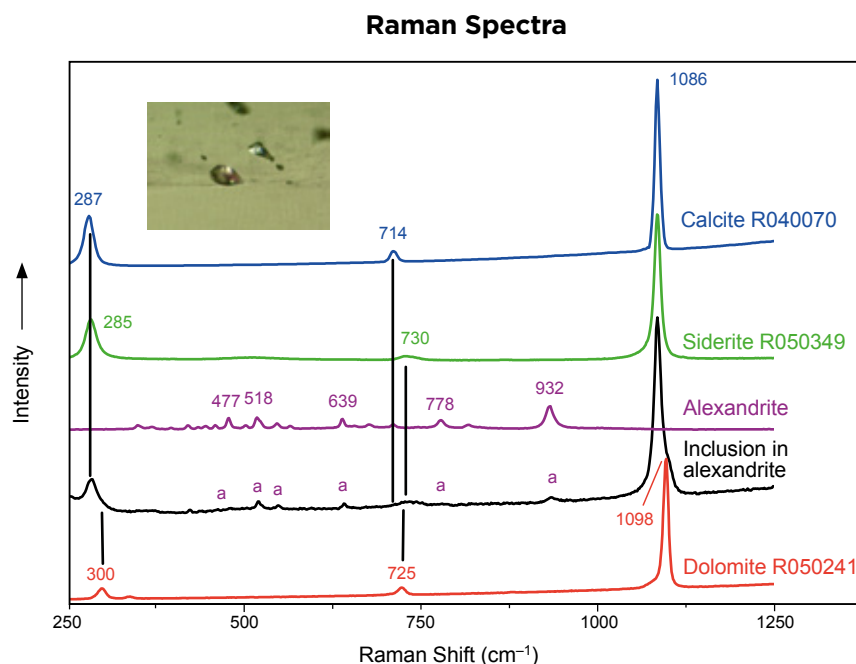


Figure 5: The Raman spectrum of the alexandrite (purple trace) is typical of natural chrysoberyl. The spectrum of an inclusion (see inset photo and black trace) shows contributions from more than one carbonate mineral, as well as the host alexandrite (peaks labelled 'a'). The spectra presented here were acquired with the Renishaw inVia Raman spectrometer using 514 nm laser excitation; reference spectra for dolomite, calcite and siderite from the RRUFF database (<https://rruff.info>) are shown for comparison. Inset photomicrograph (image width 0.5 mm) by U. Hennebois/LFG; © Mineralogy Museum, Mines Paris - PSL.

is also shown in the museum catalogue sketch in Figure 2—and this plane is accompanied by colour zoning. A linear array of inclusions crossing the stone could also be observed with the unaided eye when viewed table up (again, see Figures 1 and 3). This zone contained various internal characteristics consistent with a natural origin, such as multiphase inclusions of various sizes and shapes, ‘fingerprints’ and feathers

(Figure 4c–g), as well as particles and short needles (Figure 4h). This inclusion scene is similar to that observed in some alexandrite gems from Sri Lanka (Gunawardene & Rupasinghe 1986; Sun *et al.* 2019).

Raman spectra of the alexandrite displayed bands at approximately 477, 518, 639, 778 and 932 cm^{-1} (e.g. Figure 5, purple trace) due to Be-O and Al-O vibrations of chrysoberyl (Rybnikova *et al.* 2023). It was not possible to acquire Raman spectra from most of the inclusions, but we did obtain the spectrum of one of them (Figure 5, inset and black trace). Its main Raman band was at around 1086 cm^{-1} with a shoulder at 1098 cm^{-1} , along with less intense bands at about 285 and 735 cm^{-1} . These features correspond to the lattice modes and internal modes, respectively, of carbonates. This series of bands appears to represent a combination of signals from more than one carbonate mineral, such as dolomite, calcite and siderite (cf. Rividi *et al.* 2010; Kim *et al.* 2021).

The PL spectrum of the alexandrite (Figure 6) showed a doublet at 678 and 680 nm along with a series of other bands that are linked to Cr^{3+} in the chrysoberyl structure (Powell *et al.* 1985; Suchocki *et al.* 1987).

The FTIR spectrum of the alexandrite revealed a series of bands above 2800 cm^{-1} , centred at around 2840, 3130, 3230 and 4140 cm^{-1} (Figure 7). These bands are characteristic of natural alexandrite, and are related to OH defects and vacancies in chrysoberyl (Bauerhansl

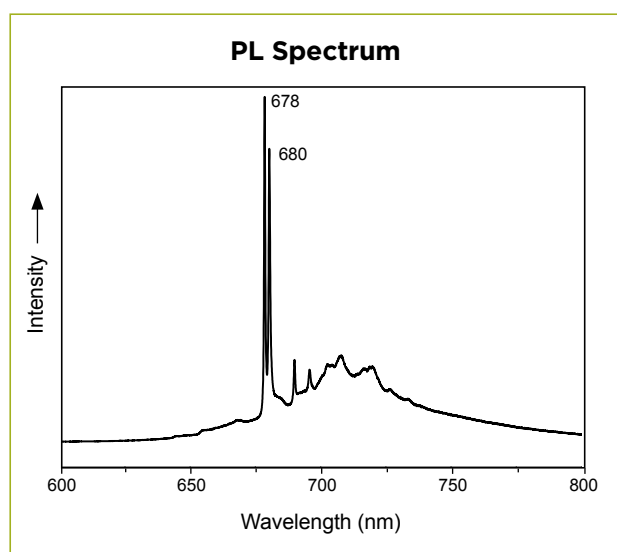


Figure 6: The PL spectrum of the alexandrite displays bands characteristic of Cr^{3+} in natural chrysoberyl. The spectrum was acquired with the Renishaw inVia Raman spectrometer using 514 nm laser excitation.

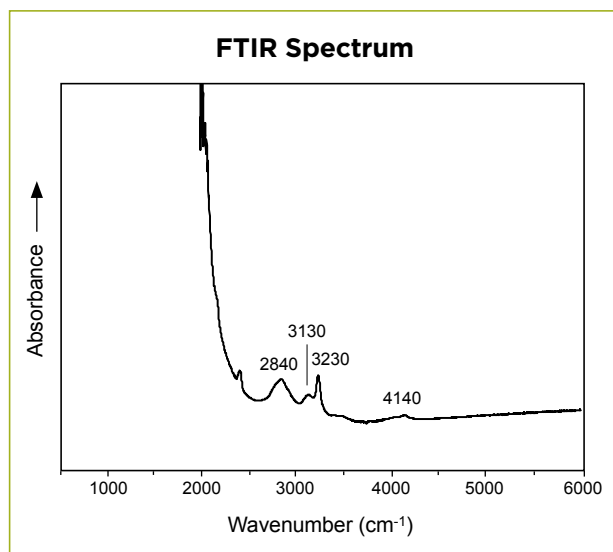


Figure 7: The FTIR spectrum of the alexandrite exhibits features characteristic of natural chrysoberyl.

& Beran 1997; Malsy & Armbruster 2012).

The Vis-NIR absorption spectrum of the alexandrite (Figure 8) showed a Cr^{3+} -related absorption (with a possible contribution from V^{3+}) centred at around 575 nm, and a cutoff at around 450 nm. The doublet seen at around 680 nm in the PL spectrum is also visible, but as a single peak. Also present is a continuum that gradually decreases in intensity towards the NIR range, possibly due to the presence of iron (Farrel & Newnham 1965; Powell *et al.* 1985; Suchocki *et al.* 1987).

EDXRF chemical analysis revealed about 9460 ppmw

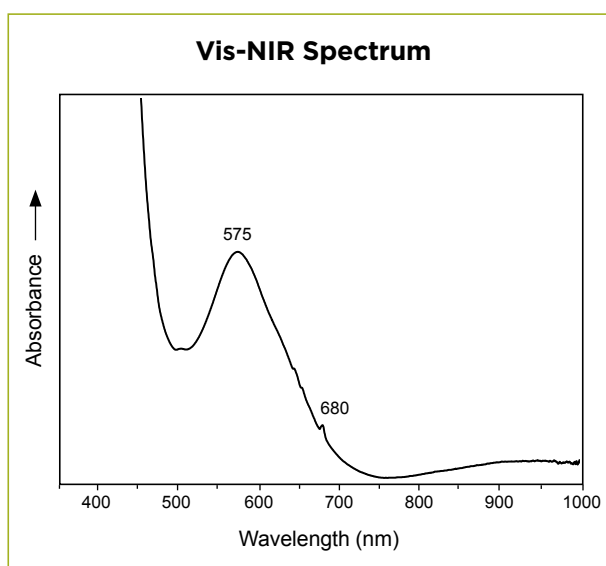


Figure 8: The Vis-NIR spectrum of the alexandrite (acquired with the GemmoSphere spectrometer) reveals absorptions at 575 and 680 nm associated with Cr^{3+} , as well as a gradually decreasing continuum towards the NIR range, possibly linked to iron.

Fe, 925 ppmw Ga, 885 ppmw Cr, 430 ppmw V and 190 ppmw Ti; all other trace elements were below the detection limit of the instrument. Such a combination of enriched Fe and Ga in gem-quality alexandrite has been reported only for material from Sri Lanka (Sun *et al.* 2019).

Inferred Sri Lankan Origin

Chrysoberyl is commonly associated with Be-rich and pegmatitic rocks, and the presence of alexandrite reflects a rare combination of enriched Be and Cr in the formation environment. In Sri Lanka, alexandrite is mined from secondary (placer) deposits (Marshall & Walton 2014) derived from the weathering of various host rocks. Most Sri Lankan gem deposits originally formed by contact metamorphism of mafic intrusions (producing charnockite) and the intrusion of Be-enriched pegmatitic fluids into highly aluminous metasediments of the Highland Group (2200 to 3000 million years [Ma] ago, with high-grade metamorphism occurring at 1100 and 550 Ma), producing beryl, chrysoberyl, taaffeite and other Be-bearing minerals (Rupasinghe *et al.* 1984). A reaction between marble and pegmatitic fluid has been postulated for the Elahera gem field (Rupasinghe & Dissanayake 1985; Dissanayake *et al.* 2000), which is consistent with the presence of a carbonate inclusion in the studied alexandrite, although there are different types of Sri Lankan alexandrite showing particular inclusion scenes and geochemical signatures (Schmetzer 2010; Sun *et al.* 2019).

Russia has commonly been considered the only source of alexandrite during the nineteenth century, and little information was available about alexandrite from Sri Lanka until the early 1920s (Sun *et al.* 2019). However, the first mention of alexandrite from Sri Lanka can be found in a Russian textbook on gems published in 1888 (Pylyaev 1888), where it was acknowledged that these stones had already been available in Russia for seven years. One can therefore assume that Sri Lankan alexandrite arrived in Russia around 1880 or before (Schmetzer 2010). Early in the twentieth century, various authors reported alexandrite of exceptional quality and size (up to 131 ct, possibly rough) coming from Morawaka (sometimes with a slightly different spelling), a town in Sri Lanka's Southern Province (Day 1904; Stokes 1908; Bauer 1909; Bingham 1923).

Additionally, there is evidence of fine alexandrite coming from Sri Lanka prior to 1880, which is consistent with the 42.54 ct stone being donated to the Mineralogy Museum of Paris School of Mines in 1882. In 1873, the Natural History Museum in London purchased a

43.18 ct alexandrite from Sri Lanka (Hansen 2022). This suggests that early production of alexandrite from Sri Lanka—and the quality and size of the stones—might have been much better than previously thought. Thus, not all alexandrite found in nineteenth-century (e.g. Victorian) jewellery necessarily originated in Russia; some could have come from Sri Lanka.

CONCLUSIONS

We examined an exceptional, historical 42.54 ct faceted alexandrite belonging to the collection of the Mineralogy Museum of Paris School of Mines (Figure 9). It was donated to the museum in 1882 by French lapidary Henri Garreaud. All characteristics of the sample are consistent with those of natural alexandrite. It shows a pronounced colour change from brownish green in daylight to brownish-reddish purple in incandescent light. The inclusion scene (e.g. needles, multiphase inclusions of various shapes and feathers), as well as chemical composition (e.g. relatively high Fe and Ga content), suggest a Sri Lankan origin. The presence of this and another large historical alexandrite gemstone in London's Natural History Museum collection further indicate that during the nineteenth century, fine



Figure 9: The studied historical alexandrite is shown here in incandescent light (2800 K). Photo E. Gaillou; © Mineralogy Museum, Mines Paris – PSL.

alexandrite came from Sri Lanka as well as Russia.

Until recently, the 42.54 ct alexandrite had not been exhibited to the public since the late 1870s or 1880, but it is on display (through 9 March 2024) in a temporary exhibit titled 'Collectible Minerals,' at the Mineralogy Museum of Mines Paris – PSL. Accompanied by the information in this article, this noteworthy stone is enriched by further knowledge of its history and a thorough gemmological characterisation.

REFERENCES

- Anonymous 1893. Ventes à l'enchère – adjudications. *La Liberté*, 7 January, p. 4, col. 1, art. 4, <https://gallica.bnf.fr/ark:/12148/bpt6k34895416>.
- Bauer, M. 1909. *Edelsteinkunde*. Chr. Herm. Tauchnitz, Leipzig, Germany, viii + 766 pp.
- Bauerhansl, P. & Beran, A. 1997. Trace hydrogen in the olivine-type minerals chrysoberyl, Al_2BeO_4 and sinhalite, MgAlBO_4 – A polarized FTIR spectroscopic study. *Schweizerische Mineralogische und Petrographische Mitteilungen*, **77**, 131–136.
- Bingham, P.M. 1923. *History of the Public Works Department, Ceylon, 1796 to 1913*, Vol. 3. H. Ross Cottle, Government Printer, Colombo, Ceylon, 170 pp.
- Day, D.T. 1904. *Mineral Resources of the United States, 1903*. U.S. Government Printing Office, Washington DC, USA, 1,204 pp., <https://doi.org/10.3133/70175773>.
- Dissanayake, C.B., Chandrajith, R. & Tobschall, H.J. 2000. The geology, mineralogy and rare element geochemistry of the gem deposits of Sri Lanka. *Bulletin of the Geological Society of Finland*, **72**(1–2), 5–20, <https://doi.org/10.17741/bgsf/72.1-2.001>.
- Farrell, E.F. & Newnham, R.E. 1965. Crystal-field spectra of chrysoberyl, alexandrite, peridot, and sinhalite. *American Mineralogist*, **50**(11–12), 1972–1981.
- Gaillou, E., Karampelas, S., Maouche, F., Herreweghe, A., Hennebois, U., Meslin Sainte Beuve, B., Nectoux, D. & Delaunay, A. 2022. A historical alexandrite at Paris School of Mines. *The Geological Curators Group (GCG) and The Society of Mineral Museum Professionals (SMMP) Meeting and Seminar*, London, 1 December, 13–14.
- Gonse, L. & de Lostalot, A. 1890. *Exposition Universelle de 1889. Les Beaux-Arts et les Arts Décoratifs : L'Art Français Rétrospectif au Trocadéro*. Journal le Temps, Paris, France, 592 pp.
- Gunawardene, M. & Rupasinghe, M.S. 1986. The Elahera gem field in central Sri Lanka. *Gems & Gemology*, **22**(2), 80–95, <https://doi.org/10.5741/gems.22.2.80>.
- Hansen, R. 2022. *Natural History Museum Book of Gemstones: A Concise Reference Guide*. Natural History Museum, London, 240 pp.
- Karampelas, S., Gaillou, E., Hennebois, U., Maouche, F., Herreweghe, A., Meslin Sainte Beuve, B., Nectoux, D. & Delaunay, A. 2023. Study of a historical alexandrite from Paris School of Mines collection. *37th International Gemmological Conference*, Tokyo, Japan, 23–27 October, 48–49.
- Kim, Y., Caumon, M.-C., Barres, O., Sall, A. & Cauzid, J. 2021. Identification and composition of carbonate

- minerals of the calcite structure by Raman and infrared spectroscopies using portable devices. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, **261**, article 119980, <https://doi.org/10.1016/j.saa.2021.119980>.
- Malsy, A.-K. & Armbruster, T. 2012. Synthetic alexandrite – Growth methods and their analytical fingerprints. *European Journal of Mineralogy*, **24**(1), 153–162, <https://doi.org/10.1127/0935-1221/2012/0024-2181>.
- Marshall, D. & Walton, L. 2014. Chrysoberyl. In: Groat, L.A. (ed) *Geology of Gem Deposits*, 2nd edn. Mineralogical Association of Canada, Québec, Canada, 207–216.
- Powell, R.C., Xi, L., Gang, X., Quarles, G.J. & Walling, J.C. 1985. Spectroscopic properties of alexandrite crystals. *Physical Review B*, **32**(5), 2788–2797, <https://doi.org/10.1103/PhysRevB.32.2788>.
- Pylyaev, M.I. 1888. *Precious Stones: Their Properties, Localities and Use*, 2nd edn. A.S. Suvorin, St Petersburg, Russia (in Russian; see pp. 76–79).
- Rividi, N., van Zuilen, M., Philippot, P., Ménez, B., Godard, G. & Poidatz, E. 2010. Calibration of carbonate composition using micro-Raman analysis: Application to planetary surface exploration. *Astrobiology*, **10**(3), 293–309, <https://doi.org/10.1089/ast.2009.0388>.
- Rupasinghe, M.S. & Dissanayake, C.B. 1985. A preliminary geochemical study of sedimentary gem deposits of Sri Lanka. *Chemie der Erde*, **44**(4), 281–298.
- Rupasinghe, M.S., Banerjee, A., Pense, J. & Dissanayake, C.B. 1984. The geochemistry of beryllium and fluorine in the gem fields of Sri Lanka. *Mineralium Deposita*, **19**(1), 86–93, <https://doi.org/10.1007/bf00206601>.
- Rybníková, O., Bačík, P., Uher, P., Fridrichová, J., Lalinská-Voleková, B., Kubernátová, M. & Hanus, R. 2023. Characterization of chrysoberyl and its gemmological varieties by Raman spectroscopy. *Journal of Raman Spectroscopy*, **54**(8), 857–870, <https://doi.org/10.1002/jrs.6566>.
- Schmetzer, K. 2010. *Russian Alexandrites*. Schweizerbart Science Publishers, Stuttgart, Germany, 141 pp.
- Stokes, R.S.G. 1908. *Mines and Minerals of the British Empire*. Edward Arnold, London, xx + 403 pp.
- Suchocki, A.B., Gilliland, G.D., Powell, R.C., Bowen, J.M. & Walling, J.C. 1987. Spectroscopic properties of alexandrite crystals II. *Journal of Luminescence*, **37**(1), 29–37, [https://doi.org/10.1016/0022-2313\(87\)90179-7](https://doi.org/10.1016/0022-2313(87)90179-7).
- Sun, Z., Palke, A.C., Muyal, J., DeGhionno, D. & McClure, S.F. 2019. Geographic origin determination of alexandrite. *Gems & Gemology*, **55**(4), 660–681, <https://doi.org/10.5741/gems.55.4.660>.
- Webster, R. & Anderson, B.W. 1983. *Gems: Their Sources, Descriptions and Identification*, 4th edn. Butterworths, London, 1,006 pp.
- Weiss, J.-J. 1883. Nouvelles diverses. *Journal des Débats Politiques et Littéraires*, 23 April, p. 2, col. 6, <https://gallica.bnf.fr/ark:/12148/bpt6k462218s>.

The Authors

Dr Eloïse Gaillou^{1*}, Dr Stefanos Karampelas^{2*}, Ugo Hennebois², Annabelle Herreweghe², Farida Maouche¹, Bérengère Meslin Sainte Beuve², Dr Didier Nectoux¹ and Aurélien Delaunay²

¹ Mines Paris – PSL, PSL University, Mineralogy Museum, 75006 Paris, France

² Laboratoire Français de Gemmologie (LFG), 30 rue de la Victoire, 75009 Paris, France

* Emails: eloise.gaillou@minesparis.psl.eu; s.karampelas@lfg.paris

Acknowledgements

The authors are grateful for the assistance of Amélie Dessens and Ludovic Bouvier, library curator and archivist, respectively, at the Paris School of Mines (Mines Paris – PSL). Thiala Magalhaes (LFG) is also thanked for taking the photos in Figure 3.

Join us on social media to keep up-to-date with the latest news, events and offers from Gem-A

 facebook.com/GemAofGB

 [@GemAofGB](https://twitter.com/GemAofGB)

 linkd.in/1GisBTP

 Instagram: @gemaofgb

 WeChat: Scan the QR code to add us on WeChat



Study of a Third-Century CE Sapphire Gold Ring in the Archaeological Museum of Thessaloniki, Greece

Maria Nikopoulou, Stefanos Karampelas, Evangelia Tsangaraki, Lambrini Papadopoulou, Christos S. Katsifas, Ioannis Nazlis, Annareta Touloumtzidou, Vasilios Melfos and Nikolaos Kantiranis

ABSTRACT: This article characterises, for the first time, a drop-shaped blue cabochon set in an important gold ring in the collections of the Archaeological Museum of Thessaloniki, Greece. The ring dates to the Roman period (before 260 CE) and was found inside an intact (unplundered) marble sarcophagus unearthed in Thessaloniki in 1929. Due to the artefact's archaeological importance, the stone was investigated on the museum's premises using non-destructive mobile techniques, which revealed that it is a sapphire (with no indications of heat treatment) with a calculated weight of about 12.4 ct. Its microscopic, spectroscopic and chemical characteristics are similar to those of blue sapphires from Sri Lanka. This is one of very few studies of a sapphire used in Roman-period jewellery.

The Journal of Gemmology, 38(8), 2023, pp. 804–809, <https://doi.org/10.15506/JoG.2023.38.8.804>

© 2023 Gem-A (The Gemmological Association of Great Britain)

In 1929, an impressive gold ring with a sapphire (Figure 1) was discovered along with two gold coins dated 254–258 CE inside an intact (unplundered) marble sarcophagus that was found accidentally during road construction in the city of Thessaloniki, Greece (Koukouvou & Ziogana 2022). The sarcophagus (Figure 2), which is currently exhibited in the atrium of the Archaeological Museum of Thessaloniki (AMTh), dates to about 250–260 CE and was originally situated in an ancient cemetery located slightly outside Thessaloniki's western fortification wall, near the junction of today's Langada and Agiou Demetriou streets (<https://www.amth.gr/en/exhibitions/exhibit-of-the-month/2110>). This luxurious funerary monument is 2.4 m long and is decorated with mythological scenes carved in relief. One side depicts a Dionysiac grape harvest scene, while the other shows a battle between centaurs and griffins. The lid features a sculpture of a married couple (the heads of both are missing) lying on a banquet couch.

According to the Greek inscription on the front of the sarcophagus, it was created for the burial of Poplia Antia Damokratia, from Pautalia (an important city of ancient Thrace, situated in what is today Kyustendil, Bulgaria), and her husband Vitalius Restitutus, a provincial governor (Castritius 1970; Despinis *et al.* 2003). During this period, Greece and ancient Thrace were gradually conquered by the Roman Empire (Theodossiev 2015).

