The Journal of Gemmology

Volume 35 / No. 7 / 2017

Gem-A THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Gemmological Association of Great Britain

SSEF SCHWEIZERISCHES GEMMOLOGISCHES INSTITUT SWISS GEMMOLOGICAL INSTITUTE INSTITUT SUISSE DE GEMMOLOGIE

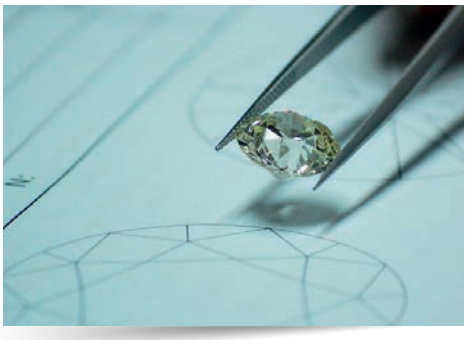
SSEF

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™

Aeschengraben 26, 4051 Basel, Switzerland Tel. +41 61 262 06 40 Fax + 41 61 262 06 41 admin@ssef.ch www.ssef.ch

The Journal of Gemmology
Volume 35 / No. 7 / 2017

COLUMNS

Cover Photo:

This cloisonné-style disc brooch (5.75 cm in diameter, from Unterhaching, near Munich, Germany) is set with thin, doubly polished garnet plates of up to 2.8 cm long and 1 mm thick. The origin of such garnets in early medieval European jewellery is widely debated and often attributed to India. A provenance study focusing on Indian garnet beads appears on pages 598–627 of this issue. Photo by M. Eberle, © Archäologische Staatssammlung, Munich, Germany.


p. 581
S. Bruce-Lockhart photo


p. 586
Thanh Nhan Bui photo

ARTICLES

Feature Articles

The Journal is published by Gem-A in collaboration with SSEF and with the support of AGL and GIT.

ISSN: 1355-4565, http://dx/doi.org/10.15506/JoG.2017.35.7

The Journal of Gemmology

Content Submission

The Editor-in-Chief is glad to consider original articles, news items, conference/excursion 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 www.gem-a.com/index.php/news-publications/publications/journal-of-gemmology/submissions, or contact the Production Editor.

Subscriptions

Gem-A members receive *The Journal* as part of their membership package, full details of which are given at www.gem-a.com/membership. Laboratories, libraries, museums and similar institutions may become direct subscribers to *The Journal*.

Advertising

Enquiries about advertising in *The Journal* should be directed to the Marketing Consultant. For more information, see www.gem-a.com/index.php/news-publications/publications/journal-of-gemmology/advertising.

Database Coverage

The Journal of Gemmology is covered by the following abstracting and indexing services: Australian Research Council academic journal list, British Library Document Supply Service, Chemical Abstracts (CA Plus), Copyright Clearance Center's RightFind application, CrossRef, EBSCO (Academic Search International, Discovery Service and TOC Premier), Gale/Cengage Learning Academic OneFile, GeoRef, Index Copernicus ICI Journals Master List, Mineralogical Abstracts, Cambridge Scientific Abstracts (ProQuest), Scopus and the Thomson Reuters' Emerging Sources Citation Index (in the Web of Science).

Copyright and Reprint Permission

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.

Printed by DG3 (Europe) Ltd.

ISSN: 1355-4565

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: www.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

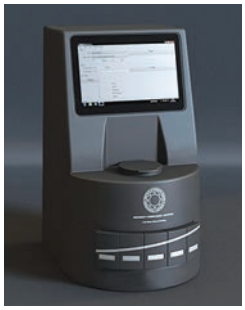
Understanding Gems™

What's New

INSTRUMENTATION

AMS2 Automated Melee Testing Instrument

In August 2017, De Beers' International Institute of Diamond Grading & Research (IIDGR) released the next-generation Automated Melee Testing instrument, called AMS2, for the separation of potential synthetics and simulants from natural diamond melee. This instrument uses a new measurement technique that enables significantly lower referral rates for natural diamonds. Compared to the first-generation AMS, the AMS2 is designed to be faster, more accurate and more affordable, with the ability to process smaller sizes and all polished shapes. Like its predecessor, AMS2 is designed to screen colourless to near-colourless diamonds. The instrumentation includes the AMS2 device and computer with proprietary software in a single desktop unit. For more information, visit www.iidgr.com/innovation/automated-melee-testing2-ams2. *CMS*