The sapphire set in the ring testifies to its owner's high social status. In ancient times, obtaining and transporting sapphires to the Roman Empire was rare. Due to their scarcity and hardness, sapphire gems were less accessible for use in jewellery than other materials available locally or through other trade routes (Thoresen 2017a, b). Gems from the same time period have been documented in various publications (e.g. Vollenweider 1974; Giuliani *et al.* 2000; Calligaro 2005; Strack & Kostov 2010; Entwistle & Adams 2011; Thoresen 2017a, b; Butini *et al.* 2018; Krzemnicki *et al.* 2019). Furthermore,



Figure 1: A Roman-period gold ring set with a blue sapphire is the focus of this article. (a) The side view of the ring (maximum diameter of 2.24 cm) reveals the acanthus-like setting, which has openings that allow light to enter the stone from the sides. (b) A top view shows the drop-shaped sapphire (15 × 10 × 7.5 mm) in its bezel setting. Photos by M. Nikopoulou, © Archaeological Museum of Thessaloniki (inv. no. MΘ 16274), Hellenic Ministry of Culture and Sports.

a gold ring similar to the one described here, containing an unidentified dark green gem and dated to 200–250 CE, is preserved in the National Archaeological Museum of Sofia (Ruseva-Slokoska 1991). Also known are two gold rings set with sapphires presumably found in the Near East that are possibly from the same period as the ring documented here (J. Ogden, pers. comm. 2023).

This article presents the results of research conducted on the ring-set sapphire in Figure 1. This is the first description of this stone, and is intended to help fill gaps in the literature concerning the study of Roman-period gem materials.

METHODS

Due to the ring's archaeological importance and value, it was investigated on-site in AMTh's archaeometry laboratory, using strictly non-destructive techniques available in the museum and mobile instruments belonging to the

Laboratoire Français de Gemmologie (Paris, France).

For macroscopic and microscopic observations, we used a Zeiss Stemmi 500 microscope equipped with fibre-optic illumination and an incorporated camera to acquire photomicrographs. Luminescence was examined with a Vilber Lourmat VL-6.LC 6-watt UV lamp with long-wave (365 nm) and short-wave (254 nm) UV radiation.

Raman and photoluminescence (PL) spectra were acquired using a Magilabs GemmoRaman-532SG Raman spectrometer with 532 nm laser excitation and a spectral resolution of 11 cm^{-1} . Raman spectra were collected in the 200–2000 cm^{-1} range with an exposure time of 1 s and four accumulations. PL spectra were recorded in the 540–760 nm range with an exposure time of 0.3–0.4 s and 30 accumulations. The Raman spectrometer was calibrated using the 1331.8 cm^{-1} band of diamond. Visible-near infrared (Vis-NIR) spectroscopy was performed in the 400–1000 nm range using a Magilabs GemmoSphere instrument equipped with



Figure 2: The marble sarcophagus from Thessaloniki in which the sapphire ring was found measures 2.4 m long. This view shows an elaborate carving on its side, as well as a sculpture (presumably of the occupants) on the lid. Photo (ATME 1062 A) by K. V. von Eickstedt, © Archaeological Museum of Thessaloniki (inv. no. MΘ 1247), Hellenic Ministry of Culture and Sports.

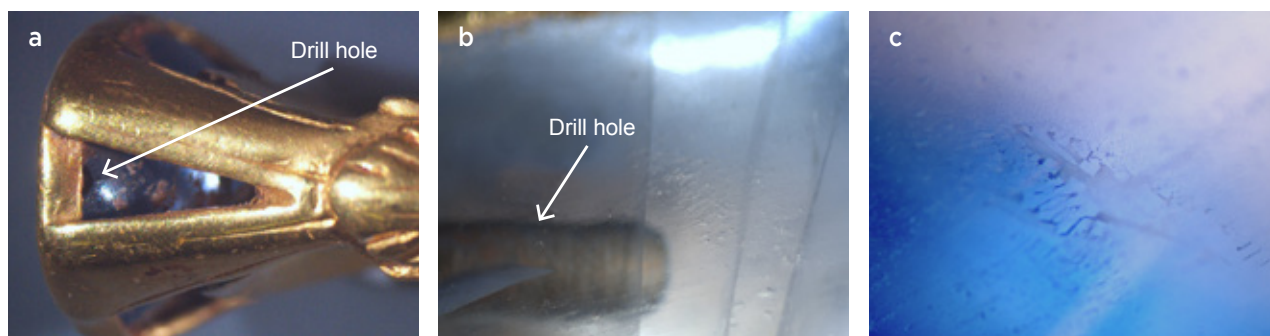


Figure 3: (a) A side view of the ring's setting shows the location of the drill hole in the sapphire, as well as details of the gold work. (b) Microscopic examination reveals twin planes in the stone, as well as details of the drill hole. (c) Colour zoning and city-map-like 'fingerprints' are also present in the sapphire. Photomicrographs by M. Nikopoulou, © Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture and Sports; image widths (a) 16 mm, (b) 8 mm and (c) 3 mm.

an integrating sphere (acquisition time of 0.05–0.10 s and 50 accumulations).

The sapphire was chemically analysed by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using AMTh's Artax 400 micro-XRF instrument manufactured by Bruker AXS. The X-ray beam was restricted by a collimator with a lateral resolution of 200–1500 μm . We used an accelerating voltage of 50 kV and a beam current of 700 μA for 100 s. Chemical elements of low atomic number were analysed with the use of an He gas purging system (Katsifas *et al.* 2019).

RESULTS AND DISCUSSION

The Roman gold ring measures 24 mm in height and weighs 10.27 g. The sapphire's setting resembles two opposing acanthus leaves, the tips of which support the bezel encasing the gem (again, see Figure 1). The four lateral openings of the ring's setting allow light to enter from the side, thus enhancing the sapphire's appearance.

The sapphire is transparent and exhibits an attractive blue colour. Its overall appearance suggests that of a rolled pebble (i.e. exhibiting a shape that is typical of alluvial transport). It is polished as a drop-shaped bead that measures approximately $15 \times 10 \times 7.5$ mm and its weight is estimated at about 12.4 ct (cf. Carmona 1998). When observed with different light sources, the sapphire shows a colour shift from blue in daylight (5800 K) to violetish blue in incandescent light (2800 K). It is inert to long- and short-wave UV radiation. The stone is partially drilled along its long axis, with a drill hole measuring about 5 mm long and 1 mm in diameter (Figure 3a, b). This suggests that the gem was previously used in a different type of setting, such as a pendant. However, it has been proposed that sapphires were drilled at the source before being traded West (J. Ogden, pers. comm. 2023), with another such example

housed in the British Museum in London (https://www.britishmuseum.org/collection/object/H_1862-0729-4).

Viewed with the microscope, the stone showed internal characteristics consistent with natural sapphire, such as colour zoning and twinning planes (Figure 3b, c), as well as geometrically structured partially healed fissures (e.g. city-map-like 'fingerprints'; Figure 3c). No indication of treatment was observed such as altered fissures etc.

The sapphire's Raman spectrum displayed main bands at approximately 380, 416 and 644 cm^{-1} due to Al-O vibrations in corundum, and the PL spectrum (Figure 4) contained two peaks at around 693 and 694 nm attributed to Cr-related *R*-lines due to Cr^{3+} in corundum (Porto & Krishnan 1967; Barone *et al.* 2014; Nasdala *et al.* 2023).

The Vis-NIR spectrum (Figure 5) exhibited a weak absorption band at 450 nm linked to Fe^{3+} , and a broad band at 580 nm attributed to Fe^{2+} – Ti^{4+} intervalence charge transfer (Townsend 1968; Ferguson & Fielding 1971; Eigenmann *et al.* 1972). A 'negative' (emission) peak at approximately 694 nm corresponds to Cr^{3+} luminescence in corundum (spin-forbidden relaxation;

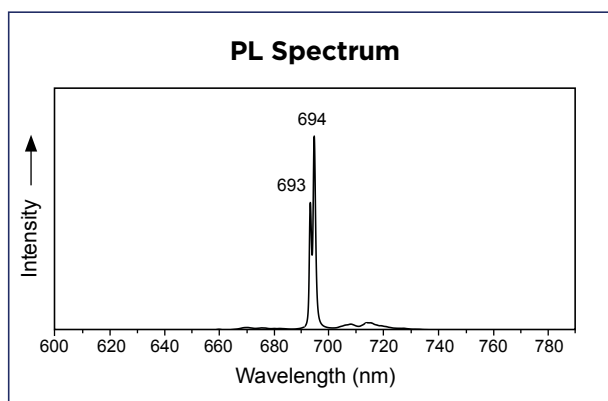


Figure 4: The PL spectrum of the sapphire shows typical peaks related to the presence of Cr^{3+} in corundum at 693 and 694 nm.

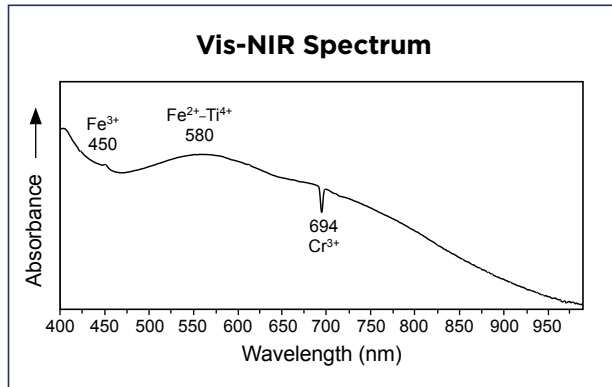


Figure 5: The Vis-NIR spectrum of the sapphire shows an absorption band at 450 nm linked to Fe^{3+} , as well as a broad band at 580 nm related to Fe^{2+} - Ti^{4+} intervalence charge transfer. The 'negative' (emission) band at 694 nm is linked to Cr^{3+} luminescence in corundum.

see Nasdala *et al.* 2023 and references therein). The Vis-NIR spectrum is typical of metamorphic sapphires, lacking features in the NIR range (i.e. above 800 nm) that are seen in basalt-related sapphires (Krzemnicki *et al.* 2019; Palke *et al.* 2019).

Micro-XRF chemical analysis of different spots on the sapphire revealed Fe (475–639 ppmw), Ti (65–103 ppmw), Ga (37–126 ppmw), V (up to 34 ppmw) and Cr (up to 19 ppmw). Figure 6 compares the results of this study with data from the literature, and shows that the composition of this stone is consistent with that of metamorphic sapphires (Abduriyim & Kitawaki 2006; Peucat *et al.* 2007; Palke *et al.* 2019).

Possible Origin of the Sapphire

As stated above, blue sapphire is relatively rare in jewellery of the Roman period. Most sapphires found in Roman jewellery are of dark colour and of basalt-related origin (presumably from the Massif Central of France), or of lighter colour and Sri Lankan origin (Thoresen 2017a, b; Butini *et al.* 2018; Krzemnicki *et al.* 2019). The sapphire examined in this study has compositional and microscopic characteristics (e.g. city-map-like fingerprints) similar to those observed in stones from Sri Lanka, as well as spectroscopic and chemical properties typical of metamorphic sapphires (Gübelin & Koivula 2005; Palke *et al.* 2019). Moreover, the shape of the sapphire is consistent with those from the secondary deposits of Sri Lankan gem gravels. Similarly shaped sapphires, partially or fully drilled, from this or a slightly later time period have been reported previously (Bedini 1995; Strack & Kostov 2010; Nasdala *et al.* 2023).

During the Hellenistic period and the time of the Roman Empire, Sri Lanka—referred to as

Taprobane—was the main source of blue sapphire (Hughes *et al.* 2017; Thoresen 2017a, b; Butini *et al.* 2018; Krzemnicki *et al.* 2019). References to Taprobane have appeared in the ancient literature since the fourth century BCE. Chronologically, ancient references to Taprobane reflect an increase in the amount of trade with the West, facilitated by the conquests of Alexander the Great and Diadochi and, later, by conquests of the Roman Empire in the East. In Roman times, trading activities focused along the Maritime Silk Route from the Far East and India to Europe.

Greek geographer, philosopher and historian Strabo reported that India and Persia acted as intermediaries between Sri Lanka and Greco-Roman trade, as gems and other goods were brought from Sri Lanka to the Indian market, and therefore Greek merchants did not go directly to Sri Lanka to buy them (Butini *et al.* 2018; Munasinghe 2021). The trade route of sapphires and other gems from Sri Lanka to the Greco-Roman world probably started along the coast of the Indian Ocean, then went up to the Persian Gulf, and finally proceeded overland to the eastern Mediterranean region (Butini *et al.* 2018). The first sapphires probably appeared in Europe during the Hellenistic period after the campaigns of Alexander the Great (Gray 1983; Entwistle & Adams 2011). Although extremely scarce, the presence of polished sapphires (engraved or otherwise worked) from the fourth to third

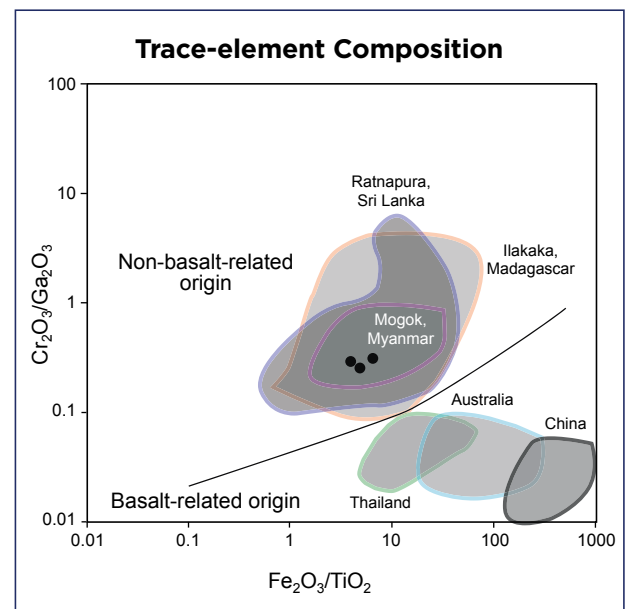


Figure 6: This trace-element plot separating magmatic from metamorphic sapphires was adapted from Abduriyim and Kitawaki (2006) and Krzemnicki *et al.* (2019). The black data points are from the analysed Roman sapphire; they all fall well within the field for sapphires from a non-basalt-related (metamorphic) origin.

century BCE (Boardman 1970; Vollenweider 1974; Henig *et al.* 1994; Krzemnicki *et al.* 2019; Ogden & Galopim de Carvalho 2020) attest to advanced manufacturing techniques for this kind of hard stone. This study further confirms the presence of trade relations that brought blue sapphires from the alluvial deposits of Sri Lanka to the Greco-Roman world.

CONCLUSIONS

This article describes the characteristics of a sapphire set in an ancient Roman gold ring—an artefact of great archaeological importance—found in Thessaloniki and dated to before 260 CE (Koukouvou & Ziogana 2022). It is currently on public display at the Archaeological

Museum of Thessaloniki. Non-destructive microscopic, spectroscopic and chemical analyses indicate that this gem is a rare example of a blue sapphire in Roman jewellery, and that it probably came from Sri Lanka.

Sapphires set in gold jewellery of the Roman period have been found only in elite burials (Bedini 1995; Butini *et al.* 2018). Thus, this rare gold ring with an approximately 12.4 ct sapphire testifies to the high social status of its owner, which is also supported by the inscription on the sarcophagus which contained it. The interdisciplinary approach employed here to study this artefact (gemmological analyses combined with archaeological documentation) highlights the importance of the synergy of different disciplines for a clearer understanding of the early trade in and use of gems in antiquity.

REFERENCES

- Abduriyim, A. & Kitawaki, H. 2006. Determination of the origin of blue sapphire using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). *Journal of Gemmology*, **30**(1), 23–36, <https://doi.org/10.15506/JoG.2006.30.1.23>.
- Barone, G., Bersani, D., Crupi, V., Longo, F., Longobardo, U., Lottici, P.P., Aliatis, I., Majolino, D. *et al.* 2014. A portable versus micro-Raman equipment comparison for gemmological purposes: The case of sapphires and their imitations. *Journal of Raman Spectroscopy*, **45** (11–12), 1309–1317, <https://doi.org/10.1002/jrs.4555>.
- Bedini, A. 1995. *Mistero di una Fanciulla. Ori e Gioielli della Roma di Marco Aurelio da una Nuova Scoperta Archeologica*. Skira Editore, Milano, Italy, 120 pp.
- Boardman, J. 1970. *Greek Gems and Finger Rings: Early Bronze Age to Late Classical*. Thames and Hudson, London, 459 pp.
- Butini, E., Butini, F., Angle, M., Cerino, P., De Angelis, A., Tomei, N. & Altamura, F. 2018. Archaeometric and gemmological analyses of a Roman imperial gold-and-sapphire jewel from Colonna (Rome, Italy). *Measurement*, **128**, 160–169, <https://doi.org/10.1016/j.measurement.2018.06.011>.
- Calligaro, T. 2005. The origin of ancient gemstones unveiled by PIXE, PIGE and μ -Raman spectrometry. In: Uda, M., Demortier, G. & Nakai, I. (eds) *X-rays for Archaeology*. Springer, Dordrecht, Germany, 101–112, https://doi.org/10.1007/1-4020-3581-0_5.
- Carmona, C. 1998. *Complete Handbook for Gemstone Weight Estimation*. Geman Publishing, Los Angeles, California, USA, 434 pp.
- Castritius, H. 1970. Die Sockelinschrift Eines Attischen Sarkophags in Saloniki. In: *Archäologischer Anzeiger*, Heft 1/1970. De Gruyter, Berlin, Germany, 93–98, <https://doi.org/10.1515/9783112320167-009>.
- Despinis, G., Stefanidou-Tiveriou, T. & Voutiras, E. 2003. *Κατάλογος Γλυπών του Αρχαιολογικού Μουσείου Θεσσαλονίκης II* [Catalog of Sculptures of the Archaeological Museum of Thessaloniki, Vol. II]. Cultural Foundation of the National Bank of Greece, Athens, Greece, 640 pp. (see pp. 333–338).
- Eigenmann, K., Kurtz, K. & Günthard, H.H. 1972. The optical spectrum of $\alpha\text{-Al}_2\text{O}_3\text{:Fe}^{3+}$. *Chemical Physics Letters*, **13**(1), 54–57, [https://doi.org/10.1016/0009-2614\(72\)80041-1](https://doi.org/10.1016/0009-2614(72)80041-1).
- Entwistle, C. & Adams, N. (eds) 2011. *'Gems of Heaven': Recent Research on Engraved Gemstones in Late Antiquity, c. AD 200–600*. British Museum Research Publication no. 177, Oxbow Books, Oxford, x + 274 pp.
- Ferguson, J. & Fielding, P.E. 1971. The origins of the colours of yellow, green and blue sapphires. *Chemical Physics Letters*, **10**(3), 262–265, [https://doi.org/10.1016/0009-2614\(71\)80282-8](https://doi.org/10.1016/0009-2614(71)80282-8).
- Giuliani, G., Chaussidon, M., Schubnel, H.-J., Piat, D.H., Rollion-Bard, C., France-Lanord, C., Giard, D., de Narvaez, D. *et al.* 2000. Oxygen isotopes and emerald trade routes since antiquity. *Science*, **287**(5453), 631–633, <https://doi.org/10.1126/science.287.5453.631>.
- Gray, F.L. 1983. Engraved gems: A historical perspective. *Gems & Gemology*, **19**(4), 191–201, <https://doi.org/10.5741/gems.19.4.191>.
- Gübelin, E.J. & Koivula, J.I. 2005. *Photoatlas of Inclusions in Gemstones*, Vol. 2. Opinio Publishers, Basel, Switzerland, 829 pp.

- Henig, M., Scarisbrick, D. & Whiting, M. 1994. *Classical Gems: Ancient and Modern Intaglios and Cameos in the Fitzwilliam Museum, Cambridge*. Cambridge University Press, Cambridge, xxx + 538 pp.
- Hughes, R.W., Manorotkul, W. & Hughes, E.B. 2017. *Ruby & Sapphire: A Gemologist's Guide*. Lotus Publishing, Bangkok, Thailand, 816 pp.
- Katsifas, C.S., Touloumzidou, A. & Zachariadis, G.A. 2019. Compositional study of bronze vessels from the Derveni tombs of Central Macedonia of the fourth century BCE using energy-dispersive micro-X-ray fluorescence (ED μ XRF) spectrometry. *Archaeometry*, **61**(6), 1313–1332, <https://doi.org/10.1111/arcm.12486>.
- Koukouvou, A. & Ziogana, M. (eds) 2022. 60 Years | 60 Moments – *Archaeol·Museum of Thessaloniki*. Archaeological Museum of Thessaloniki, Greece, 284 pp. (see pp. 253–256).
- Krzemnicki, M.S., Butini, F., Butini, E. & De Carolis, E. 2019. Gemmological analysis of a Roman sapphire intaglio and its possible origin. *Journal of Gemmology*, **36**(8), 710–724, <https://doi.org/10.15506/JoG.2019.36.8.710>.
- Munasinghe, D.S.A. 2021. Sri Lanka and Greco-Roman maritime trade relations (according to literary sources & archaeological evidence). *International Journal of Archaeology*, **9**(2), 55–61, <https://doi.org/10.11648/j.ija.20210902.14>.
- Nasdala, L., Chanmuang N, C., Erlacher, A., Giester, G., Lamers, T., Griesser, M., Kirchweger, F., Gilg, H.A. et al. 2023. The Imperial crown of the Holy Roman Empire, Part I: Photoluminescence and Raman spectroscopic study of the gemstones. *Journal of Gemmology*, **38**(5), 448–473, <https://doi.org/10.15506/JoG.2023.38.5.448>.
- Ogden, J. & Galopim de Carvalho, R. 2020. Sapphire, the Early History. YouTube, <https://www.youtube.com/watch?v=rBALoo7Bzs>, accessed 29 August 2023.
- Palke, A.C., Saeseaw, S., Renfro, N.D., Sun, Z. & McClure, S.F. 2019. Geographic origin determination of blue sapphire. *Gems & Gemology*, **55**(4), 536–579, <https://doi.org/10.5741/gems.55.4.536>.
- Peucat, J.J., Ruffault, P., Fritsch, E., Bouhnik-Le Coz, M., Simonet, C. & Lasnier, B. 2007. Ga/Mg ratio as a new geochemical tool to differentiate magmatic from metamorphic blue sapphires. *Lithos*, **98**(1–4), 261–274, <https://doi.org/10.1016/j.lithos.2007.05.001>.
- Porto, S.P.S. & Krishnan, R.S. 1967. Raman effect of corundum. *Journal of Chemical Physics*, **47**(3), 1009–1012, <https://doi.org/10.1063/1.1711980>.
- Ruseva-Slokoska, L. 1991. *Roman Jewellery: A Collection of the National Archaeological Museum, Sofia*. Publishing House of the Bulgarian Academy of Sciences, Sofia, Bulgaria, 219 pp.
- Strack, E. & Kostov, R.I. 2010. Emeralds, sapphires, pearls and other gemmological materials from the Preslav gold treasure (X century) in Bulgaria. *Bulletin of Mineralogy Petrology and Geochemistry*, **48**, 103–123.
- Theodossiev, N. 2015. An introduction to studying ancient Thrace. In: Valeva J., Nankov E. & Graninger D. (eds), *A Companion to Ancient Thrace*. John Wiley & Sons, New York, New York, USA, 1–11, <https://doi.org/10.1002/9781118878248>.
- Thoresen, L. 2017a. Archaeogemmology and ancient literary sources on gems and their origins. In: Greiff, S., Hilgner, A. & Quast, D. (eds) *Gemstones in the First Millennium AD: Mines, Trade, Workshops and Symbolism*. Römisch-Germanisches Zentralmuseum, Mainz, Germany, 155–217.
- Thoresen, L. 2017b. Archaeogemmology of sapphire. In: Overlin, S. (ed), *Fourteenth Annual Sinkankas Symposium—Sapphire*, Pala International, Fallbrook, California, USA, 74–91.
- Townsend, M.G. 1968. Visible charge transfer band in blue sapphire. *Solid State Communications*, **6**(2), 81–83, [https://doi.org/10.1016/0038-1098\(68\)90005-7](https://doi.org/10.1016/0038-1098(68)90005-7).
- Vollenweider, M.-L. 1974. Le plus beau saphir antique. *Revue de Gemmologie A.F.G.*, No. 39, 25.

The Authors

Maria Nikopoulou^{1*}, Dr Stefanos Karamelas^{2*}, Dr Evangelia Tsangaraki³, Dr Lambrini Papadopoulou¹, Dr Christos S. Katsifas⁴, Ioannis Nazlis⁴, Dr Annareta Touloumzidou⁵, Dr Vasilios Melfos¹ and Dr Nikolaos Kantiranis¹

¹ Aristotle University of Thessaloniki, School of Geology, Department of Mineralogy-Petrology-Economic Geology, 54124 Thessaloniki, Greece

² Laboratoire Français de Gemmologie, 30 rue de la Victoire, 75009 Paris, France

³ Archaeological Museum of Thessaloniki, Department of Ceramics, Metalwork and Minor Arts Collections, 54621 Thessaloniki, Greece

⁴ Archaeological Museum of Thessaloniki, Laboratory of Chemical – Physical Studies and Archaeometry, 54621 Thessaloniki, Greece

⁵ Archaeologist, independent researcher

* E-mails: marthonik@geo.auth.gr; s.karamelas@lfg.paris

Acknowledgements

Dr Jack Ogden (London) is thanked for providing helpful insights and information on two Roman rings set with sapphires that he has examined.

Conferences

20TH RENDEZ-VOUS GEMMOLOGIQUES DE PARIS



Figure 1: Speakers at the 20th Rendez-Vous Gemmologiques de Paris conference include (from left to right) Jean-Philippe Giordano, Dr Laurent Cartier, Hervé Obligi, Mathieu Moulin, Eddy Vleeschdrager, Érik Gonthier, Philippe Bloch and Christophe Péray. Photo courtesy of AFG.

The 20th conference of the Association Française de Gemmologie (AFG; French Gemmological Association) took place in Paris, France, on 13 October 2023, with the theme *Ethique* (Ethics). It was attended by about 150 people. AFG president **Dr Érik Gonthier** chaired the conference and was assisted by gemmologist **Anne Valtat**, who moderated events. Eight speakers gave presentations (Figure 1).

Jean-Philippe Giordano (Corsica, France) is one of five licensed coral divers on the Mediterranean island of Corsica. He shared with passion his decades-long quest of diving 60–120 m for *Corallium rubrum* specimens, as well as processing the raw material and creating coral jewellery. He also discussed the ongoing need for conservation measures and the importance of artisanal diving, which allows for the selection and harvesting of specific coral branches.

Mathieu Moulin (Compagnie des Minéraux d'Auvergne, France) described an ambitious project to establish an amethyst mine (Mine de Poux) in the Puy-de-Dôme region of central France, which began in 2018. The 90 km² area near the village of Issoire was

previously a source of amethyst during Roman times. It was last mined at the beginning of the twentieth century. The project seeks to revive the Poux mine and local cutting facilities to ensure that the amethyst gems are 100% 'made in France'. He outlined many of the administrative and financial hurdles they have been facing in bringing this project to market, along with a zero-waste vision for the mine.

Christophe Péray (Chamonix, France) is one of the few high-altitude *cristalliers* (crystal hunters) in the Chamonix region. Unlike in Switzerland, the Mont Blanc region of France permits no explosives or mechanised tools in the search for rock crystal, smoky quartz, fluorite and other minerals. Much of the work is done in remote and very difficult terrain that is only accessible during the summer months. He shared stories from his six decades of crystal hunting, highlighting the joys and perils of his passion. Christophe also presented his recently published book, *Carnet de Cristallier*.

Eddy Vleeschdrager (Antwerp, Belgium) spoke about the history of synthetic diamonds and how their

identification has developed over the past decades. He also discussed synthetic diamond pricing, as prices are rapidly dropping. He highlighted the upcoming G7 sanctions on Russian diamonds, notably that much of the trade will shift to Dubai (as UAE has no plans for a ban on Russian diamonds), which will negatively impact the strength of Antwerp as a diamond-trading hub.

This author (Swiss Gemmological Institute SSEF, Basel, Switzerland) provided a historical review of ethics in the gem and jewellery industry. An increasing focus on ethical certification and traceability has led the industry to a more corporate approach to ethics in recent years. However, traceability solutions are not a silver bullet, and must be complemented by appropriate systems that ensure best practices. Finally, after showing the film *The Divers of Sewa*, he emphasised the need for authentic storytelling so that ethics and traceability can provide true value to all participants across the supply chain, including consumers.

Philippe Bloch (Raymond Bloch SA, Paris) described the evolution of a diamond-trading family over more than three generations. He shared many anecdotes on how the trade has evolved over the past decades, and how globalisation, ethical requirements and digitalisation have changed the job of a diamond

trader. In the 1950s and 1960s, traders in Paris would hand-carry large diamonds and had never heard of bullet-proof doors, but security risks have also greatly changed the industry.

Dr Érik Gonthier (Muséum National d'Histoire Naturelle, Paris) documented the ecological and paleontological risks of mammoth ivory extraction (in Russia) and its trade. He shared insight into the historic use of mammoth ivory, which has been widely marketed as an alternative to elephant ivory in China. The extraction of fossilised mammoth ivory from the Siberian tundra is having an ecological impact, begging the question of whether more stringent trade regulations will appear.

Hervé Obligi (Obligi, Montreuil, France) argued that more and more ornamental rocks are today being protected for environmental reasons, drastically curtailing the supply for gem carvers. Similarly, as this lapidary speciality begins to be lost, the know-how may also disappear due to a lack of younger artisans. Ethical questions arise.

*Dr Laurent E. Cartier FGA (laurent.cartier@ssef.ch)
Swiss Gemmological Institute SSEF
Basel, Switzerland*

GEM-A CONFERENCE

On 5 November 2023, approximately 250 attendees gathered for the annual Gem-A Conference at etc.venues County Hall in London. Gem-A CEO **Alan Hart** opened the sold-out event and introduced each of the seven distinguished speakers (e.g. Figure 2).

Dr Mike de Wit (University of Stellenbosch, South Africa) reviewed economically important alluvial

diamond deposits, with a focus on South Africa. Of the 6.3 billion carats of diamonds mined worldwide so far, approximately 60% have come from Africa and 30% were sourced from South Africa in particular. Alluvial diamond deposits in South Africa are characterised by low grade but high values (USD650–2,500/ct), and are found along the Middle and Lower Orange River,



Figure 2: This year's Gem-A Conference speakers included (from left to right): Richard Drucker, Wenhao Yu, Dr Mike de Wit, Dr Sally Magaña, Dr Emmanuel Fritsch and Dr Clemens Schwarzing. Gem-A CEO Alan Hart is on the far right, and speaker Prof. Andy Shen is not shown here since he joined the conference remotely. Photo by Tempest Photography.



Figure 3: Dr Emmanuel Fritsch describes the factors that allow minerals to form in gem quality. Photo by Tempest Photography.

as well as in the Lichtenburg-Vendersdorp and Schweizer-Reneke regions. The diamonds eroded from kimberlite pipes in South Africa (Kimberley and Cullinan areas) and in Lesotho, and were transported westward, eventually making their way to the marine deposits along the west coast of southern Africa.

Dr Emmanuel Fritsch (Institut des Matériaux de Nantes Jean Rouxel and Centre National de la Recherche Scientifique, University of Nantes, France; Figure 3) examined the main factors responsible for the occurrence of minerals in gem quality. These include: the presence of a few seed crystals, a ‘slow’ growth mechanism (particularly spiral dislocation growth), free volume (such as an open cavity), stable conditions over a relatively short time period of formation, and the lack of detrimental post-growth events such as tectonic shock or chemical dissolution.

Prof. Andy Shen (Gemological Institute, China University of Geosciences, Wuhan, China) delivered his presentation remotely via live streaming, in which he discussed the application of machine-learning algorithms in gem provenance research. After explaining various ways that machine learning can assist artificial intelligence by training models with data, he demonstrated how the technique can be applied to the geographic origin determination of peridot. Ten chemical elements were used to differentiate peridot from three basaltic localities (Jilin in China, Hebei in China and North Korea) with 90–95% accuracy for a training set and 83–89% accuracy for a testing set.

Dr Sally Magaña (Gemological Institute of America, Carlsbad, California, USA) reviewed the growth

technology, characteristics and identification of synthetic diamonds. The main producing countries are currently China (ca. 3 million carats [Mct] annually, mostly HPHT grown), India (ca. 1.5 Mct, principally CVD grown), the USA (ca. 1 Mct, principally CVD), Singapore (ca. 1 Mct, both CVD and HPHT), and Europe and the Middle East (ca. 0.5 Mct each, principally CVD). New techniques for identifying particularly challenging synthetic diamonds are being developed, such as photoluminescence mapping of SiV^- defects and three-dimensional hyperspectral imaging of multiple defects (NV^0 , SiV^- , N_3 and 468 nm).

Wenhao Yu (Sotheby’s, Hong Kong) examined the post-pandemic jewellery auction market. He differentiated between acquiring jewellery for enjoyment vs investment, and then explained how the economic challenges and uncertainties caused by the COVID-19 pandemic caused a gradual decline in jewellery auctions since 2000. Auction houses have adapted by transitioning to online platforms and virtual events. In addition, conservative pricing strategies can improve lot sales performance by encouraging more bidding activity.

Gem-A president **Richard Drucker** (Gemworld International Inc., Glenview, Illinois, USA) provided an update on gem-market trends. He noted a continued rise in mining and transportation costs, and a lower demand for mid- to low-end coloured stones, requiring caution at the wholesale level. Prices for diamonds have declined significantly, mainly due to global economic factors; the rise in synthetic diamonds (which now are estimated to constitute 50% by volume of the engagement ring market in the USA) is only partially to blame.

Gem traceability and sustainability continue to gain importance in the industry, although buyers should be aware of false claims and ‘greenwashing’.

Dr Clemens Schwarzing (Johannes Kepler University Linz, Austria) took the audience on a colourful tour of gem zoisite, including its composition, cause of colour and faceting. Nearly all gem-quality zoisite comes from the Merelani area of Tanzania, which produces approximately 80% brownish colour, 10% yellow, 5% blue (i.e. without heat treatment), 2% ‘salmon’ orange, <1% pink, <1% saturated blue and <<1% ‘emerald’ green. When cutting zoisite, which is trichroic, it is necessary to properly orient the stone to help separate the pleochroic colours rather than mixing them into an unattractive brownish appearance.

On 6–7 November, several workshops were held at Gem-A’s headquarters: coloured stone grading and pricing with **Richard Drucker**, screening coloured gemstones with **Pat Daly** (Gem-A, London), photomicrography and the study of inclusions with **Sammantha**

Maclachlan (Glasgow, Scotland), the science of gem cutting with **Justin Prim** (Magus Gems, Bangkok, Thailand), assessing and testing mounted gemstones with **Shirley Mitchell** (Windsor, Berkshire), spotting the difference between stones having similar appearances with **Charlie Bexfield** (Gem-A, London), investigating jade and its imitations with **Pat Daly** (Gem-A, London) and black stone identification with **Sarah Caldwell Steele** (Ebor Jetworks Ltd, Whitby). In addition, field trips on 6 November took attendees to a private viewing of the British Crown Jewels at the Tower of London, a behind-the-scenes tour at the gem and mineral collection at the Natural History Museum, a special look at the jewellery gallery at the Victoria and Albert Museum, and a walking tour through London’s history of gem cutting (with **Justin Prim**). That evening marked Gem-A’s graduation ceremony and presentation of awards at Goldsmiths’ Hall in London.

Brendan M. Laurs FGA

37TH INTERNATIONAL GEMMOLOGICAL CONFERENCE

The 37th biennial IGC took place 23–27 October 2023 at the National Museum of Nature and Science in Tokyo, Japan. The conference was arranged by IGC Japan organising committee members **Dr Hiroshi Kitawaki** (Central Gem Laboratory, Tokyo), **Dr Ahmadjan Abduriyim** (Tokyo Gem Science LLC and GSTV Gemmological Laboratory, Tokyo), **Kentaro Emori** (Central Gem Laboratory, Tokyo), **Masaki Furuya** (Japan Germany Gemmological

Laboratory, Kofu, Japan) and **Yoko Okubo** (Kanagawa-Ken, Japan), in collaboration with the IGC Executive Committee. In attendance were 33 delegates, 17 observers and numerous guests, representing 24 countries (e.g. Figure 4). A proceedings volume containing extended abstracts can be downloaded at <https://www.igc-gemmology.org/igc-2023>. The conference was accompanied by several field trips. A pre-conference tour to the

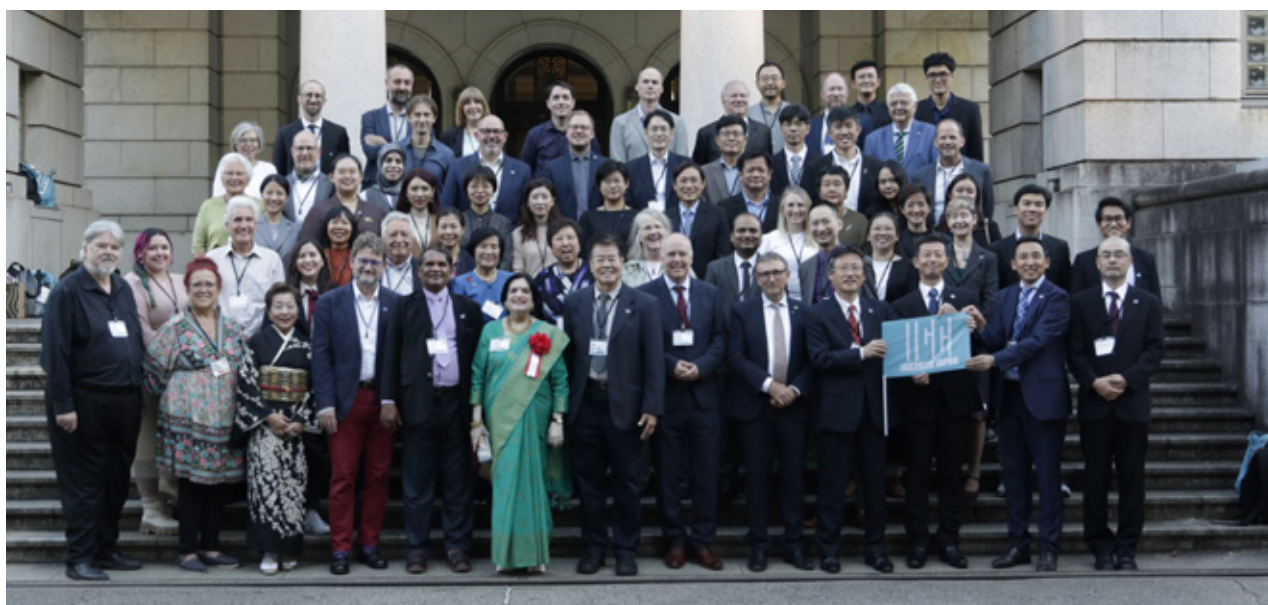


Figure 4: Delegates, observers and guests assemble for the 37th International Gemmological Conference. Photo courtesy of GSTV.

Itoigawa jadeite area took place on 20–22 October. Concurrent with the IGC, participants visited a jade museum in Tokyo (Hisui Genseki-Kan) and also were given the opportunity to tour the National Museum of Nature and Science where the conference was held. After the IGC, participants had the option of touring the Mount Fuji area and visiting the city of Kofu, and on 29–31 October there was a post-conference excursion to the Mikimoto Island akoya cultured-pearl farm in Mie Prefecture.

The first day of the conference featured an ‘open colloquium’ that was attended by many local guests who could not otherwise participate in the IGC (a members-only event). **Dr Ahmadjan Abduriyim** opened the colloquium (Figure 5) and introduced the six invited presenters. **Dr Jayshree Panjkar** (Pangem Testing Laboratory and PANGEMTECH – Panjkar Gem Research & Tech Institute, Pune, India) first chronicled the history of the IGC, starting with its inaugural meeting in 1952 in Lugano, Switzerland. After 71 years, the IGC is the longest-running gemmological conference to remain in its original format. **Prof. Hisao Kanda** (National Institute for Materials Science, Tsukuba, Japan) gave a brief history of synthetic diamond production in Japan. Since the first successful growth of diamond there in 1962, the technology has evolved rapidly. In 1982, synthetic diamonds were grown using a 30,000 tonne press, and the 1990s saw the production of gem-quality synthetics up to 10–12 mm in diameter by Sumitomo Electric Industries. **Dr J. C. (Hanco) Zwaan** (Netherlands Gem

Laboratory, Naturalis Biodiversity Center, Leiden, The Netherlands) then reviewed the geology of diamond deposits and the identification of synthetic diamonds.

The open colloquium continued with a presentation by **Yuichi Nakamura** (Mie Prefecture Pearl Promotion Council, Ise City, Japan, and PJ Nakamura International, Tokyo), who described initiatives for sustainable pearl cultivation in Japan. By-products of pearl culturing include mollusc shell material, which is used for buttons for clothing, and adductor muscle, which is a delicacy consumed during the winter harvest months. Recent initiatives are developing other pearl culturing by-products for use in fruit and vegetable gardens, including fouling materials (barnacles etc.) cleaned from the molluscs that are turned into a soil additive, and chopped oyster meat that is composted with rice husks to make a new product called ‘Pearl Compost’. **Dr Pornsawat Wathanakul** (Kasetsart University, Bangkok, Thailand) then explained the importance of research activities for the gem and jewellery industry. Such research occurs at gem laboratories, universities and research-and-development institutions, and helps address challenging issues such as geographic origin determination, treatment detection, quality standard definitions (e.g. colour terms and boundaries) and colour authenticity. For the final presentation of the open colloquium, **Dr Michael Krzemnicki** (Swiss Gemmological Institute SSEF, Basel, Switzerland) examined where to set the boundary between colour varieties of gems, including ruby/sapphire, padparadscha/fancy sapphire,

Figure 5: Dr Ahmadjan Abduriyim provides an introduction to the open colloquium at the 37th International Gemmological Conference. Photo by B. M. Lours.



cobalt/blue spinel, emerald/green beryl, alexandrite/chrysoberyl and Paraíba-type/non-Cu-bearing tourmaline. Depending on the specific variety being evaluated, the following factors may be helpful to take into consideration: colour zoning, hue and saturation levels, light-source characteristics, trace-element composition and absorption spectral features.

Diamonds were the subject of the first session of the IGC conference. **Dr Robert Coenraads** (Gemmological Association of Australia, Rozelle, New South Wales, Australia) performed detailed mapping of former river channels at the Copeton diamond field in New South Wales, Australia, in order to further develop alluvial exploration targets there. So-called *deep leads* hosting the diamonds consist of paleochannels that were buried by lava flows 18–20 million years ago. Subsequently, a process called *relief inversion* occurred when new drainages eroded along the sides of the more resistant lava flows, which subsequently left ridges and hills along the former paleochannels. The locations of today's drainages are therefore completely different than the diamond-bearing paleochannels. **Dr Thomas Hainschwang** (GGTL Liechtenstein, Balzers, Liechtenstein) described recent research on the cause of colour in violet diamonds from Argyle, Australia. They are almost always type IaB, with elevated contents of N and H, and display bands of unknown origin at 7491 and 7823 cm⁻¹ in their infrared spectra. In addition, their PL spectra show a series of features near 990 and 1330 nm that are probably related to Ni. The violet colour appears to result from a lack of N3 centres combined with a large amount of aggregated B and elevated Ni and H contents. **Dr Hiroshi Kitawaki** and co-authors studied 'hybrid diamonds' composed of natural diamonds with CVD synthetic overgrowths. They characterised four samples produced for research purposes in India that had a CVD overgrowth thickness of approximately 2 mm; they consisted of a 0.12 g rough sample and three faceted specimens weighing 0.33–0.49 ct. They showed brush-like birefringence patterns in the CVD portion, as well as pinpoints and a layer of phosphorescence along the boundary between the two layers. **Roman Serov** (Octonus Software, Moscow, Russia) and **Sergey Sivovolenko** (Octonus Finland Oy, Tampere, Finland) studied the effect of growth striae on the dispersion or 'fire' shown by faceted CVD synthetic diamonds. Recent improvements in CVD growth technology combined with HPHT processing of as-grown material have decreased the visibility of growth striae, leading to better optical performance (i.e. dispersion), particularly in cuts that produce larger flashes. **Dr J. C. (Hanco) Zwaan** and his

co-author documented the history and properties of the Banjarmasin diamond from Borneo (see their article in *The Journal*, Vol. 38, No. 7, 2023, pp. 662–677).

Among the presentations on coloured stones, there was extensive coverage of gem corundum. **Shane McClure** and co-authors (Gemological Institute of America [GIA], Carlsbad, California, USA) documented their observations of unstable colouration in padparadscha sapphires. They found that visible-light wavelengths cause the stones to lose their orange colour component. The sapphires show varying amounts of sensitivity to light for reasons that remain unknown, and McClure indicated that their colour should be described as it is seen after stability testing. **Dr Pornsawat Wathanakul** and co-authors examined the causes of yellow, green and brown colouration in basaltic sapphires from Bangkok in the Chanthaburi region of Thailand. This area is particularly well known for producing orangey yellow (so-called Mekong whisky colour) to brown sapphires, which are coloured by a combination of Fe³⁺ and Fe³⁺–Fe³⁺ pairs. **Dr Walter Balmer** (Swiss Gemmological Institute SSEF, Basel, and Collection Balmer LLC, Bern, Switzerland) obtained FTIR spectra of rubies from various marble-hosted deposits using an expanded range (1500–5000 cm⁻¹) in order to perform mineral inclusion identification. He compared the positions of low-intensity spectral bands in the rubies with FTIR spectra obtained from reference samples of pargasite, dravite-uvite tourmaline and gibbsite to confirm the presence of these minerals as inclusions in the ruby samples. **Kentaro Emori** and co-authors performed detailed studies of nano-inclusions in blue basaltic sapphires from Diego Suarez, northern Madagascar, which contain traces of naturally occurring Be. The nano-inclusions were found to have a twinned 'srilankite'-like structure, and they contained Ti, Nb, Sn, Ta and possibly Be. The epitaxial relationship of the nano-inclusions with the corundum matrix suggests that they formed by exsolution from their host corundum. **Stephen Kennedy** (The Gem & Pearl Laboratory Ltd, London) and co-authors studied natural and synthetic rubies and pink sapphires recovered from the steamship SS Persia that was sunk in 1915 by a German U-boat south-east of the Greek island of Crete. The 166 natural rubies and pink sapphires were mostly melee-sized, although some were in the 0.5–1.0 ct range; they showed characteristics consistent with stones from Thailand, Myanmar and Sri Lanka. The 162 synthetic rubies were likewise mainly composed of melee (although some ranged up to the 2–3 ct range), and they had internal features consistent with the Verneuil growth technique.