MiNi 360° Photography System

Version 4.0 of the Vision360 MiNi diamond photography system was released in June 2017 at the JCK show in Las Vegas, Nevada, USA. This version—B2B—offers a reduced device size without image deterioration, as well as more advanced colour correction and customizable colour background. The system generates still images and 360° videos of diamonds ranging from 50 to 0.10 ct (and smaller, with an additional lens), along with table-to-culet and 'hearts and arrows' imaging. The unit is approximately 61 cm long and weighs about 7 kg. A vacuum-based stone holder permits up to 99% of a polished diamond to be displayed. Visit https://v360.in/b2bmini.aspx. *CMS*

Spectra Diamond Colorimeter

Released in May 2017, the Spectra portable diamond colorimeter from OGI Systems Ltd. is designed to colour-grade polished diamonds weighing 0.30–100 ct of any shape in the D-to-M range, using GIA and other grading systems. It also measures and grades fluorescence. The unit's dimensions are approximately 15.0 × 10.2 × 10.5 cm and it operates for 15 hours on rechargeable batteries. Visit www.ogisystems.com/spectra.html. *CMS*

NEWS AND PUBLICATIONS

Gem Testing Laboratory (Jaipur, India) Newsletter

Volume 74 (June 2017) of the *Lab Information Circular* of the Gem Testing Laboratory, Jaipur, is now available at http://gtljaipur.info/ProjectUpload/labDownLoad/LIC%2074%20_June2017.pdf. This issue features informative reports on cobalt-diffused blue spinel, gem-quality grandidierite seen in the past year, convincing synthetic ruby rough sold as natural in mining areas in Mozambique, plastic imitation 'play-of-colour opal', californite (cryptocrystalline vesuvianite) as a jade imitation and silicified siltstone marketed as pink opal from Australia. *CMS*

Gemmological Society of Japan Abstracts

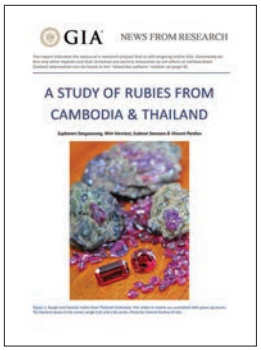
Abstracts of lectures from the 2017 Annual Meeting of the Gemmological Society of Japan, held 23–26 January, were released in June 2017 at www.jstage.jst.go.jp/browse/gsj. The topics of the 22 lectures include new analytical methods, CVD synthetic diamond, photoluminescence of type IIa natural pink diamond, emerald coloration, opal, chalcedony, agate, 'Herkimer diamond', liddicoatite, ruby, sapphire, spinel and pearls. The abstracts are in Japanese and often also in English, and those from previous meetings dating back to 2001 are available as well. *CMS*

GIA News from Research: Bead-Cultured Blister Pearls from *Pinctada maculata*

In April 2017, the Gemological Institute of America (GIA) reported on cultured blister pearls originating from Penrhyn Island, the northernmost atoll of the Cook Islands in the Pacific Ocean. *P. maculata* is the smallest of the *Pinctada* molluscs, and the natural 'pipi' pearls it produces are usually 4–5 mm in diameter and can occur in various colours. The cultured blister pearls are produced by inserting a near-spherical freshwater shell bead between the inner shell surface and the overlying mantle tissue. Download the report at www.gia.edu/gia-news-research/pinctada-maculata-bead-cultured-blister-pearls-shells. *CMS*

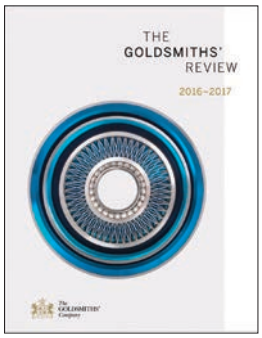
GIA News from Research: Rubies from Cambodia and Thailand