Corundum treatments were the subject of six

presentations. **Dr Michael Krzemnicki** and co-authors studied the use of phase transformations of inclusions as important markers for low-temperature heat-treatment detection in corundum and other gems. The transformations are: 2 diaspora (AlOOH) → 1 corundum (Al_2O_3) + water (H_2O) that takes place at about 500°C, and 2 goethite (FeOOH) → 1 hematite (Fe_2O_3) + water (H_2O) that occurs at about 350°C; the specific temperatures of the transitions depend on the heating duration. The inclusions can be reliably identified by Raman spectroscopy, and the presence of diaspora and/or goethite provides proof that a sample has not undergone low-temperature heat treatment (which typically starts at 800°C). **Dr Hao Wang** (Swiss Gemmological Institute SSEF, Basel) and co-authors examined the effects of gamma-ray irradiation on ruby and pink sapphire and the potential detection of this treatment by gem labs. Their experiments using gamma-ray irradiation showed no obvious reduction in the blue colouration of (synthetic) blue sapphire, while pink-to-purple sapphires developed orange colouration. However, it was not possible to conclusively identify gamma-irradiated pink-to-purple sapphires using UV-Vis spectroscopy. **Waratchanok Suwanmanee** (The Gem and Jewelry Institute of Thailand [GIT], Bangkok) and co-authors found that irradiation by either gamma rays or an electron beam may produce a slight yellowish tint in purplish red ruby, particularly in stones from East Africa. This colouration results from a slight increase in absorption in the 300–600 nm region caused by a colour centre. Colour-stability testing partially removed the yellowish hue from a Mozambique ruby, but it did not fully revert to its original purplish red colour. **Sudarath Saeseaw** and co-authors (GIA, Bangkok) performed heating and irradiation experiments on sapphires from various localities to enhance their yellow colouration. The results were dependent upon the types of iron-related chromophores present in the sapphires. The yellow colouration of sapphires dominated by Fe^{3+} (i.e. high-Fe basalt-associated stones) cannot be enhanced by either treatment, whereas acceptor-dominated sapphires will react to both treatments with the creation of the trapped hole- Fe^{3+} chromophore (i.e. in low-Fe metamorphic stones) to produce yellow colouration. **Bhuwadol Wanthanachaisaeng** (GIT, Bangkok) and co-authors studied milky ‘geuda’ sapphires from Sri Lanka, which changed from whitish or pale blue to blue after heating to 1650°C for 5 hours in a nitrogen atmosphere. The transparency of the heated samples improved due to the disappearance of minute particles, and UV-Vis spectroscopy showed the development of an absorption edge at 300–350 nm. **E. Billie Hughes** (Lotus Gemology,

Bangkok) and her co-author documented the effects of low-temperature heat treatment on Burmese rubies (see <https://doi.org/10.5741/gems.58.4.400>).

Beryl was covered in three presentations. **Dr Tom Stephan** (German Gemmological Association, Idar-Oberstein, Germany) and co-authors used gamma spectroscopy to detect the radiation treatment of morganite. They irradiated 15 samples showing variable amounts of Cs impurities with 10 MeV of electrons for six hours. The radioactive isotope ^{134}Cs provided diagnostic evidence of artificial irradiation, and it should remain detectable by gamma spectroscopy for at least 10 years for smaller samples (< 4 ct), and possibly for more than 20 years for larger specimens and/or those that contain a greater amount of Cs. **Miro Ng** (Centre for Gemmological Research, Hong Kong & Shenzhen, China) reviewed various substances used for filling fractures in emerald, and described his research towards developing new tunable-RI and inorganic fillers. Among the latter, Na_2SiO_3 -based solutions appear to show good potential but may also pose identification challenges for gem laboratories. **Nathan Renfro** (GIA, Carlsbad) documented the microfeatures in beryl-group gems. Solid inclusions most commonly consist of pegmatitic minerals such as albite, muscovite, spessartine and quartz. A detailed examination of a sample of the newest member of the beryl group, johnkoivulaite, revealed only the presence of etch features on the exterior and interior of the crystal.

Talks on jadeite covered origin determination and treatment. **Ka-Yi (Angela) Man** (Hong Kong Polytechnic University) and co-authors applied multivariate analysis to the geographic origin determination of high-quality green samples obtained from three localities: Myanmar (75% jadeite and 25% omphacite), Guatemala (54% omphacite and 46% jadeite) and Italy (100% Cr-omphacite). The origin determination was much more robust using data obtained by LA-ICP-MS than EDXRF. **Elizabeth Su** (Gemsu Rona Jewellery Co. Ltd, Shanghai, China) collaborated with a researcher (Dr Xueliang Liu) from the Gemstone Testing Center of East China University of Science and Technology in Shanghai to investigate the characteristics of high-quality green jadeite from Myanmar and Guatemala. Chemical analysis by EDXRF showed lower Na and higher Ca, Mg and Fe in the Guatemalan material due to the significant presence of an omphacite component. Raman spectra of samples from both localities showed peaks related to jadeite, but the Guatemalan material also showed bands at 401 and 345 cm^{-1} due to omphacite. **Supparat Promwongnan** (GIT, Bangkok) and co-authors described treated jadeite jade

showing unusually bright colours: purple, purplish red, bluish green and yellow. Strong bluish white fluorescence to long-wave UV radiation indicated they were polymer impregnated, and microscopic examination revealed colour concentrations along fractures and grain boundaries corresponding to dye treatment. UV-Vis absorption spectra showed a small Fe^{3+} -related peak at 437 nm and various broad absorption bands related to the specific colour of each dye.

Three presentations focused on opal. **Dr Boris Chauviré** (GeoGems, Guérande, France) and co-authors examined factors affecting hydrophane opal stability. They found that both cracking (due to shrinkage) and whitening (due to light scattering) are related to porosity, and specifically to pore size. Hydrophane opal was found to contain pores of 2.5–3 nm, consistent with light scattering. **Gagan Choudhary** (IIGJ Research & Laboratories Centre, Jaipur, India) described new yellow to grey-brown transparent opals from Lightning Ridge, Australia. The material typically lacks play-of-colour and shows light-coloured transparent areas as well as darker translucent zones with a patchy appearance. It will be released into the market after sufficient quantities have been mined and processed. **Terry Coldham** (Intogems Pty Ltd, Normanhurst, New South Wales, Australia) reviewed three recent Australian opal initiatives: (1) a proposed CIBJO opal guide that will include opal classification, (2) an online opal course that will soon be offered by the Gemmological Association of Australia and (3) the construction of a new building at the Australian Opal Centre in Lightning Ridge, New South Wales, which is expected to be completed at the end of 2024.

Spinel was the subject of two presentations. **Dr Chengsi Wang** and co-authors (Gemological Institute, China University of Geosciences, Wuhan, China) studied the thermal and geothermal history of spinel using photoluminescence (PL) spectroscopy. Heating causes disorder in spinel's crystal structure, and this is seen in PL spectra by evaluating the integrated areas of the R peaks (emitted by ordered PL centres) and the N peaks (due to disordered PL centres). The ratio of these integrated areas provides a measure of the degree of disorder (i.e. closure temperature). A progression from lowest to highest disorder was shown by spinels from Tanzania, Tajikistan, Vietnam and Myanmar, respectively. **Masaki Furuya** studied Co-spinel from the Bai Buoi mine in Yen Bai, Vietnam. The stones showed UV-Vis spectra and trace-element contents similar to Co-spinels from Tanzania, but their inclusions were quite different. Bai Buoi Co-spinels contain flake- and

snowflake-like inclusions, as well as apatite and clusters of titanite, while those from Tanzania are identified by hōgbomite inclusions.

Other presentations on coloured stones covered various gem materials. **Dr Emmanuel Fritsch** and co-authors (Institut des Matériaux de Nantes Jean Rouxel and Centre National de la Recherche Scientifique, University of Nantes, France) explained the role of titanate groups (TiO_6) in causing blue short-wave UV luminescence in benitoite, synthetic corundum and spinel, dumortierite, morganite, elbaite, pezzottaite, etc. Luminescence spectroscopy showed a broad emission band in the 400–500 nm region and a broad excitation band in the 240–294 nm range. All of the samples contained at least 20 ppm Ti. **Dr Claudio Milisenda** and his co-author (DSEF German Gem Lab, Idar-Oberstein) examined rare colour-change Paraíba tourmaline from Brazil. The stones originated from old stock mined in the early 1990s, and they appear violetish blue to blue-violet in daylight and greyish green-blue to greyish blue-green in incandescent light (Figure 6). UV-Vis-NIR spectra showed an absorption band at 520 nm due to Mn^{3+} that forms transmission windows in the blue-violet and yellow-green portions of the visible spectrum, which are responsible for the colour change. This colour behavior is rare because it is only shown by unheated material (whereas most Paraíba tourmaline is heat treated). **Dr Jayshree Panjekar** and her co-author characterised almandine-pyrope from Balangir in Odisha, India. The garnet is hosted by khondalite-charnockite-granite gneiss and the following inclusions were identified by Raman micro-spectroscopy: apatite, ilmenite, rutile (as black crystals and oriented needles), zircon (surrounded by tension haloes), quartz and sillimanite. **Prof. Andy Shen**



Figure 6: Dr Claudio Milisenda describes unusual colour-change Paraíba tourmaline from Brazil. Photo by B. M. Laurs.

and co-authors (Gemological Institute, China University of Geosciences, Wuhan) reviewed the mechanisms of high-temperature Cu diffusion for the colouration of labradorite, with applications to separating such material from naturally coloured reddish plagioclase, based on experiments performed by his student Qingchao Zhou (see <https://doi.org/10.3390/min12080920>). **Dr Stefanos Karampelas** (Laboratoire Français de Gemmologie, Paris, France) and co-authors described a historical alexandrite from the Paris School of Mines collection (see their article on pp. 796–803 of this issue of *The Journal*).

Dr Lore Kiefert (Gemmology Consulting, Heidelberg, Germany) and co-authors described purple-to-bluish grey chalcedony from Ethiopia. Although this type of chalcedony was discovered in 2019, it wasn't introduced until the 2022 gem shows in Tucson, Arizona, USA, after delays related to the COVID-19 pandemic. Although its colouration appears similar to that shown by dyed chalcedony, its UV-Vis spectra show a diagnostic absorption at 540 nm in purple samples (similar to amethyst) or at 590 nm in the bluish grey material. **Dr Karen Fox** (University of Waterloo, Canada) and her co-author reviewed the cause of colour of massive rose quartz, which has been attributed to a nano-scale fibrous dumortierite-like material (DLM). Variations in the colour of rose quartz may be related to differences in the concentrations of Fe and Ti in the DLM fibres. Asterism is shown by some—but not all—rose quartz, and may correspond to a crystallographically controlled vs random orientation of the DLM fibres, which could be related to the cooling history of the rose quartz. **Bahareh Shirdam** (Gemological Institute, China University of Geosciences, Wuhan) and co-authors investigated turquoise from the Kuh Zar gold deposit in Semnan Province, Iran. Black schorl is the most diagnostic inclusion in turquoise from this locality, and is intergrown with quartz and jarosite. Compared to blue material, the green turquoise from this deposit contains more Fe and less Cu. **Dr Qian Zhang** (Gemological Institute, China University of Geosciences, Wuhan) and co-authors studied taaffeite from Mogok, Myanmar (see <https://doi.org/10.3390/min13030346>).

Three presentations covered different gem localities. **Michael Hügi** (Swiss Gemmological Society, Bern, Switzerland) examined the formation and the historical significance of quartz crystals from alpine fissures in the Central Alps. The silica needed for quartz formation is inferred to have come from the leaching of the host rock, and crystallisation occurred over a long duration (perhaps several million years) in fractures created by tectonic processes. The quartz provided an important

source of raw material for making large works of art (vases, goblets, etc.) from the Middle Ages to the Renaissance. The largest recent discovery—the Planggenstock crystal fissure—occurred in 1993 and continues to be mined for quartz and gem-quality pink fluorite. So far it measures 82 m long. **Anette Juul-Nielsen** and her co-author (Ministry of Mineral Resources and Justice, Nuuk, Greenland) investigated a 'new' nuummite occurrence from Kangerluarsuk in the Maniitsoq region of western Greenland. Although it has been mentioned previously in the literature, the geology and gemmology of this material were not documented until recently. The nuummite consists of the amphiboles anthophyllite and gedrite with minor biotite and pyrite, and it displays blue iridescence from < 1 mm thin elongate amphibole grains. By contrast, nuummite from the better-known occurrence at Simiuttat (in the Nuuk area of Greenland) is coarser grained and may display golden or blue iridescence. **This author** reviewed the geology and gem resources of granitic pegmatites in Southern California, USA. The pegmatites occur in several districts in San Diego and Riverside counties, and have ages ranging from 90 to 99.4 Ma, younging to the east. The main gem resources are tourmaline, morganite, kunzite and quartz, although some districts contain topaz, spessartine and aquamarine. The Tourmaline King mine in the Pala District is currently a source of pink and green tourmaline and shows good potential for future production.

Presentations on biogenic materials covered pearls and amber. **Dr Laurent Cartier** (Swiss Gemmological Institute SSEF, Basel, and University of Lausanne, Switzerland) and co-authors were involved with two case studies that combined DNA fingerprinting and age dating of historic natural pearls. (1) The Queen Mary Pearl—originally owned by Queen Mary (1867–1953), the wife of King George V of England (1865–1936)—likely formed between 1707 and 1876 CE in coastal waters along the Pacific coast of Mesoamerica, and came from a *Pinctada mazatlanica* mollusc (Panama or La Paz pearl oyster). (2) Three pearls randomly selected from a jewellery set containing 63 natural pearls showed surprising results: one of them was from *Pinctada radiata* (Persian Gulf or Ceylon pearl oyster) and the other two were attributed to *Pinctada persica* (from the Persian Gulf), a new species for the pearl trade. They probably formed in the 17th century CE. **Tay Thye Sun** (Far East Gemmological Institute, Singapore) and co-authors performed a gemmological characterisation of pearls cultured from gold-lipped oysters in Myanmar. Their research confirmed that they are typical bead-nucleated saltwater cultured pearls with a natural yellow colour.

Sutas Singbamroong (Dubai Central Laboratory, Dubai, United Arab Emirates) and co-authors documented a blister pearl discovered in an edible oyster (*Crassostrea gigas*). The $18.1 \times 11.7 \times 10.6$ mm pearl derived from an edible oyster was very unusual because it was nacreous.

Dr Yan Li (Gemological Institute, China University of Geoscience, Wuhan) and her co-authors studied the effects of weathering on the FTIR spectra and origin traceability of archaeological amber. Four artefacts were analysed from the Western Han Dynasty tomb of the Marquis of Haihun (Liu He, 92–59 BCE), located near Nanchang in China's Jiangxi Province. Non-destructive ATR-FTIR spectroscopy combined with principal component analysis and linear discriminant analysis of the infrared spectral data revealed that all four artefacts were made from Burmese amber. **Dr Alessandra Costanzo** (University of Galway, Ireland) and co-authors documented fluid inclusions in Baltic amber that typically were relatively large (>1 mm) and contained mobile bubbles within a liquid of unknown origin.

Two presentations focused on applications of artificial intelligence for addressing gemmological challenges. **Tasnara Sripoonjan** (G-ID Laboratories, Bangkok) and his co-author used the Python programming language to facilitate complex gemmological data analysis using machine-learning algorithms. The five main steps in

this process entail: data collection, pre-processing, data cleaning, feature extraction, and modelling and evaluation. **Montira Seneewong-Na-Ayutthaya** (GIT, Bangkok) and co-authors applied machine learning to the origin determination of ruby and sapphire by trace-element data fingerprinting. They used Python to process chemical data obtained by EDXRF and LA-ICP-MS instrumentation, and obtained better results for the latter dataset.

Museums were the subject of two IGC presentations. **Dr Koichi Momma** and **Prof. Ritsuro Miyawaki** (National Museum of Nature and Science, Tokyo, Japan) were instrumental in organising the *Gem* special exhibition that took place during February–June 2022 at the National Museum of Nature and Science in Tokyo. The exhibit attracted over 300,000 visitors and displayed 200 gem varieties and thousands of individual pieces. There were five sections, covering 'The Birth of a Gem', 'From Gem to Jewel', 'The Essence and Diversity of Gems', 'How a Gem Becomes Jewelry' and 'Ultimate of Gems' (presenting historic masterpieces from the collection of the Albion Art Jewellery Institute in Tokyo). **Dr Ahmadjan Abduriyim** described his work building a new museum from the collections of Akira Chikayama, a famous gemmologist, educator and author who taught gemmology and gem fashioning in Yamanashi Prefecture, Japan. For more than 40 years he amassed more than 30,000 specimens of rough and cut gem and rock materials. The specimens were divided into research and display categories, and the latter were classified into three separate sections titled 'Earth Miracles', 'Crystals World' and 'Education of Gemology'. May 2022 marked the opening of 'The Chikayama's Collection, GSTV Gem Museum'.

There were two IGC poster presentations, given by: (1) **Dr Yuri B. Shelementiev** (MSU Gemmological Center, Moscow State University, Russia) on gemmological education in the 21st century, and (2) **Seung Kwon Lee** (Wooshin Gemmological Institute of Korea and Hanyang University, Seoul, South Korea) and his co-author on photochromism in sodalite.

During the closing ceremony of the conference, Dr Jayshree Panjikar announced that Dr Ahmadjan Abduriyim and Anette Juul-Nielsen have joined the IGC executive committee. In addition, six IGC observers became delegates (Kentaro Emori, Dr Rainer Schultzt Güttler, Michael Hügi, Anette Juul-Nielsen, Bahareh Shirdam and Dr Tom Stephan) and six new observers joined the IGC. The next IGC will take place in Athens, Greece, in 2025 (Figure 7).

Brendan M. Laurs FGA



Figure 7: The IGC banner is passed to Dr Stefanos Karampelas (second from the left), who will co-host the 2025 IGC in Athens, Greece. Also shown (from left to right) is Tay Thye Sun, Dr Hiroshi Kitawaki, Dr Ahmadjan Abduriyim, Dr Jayshree Panjikar, Yoko Okubo, Masaki Furuya and Kentaro Emori. Photo by B. M. Laurs.

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 2023. For those of you who attended the conference, we would like to extend our sincerest thanks for

joining the fascinating sessions throughout the day. Our knowledgeable speakers provided a well-rounded program, and then the day ended perfectly with a private tour of the Crown Jewels and dinner at the historic Tower of London. After dinner, we held a raffle that raised approximately GBP2,080 for the London-based Silversmiths & Jewellers Charity, which supports silversmiths, jewellers and associated trade members who for various reasons have fallen on hard times. We thank all those who generously donated items for the raffle and purchased tickets.

This year's Gem-A Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall in London and was a resounding success. Meeting and awarding our enthusiastic graduates are always among the genuine highlights of my year. I would like to take this opportunity to offer personal thanks to David Nassi, president of 100% Natural Ltd. and president of Gem-A USA, for delivering such an inspirational graduation speech. I would also like to thank Dr Dominic Mok for addressing the graduates as our Diamond Sponsor. The song that he sang at the end was a fun surprise for all! For those graduates who were not able to join us, you were in our thoughts, as the celebration was indeed for

all our global graduates. Congratulations once again to all involved.

Although 2023 is drawing to a close, Gem-A is thrilled to announce that we are already busy planning the year ahead, starting with the gem and mineral shows in Tucson, Arizona, USA. I look forward to catching up with many of you there.

You should have received communication about the Gem-A brand refresh, which I unveiled at the Gem-A Conference. You will soon notice subtle changes to our logo and branding that add a contemporary twist while retaining our rich brand history and heritage. In the coming weeks, we will launch the brand-new Gem-A website and Membership Portal. In early 2024, we will also debut the Gem-A Community Hub. All these changes will provide you, our Members, with the best possible experience and will add value for the next generation of students who choose to kick-start their gemmology careers with us.

We are also working to deliver our upcoming examinations in February, and we look forward to welcoming our on-site and our online distance-learning students for the February and March terms, respectively.

We have now opened the window on Membership renewals for 2024. 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 we hope you enjoy the many benefits of Gem-A Membership.

I 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. We look forward to seeing you in 2024.

GEM-A CONFERENCE, GRADUATION AND PRESENTATION OF AWARDS

The Gem-A Conference 2023 took place on Sunday, 5 November, and included a line-up of seven speakers. They addressed a wide range of topics, including alluvial diamond deposits in South Africa, laboratory-grown diamonds, artificial intelligence applied to peridot origin

determination, current trends in the auction market, the colouration of tanzanite and fancy-colour zoisite, understanding why some minerals occur in gem quality and an update on the current gem market. For more details, see the Conferences section of this issue of *The Journal*.

The event was followed by a gala dinner at the historic Tower of London, where attendees were entertained with a private tour of the British Crown Jewels.

During the mornings of 6 and 7 November, we organised four private tours and eight workshops, all of which received fantastic feedback from attendees. The Gem-A Graduation Ceremony and Presentation of Awards was held on the evening of 6 November at Goldsmiths' Hall, accompanied by a reception for graduates and guests.

Hall, accompanied by a reception for graduates and guests.

We would like to thank all our sponsors for their support in making the Gem-A Conference a huge success: Fuli Gemstones (Gold Sponsor), Marcus McCallum (Silver Sponsor), and the Canadian Gemmological Association, The Curious Gem, Gemworld International, the Jewellery Valuers Association, John J. Bradshaw, and the National Association of Jewellers (Bronze Sponsors).



Participants at Gem-A's 2023 graduation ceremony. Photo by Tempest Photography.

GEMMOLOGY DIPLOMA PASSES

Hasan Abdulla, *Bahrain*

Yuko Aizawa, *Japan*

Claudio Alessandri, *Switzerland*

Thom Amar, *United Kingdom*

Miki Asazuma, *Japan*

Caroline Baron, *France*

Marie-Amélie Bienaimé, *France*

Rebecca Bohle, *United Kingdom*

Jiayi Cai, *P.R. China*

Huacun Cao, *P.R. China*

Anna Chan, *Hong Kong (S.A.R.)*

Cheng-Chang Chan, *Taiwan (R.O.C.)*

Ka Ying Nicole Chan,
Hong Kong (S.A.R.)

Lui Chan, *Singapore*

Man Shun Casper Chan,
P.R. China

Sur-Han Chang, *Taiwan (R.O.C.)*

Yun Chang, *Taiwan (R.O.C.)*

Ka Yee Chau, *Hong Kong (S.A.R.)*

Anan Chen, *P.R. China*

I-Chun Chen, *Taiwan (R.O.C.)*

Kun-Tsung Chen, *Taiwan (R.O.C.)*

Po-Ching Chen, *Taiwan (R.O.C.)*

Qiuyun Chen, *P.R. China*

Yanlin Chen, *P.R. China*

Yi-Syuan Chen, *Taiwan (R.O.C.)*

Yi-Wen Chen, *Taiwan (R.O.C.)*

Ying Chen, *P.R. China*

Hui Ling Cheng,
Hong Kong (S.A.R.)

Yuen King Cheng,
Hong Kong (S.A.R.)

King Ping Cheung,
Hong Kong (S.A.R.)

Yi Man Cheung,
Hong Kong (S.A.R.)

Man Chun Chien,
Taiwan (R.O.C.)

Wing Sing Cho,
Hong Kong (S.A.R.)

Zaw Win Cho, *Myanmar*

Pui Suen Chu,
Hong Kong (S.A.R.)

- Hiu Tung Barbie Chui,
Hong Kong (S.A.R.)
 Yiting Chung, *Taiwan (R.O.C.)*
 David Clark, *United Kingdom*
 Yue Deng, *P.R. China*
 Riccardo Donda, *Italy*
 Hengzhi Dong, *P.R. China*
 Jie Dong, *P.R. China*
 Zhen Dong, *P.R. China*
 Maude Druoton, *France*
 Xi Duan, *P.R. China*
 William Ellin, *United Kingdom*
 Rosie Feenstra, *United Kingdom*
 Charles Filliaudeau, *France*
 Victoria Fletcher, *United Kingdom*
 Ka Lee Fu, *Hong Kong (S.A.R.)*
 Minori Fukushima, *Japan*
 Yim Fong Fung,
Hong Kong (S.A.R.)
 Hei Yu Fung, *Hong Kong (S.A.R.)*
 Yu Gao, *P.R. China*
 Fang Ge, *P.R. China*
 Hong Ge, *P.R. China*
 Jonathan Gee, *France*
 Yolande Gennaoui, *France*
 Amanda Gomez, *United Kingdom*
 Marianne Grigoli,
United States of America
 Yifei Gu, *P.R. China*
 Sijing Han, *P.R. China*
 Yutong Han, *P.R. China*
 Ziyao Hao, *P.R. China*
 Eleanor Harrison, *United Kingdom*
 Richard Hitchens, *France*
 Andrew Hnatyshyn, *Canada*
 Pauline Hodée, *France*
 Qu Hongyi, *P.R. China*
 David Horton III,
United States of America
 Hillary Hosinger,
United States of America
 In-Kang Hsieh, *Taiwan (R.O.C.)*
 Kui Mei Hsieh, *Taiwan (R.O.C.)*
 Zin Linn Htet, *Myanmar*
 Aung Naing Htwe, *Myanmar*
 Jie Hu, *P.R. China*
 Yan Hu, *P.R. China*
 Ching-Hsiang Huang,
Taiwan (R.O.C.)
 Li Huang, *P.R. China*
 Shang Ling Huang,
Taiwan (R.O.C.)
 Wei Huang, *Taiwan (R.O.C.)*
 Wenjia Huang, *P.R. China*
 XiaoTing Huang, *P.R. China*
 Xiaoyu Huang, *P.R. China*
 YingRu Huang, *P.R. China*
 Ran Inoue, *Japan*
 Wai Man Iu, *Hong Kong (S.A.R.)*
 Ying Ji, *P.R. China*
 Wu Jia, *P.R. China*
 Chen Jiang, *P.R. China*
 Jie Jiang, *Hong Kong (S.A.R.)*
 Leman Jiang, *P.R. China*
 Nan Jiang, *P.R. China*
 Wenxu Jiang, *P.R. China*
 Yanni Jiang, *P.R. China*
 LiYun Jin, *Hong Kong (S.A.R.)*
 Zhuying Jin, *P.R. China*
 Emma Johansson, *Sweden*
 Lisa Joyce,
United States of America
 Shao-I Kao, *Taiwan (R.O.C.)*
 Kana Kasahara, *Japan*
 Kerri Keeling, *United Kingdom*
 Anna Kerr, *United Kingdom*
 Michael Kessler, *Switzerland*
 Rosanna King, *Republic of Ireland*
 Sayaka Kiryu, *Japan*
 Yuuki Kondo, *Japan*
 Xiaoxue Kou, *P.R. China*
 Bal Kumary, *Myanmar*
 Kit Ho Kwan, *Hong Kong (S.A.R.)*
 Ka Man Kwok, *Hong Kong (S.A.R.)*
 Carole Lachavanne, *Switzerland*
 I Lin Lam, *Macau*
 Nga Yi Lam, *Hong Kong (S.A.R.)*
 Maria Lampiri, *Greece*
 Ka Yi Lau, *Hong Kong (S.A.R.)*
 Ming Wing Lau,
Hong Kong (S.A.R.)
 Laurène Le Coq de Kerland,
France
 I-Ping Lee, *Taiwan (R.O.C.)*
 Yu Yun Lee, *Taiwan (R.O.C.)*
 Alexandre Lefrançois, *France*
 Pik Chiu Leung,
Hong Kong (S.A.R.)
 Huiling Li, *P.R. China*
 Jiayang Li, *P.R. China*
 Jingjing Li, *P.R. China*
 Ke yao Li, *P.R. China*
 Mengyu Li, *P.R. China*
 Qian Li, *P.R. China*
 Tao Li, *P.R. China*
 Yiyang Li, *P.R. China*
 Yuanqing Li, *P.R. China*
 Yuxiao Li, *Japan*
 Zehang Li, *P.R. China*
 Hsiu-Chuan Lin, *Taiwan (R.O.C.)*
 Wensi Lin, *P.R. China*
 Susan Lister Kroening,
United Kingdom
 Jinling Liu, *P.R. China*
 Jiyang Liu, *P.R. China*
 Qian Liu, *P.R. China*
 Yuchong Liu, *P.R. China*
 Zijing Liu, *P.R. China*
 Amanda Livsey, *United Kingdom*
 Anushree Lohia, *India*
 Wan Yu Lu, *Taiwan (R.O.C.)*
 Tsz Yin Esther Luk,
Hong Kong (S.A.R.)
 Na Luo, *P.R. China*
 Xuan Luo, *P.R. China*
 Yiyi Ma, *P.R. China*
 Mei Yee May Mak, *P.R. China*
 Aoi Mano, *Japan*
 Lucinda Marsh, *United Kingdom*
 Charlene Marzabal, *France*
 Maija Melchakova, *Sweden*
 Juliette Merlino, *France*
 Nami Miyauchi, *Japan*
 Xuan Jing Mo, *P.R. China*

Sinead Michelle Mooney, <i>United Kingdom</i>	Eric Stewart Carter, <i>United Kingdom</i>	Yajun Wen, <i>P.R. China</i>
Saiko Morikawa, <i>Japan</i>	Hifumi Takagi, <i>Japan</i>	Zihan Wen, <i>P.R. China</i>
Myat Phyo Myint, <i>Myanmar</i>	Moegi Takeuchi, <i>Japan</i>	Francesca Wilcox, <i>United Kingdom</i>
Kayano Nagashima, <i>Japan</i>	Ho Tung Tam, <i>Hong Kong (S.A.R.)</i>	Hiu Kiu Wong, <i>Hong Kong (S.A.R.)</i>
Takahiro Nakakuni, <i>Japan</i>	Xiaohang Tan, <i>P.R. China</i>	King Yan Wong, <i>Hong Kong (S.A.R.)</i>
Hirzan Nasar, <i>Sri Lanka</i>	Chun Ho Tang, <i>Hong Kong (S.A.R.)</i>	Sze Ling Wong, <i>Hong Kong (S.A.R.)</i>
Marzena Nazz, <i>United States of America</i>	Jiahuan Tao, <i>P.R. China</i>	Jiapei Wu, <i>P.R. China</i>
Wing Yan Ng, <i>P.R. China</i>	Ziwei Tao, <i>P.R. China</i>	Xiaolong Wu, <i>P.R. China</i>
Hisae Ninomiya, <i>Japan</i>	May Thu, <i>Myanmar</i>	Zhiqi Wu, <i>P.R. China</i>
Myat Phone Nyo, <i>Myanmar</i>	Silue Tian, <i>P.R. China</i>	Na Xiao, <i>P.R. China</i>
Despoina Ofidou, <i>Greece</i>	Yuzhou Tian, <i>P.R. China</i>	Xiaohuan Xie, <i>P.R. China</i>
Chie Ogawa, <i>United Kingdom</i>	Tsz Sun Tin, <i>Hong Kong (S.A.R.)</i>	Xinyu Xie, <i>P.R. China</i>
Kanon Okumura, <i>Japan</i>	Yao Tong, <i>P.R. China</i>	Kewei Xu, <i>P.R. China</i>
Jahnvi Pachchigar, <i>India</i>	Bertand Tridon, <i>France</i>	Lili Xu, <i>P.R. China</i>
Christopher Page, <i>United States of America</i>	Panlada Trirotanan, <i>Thailand</i>	Liumanyu Xu, <i>P.R. China</i>
Yanlei Pang, <i>P.R. China</i>	Mio Tsumanuma, <i>Japan</i>	Xinyuan Xu, <i>P.R. China</i>
Tena Parkinson, <i>United Kingdom</i>	Kuo-Hao Tu, <i>Taiwan (R.O.C.)</i>	Youko Yagi, <i>Japan</i>
Francis Pirrie, <i>United Kingdom</i>	Hing Yu Tung, <i>Hong Kong (S.A.R.)</i>	Mei Yamashita, <i>Japan</i>
Chi Ying Vianna Poon, <i>Hong Kong (S.A.R.)</i>	Olivia Uliana, <i>South Africa</i>	Guifang Yan, <i>P.R. China</i>
Catherine Prieur, <i>France</i>	Naoko Umezaki, <i>Japan</i>	Hang Yan, <i>P.R. China</i>
Xi Yan Qian, <i>P.R. China</i>	Isabelle Vander Elst, <i>France</i>	ChiaYing Yang, <i>Taiwan (R.O.C.)</i>
Zishan Qin, <i>P.R. China</i>	Chenya Wang, <i>P.R. China</i>	Jia-Yi Yang, <i>Taiwan (R.O.C.)</i>
Lei Qiu, <i>P.R. China</i>	Heyin Wang, <i>P.R. China</i>	Jingjing Yang, <i>P.R. China</i>
Xin Qu, <i>P.R. China</i>	Hsuan-Jung Wang, <i>Taiwan (R.O.C.)</i>	Qian Yang, <i>P.R. China</i>
Salma Rahmouni, <i>United Kingdom</i>	Jiaze Wang, <i>P.R. China</i>	Sidong Yang, <i>P.R. China</i>
Kristin Reinheimer, <i>United States of America</i>	Liu Wang, <i>P.R. China</i>	Yun Yang, <i>P.R. China</i>
Mathilde Rispe, <i>France</i>	Shujiao Wang, <i>P.R. China</i>	Yutao Yang, <i>P.R. China</i>
Romdoul Ros, <i>Switzerland</i>	Xianfang Wang, <i>P.R. China</i>	Linfang Yao, <i>P.R. China</i>
Aamir Sayed, <i>Bahrain</i>	Xiaoliang Wang, <i>P.R. China</i>	Jiahui Ye, <i>Hong Kong (S.A.R.)</i>
Ajane Sandunika Shyamalee	Xin Wang, <i>Taiwan (R.O.C.)</i>	Pui Fung Yeung, <i>Hong Kong (S.A.R.)</i>
Sepala Dissanayake Mudiyanse-	Xuege Wang, <i>P.R. China</i>	Sze Nga Yip, <i>Hong Kong (S.A.R.)</i>
lage Sandunika, <i>Sri Lanka</i>	Yue Wang, <i>P.R. China</i>	Shui King Yiu, <i>Hong Kong (S.A.R.)</i>
Yingli Shang, <i>P.R. China</i>	Yuqing Wang, <i>P.R. China</i>	Wang Yizhou, <i>P.R. China</i>
Shuyuan Shi, <i>P.R. China</i>	Dan Wang, <i>P.R. China</i>	Syotaro Yoshida, <i>Japan</i>
Yanni Shi, <i>P.R. China</i>	Kehan Wang, <i>P.R. China</i>	Fei Yu, <i>P.R. China</i>
Lakshmiprasad Shikhare, <i>India</i>	Minou Carmen Warbroek, <i>The Netherlands</i>	Hsiao-Ying Yu, <i>Taiwan (R.O.C.)</i>
Sin Yi Sill, <i>Hong Kong (S.A.R.)</i>	Manuella Warin, <i>France</i>	Liyuan Yu, <i>P.R. China</i>
Arumugam Sivakumar, <i>Sri Lanka</i>	Eriko Watanabe, <i>Japan</i>	Minda Yu, <i>P.R. China</i>
Katherine Snow, <i>United Kingdom</i>	Rachel Weekes, <i>United Kingdom</i>	Zijun Yuan, <i>P.R. China</i>
Linlin Song, <i>P.R. China</i>	Wei Wei, <i>P.R. China</i>	Ching Chi Yuen, <i>Hong Kong (S.A.R.)</i>
	Xin Wei, <i>P.R. China</i>	

Marlon Zatti, *Monaco*
 Jia Yang Zeng, *P.R. China*
 Hanlei Zhai, *P.R. China*
 Fengwan Zhang, *P.R. China*
 Hao Zhang, *P.R. China*
 Jinxin Zhang, *P.R. China*
 Qiaoling Zhang, *P.R. China*
 Qing Zhang, *P.R. China*
 Runqing Zhang, *P.R. China*
 Ruotong Zhang, *P.R. China*

Wanting Zhang, *P.R. China*
 Xian Zhang, *P.R. China*
 Xibei Zhang, *P.R. China*
 Xu Zhang, *P.R. China*
 Xue Zhang, *P.R. China*
 Yi Zhang, *P.R. China*
 Youyang Zhang, *P.R. China*
 Yuhan Zhang, *P.R. China*
 Yumeng Zhang, *P.R. China*

Baoyong Zhao, *P.R. China*
 Jing Zhao, *P.R. China*
 Ning Zhao, *P.R. China*
 Xurui Zhao, *P.R. China*
 Junyan Zhi, *P.R. China*
 Zhiyi Zhou, *P.R. China*
 Wanqi Zhu, *P.R. China*
 Yuan Zhuang, *P.R. China*
 Wang Zikang, *P.R. China*

GEMMOLOGY DIPLOMA PASSES WITH MERIT

Georgina Agnew, *United Kingdom*
 Matthew Bland, *United Kingdom*
 Emily Brown, *United Kingdom*
 Mei Shan Chan, *Hong Kong (S.A.R.)*
 Andrea Čobić, *Croatia*
 Mingying Cui, *P.R. China*
 Yi Deng, *P.R. China*
 Tiange Fan, *P.R. China*
 Tatsuya Fukunaga, *Japan*
 Sin Ying Ho, *Hong Kong (S.A.R.)*
 Xiaoyan Huang, *P.R. China*
 Kexin Jiang, *P.R. China*
 Zelda Kahtan, *United Kingdom*
 Zoe Kay, *United Kingdom*
 Cheng Li, *P.R. China*
 Yukai Li, *P.R. China*
 Xiaoxiao Liu, *P.R. China*
 Yupeng Liu, *P.R. China*

Ziqi Liu, *P.R. China*
 Danielle Lizdek, *United Kingdom*
 Miao Miao Lu, *P.R. China*
 Yiru Lu, *P.R. China*
 Sarah MacLeod, *United Kingdom*
 Shuyuan Meng, *P.R. China*
 Cornelia Merk, *Switzerland*
 Julia Proctor, *United Kingdom*
 ChanYu Sang, *P.R. China*
 Yuka Sato, *Japan*
 Ching Yin Sin, *Hong Kong (S.A.R.)*
 Sarah Streatfeild, *United Kingdom*
 Lin Su, *P.R. China*
 Marino Takahashi, *Japan*
 Xurui Tan, *P.R. China*
 Wanjuan Tang, *P.R. China*
 Shan Tao, *P.R. China*
 Min Thurain Ko, *Myanmar*
 Hannah Waters, *United Kingdom*

Jiabao Wen, *P.R. China*
 Jack Whibley, *United Kingdom*
 Hing Yee Wong, *Hong Kong (S.A.R.)*
 Kate Woolley, *United Kingdom*
 Song Wu, *P.R. China*
 Xinru Wu, *P.R. China*
 Yan Xing, *P.R. China*
 Jiayue Xu, *P.R. China*
 Wenyi Xu, *P.R. China*
 Xingxing Xu, *P.R. China*
 Yu Xu, *P.R. China*
 Biao Yang, *P.R. China*
 Shujing Yang, *P.R. China*
 Sijie Yu, *P.R. China*
 Jiajia Zhang, *P.R. China*
 Linjing Zhang, *P.R. China*
 Lufan Zhang, *P.R. China*
 Yongsheng Zhang, *P.R. China*
 Jingtian Zhou, *P.R. China*

GEMMOLOGY DIPLOMA PASSES WITH DISTINCTION

Ying Wai Au, *Hong Kong (S.A.R.)*
 Man Ching Chu, *Hong Kong (S.A.R.)*
 Catherine Eisele, *Germany*
 Qiyun Guan, *P.R. China*
 Jing Hu, *P.R. China*
 Yuanyuan Hu, *P.R. China*
 Wenxian Hua, *P.R. China*
 Hongyue Jiang, *P.R. China*

Xueer Jiang, *P.R. China*
 Rie Kobayashi, *Japan*
 Yutao Lin, *P.R. China*
 Fiona Linten, *United Kingdom*
 Jiarui Liu, *P.R. China*
 Jiawen Ma, *P.R. China*
 Rebecca Minnaar, *United Kingdom*
 Kinga Pucci, *Spain*
 Amy Reynolds, *United Kingdom*

Samyah Shadid, *Switzerland*
 Li Shi, *P.R. China*
 Tong Shu, *P.R. China*
 Hui Tian, *P.R. China*
 Qiaoli Wang, *P.R. China*
 Yahui Wang, *P.R. China*
 Jingyi Xu, *P.R. China*
 Yanshuang Zhou, *P.R. China*

DIAMOND DIPLOMA PASSES

Chi Ting Chan, <i>Hong Kong (S.A.R.)</i>	John Neville, <i>Republic of Ireland</i>	Shujuan Li, <i>P.R. China</i>
Chun Ho Chan, <i>Hong Kong (S.A.R.)</i>	Joshua Walker, <i>United Kingdom</i>	Ka Yi Tam, <i>Hong Kong (S.A.R.)</i>
Pik Wah Chan, <i>Hong Kong (S.A.R.)</i>	Kai Shi, <i>P.R. China</i>	Chor-Man Tang, <i>Taiwan (R.O.C.)</i>
Suet Ting Chan, <i>Hong Kong (S.A.R.)</i>	Kuo-Hao Tu, <i>Taiwan (R.O.C.)</i>	Mohammed Amaan Vaseem, <i>United Kingdom</i>
Cho Yu Ng, <i>Hong Kong (S.A.R.)</i>	Hiu Ching Lam, <i>Hong Kong (S.A.R.)</i>	Weizhao Wang, <i>P.R. China</i>
Hei Tung Chui, <i>Hong Kong (S.A.R.)</i>	Caitlin Little, <i>Scotland, UK</i>	Mo Wa Wong, <i>Hong Kong (S.A.R.)</i>
Amy Rose Courtneage, <i>United Kingdom</i>	Wai Ping Lo, <i>Hong Kong (S.A.R.)</i>	Leah Wylie, <i>Scotland, UK</i>
Craig Hagon, <i>United Kingdom</i>	Man Kwan Lui, <i>P.R. China</i>	Yuzhen Yi, <i>Hong Kong (S.A.R.)</i>
Daria Sterlikova, <i>United Kingdom</i>	Xinyu Ma, <i>P.R. China</i>	Ying-Hui Kuo, <i>Taiwan (R.O.C.)</i>
Jacquelyn Ding, <i>United Kingdom</i>	Tze Hang Mau, <i>P.R. China</i>	Yosef Caldaron, <i>United States of America</i>
Shumei Fang, <i>P.R. China</i>	Myo Than, <i>United Kingdom</i>	Younan Zhu, <i>P.R. China</i>
Fangyi Liu, <i>P.R. China</i>	Nap Sze Kathy Chan, <i>United Kingdom</i>	Yu Deng, <i>P.R. China</i>
Rachel Fox, <i>United Kingdom</i>	Nicola Noakes, <i>United Kingdom</i>	Yunjia Sun, <i>P.R. China</i>
I-Chuan Hsia, <i>United Kingdom</i>	Nicole Singer, <i>Canada</i>	Zhili Wei, <i>United Kingdom</i>
Zhe Hu, <i>P.R. China</i>	Pei Chu Wu, <i>Taiwan (R.O.C.)</i>	Lingjun Zhou, <i>P.R. China</i>
Tianxiu Hua, <i>P.R. China</i>	Cheryl Pyke, <i>United Kingdom</i>	Zijia Feng, <i>P.R. China</i>
Wenru Huang, <i>P.R. China</i>	Rebecca Tomlinson, <i>United Kingdom</i>	

DIAMOND DIPLOMA PASSES WITH MERIT

Hiu Yan Chan, <i>Hong Kong (S.A.R.)</i>	Rebecca Pelmus, <i>United Kingdom</i>	Niamh Thomas, <i>Republic of Ireland</i>
Hei Ting Chiu, <i>Hong Kong (S.A.R.)</i>	Jayne Sambrook Smith, <i>United Kingdom</i>	Beth Woodhouse, <i>United Kingdom</i>
Grace Hall, <i>United Kingdom</i>	Yanran Shang, <i>P.R. China</i>	Mudan Xu, <i>P.R. China</i>
Penelope Harris, <i>United Kingdom</i>	Ruweesha Suriyaarachchillage, <i>United Kingdom</i>	Shuang Yan, <i>P.R. China</i>
Pik Chiu Leung, <i>Hong Kong (S.A.R.)</i>	Alexia Taylor, <i>United Kingdom</i>	Ye Yuan, <i>P.R. China</i>
Louis Meyer, <i>United Kingdom</i>		Yuan Zhu, <i>P.R. China</i>

DIAMOND DIPLOMA PASSES WITH DISTINCTION

Meritxell Lavanchy, <i>United Kingdom</i>	Chun Fung Ng, <i>Hong Kong (S.A.R.)</i>	So Mei Vivian Wong, <i>Hong Kong (S.A.R.)</i>
Mun Kay Livy Leung, <i>Hong Kong (S.A.R.)</i>	Charlotte Parkin, <i>United Kingdom</i>	Zoe Kay, <i>United Kingdom</i>

PRIZE AND MEDAL WINNERS

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

GEMMOLOGY FOUNDATION CERTIFICATE

Anderson Medal

Awarded to the candidate 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

2023 Winner: Amy Reynolds, a student from Gem-A, London

GEMMOLOGY DIPLOMA

Anderson Bank Prize

Awarded to the candidate submitting the best theory papers of the year for the Gemmology Diploma examination. This prize was 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.

2023 Winner: Amy Reynolds, a student from Gem-A, London

Christie's Prize for Gemmology

Awarded to the overall best candidate of the year in the Gemmology Diploma examination. This prize was established in 1954 as the Rayner Prize, renamed the Diploma Trade Prize in 1991, and replaced and sponsored from 2001 by Christie's London.

2023 Winner: Fiona Linten, an online distance learning student from Ilminster, Somerset

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; since 2018, the prize has been sponsored by Richard Drucker FGA (HONS) of Gemworld International.

2023 Winner: Man Ching Chu, a student from HKJMA, Hong Kong (S.A.R.)

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.

2023 Winner: Mun Kay Livy Leung, a student from AGIL, Hong Kong (S.A.R.)

Deeks Diamond Prize

Awarded to the candidate submitting the best theory papers of the year in the Diamond Diploma examination. First awarded in 2001, the prize is sponsored by the late Noel W. Deeks FGA DGA, a former vice president of the Association who taught the diamond course for many years.