Posted in August 2017, this report from GIA describes a study of 41 rubies of known provenance from Pailin, Cambodia, and Chanthaburi-Trat, Thailand. Characterization with optical microscopy, Raman spectroscopy, LA-ICP-MS chemical analysis, and UV-Vis-NIR and FTIR spectroscopy revealed features that can readily separate these stones from similar-appearing rubies of basaltic origin from Kenya, as well as those from amphibolite-related deposits. Download the report at www.gia.edu/gia-news-research/study-rubies-cambodia-thailand. *CMS*



The Goldsmiths' Review 2016–2017

The most recent Goldsmiths' Company annual review publication is now available at www.thegoldsmiths.co.uk/company/today/news/2017/07/28/goldsmiths-company-review-2017. It includes a description of the previous year's activities, introduces the new Prime Warden, profiles contemporary jewellery and galleries in the UK, features women involved in the Goldsmiths' Company, and explores various current and historical facets of precious metals in the UK, from Shakespeare and sovereigns to miniatures and memberships. *CMS*



Polished Topaz and Synthetic Moissanite Imitating Rough Diamonds

In July and August 2017, HRD Antwerp reported on two pieces each of polished topaz (38.18 and 50.08 ct) and synthetic moissanite (5.01 and 7.14 ct) that were submitted as rough diamonds. The octahedral-like shapes of the samples were typical of diamond, which strongly suggests that these specimens were created with the intent to deceive. Visit www.hrdantwerp.com/en/news/polished-topaz-imitating-rough-diamonds and www.hrdantwerp.com/en/news/yet-another-rough-diamond-imitation-analyzed-by-our-research. *CMS*

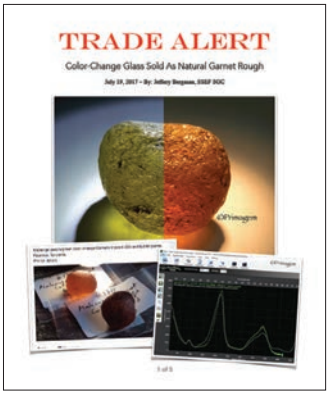
Santa Fe Symposium Proceedings

Papers associated with 22 presentations delivered at the 2016 Santa Fe Symposium (held in Albuquerque, New Mexico, USA) are available for download, on topics including innovative alloys, new technologies,

manufacturing techniques and more. Visit www.santafesymposium.org/papers to obtain PDF files of the 2016 papers, as well as those from earlier symposia dating back to 2000. *BML*

Colour-Change Glass Sold as Garnet Rough

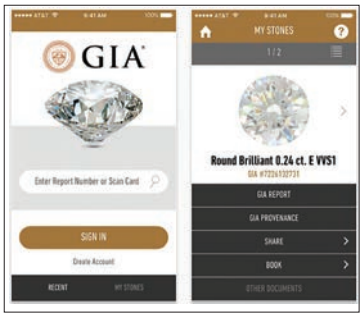
In July 2017, Jeffery Bergman (Primagem, Bangkok, Thailand) distributed a trade alert on two water-worn pebbles represented as colour-change garnet from Mahenge, Tanzania. Their colours were yellowish green in fluorescent illumination and orange in incandescent lighting. The RI of 1.66 and SG of 3.48 matched those of colour-change sinhalite from Sri Lanka and Tanzania, except that only a single RI reading was observed. The visible-range spectra revealed a match with the artificial colour-change glass-ceramic called Nanosital. To read the full report, visit www.academia.edu/33940879/TRADE_ALERT_Color-Change_Glass_Sold_As_Natural_Garnet_Rough?auto=download. *CMS*



MISCELLANEOUS

M2M Diamond-Origin Tracking Service

GIA announced its new M2M (Mine to Market) programme at the June 2017 JCK show in Las Vegas. The goal of the programme is to track the complete history of a polished diamond from mine to retailer. The service requires that a manufacturer submit appropriately documented rough to GIA's laboratory, which then collects detailed data on each diamond (morphology, spectroscopy and growth structure) and assigns it a serial number. The rough is returned to the manufacturer for cutting, and the polished stones are then sent to GIA for further documentation and matching. It should be possible to verify approximately 90% of the polished stones for which the history has been recorded. A consumer-oriented app, available for iOS and Android devices, will then enable retailers to access an individual diamond's history. Currently it is free to submit rough to GIA, but retailers must pay to access the complete information via the app. To learn more, visit www.gia.edu/gia-news-press/jck-las-vegas-2017. A video with additional information is also available at www.youtube.com/watch?v=n6RUoYZJRvg. *CMS*