2023 Winner: Mun Kay Livy Leung, a student from AGIL, Hong Kong (S.A.R.)

Mok Diamond Practical Prize

Awarded to the candidate submitting the best practical papers of the year for the Diamond Diploma examination. First awarded in 2009, this prize is sponsored by Dr Dominic Mok FGA DGA of the Asian Gemmological Institute and Laboratory Ltd, Hong Kong.

2023 Winner: Jessie Edmonds, an online distance learning student from Witney, Oxfordshire

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

2023 ANNUAL GENERAL MEETING REPORT



This year, Gem-A's Annual General Meeting (AGM) was held on 18 October at Gem-A's Headquarters on Ely Place. More than 230 Gem-A Members participated in our 2023 AGM by logging into the secure Civica Election Services (CES) platform and submitting their votes on the ordinary resolutions. Maggie Campbell Pedersen, Kate Flitcroft and Pia Tonna were re-appointed to the Gem-A Council by the Members. Richard Drucker was re-appointed by the Members as the president of the Association. Results of the Members' CES votes on ordinary resolutions were announced at the AGM by board chair Justine Carmody. We thank all Members who participated and voted at the AGM this year.

MEMBERSHIP RENEWAL



The renewal window for 2024 is now open to Members. Renew your membership before 31 December 2023 and take advantage of our early-bird discount! Pay now just GBP120* and get your post-nominals, access to eight publication issues a year—including the prestigious *Journal of Gemmology* and insightful *Gems&Jewellery*—as well as access to the new Gem-A Community Hub, and a discount on all Gemmological Instruments (GI) instruments and equipment. Check your email for our invitation to renew. If you haven't received an email from us or require assistance with your renewal, please email membership@gem-a.com.

* Membership fee increases to GBP145 after 31 December 2023.

GIFTS TO THE ASSOCIATION

Gem-A is most grateful to the following for their generous donations, which will support continued research and education:

Andrew Campin, United Kingdom, for a Beck spectroscope and stand.

Akira Ito, Japan, for three books on Japanese jewellery and accessories.

Thank You, Guest Reviewers

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.

Dr Ilaria Adamo

Italian Gemological Institute,
Milan, Italy

Shigeru Akamatsu

Pearl consultant, Toba, Japan

Prof. Dr H. Albert Gilg

Technische Universität München,
Munich, Germany

Prof. Dr Jens Götze

TU Bergakademie Freiberg, Germany

Dr George E. Harlow

American Museum of Natural History,
New York, New York, USA

Dr Le Thi Thu Huong

Staatliche Zeichenakademie Hanau, Germany

Dr Vít Kršul

Občanské sdružení Muzeum vltavínů,
Český Krumlov, Czech Republic

Dr Ren Lu

Gemmological Institute, China University
of Geosciences, Wuhan, China

Dr George Mustoe

Western Washington University,
Bellingham, Washington, USA

Dr Daniel Nyfeler

Gübelin Gem Lab Ltd, Lucerne,
Switzerland

Dr Hao A. O. Wang

Swiss Gemmological Institute SSEF,
Basel, Switzerland

Learning Opportunities

CONFERENCES AND SEMINARS

24th Federation for European Education in Gemmology (FEEG) Symposium

13 January 2024

Barcelona, Spain

<http://www.feeg-education.com/symposium/events>

NAJA 61st Winter Education Conference

28–29 January 2024

Tucson, Arizona, USA

<https://najaappraisers.com/event/61st-annual-aceit-winter-education-conference>

Tucson Fine Mineral Gallery Presentations

28 January–9 February 2024

Tucson, Arizona, USA

<https://tucsonfineminerals.com>

AGTA Gemfair Tucson

30 January–4 February 2024

Tucson, Arizona, USA

<https://agta.org/agta-gem-fair-tucson>

Note: Includes a seminar programme

Accredited Gemologists Association (AGA) Tucson Conference

31 January 2024

Tucson, Arizona, USA

<https://accreditedgemologists.org>

Tucson Gem and Mineral Show

8–11 February 2024

Tucson, Arizona, USA

<https://www.tgms.org/show>

Note: Includes a seminar programme

Inhorgenta Munich

16–19 February 2024

Munich, Germany

<https://inhorgenta.com/en/trade-fair/program> *Note:*

Includes a seminar programme

69th Bangkok Gems & Jewelry Fair

21–25 February 2024

Bangkok, Thailand

<https://www.bkkgems.com>

Note: Includes a seminar programme

Hasselt Diamond Workshop 2024 (SBDD XXVIII)

28 February–1 March 2024

Hasselt, Belgium

<https://www.uhasselt.be/SBDD#anch-bce-sbdd-xxviii>

Hong Kong International Jewellery Show

29 February–11 March 2024

Hong Kong

<https://www.hktdc.com/event/hkjewellery/en/intelligence-hub>

Note: Includes a seminar programme

Copenhagen Gemmological Symposium

9–10 March 2024

Copenhagen, Denmark

<https://danskgemmologiskelskab.dk/symposium>

Note: This event marks the 70th anniversary of the Danish Gemological Society. A workshop will take place on 11 March.

Independent Jewelers Organization (IJO) Conference

9–12 March 2024

Dallas, Texas, USA

<https://www.ijo.com/events/conferences>

MJSA Expo

10–12 March 2024

New York, New York, USA

<https://www.mjsa.org/events/mjsa-expo>

Note: Includes a seminar programme

American Gem Society Conclave

15–17 April 2024

Austin, Texas, USA

<https://www.americangemsociety.org/conclave-2024>

Jewellery & Gem ASEAN Bangkok

1–4 May 2024

Bangkok, Thailand

https://jewellerygemaseanbkk.com/2024/en/highlight_activities.asp

Note: Includes a seminar programme

Scottish Gemmological Association Conference

3–6 May 2024

Location in Scotland TBA

<https://www.scottishgemmology.org/conference-2023>

7th Mediterranean Gem and Jewellery Conference

7–11 May 2024

Cavalese, Italy and Piran, Slovenia

<https://www.gemconference.com>

Notes: Workshops will take place 7–9 May in Italy and the conference will occur on 11 May in Slovenia.

GAC-MAC-PEG 2024

19–22 May 2024

Brandon, Manitoba, Canada

<https://event.fourwaves.com/gacmac2024/pages>

Sessions of interest: (1) Pegmatite Minerals and Gems (part of the 10th International Symposium on Granitic Pegmatites); and (2) Precious and Semi-Precious Gems and Earth Materials

JCK Las Vegas

31 May–3 June 2024

Las Vegas, Nevada, USA

<https://lasvegas.jckonline.com>

Note: Includes a seminar programme

51st Annual Society of North American Goldsmiths Conference (SNAG x San Diego)

5–8 June 2024

San Diego, California, USA

<https://snagmetalsmith.org/conferences>

Swiss Gemmological Society Conference

9–11 June 2024

Nottwil, Switzerland

<https://gemmologie.ch/en/current>

Jewellery & Gem Asia Hong Kong

20–23 June 2024

Hong Kong

<https://jga.exhibitions.jewellerynet.com/specialevent>

Note: Includes a seminar programme

Sainte-Marie-aux-Mines Mineral & Gem Show

26–30 June 2024

Sainte-Marie-aux-Mines, France

<https://www.sainte-marie-mineral.com>

Note: Includes a seminar programme

12th International Kimberlite Conference

8–12 July 2024

Yellowknife, Northwest Territories, Canada

<https://12ikc.ca>

Note: A field trip titled ‘Northwest Territories Diamond Mines’ will take place 2–6 July.

Independent Jewelers Organization (IJO) Conference

13–16 July 2024

Chicago, Illinois, USA

<https://www.ijo.com/events/conferences>

17th International Conference on Applied Mineralogy (ICAM 2024)

29–30 July 2024

Zurich, Switzerland

<https://waset.org/applied-mineralogy-conference-in-july-2024-in-zurich>

Theme of interest: Industrial Minerals, Gems, Ores, and Mineral Exploration

Turquoise United 2024

8–10 August 2024

Albuquerque, New Mexico, USA

<https://turquoiseunited.com>

Note: Includes a seminar programme

NAJA 62nd Mid-Year Education Conference

10–12 August 2024

Rosemont, Illinois, USA

<https://najaappraisers.com/event/62nd-annual-aceit-mid-year-education-conference>

4th European Mineralogical Conference (emc2024)

18–23 August 2024

Dublin, Ireland

<https://emc-2024.org>

Sessions of interest: (1) Gem Minerals and Their Characterization: Advances in Both Fundamental and Applied Studies of Natural and Laboratory-Grown Gem Material; (2) Natural Gem Material and Their

Paragenesis; and (3) Mineralogy, Museums and Collections

37th International Geological Congress 2024

25–31 August 2024

Busan, South Korea

<https://www.igc2024korea.org>

Sessions of interest: (1) Gemstone and Geological Formation; (2) Geochemistry, Isotopic Characteristics, and Geochronology of Gem Deposits; and (3) Gem Materials

The Jewellery Show

1–2 September 2024

London

<https://www.thejewelleryshow.co.uk/programme>

Note: Includes a seminar programme

HardRock Summit 2023

12–15 September 2024

Denver, Colorado, USA

<https://hardrocksummit.com>

Note: Includes a seminar programme

Jewellery & Gem World Hong Kong

16–22 September 2024

Hong Kong

<https://jgw.exhibitions.jewellerynet.com>

Note: Includes a seminar programme

16th GeoRaman Conference

24–27 September 2024

Rhodes, Greece

<http://georaman2024.ntua.gr>

Note: Gemmology is one of the conference themes.

25th Federation for European Education in Gemmology (FEEG) Symposium

19 October 2024

Brussels, Belgium

<http://www.feeg-education.com/symposium>

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses

Gem-A, London

<https://gem-a.com/education>

American Society of Appraisers Courses for Gem and Jewellery Appraisers

January–May 2024

Online

Courses include ‘Foundation I: Fundamentals of Jewelry Appraisal’, ‘Core Principles of Appraising Gems and Jewelry’, ‘Foundation II: Appraising Gems & Jewelry for Insurance Scheduling’, and ‘Appraising Gems & Jewelry for Advanced Assignments: Development and Report Writing’

<https://learn.appraisers.org/gj-education>

Gemstone Safari to Tanzania

10–27 January 2024 and 3–20 July 2024

<https://www.free-form.ch/tanzania/gemstonesafari.html>

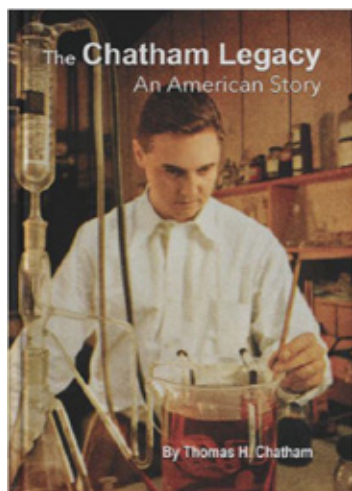
Lectures with The Society of Jewellery Historians

Society of Antiquaries of London, Burlington House

https://www.societyofjewelleryhistorians.ac.uk/current_lectures

- Sarah Laurenson—Crafting Colour Worlds in Scottish Stones
23 January 2024
- Melanie Eddy—Meditations on Form: Reflections on the Geometric Explorations of a Contemporary Jeweller
27 February 2024
- Frances Parton and Dora Thornton—Working with The Goldsmiths’ Company Jewellery Collection 1961–2024
23 April 2024
- Beatriz Chadour-Sampson—Jewellery by Johann Karl and Karl Thomas Bossard, Lucerne, from Historicism to Art Deco
28 May 2024
- Carolina Beatriz Naya—The Treasury of Our Lady of the Pillar
25 June 2024
- Jane Kershaw—Viking-age Jewellery
24 September 2024

New Media



The Chatham Legacy: An American Story

By Thomas H. Chatham, 2023. Thomas H. Chatham, Half Moon Bay, California, <https://www.chatham.com/products/the-chatham-legacy>, 219 pages, illus., ISBN 979-8987916100. USD90.00 hardcover.

In the fascinating and challenging realm of gemmology, we may sometimes encounter novel treatments or new cutting-edge synthetic materials that mimic natural stones, and some of these may require advancements in detection methods and the use of innovative testing equipment. Staying at the forefront of these emerging technologies can sometimes be exhilarating yet overwhelming. Rarely do we get a chance to delve into the minds of the creative forces driving our gem-centric world. Imagine the thrill of peeking behind the curtain and witnessing the significant breakthroughs in our industry. This is precisely the exhilarating treat that Thomas Chatham's sometimes chatty reminiscing offers us in the pages of this book.

It is a captivating odyssey of 37 chapters and 219 pages, brimming with illustrations (more than 120 of them, many full-page) of family and business photographs, correspondence, ads, and news articles that weave together the intriguing tales of Carroll Chatham's and Thomas Chatham's breakthroughs, setbacks, blind luck, challenges, and various legal battles over terminology with industry members, the Jewelers Vigilance Committee and the Federal Trade Commission (FTC). The book unravels the inspiring personal tales of these two tenacious men: Carroll's relentless

resilience complementing Thomas' unwavering perseverance as he followed in his father's footsteps. Together, their unyielding focus and single-mindedness revolutionised parts of the gem industry, introducing truly laboratory-grown—or 'created'—gems and establishing precise terminology to describe or label them. However, correctly identifying these gems and using precise terminology was challenging for decades.

The book features 'wow' moments, such as Carroll's initial attempts at creating emeralds (beginning in 1931), which usually met with failure. His understanding of chemistry prompted him to devise a furnace method to replicate crystal growth. He ingeniously crafted a furnace in his father's basement using a repurposed 20-gallon strawberry bucket with a factory clay lining and a basic resistance-wire heater. Carroll's first crucible was the size of a coffee cup and was made of platinum, which was more affordable back then. He also incorporated highly corrosive chemicals in his process. He set up a lamp that would shine when the furnace was operational to ensure an uninterrupted power supply.

One day, he started the oven and speculated that it would take weeks for the crystals to grow. He would check on them during a school break. So far, he had been unsuccessful. However, while he was away at college, his father unknowingly switched the power off after noticing the light on. Upon returning home, Carroll discovered a cold furnace and feared the element had burned out. The furnace was intact, to his relief, but the crucible had bulged and partially split open, revealing solid contents. When he broke it open, he was surprised to find minuscule emerald crystals inside. From his first experiments until that moment had taken nearly three years. Recreating these results took him another three years of relentless trials. His fellow students at the California Institute of Technology (California, USA), including Linus Pauling, urged him to publish an article about his work, but Carroll chose to keep his secrets. Unsuccessfully, Caltech tried to claim ownership of his work. They would not be the last.

The tenacity of Chatham is recounted over and over in this book, beginning with his thousands of experiments to produce gem-quality emeralds. The largest created to date is over 2,000 ct.

A December 1947 letter from Richard Liddicoat, then director of education at the Gemological Institute of America, provided another eye-opener because gem

identification was in its infancy: ‘...we doubt that it would be possible to teach a method of identification by recognition of the difference between inclusions in your product and in natural emerald,’ and ‘Most jewelers do not possess magnifying instruments of high enough power to resolve the tiny three-phase inclusions.’

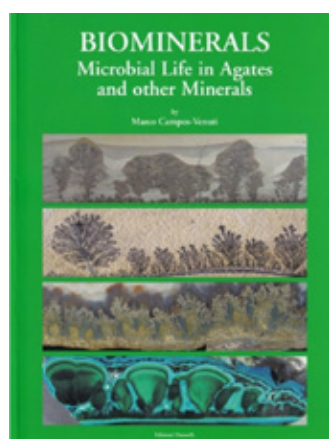
Another ‘wow’ moment came in 1955, during a nationwide (USA) live interview on the popular TV program *You Asked for It*, when Carroll Chatham showed viewers how to tell the difference between one of his emeralds and a natural, mined emerald. Using a natural 1 ct emerald of good quality purchased by the TV show from a local jeweller for comparison, Carroll said, ‘I am often asked how you can tell the difference between a Chatham stone and a natural stone. I have two emeralds being held by a thin wire. I am going to prove beyond a doubt which one is a Chatham, and which one is a mined stone.’ With two cameras rolling, one pointed toward the show’s host (Jack Smith) and the other on the two emeralds, Carroll lit a torch and heated both stones. The natural emerald exploded with a loud bang and the host gasped, realising that it was now in pieces. Nonchalantly, Carroll said, ‘Jack, I just proved that the stone that exploded was natural because it has water trapped in its structure. The Chatham stone is devoid of any water and is grown at 1000 degrees Celsius, so the torch won’t hurt it.’

The book also provides an enthralling account of the intense, four-year clash with the FTC surrounding the term *synthetic* and its relationship to Chatham’s laboratory-grown emeralds. The stalemate was eventually ended in court by the judge, who proposed the name ‘Chatham Created Emerald’. This relentless struggle devoured hundreds of thousands of dollars in legal fees, only for the FTC to concede.

Many will be captivated by Carroll’s and Thomas’ natural candour as they describe navigating industry judgements and trade-association biases, explaining why they took various approaches. I soon found myself taking sides with them, the perpetual underdogs. Some may find Thomas’ casual writing style off-putting, but it captured me. It felt personal, as if Thomas was in the room chatting quietly with me. The book chronicles their battles with competing manufacturers, their hands-on approach to creating various gems and, most notably, their foray into the world of laboratory-grown diamond production. The Chatham legacy has left an indelible mark on our industry, and this book provides insight after insight into the lives and passions of these two dynamic individuals.

Al Gilbertson

Gemological Institute of America
Carlsbad, California, USA



Biominerals: Microbial Life in Agates and Other Minerals

By Marco Campos-Venuti, 2022. Edizioni DanzaSi, Rome, Italy, <https://www.agatesandjaspers.com/product/biominerals>, 528 pages, illus., ISBN 978-8894582789. EUR85.00 softcover.

Biominerals is a large and profusely illustrated book. It is the third in a series on agates by Dr Marco Campos-Venuti, the first two being *Genesis and Classification of Agates and Jaspers: A New Theory* and *Banded Agates: A Genetic Approach*. (Disclaimer: This reviewer has not read the first two books.) In this volume, the author contends that many of the patterns seen in cryptocrystalline quartz and other ornamental materials can be ascribed to interaction with once-living organisms, resulting in ‘geometries that are difficult to explain by following the rules of classical mineralogy’.

I liked this book, although the text can be heavy going for two reasons. First, the topic of macroscopic effects of microbiological creatures requires ideas and terminology unfamiliar to most gemmologists. Second, English is not the author’s first language, thus adding another layer of unfamiliar words or phraseology (such as *chemismus* for chemistry in some places).

Dr Campos-Venuti's thesis is that many familiar structures in ornamental materials—dendrites, 'moss', plumes, spheroids in agates, and more—can be ascribed to the actions of microbes. (He speculates further that there may have been life on Mars, with meteorites from Mars possibly seeding Earth with life.) Microbes do not need light to grow; they need only water, an energy source—such as ions that can be found in more than one oxidation state (e.g. those of iron)—and a comfortable temperature regime. Agates form in environments that provide all of these, and many show signs of involvement with microscopic life. So do jaspers, ornamental materials from cave deposits (e.g. malachite) and dendrites that formed in fissures within quartz.

Some structures in the discussed materials show evidence of both biotic (life-derived) and abiotic (inorganic crystallisation) events. Each of these materials (and more) is illustrated with many coloured plates. Microbial remains also provide stratigraphic information, such as which way was up at the time

of formation. Some exotic quartz varieties, such as Brazilian (not Bolivian) ametrine and trapiche quartz, may also contain evidence of the presence or action of microbes.

The book is organised in sections based on how much space the organisms had to grow—from fissures to open caves. Unfortunately, there is no index, and some references cited in the text are not found in the otherwise exhaustive reference list. However, the many photos of agates, jaspers, and other ornamental materials—and the descriptions of the causes of their appearances—go far beyond compensating for these shortcomings. Even if you do not understand the biochemistry in the book, it is worthwhile to at least look at the pictures (more than 1,000 of them) and consider how the various highlighted features could have had a microbial origin.

Dr Mary L. Johnson

Mary Johnson Consulting
San Diego, California
USA



Magic Rock Crystal

Ed. by Manuela Beer (translated from the German *Magie Bergkristall*), 2022. Hirmer Verlag GmbH, Munich, Germany, 448 pages, illus., ISBN 978-3777440545. EUR55.00 hardcover.

This book was compiled and published to accompany the exhibition *Magie Bergkristall* held at the Schnütgen Museum in Cologne, Germany, from November 2022 to March 2023. *Magie Bergkristall* was a spectacular and groundbreaking exhibition of some 130 rock-crystal objects, primarily of medieval date. This book, however, is not a catalogue as such; it is a series of scholarly essays on many aspects of the historical uses of rock-crystal

quartz, taking the exhibition as a point of departure. The core of the exhibition consisted of high-quality, medieval rock-crystal objects in the Museum's collection, including finds from the 12th-century rock-crystal-cutting workshop near Cologne Cathedral.

The book is primarily about medieval objects, but sections on the earlier use and the nature of rock crystal itself lead into this. It has 34 chapters divided into five sections—'Introduction', 'From Mineral to Artefact', 'Rediscovery and Appropriation of Antiquity', 'Manifestation of Power and Beauty' and 'Seeing and Touching'—followed by endnotes and a copious bibliography. The absence of an index is a shame, but this is not unusual for multi-author, translated works.

The objects illustrated and discussed range from small items—such as beads, beautifully carved chess pieces and sword pommels—up to entire vessels carved from single pieces of rock crystal. Pride of place among the medieval works is a 14th-century ewer measuring over 26 cm high that is now in the Kunstkammer museum in Vienna (and is described in detail in the chapter by Franz Kirchweiger titled 'The Monolithic Ewer with Handle in Vienna').

Following the introductory chapters is Susanne Greiff's 'The Mineralogy of Rock Crystal: Anecdotes and Geological Realities'. She writes eloquently about the chemistry, structure and properties of rock crystal,

with relevant links to historical mentions. A table of the colour characteristics of the most important macro-crystalline quartz varieties provides a good overview, but the literature cited here seems overly specialist for the nature of the book. Incidentally, the table uses the spelling *citrin* rather than *citrine*, one of the few translation oversights I noted in the book.

There is neither the space nor the necessity to describe each chapter in any detail here, but they cover a fascinating range. Concerning pre-medieval use of rock crystal is Dietrich Boschung's 'Luxury from the Cold: Rock Crystals in Greek and Roman Antiquity'. He discusses knowledge of rock crystal in the ancient world and highlights some of the truly extraordinary surviving Roman vessels that were carved from single pieces of rock crystal. There is a chapter on rock crystal in the post-Roman early medieval period in Europe, from the fifth and sixth centuries: Genevra Kornbluth's 'Rock Crystal in the Early Middle Ages: Merovingian Amulets and Carolingian Intaglios'. She tackles the debate about the extent to which such objects were imported from the Byzantine world. Surprisingly, there is little about Early Byzantine rock-crystal objects in this volume, and pre-Classical Greek and Roman use is barely mentioned. Nor is there anything on the transformation of rock crystal, such as the use of blue-glazed rock-crystal before 2000 BCE in Egypt and Western Asia.

The important aspects of early trade and sources are covered by Julia Bruch in 'Rock Crystal as a Commodity: Sources and Routes – Craft and Trade'. She describes in some detail the rise of Baghdad as a working centre in the eighth century and then Cairo a couple of centuries later. Readers of this journal might be particularly interested to learn that recent excavations along the coast of East Africa strongly suggest that large pieces of rock crystal used in medieval Islamic workshops came from Madagascar.¹ By the fourteenth century, Paris and Vienna became equally proficient at creating rock-crystal vessels and other objects. Marcus Pilz continues with 'From Baghdad to Paris: Rock Crystal Carving in Mediterranean Culture Exchange', which deals at length with the Islamic production centres and their characteristics, and the transfer of both objects and manufacturing skills to Europe. Linking with this is a chapter on Venice as a working centre by Michela Agazzi: 'Production and Export of Rock Crystal Objects in the Middle Ages: The

Example of Venice'.

With the chapters on medieval use is a preponderance of non-secular objects, as might be expected. According to the book, some people suggested that the words *Christ* and *crystal* came from the same root. They don't, as Holger Kempkens explains in '*Christus crystallus*: Christological References in the Use of Rock Crystal'. Intriguing in this context is 'Rock Crystals on Medieval Sculptures' by Gerhard Lutz, who describes, among other things, rock-crystal cabochons on the bellies of a fourteenth-century representation of the Virgin Mary and Elizabeth, mother of John the Baptist.

There are chapters dealing with medieval reliquaries, with rock crystal typically forming the covers or windows through which sacred remains could be observed. Many such objects have survived into modern times, but a far greater number persisted into the Renaissance, and one fascinating chapter illustrates this—literally. Moritz Woelk's abundantly illustrated 'Rock Crystals in the *Hallesches Heuultum* of Cardinal Albrecht of Brandenburg' details the 1526–1527 inventory of the relic collection amassed by Albrecht of Brandenburg in Halle. Other chapters cover a reliquary on which oaths were taken, rock-crystal amulets, talismans and magic, including the use of crystal balls in divination.

Secular use is covered in 'Rock Crystal Objects as Insignia of Majesty and Status' by Karen Straub, and also by Kristen Lee Bierbaum's 'Rock Crystal at the Courtly Table'. An extraordinary two-sided chess/backgammon board with squares in red jasper and rock crystal over clay reliefs depicting mythical creatures is described by Thomas Schauerte in 'The Game Board in Aschaffenburg'.

An always fascinating topic is Bernd Lingelbach and Olaf Schmidt-Kiy's 'Did the Vikings have Perfect Magnifying Glasses? Rock Crystal as Optical Aid'. Lens-shaped pieces of rock crystal date back some 3,000 years, but whether they were used as magnifiers is a perennial debate. Of course, the principle of magnification was known, but the authors astutely note that the very short focal lengths mean that it would be impossible to do any work under such 'lenses'. They conclude that 'the Vikings likely used the lenses exclusively as jewellery'. Surprisingly, there is no mention of the possible use of these lenses for lighting fires by concentrating the rays of the sun. The ancient Greek writers Aristophanes and

¹ See Horton, M., Boivin, N., Crowther, A., Gaskell, B., Radimilahy, C. & Wright, H.T. 2017. East Africa as a source for Fatimid rock crystal: Workshops from Kenya to Madagascar. In: Hilgner, A., Quast, D. & Greiff, S. (eds) *Gemstones in the First Millennium AD: Mines, Trade, Workshops and Symbolism*. Römisch-Germanisches Zentralmuseum, Mainz, Germany, 103–118.

Socrates both mentioned lighting fires with lenses. Might the Viking lenses have been the pocket lighters of their day—at least their sunny ones?

A chapter on rock crystal in medieval European documentary sources (Christel Meier-Staubach in ‘Between Knowledge and the Realm of Legend: Rock Crystal in Medieval Sources’) covers a range of early manuscripts, some with exquisite illustrations that include one of particular interest to readers of this journal: a full-page image of the gem cutter at work from Conrad of Megenberg’s fourteenth-century *Das Buch der Natur*. Then there is a discussion about the popularity of lion heads carved in rock crystal (by Isabelle Bardiès in ‘The Lion, King of the Crystalline Bestiary’) and, of course, the reuse of early rock-crystal objects in later works covered by Hiltrud Westermann-Angerhausen in ‘Rock Crystal Objects in Reuse: Materiality and Bearer of Meaning’. Svenja Trübenbach’s ‘Fantastic Rock Crystal Objects in 15th- and 16th-Century Painting’ covers the ‘astonishing number’ of mostly northern European paintings that portray rock-crystal objects (often spheres).

All in all, this is a remarkable volume. Unlike some

books accompanying exhibitions, it is not dumbed down but rather deals with its topic in a serious but highly readable way. The extensive bibliographies guide those who want to pursue particular aspects in greater detail. My only minor criticism is that the English version of the book, as reviewed here, might have benefitted from another editorial once-over by a native-English speaker more conversant with mineralogy and history.

But this minor quibble pales in significance against the usefulness and value of the book as a whole. It is a major work of reference that deserves a place on the bookshelf of every gemmologist, mineralogist and historian, and with its magnificent and abundant illustrations of astonishing objects, on many a coffee table.

Editor’s note: Readers may be interested in an exhibition on the history of rock crystal from the Middle Ages to the present day taking place through 14 January 2024 at the Musée de Cluny – musée national du Moyen Âge in Paris, France.

Dr Jack M. Ogden FGA
London



Shells: A Natural and Cultural History

By Fabio Moretzsohn with M. G. Harasewych, 2023. Reaktion Books, London, <https://reaktionbooks.co.uk/work/shells>, 176 pages, illus., ISBN 978-1789147131 or e-ISBN 978-1789147438. GBP20.00 hardcover or eBook.

The subtitle for title *Shells—A Natural and Cultural History*—accurately describes the contents of this attractive small book. Author Dr Fabio Moretzsohn specialised in shells for many years. Among his earlier books is the shell

reference ‘bible’, *The Book of Shells*, which he wrote together with Dr M. G. Harasewych (who wrote the last two chapters and also did the final editing of the present book, as it was published posthumously).

The book is divided into nine chapters. The first, ‘The Shell Makers’, describes in some detail several of the species of the vast family of animals called molluscs, including their various characteristics, life cycles and now-fossilised ancestors.

Chapter 2, ‘Tribal Shell Use’, explores how humans have admired and used shells for more than 500,000 years, their utilitarian applications (e.g. as a musical instrument), and their use as status symbols in life and after death. It also describes the shells from which could be extracted the purple dye used to colour wool cloths that were ‘worth their weight in gold’.

Chapter 3, ‘Shells and Religion’, covers the symbolism of shells in various religions, and how they have been depicted through the centuries in paintings, carvings and statues of a religious nature. An example is the small scallop shell which represents pilgrims on the Camino de Santiago, the Christian pilgrimage to the shrine dedicated to St James in what is now Spain.

Shells have a long historical use as currency, as described in chapter 4, ‘Picking up Money on the

Beach'. The best-known shell type was a small cowrie, but money was also made by carving discs from giant clam shells. The smaller money shells were not carried in a bag but were usually worn.

Chapter 5, 'How the Cowrie Got Its Spots', goes into some detail on the structure of shells, especially the cowrie and how it produces the outer layer which, unlike other shell types, is not a thin, organic layer of material but rather is patterned and almost translucent.

Chapter 6, 'Iridescent Beauty', is about the pearls produced by various molluscs. The author states that pearls are the only gems produced by animals, a statement which may be literally correct but with which this reviewer would argue, as the *shells* of the animals producing the pearls have also been used as gems, as have many other materials from animals (e.g. coral, tortoiseshell, ivory, feathers and so forth). The author describes especially the lustrous pearls and how they have been used in jewellery, not forgetting La Peregrina and the huge, non-nacreous Pearl of Allah that was collected in 1934 from a giant clam in the Philippines.

Chapter 7, 'Shell in the Arts', tells of the myriad ways in which shells have been used in the arts—such as in carvings, jewellery and furniture—and illustrates the wide range of shells' attraction to artists through the ages, from Botticelli's *The Birth of Venus*, to Ursula Andress coming ashore carrying two queen conches in the James Bond film *Dr No*.

Chapter 8, 'Molluscs and Medicines', warns of some of the dangers of consuming molluscs due to their poisonous content or the parasites that they can carry.

However, in past times certain parts of some molluscs were used as cures for various ailments.

'Shells in a Changing World' is the title of chapter 9, which considers the impact humans have had on this very old family of animals: how we have used them, eaten them, and destroyed many of them by altering their habitats, so that many are now protected species.

The chapters are followed by several pages of references (listed by chapter) and a short bibliography.

From the jewellery/gemmology point of view, I couldn't help wishing that there had been more coverage of some topics, such as the many uses for the New Zealand *Pāua* (abalone) shell and pearl-oyster shells, including in beautiful and costly jewellery.

The author has used his own vast experience with shells, plus research on their history and uses, to look at the subject from all angles, resulting in a complete, interesting and attractive book. It is easily read and nicely presented on high-quality paper, and it contains lots of good illustrations throughout.

Is this a book that will be invaluable to gemmologists? No, but it is one that could awaken their interest in one of the less-studied materials—a subject about which the gemmology student learns a few facts and, sadly, often doesn't really see shell as a beautiful material in its own right. So, although not invaluable, it will make an excellent addition to the gemmologist's bookshelf.

Maggie Campbell Pedersen FGA
London

Other Book Titles

COLOURED STONES

The Other Lake Superior Agates

By John D. Marshall and Denise M. Harrison, 2023.
Self-published, 383 pages, ISBN 978-0997696387.
USD125.00 hardcover.

Virtuous Treasures: Chinese Jades for the Scholar's Table

By Humphrey Hui and Tina Yee-Wan Pang, 2023.
CA Book Publishing, Hong Kong, 224 pages, ISBN
978-9628038831. HK800.00 hardcover.

GENERAL REFERENCE

Crystals & Gems: From Mythical Properties to Magical Stories

2023. Dorling Kindersley Ltd, London, 192 pages,
ISBN 978-0241569924 or e-ISBN 978-0241650073.
GBP12.99 hardcover or GBP5.99 eBook.

Jewel: The Definitive Visual Guide

2023. Dorling Kindersley Ltd, London, 360 pages,
ISBN 978-0241601570 or e-ISBN 978-0241632949.
GBP35.00 hardcover or GBP9.99 eBook.

INSTRUMENTATION

Non-destructive Material Characterization Methods

Ed. by Akira Otsuki, Seiko Jose, Manasa Mohan and Sabu Thomas, 2023. Elsevier, Amsterdam, The Netherlands, 916 pages, ISBN 978-0323911504 or e-ISBN 978-0323984782, <https://doi.org/10.1016/C2020-0-04069-7>. USD330.00 softcover or eBook.

JEWELLERY HISTORY

Un Art Nouveau. Métamorphoses du Bijou/A New Art. Metamorphoses of Jewelry

By Rossella Froissart, 2023. Éditions Norma, Paris, France, 208 pages, ISBN 978-2376660750 (in French and English). EUR39.00 hardcover.

Bossard Luzern 1868–1997: Gold- und Silberschmiede, Kunsthändler, Ausstatter

Ed. by Christian Hörack, 2023. Arnoldsche Art Publishers, Stuttgart, Germany, 512 pages, ISBN 978-3897906617 (in German). EUR58.00 hardcover.

Cartier Design: A Living Legacy

By Ana Elena Mallet, Michel Aliaga, Eugenio López Alonso, Pierre Rainero and Cyrille Vigneron, 2023. Rizzoli, New York, New York, USA, 288 pages, ISBN 978-8891838995. USD65.00 hardcover.

Fabergé: The Twilight Years: Drawings and Objects from the Workshop of Henrik Wigström

By Ulla Tillander-Godenhjelm, 2023. Unicorn Publishing Group, London, 288 pages, ISBN 978-1911397670. GBP45.00 hardcover.

Stage Jewels of the Comédie-Française

Ed. by Guillaume Glorieux and Agathe Sanjuan, 2023. Gallimard/L'École, School of Jewelry Arts, Paris, France, 300 pages, ISBN 978-2073012456. EUR39.00 hardcover.

JEWELLERY AND OBJETS D'ART

Art d'Objet: Modern and Historic Masterpieces of Natural History Art

By Mark Mauthner and Dieter Heinlein, 2023. The Munich Show – Mineralientage München, Munich, Germany, 160 pages, ISBN 978-3921656969. EUR20.00 softcover.

The Art of David Webb: Jewelry and Culture

By Ruth Peltason, 2023. Rizzoli, New York, New York,

USA, 256 pages, ISBN 978-0847873333. USD85.00 hardcover.

Cartier: Le Voyage Recommencé—High Jewelry and Precious Objects

By François Chaille and Hélène Kelmachter, 2023. Flammarion, Paris, France, 256 pages, ISBN 978-2080430533. EUR95.00 hardcover.

Chaumet: Drawing from Nature

By Gaëlle Rio and Marc Jeanson, 2023. Thames & Hudson, London, 256 pages, ISBN 978-0500023815. GBP65.00 hardcover.

Dolce & Gabbana Alta Gioielleria: Masterpieces of High Jewellery

Ed. by Carol Woolton, 2023. Rizzoli, New York, New York, USA, 384 pages, ISBN 978-8891836946. USD125.00 hardcover.

Francesca Amfitheatrof: Fantastical Jewels

By Stefania Amfitheatrof, 2023. Rizzoli, New York, New York, USA, 264 pages, ISBN 978-0847873210. USD115.00 hardcover.

Pharrell: Carbon, Pressure & Time: A Book of Jewels

By Pharrell Williams, 2023. Rizzoli, New York, New York, USA, 216 pages, ISBN 978-0847899173. USD65.00 hardcover.

Women of Jewelry

By Linda Kozloff-Turner, 2023. 100 Women Publications, Denver, Colorado, USA, 602 pages, ISBN 978-1737218517. USD229.99 hardcover (two-volume set).

MISCELLANEOUS

Atlas

By Stuart Wilensky, Troy Wilensky and Evan D'Arpino, 2023. Wilensky Exquisite Minerals, New York, New York, USA, 65 pages, no ISBN. USD25.00 hardcover.

The Object at Hand: Intriguing and Inspiring Stories from the Smithsonian Collections

By Beth Py-Lieberman, 2023. Smithsonian Books, Washington DC, USA, 272 pages, ISBN 978-1588347497. USD29.95 hardcover.

Stones: A Material and Cultural History

By Cally Oldershaw, 2023. Reaktion Books, London, 296 pages, ISBN 978-1789147711 or e-ISBN 978-1789148183. GBP25.00 hardcover or eBook.

Literature of Interest

COLOURED STONES

Analysis of the causes of colours in blue and green chalcedony. J. Guo, R. Liao and L. Wang, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 29–38, www.gahk.org/journal/2023/a11.pdf (in Chinese with English abstract).*

The characteristics of Hetian jade (nephrite jade) pebbles. J. Liu, J. Li, S. Liu and L. Wang, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 63–70, www.gahk.org/journal/2023/a15.pdf (in Chinese with English abstract).*

Colorimetry characteristics and color contribution of fluorescence in natural Cr-containing spinel. J. Tang, Y. Guo and J. Zhang, *Scientific Reports*, **13**(1), 2023, article 2426 (11 pp.), <https://doi.org/10.1038/s41598-023-29675-w>.*

Comparative study on gemmological characteristics and luminescence of colorless and yellow scapolites. Y. Rao, Q. Guo, S. Zhang and L. Liao, *Crystals*, **13**(3), 2023, article 462 (12 pp.), <https://doi.org/10.3390/cryst13030462>.*

Comparative study on gemmological and mineralogical characteristics and coloration mechanism of four color types of fluorite. Y. Liu, Q. Guo, L. Liu, S. Zhang, Q. Li and L. Liao, *Crystals*, **13**(1), 2023, article 75 (11 pp.), <https://doi.org/10.3390/cryst13010075>.*

Crystal chemical features of green and light-blue amazonite and geochemical aspects of their formation processes. T.M. Lupashko, A.N. Tarashchan, K.O. Ilchenko and E.E. Grechanovskaya, *Mineralogical Journal*, **45**(1), 2023, 21–40, <https://doi.org/10.15407/mineraljournal.45.01.021> (in Ukrainian with English abstract).*

Crystal-chemical and spectroscopic study of gem sphalerite from Banská Štiavnica, Slovakia. P. Bačík, J. Fridrichová, O. Rybníková, J. Štubňa, Ľ. Illášová, R. Škoda, T. Vaculovič, Z. Pulišová *et al.*, *Minerals*, **13**(1), 2023, article 109 (13 pp.), <https://doi.org/10.3390/min13010109>.

The effects of excess iron on the properties of chrysoberyl. S. Noh, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 72–78, www.gahk.org/journal/2023/a16.pdf.*

Etch pits in heliodor and green beryl from the Volyn pegmatites, northwest Ukraine: A diagnostic feature. G. Franz, O.A. Vyshnevskiy, V.M. Khomenko, P. Lyckberg and U. Gernert, *Gems & Gemology*, **59**(3), 2023, 324–339, <https://doi.org/10.5741/gems.59.3.324>.*

Un exceptionnel zircon photochrome de 9,89 carats [An exceptional photochromic zircon of 9.89 carats]. F. Blumentritt and F. Notari, *Gemmes*, No. 1, 2023, 15–17, <https://tinyurl.com/2pdw62mt> (in French with English abstract).*

Gemmological characteristic of pink spinel from Yên Bái, Vietnam. Y. Wu and J. Di, *Journal of Gems & Gemmology*, **25**(2), 2023, 11–20, <https://tinyurl.com/mr4cybnj> (in Chinese with English abstract).*

The gemmological characteristics of opal from Lightning Ridge, Australia. J. Yang, X. He, C. Yun and Y. Ye, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 83–89, www.gahk.org/journal/2023/a18.pdf (in Chinese with English abstract).*

Gemmological and mineralogical characteristics of lapis lazuli. M. Zhang, Z. Wang, Q. Zheng, C. Suqiao and F. Wang, *Journal of Gems & Gemmology*, **25**(3), 2023, 54–59, <https://tinyurl.com/43cbdd2n> (in Chinese with English abstract).*

Gemmological and spectral characteristics of pink garnet from Mogok, Myanmar. L. Zhang, B. Lin, S. Wan, T. Chen and Q. Zhang, *Journal of Gems & Gemmology*, **25**(3), 2023, 16–21, <https://tinyurl.com/f34436se> (in Chinese with English abstract).*

Gemmological characteristics and color genesis analysis of “Dubai Jade”. Y. Qiu and X. He, *TGI*

Taiwan Gemmological Institute & Gem Lab, 2023, 84–90 (in Chinese with English abstract).

Gemmological and chemical characterization of varicolored gem-grade spinel from Mogok, Myanmar. Y. Zhao, B. Xu, Z. Zhao, Q. Xu and Z. Li, *Crystals*, **13**(3), 2023, article 447 (18 pp.), <https://doi.org/10.3390/cryst13030447>.*

Gemmological and luminescence characteristics of taaffeites from Mogok, Myanmar. B. Lin, X. Li, L. Zhang, X. Lai and Q. Zhang, *Minerals*, **13**(3), 2023, article 346 (11 pp.), <https://doi.org/10.3390/min13030346>.*

Gemmological and mineralogical characteristics of emerald from Ethiopia. Z. Huang, G. Li, L. Weng and M. Zhang, *Crystals*, **13**(2), 2023, article 233 (17 pp.), <https://doi.org/10.3390/cryst13020233>.*

Genesis of the body color of Brazilian gem-quality yellow-green opal. H. Lv and Y. Guo, *Crystals*, **13**(2), 2023, article 316 (13 pp.), <https://doi.org/10.3390/cryst13020316>.*

Growth heterogeneity and zonation characteristics of emeralds from Daxin, Xinjiang. D. Cui, Q. Wu, Z. Liao, L. Qi, Z. Zhou, L. Zhang, Q. Zhong and L. Yiceng, *Earth Science Frontiers*, **30**(2), 2023, 410–414, <https://www.earthsciencefrontiers.net.cn/EN/10.13745/j.esf.sf.2021.11.9> (in Chinese with English abstract).

The hardness of fei cui: A gemmological perspective. K. Khourie, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 45–57, www.gahk.org/journal/2023/a13.pdf.*

Inclusions communes et rares dans l'aigue-marine [Common and rare inclusions in aquamarine]. M. Bouvier, *Gemmes*, No. 1, 2023, 39–45, <https://tinyurl.com/2pdw62mt> (in French with English abstract).*

Jedi spinel from Man Sin, Myanmar: Color, inclusion, and chemical features. Y. Gao, M. He, X. Sun, C. Zhen, H. Li, X. Wei and Y. Zhao, *Crystals*, **13**(1), 2023, article 103 (24 pp.), <https://doi.org/10.3390/cryst13010103>.*

Locality determination of inky black omphacite jades from Myanmar and Guatemala by nondestructive analysis. B. Xing, G. Shi, T. Long and M.

Shih, *Journal of Raman Spectroscopy*, **53**(11), 2022, 2009–2018, <https://doi.org/10.1002/jrs.6436>.

Micro-PIXE and micro-IBIL characterization of lapis lazuli samples from Myanmar mines and implications for provenance study. L. Guidorzi, A. Re, M. Magalini, D. Angelici, A. Borghi, G. Vaggelli, F. Fantino, V. Rigato *et al.*, *European Physical Journal Plus*, **138**(2), 2023, article 175 (13 pp.), <https://doi.org/10.1140/epjp/s13360-023-03768-x>.*

A multi-strategy linear discriminant analysis (LDA) method coupled with laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for discriminating the geographical origin of nephrite. Y. Su and M. Yang, *Journal of Analytical Atomic Spectrometry*, **38**(3), 2023, 667–680, <https://doi.org/10.1039/d2ja00386d>.

Nouvelles considérations sur la sodalite-hackmanite de la région de Mogok, Myanmar [New considerations of sodalite-hackmanite from the Mogok region, Myanmar]. E. Fritsch, N. Hébert, F. Blumentritt and C. Moinard, *Gemmes*, No. 1, 2023, 32–38, <https://tinyurl.com/2pdw62mt> (in French with English abstract).*

Origin characteristics of Sr and Pb isotopes of turquoise from Guaiyu mining site in Lushi County, Henan Province. H. Ai, Y. Xian, Y. Wang, C. Yu, Y. Liang, W. Bao, Y. Chen and Q. Chen, *Acta Petrologica et Mineralogica*, **42**(2), 2023, 250–262 (in Chinese with English abstract).*

Petrogenesis of chatoyant green nephrite from serpentinite-related deposits, Ospinsk, Russia: Insights from mineralogy and geochemistry. W. He, F. Bai, C. Zhao, H. Qu and X. Li, *Crystals*, **13**(2), 2023, article 252 (25 pp.), <https://doi.org/10.3390/cryst13020252>.*

Purple-violet gem spinel from Tanzania and Myanmar: Inclusion, spectroscopy, chemistry, and color. J. Wu, X. Sun, H. Ma, P. Ning, N. Tang, T. Ding, H. Li, T. Zhang *et al.*, *Minerals*, **13**(2), 2023, article 226 (22 pp.), <https://doi.org/10.3390/min13020226>.*

Shortwave UV blue luminescence of some minerals and gems due to titanate groups. M. Vigier, E. Fritsch, T. Cavignac, C. Latouche and S. Jobic, *Minerals*,

13(1), 2023, article 104 (17 pp.), <https://doi.org/10.3390/min13010104>.*

Silicification of wood: An overview. G.E. Mustoe, *Minerals*, **13**(2), 2023, article 206 (46 pp.), <https://doi.org/10.3390/min13020206>.*

Spatial distribution of Fe²⁺ in the tetrahedral structural position of Be²⁺ in crystals of natural beryl. M.M. Taran and O.A. Vyshnevskiy, *Mineralogical Journal*, **45**(2), 2023, 16–31, <https://doi.org/10.15407/mineraljournal.45.02.016-d> (in Ukrainian with English abstract).*

Special colors and optical effects of Oregon sunstone: Absorption, scattering, pleochroism, and color zoning. S. Jin, A.C. Palke, N.D. Renfro and Z. Sun, *Gems & Gemology*, **59**(3), 2023, 298–322, <https://doi.org/10.5741/gems.59.3.298>.*

Spectra characterization of Cr-grossular (tsavorite) with “frogspawn” color zoning from Canada. X. Mao, C. Chen, Z. Yin and Z. Wang, *Spectroscopy and Spectral Analysis*, **43**(2), 2023, 520–525, <http://www.gpxygpfx.com/EN/Y2023/V43/I02/520> (in Chinese with English abstract).*

Study on the chromogenic mechanism of violet-red to orange-red spinel. Y. Du and Y. Guo, *Crystals*, **13**(2), 2023, article 339 (13 pp.), <https://doi.org/10.3390/cryst13020339>.*

Study on difference of color genesis between yellow and brown tremolite jade. Y. Liu, Z. Zhou, X. Yang, Y. Chen, W. Ruan and L. Zhang, *TGI Taiwan Gemmological Institute & Gem Lab*, 2023, 53–59 (in Chinese with English abstract).

Study on gemological characteristics and inclusions of yellow topaz. Z. Song, Q. Guo and L. Liao, *Crystals*, **12**(12), 2022, article 1746 (8 pp.), <https://doi.org/10.3390/cryst12121746>.*

Yellow sapphire: Natural, heat-treated, beryllium-diffused, and synthetic. J.L. Emmett, U. Atikarnsakul, J. Stone-Sundberg and S. Sangsawong, *Gems & Gemology*, **59**(3), 2023, 268–297, <https://doi.org/10.5741/gems.59.3.268>.*

CULTURAL HERITAGE

The hand of the connoisseur: Gems and hardness in Enlightenment mineralogy. M. Bycroft, *History of Science*, **60**(4), 2022, 500–523, <https://doi.org/10.1177/00732753221087558>.

Identification of a source of nephrite from late Shang Yinxu by multispectral imaging. D. Chen, J. Tang, M. Yu, Y. Yang and C. Wang, *Heritage Science*, **11**(1), 2023, article 4 (12 pp.), <https://doi.org/10.1186/s40494-022-00849-5>.*

A non-destructive analytical study of cultural heritage object from Late Antiquity: Gold framework and gemstone inlays. R. Hanus, K. Sobek, K. Souček, L. Staš, L. Georgiou and A. Selucká, *Heritage Science*, **11**(1), 2023, article 33 (11 pp.), <https://doi.org/10.1186/s40494-023-00874-y>.*

Non-invasive analyses of Italian “Ostrogothic” jewellery: The Desana treasure. M. Aceto, E. Calà, F. Robotti, J.P. Gil, S. Castronovo, M. Gulmini, M. Labate and A. Agostino, *Heritage*, **6**(2), 2023, 1680–1697, <https://doi.org/10.3390/heritage6020089>.*

DIAMONDS

Comparative analysis of spectral characteristics and color origin of chameleon diamond and similar yellow diamond. Y. Li, Z. Song, D. Han, Y. Xu and H. Liu, *Rock and Mineral Analysis*, **42**(3), 2023, 491–501, <https://tinyurl.com/3vznuars> (in Chinese with English abstract).*

Eclogite: Diamond-encrusted ancient seafloor. E.M. Smith and M.F. Hardman, *Gems & Gemology*, **59**(3), 2023, 380–386, <https://tinyurl.com/42d8wnna>.*

Going inside a diamond. F. Nestola, M.G. Pamato and D. Novella, in L. Bindi & G. Cruciani, Eds., *Celebrating the International Year of Mineralogy*. Springer, Cham, Switzerland, 2023, 249–263, https://doi.org/10.1007/978-3-031-28805-0_10.

Imperfections in natural diamond: The key to understanding diamond genesis and the mantle. M.C. Day, M.G. Pamato, D. Novella and F. Nestola, *La Rivista del Nuovo Cimento*, **46**(7), 2023, 381–471, <https://doi.org/10.1007/s40766-023-00045-6>.*

Spectroscopic characteristics of a natural diamond suspected of synthetic diamond. H. Zhu, Y. Cheng, S. Chen, C. Fan, T. Li, H. Liu, X. Zhao, G. Shan *et al.*, *Spectroscopy and Spectral Analysis*, **43**(6), 2023, 1690–1696, <http://www.gpxygpx.com/EN/Y2023/V43/I06/1690> (in Chinese with English abstract).*

Sublithospheric diamond ages and the super-continent cycle. S. Timmerman, T. Stachel, J.M. Koornneef, K.V. Smit, R. Harlou, G.M. Nowell, A.R. Thomson, S.C. Kohn *et al.*, *Nature*, **623**, 2023, 752–756, <https://doi.org/10.1038/s41586-023-06662-9>.*

FAIR TRADE

Blockchain adoption in the supply chain – A game theoretic perspective: The case of the diamond industry. S.R. Gordon, R. Gilleran, G. Shankararayanan, D.B. Stoddard and B.A. Johnson, *Journal of Information Technology Case and Application Research*, **25**(3), 2023, 241–276, <https://doi.org/10.1080/15228053.2023.2234267>.

Blue print: The African mining vision. *Gemmology Today*, September 2023, 20–26, <https://tinyurl.com/bw3mhxbv>.*

Le chemin de la durabilité [The path to sustainability]. C. Picard, *Gemmes*, No. 1, 2023, 10–14, <https://tinyurl.com/2pdw62mt> (in French with English abstract).*

GEM LOCALITIES

An assessment of multi-criteria predictive model for alluvial sapphire exploration in Belel and environs, Adamawa Yadé-domain, northern Cameroon. M.I.N. Fru, C.E. Suh, A.W. Tende, F.V. Embui and T.A. Carrino, *Journal of Sedimentary Environments*, **8**(1), 2023, 97–113, <https://doi.org/10.1007/s43217-022-00122-6>.

The Burmese jade mines belt: Origins of jadeitites, serpentinites, and ophiolitic peridotites and gabbros. M.P. Searle, R.M. Palin, N.J. Gardiner, K. Htun and J. Wade, *Journal of the Geological Society*, **180**(4), 2023, article jgs2023-004 (15 pp.), <https://doi.org/10.1144/jgs2023-004>.*

Collector's Note: Indicolite discovery at the Mt. Mica Pegmatite, Oxford County, Paris, Maine. G. Freeman, *Rocks & Minerals*, **98**(6), 2023, 554–557, <https://doi.org/10.1080/00357529.2023.2235985>.

Der Fluss „Achates“ in Sizilien: Historie – Irrtümer – Neuordnung [The river 'agates' in Sicily: History – mistakes – reassignment]. R. Schmidt, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **72**(1/2), 2023, 3–24 (in German with English abstract).

Iolite from the Thor-Odin dome, British Columbia, Canada: Geology, chemical composition, inclusions, and cause of chatoyancy. P.M. Belley, *Gems & Gemology*, **59**(3), 2023, 340–355, <https://doi.org/10.5741/gems.59.3.340>.*

A method for detrital corundum characterization in sediments: Case study of the Gem Mountain mine placer sapphire deposit (Rock Creek, Montana, USA). P.M. Belley, *Canadian Journal of Mineralogy and Petrology*, **61**(1), 2023, 61–85, <https://doi.org/10.3749/2200033>.

The mineralogy of the gem-bearing miarolitic pegmatites and hydrothermal veins at Phnom Bayong, Kirivong, Takeo Province, Cambodia. P.C. Piilonen, I. Lykova, G. Poirier, R. Rowe, K. Shepherd, M. Bainbridge, R. Barlow and S. Ly, *Rocks & Minerals*, **98**(4), 2023, 310–327, <https://doi.org/10.1080/00357529.2023.2192165>.

Mineralogy, geochemistry, and genesis of agates from Chihuahua, northern Mexico. M. Mrozik, J. Götze, Y. Pan and R. Möckel, *Minerals*, **13**(5), 2023, article 687 (31 pp.), <https://doi.org/10.3390/min13050687>.*

Moldavit-Abbau in Chlum, Tschechien [Moldavite mining in Chlum, Czech Republic]. T. Stephan, Š. Jaroměřský, L. Zahradníček and S. Müller, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **72**(1/2), 2023, 41–56 (in German with English abstract).

Nyrdvomenshor nephrite deposit, Polar Urals, Russia. E.V. Kislov, M.P. Popov, F.M. Nurmukhametov, V.F. Posokhov and V.V. Vanteev, *Minerals*, **13**(6), 2023, article 767 (8 pp.), <https://doi.org/10.3390/min13060767>.*

Opale aus Honduras [Opal from Honduras]. U. Henn, S. Müller, Q. Wang and A. Seibt, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **72**(1/2), 2023, 25–40 (in German).

The revival of Ceylon sapphires captured in the photos of the resilient artisanal mining. F. Natale, *IGR: Rivista Italiana de Gemmologia/Italian Gemmological Review*, No. 17, 2023, 41–46.

INSTRUMENTATION AND TECHNOLOGY

Artificial intelligence in images and beyond. R. Weldon, *GemGuide*, **42**(5), 2023, 4–6.

Conventional instrumentation to distinguish between inlaid blue chalcedony and blue opal: Application of polarized light imaging technology. M. Shen and T. Wang, *TGI Taiwan Gemmological Institute & Gem Lab*, 2023, 20–23.

Fluorescence and phosphorescence spectroscopies and their applications in gem characterization. Z. Zhang and A. Shen, *Minerals*, **13**(5), 2023, article 626 (15 pp.), <https://doi.org/10.3390/min13050626>.*

LA-ICP-MS imaging analysis of gem-quality tourmaline: A novel method for direct identification of chromophore in gemstone samples. T. Luo, *Atomic Spectroscopy*, **44**(1), 2023, 1–7, <https://doi.org/10.46770/as.2022.249>.*

Non-invasive grading technique for ruby gemstone using charge-coupled device (CCD). F. Mohd Rahalim, J. Jamaludin and S.N. Raisin, *ASEAN Engineering Journal*, **13**(1), 2023, 69–74, <https://doi.org/10.11113/aej.v13.18267>.*

Research on the influence of standard illuminants on the color digitization of ruby. X. Yang, X. Wang, Y. Zhu, T. Yang, L. Li, W. Huang, S. Li, M. Li *et al.*, *International Conference on Optoelectronic Information and Functional Materials (OIFM 2023)*, 2023, article 127811C (5 pp.), <https://doi.org/10.1117/12.2687809>.

JEWELLERY HISTORY

Fabergé hardstone in imperial gifting from Russia to England. C.C. Sparke, in L. Hardiman,

Ed., *Courtly Gifts and Cultural Diplomacy*. Royal Collection Trust and Brill Deutschland, Paderborn, Germany, 2023, 193–219, https://doi.org/10.30965/9783657793761_009.

London ringmakers' marks from the seventeenth century. D. Mitchell and H. Forsyth, *Jewellery Studies—The Journal of The Society of Jewellery Historians*, No. 2, 2023, 3–26, https://www.societyofjewelleryhistorians.ac.uk/JSO_2023_2.pdf.*

LAPIDARY TOPICS

Game changers: The artisans. N. Zolotukhina, *Gemmology Today*, September 2023, 76–80, <https://tinyurl.com/36rkrvdy>.*

NEWS PRESS

Fuli ramps up peridot mining operations. E. Anniss, *Financial Times*, 5 October 2023, www.ft.com/content/4dd96f87-2f9f-491f-b6df-998285099466.*

G7 to phase in direct, indirect bans of Russian diamonds from Jan. 1. J. Payne, Reuters, 6 December 2023, www.reuters.com/world/europe/g7-phase-direct-indirect-bans-russian-diamonds-jan-1-2023-12-06.*

Soon you may know exactly where your diamond was mined. V. Gomelsky, *New York Times*, 20 November 2023, www.nytimes.com/2023/11/20/fashion/jewelry-diamond-origin-tracing-de-beers.html.*

Uncut gems: Are they worth the gamble? N. Foulkes, *Financial Times*, 5 November 2023, www.ft.com/content/03d84a2d-dc81-461a-94d1-63325bec68c6.*

US lab-grown diamond producer [WD Lab Grown Diamonds] files for bankruptcy. H. Dempsey, *Financial Times*, 12 October 2023, www.ft.com/content/cf288769-2af9-4bc2-bbd9-b1182d93c62f.*

ORGANIC/BIOGENIC GEMS

Five years of the ivory ban in China: Developments, limitations, and potential for improvement. Y. Chen, Y. Wang and H.S. Mumby, *Biological Conservation*, **284**, 2023, article 110177 (5 pp.), <https://doi.org/10.1016/j.biocon.2023.110177>.

Precious coral terminology. R. Galopim de Carvalho, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 21–23, www.gahk.org/journal/2023/a9.pdf.*

Spectral characteristics of unique species of Burmese amber. Z. Shi, C. Xin and Y. Wang, *Minerals*, **13**(2), 2023, article 151 (17 pp.), <https://doi.org/10.3390/min13020151>.*

PEARLS

Deciphering the color origin of pink conch pearl using nondestructive spectroscopies and DFT calculations. C. Chen, J. Yu, X. Ye and A.H. Shen, *Minerals*, **13**(6), 2023, article 811 (14 pp.), <https://doi.org/10.3390/min13060811>.*

Natural wonders: Pearls. L. Langeslag, *Gemmology Today*, September 2023, 50–55, <https://tinyurl.com/47tubkc9>.*

Spectrum and chemical composition characteristics between white “freshwater akoya pearls” and akoya pearls. X. Zhao, L. Li, Z. Chen and S. Li, *Journal of Gems & Gemmology*, **25**(2), 2023, 32–41, <https://tinyurl.com/ch78jns7> (in Chinese with English abstract).*

SIMULANTS

Gemmological characteristic and density genesis of high density colourless synthetic cubic zirconia. X. Wu, S. Pan, J. Shu and Y. He, *Journal of Gems & Gemmology*, **25**(3), 2023, 60–67, <https://tinyurl.com/3np8yws7> (in Chinese with English abstract).*

Gemmological characteristic of sugilite imitation. Y. Chen, L. Wang, F. Zhang, M. Ge and H. Wang, *Journal of Gems & Gemmology*, **25**(3), 2023, 68–73, <https://tinyurl.com/3daspmk7> (in Chinese with English abstract).*

Preliminary study on forgery identification of Hetian jade with instrumental neutron activation analysis. K. Nangeelil, P. Dimpfl, M. Mamtimin, S. Huang and Z. Sun, *Applied Radiation and Isotopes*, **191**, 2023, article 110535 (6 pp.), <https://doi.org/10.1016/j.apradiso.2022.110535>.

SYNTHETICS

Blue CVD synthetic diamond coloured by SiV and GR1 defects. X. Zhang, Z. Sing, Y. Wang, M. Li, M.

Liu and B. Gao, *Journal of Gems & Gemmology*, **25**(3), 2023, 1–6, <https://tinyurl.com/5cpetups> (in Chinese with English abstract).*

Gemmological and spectral characteristics of a new type of emerald synthesized by the hydrothermal method. H. Zhu, Y. Cheng, Z. Li, X. Ma, X. Ding, C. Fan, Z. Zhao, S. Chen *et al.*, *Rock and Mineral Analysis*, **42**(2), 2023, 307–316, <https://tinyurl.com/2pbkevr5> (in Chinese with English abstract).*

Past, present, and the future of the research and commercialization of CVD diamond in China. F.X. Lu, *Functional Diamond*, **2**(1), 2022, 119–141, <https://doi.org/10.1080/26941112.2022.2144769>.*

Pure genius: The rise of CVD laboratory-grown diamond. B. West, *Gems&Jewellery*, **32**(3), 2023, 36–38.

Running scared: Lab-grown diamonds. G. Dominy, *Gemmology Today*, September 2023, 6–15, <https://tinyurl.com/mr952juh>.*

Spectral characteristic and colour genesis of a kind of pink synthetic opal. J. Wu, H. Ma and H. Li, *Journal of Gems & Gemmology*, **25**(2), 2023, 42–49, <https://tinyurl.com/bde55r4m> (in Chinese with English abstract).*

Synergistic influences of titanium, boron, and oxygen on large-size single-crystal diamond growth at high pressure and high temperature. G. Zhou, Y. Mu, Y. Song, Z. Zhang, Y. Zhang, W. Shen, Q. Wang, B. Wan *et al.*, *Chinese Physics B*, **31**(6), 2022, article 068103 (7 pp.), <https://doi.org/10.1088/1674-1056/ac4650>.

Synthetische Korunde, hergestellt im Kyropoulos-Verfahren [Synthetic corundum, produced by the Kyropoulos method]. L. Ackermann and T. Stephan, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **72**(1/2), 2023, 57–62 (in German with English abstract).

Synthétiser des diamants au laboratoire comme ils se forment dans la nature [Synthesise diamonds in the laboratory as they form in nature]. H. Bureau, *Gemmes*, No. 1, 2023, 18–23, <https://tinyurl.com/2p-dw62mt> (in French with English abstract).*

TREATMENTS

Alert: New artificially colour treated fei cui jewellery – Applying colour through electroplating.

M. Ou Yang, E. Fan and H. Yen, *Journal of The Gemmological Association of Hong Kong*, **44**, 2023, 80–81, www.gahk.org/journal/2023/a17.pdf (in Chinese with English abstract).*

Characterization and comparison of natural and Zachery-treated turquoise: New data. V. Diella, M. Cantaluppi, R. Bocchio, E. Possenti, I. Adamo, G. Della Ventura, L. Mancini and N. Marinoni, *Physics and Chemistry of Minerals*, **50**(3), 2023, article 50 (14 pp.), <https://doi.org/10.1007/s00269-023-01241-w>.

Comparison of the microscopic characteristics of beryl before and after heat treatment. X. Chen, T. Chen, J. Zheng, N. Cao, X. Xu, Y. Zhuang and Z. Wang, *Journal of Gems & Gemmology*, **25**(3), 2023, 22–35, <https://tinyurl.com/yc2cdwfc> (in Chinese with English abstract).*

The detection of a [coated] green topaz sample. M. Zeng and Z. Luo, *Superhard Material Engineering*, **35**(3), 2023, 57–61, <https://tinyurl.com/yc8r867m> (in Chinese with English abstract).

Our friends the inclusions. The detective at the party of inclusions. Fifteenth episode [corundum treatments]. L. Costantini and C. Russo, *IGR: Rivista Italiana de Gemmologia/Italian Gemmological Review*, No. 17, 2023, 7–11.

Preliminary study on the experiment of nephrite bracelet soaked in colorless oil. Y. Xiong, Z. Xu and B. Wei, *Superhard Material Engineering*, **35**(2), 2023, 57–60, <https://tinyurl.com/akcr3yes> (in Chinese with English abstract).

Spectroscopic characteristic of irradiated and annealed blue type Ia diamond. S. Xu, Y. Xia and W. Qu, *Journal of Gems & Gemmology*, **25**(2), 2023, 1–5, <https://tinyurl.com/ycxhfn8y> (in Chinese with English abstract).*

Study on spectroscopic characteristics of turquoise treated with phosphate and porcelain. A. Zhao, Q. Chen, X. Zheng, X. Li, Y. Wu and P. Bao, *Spectroscopy and Spectral Analysis*, **43**(4), 2023, 1192–1198, <http://tinyurl.com/57d9sdwp> (in Chinese with English abstract).*

COMPILATIONS

G&G Micro-World. Breyite in diamond • Columbite crystals in topaz • Diamond inclusions resembling a *gada* • Iridescent inclusions in brown diamond • Diamond with twinning wisps resembling a whale • Gas bubbles in garnet-and-glass doublet • Heliodor with large schorl inclusions • Blade-like magnetite in Burmese peridot • Zigzag ‘fingerprint’ in Sri Lankan sapphire • Fissure with moiré pattern in spinel • Large stellate dislocation in spinel • Tourmaline in emerald • Turquoise sphere resembling planet Earth • Dravite in fluorapatite. *Gems & Gemmology*, **59**(3), 2023, 370–379, <https://tinyurl.com/3fy8edv7>.*

Gem News International. Burmese “chameleon” amber • Iridescent andradite from Inner Mongolia • Zigzag growth lines in aquamarine • Blackish green omphacite jade from Guatemala • Blister on *Isognomon isognomon* shell • Basalt-related gems from Southeast Vietnam • Donna Jewel survey of colored stone preferences • Mantle eclogite xenolith with inclusion-bearing diamond • Sustainability assessment of Cygnet Bay Pearl Farm in Australia • Chicago Responsible Jewelry Conference • Turquoise United conference • *Gems & Gemmology*, **59**(3), 2023, 388–412, <http://tinyurl.com/ykvr2k4>.*

Lab Notes. Chameleon diamond with ‘naturals’ showing etch features • Diamond with unusual phosphorescence • Type IIa diamond with unusual red fluorescence distribution • ‘Etch’ channel in a CVD synthetic diamond • CVD synthetic diamond with few diagnostic features • Ring made of CVD synthetic diamond • ‘Bombay bunch’ of natural pearls • Flame-like structure on nacreous bead-cultured pearl • Natural pearls set in Indian nose rings • Fractures in ruby healed with Be-rich flux • Ruby filled with Zn-bearing glass. *Gems & Gemmology*, **59**(3), 2023, 356–369, <https://tinyurl.com/ywa6rz9p>.*

CONFERENCE PROCEEDINGS

Fossil Record in Resins and Sediments: Book of Abstracts. 23–26 May 2023, Gdańsk, Poland, 122 pp., https://amberfossil.ug.edu.pl/book_fossilrrs.*

International Gemmological Conference. 23–27 October 2023, Tokyo, Japan, 176 pp., <https://tinyurl.com/y8tdyywt>.*

*Article freely available for download, as of press time

Over 110 years of experience in gemmology education

**Our FGA and DGA Members are located around the world
– join them by studying with Gem-A in one of three ways**

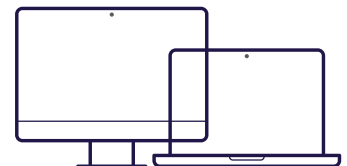
AT GEM-A HQ
London



WORLDWIDE
at one of our ATCs



ONLINE
with in-person
practical lab classes



Find out more by contacting: education@gem-a.com

Buy Gem-A Instruments online



**OVER 100
PRODUCTS
AVAILABLE**

View the full collection and offers at: **shop.gem-a.com**



Gem-A

THE GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN



Gem-A, 21 Ely Place, London, EC1N 6TD, UK
+44 (0)20 7404 3334 www.gem-a.com.
Registered charity no. 1109555

CREATING GEMMOLOGISTS SINCE 1908