More Historical Reading Lists

GIA's Richard T. Liddicoat Gemological Library recently added four new topics to its 'Historical Reading' lists of articles and books that are available in the Library's holdings: Ancient Emerald Mines of Egypt, Baltic Amber, California Gold Rush and Diamond Fields of South Africa. The ancient Egyptian emerald listing includes 22 articles and books dating from 1817 to 2008. The Baltic amber list encompasses 83 articles and books from 1809 to 2012. The California Gold Rush list begins with a *Scientific American* article published in 1848 (just six months after the discovery) and continues with 98 more articles through 1998. The South African diamond fields listings are divided into Part 1 (1868–1893) and Part 2 (1893–2014), and include 239 holdings. Access the lists at www.gia.edu/library. *CMS*

What's New provides announcements of 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 (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Gem Notes

COLOURED STONES

Cat's-eye Aquamarine from Meru, Kenya

For more than two decades, small amounts of aquamarine have been mined from granitic pegmatites in central Kenya, mostly in the Embu-Meru (Tharaka) and Isiolo areas (Simonet et al., 2000). According to gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA), the stones are typically medium to light blue and facetable in modest sizes, with generally small parcels (i.e. <250 g) being sporadically available. The mines are reportedly worked with hand tools (and no explosives), and the gem rough is typically 'frozen' within massive quartz, making it difficult to extract. The rough material is commonly somewhat hazy in appearance.

In August 2016, Blauwet obtained a 'silky' piece of rough aquamarine from the Meru area weighing 4.75 g, and it yielded an 11.09 ct cabochon (Figure 1). The chatoyancy was caused by abundant parallel needles and platelets that were oriented parallel to the c-axis (Figure 2). Raman analysis of these features only yielded spectra for the host beryl. Considering their orientation parallel to the c-axis, they are likely fluid-filled tubes resulting from growth blockages.

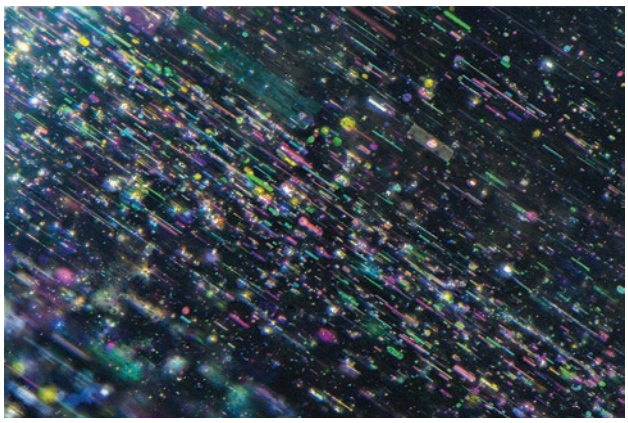
Similar inclusions were documented in a cat's-eye aquamarine from Embu, Kenya, by Barot et al. (1995). Its chatoyancy was ascribed to abundant parallel, hair-like tubes (pictured in Figure 4 of their article); they also reported the presence of laminae and platelets of biotite and muscovite. In addition, Barot et al. (1995) mentioned a cat's-eye beryl from the Meru area that displayed 'sea-green' and 'yellowish' pleochroism and contained parallel tubes that contained hematite impurities.

Brendan M. Laurs FGA

Nathan D. Renfro FGA
Gemological Institute of America
Carlsbad, California, USA

Figure 1: These aquamarines are from Meru, Kenya. The chatoyant cabochon is 11.09 ct, and the faceted gems weigh 0.81–1.24 ct. Photo by Robison McMurtry, © GIA.

Figure 2: Abundant parallel needles and platelets are the cause of the chatoyancy in the cat's-eye aquamarine. Photomicrograph by N. D. Renfro using oblique fibre-optic illumination, © GIA; image width 2.8 mm.



References

Barot N.R., Graziani G., Gübelin E. and Rettig M., 1995. Cat's-eye and asteriated gemstones from East Africa. *Journal of Gemmology*, **24**(8), 569–580, http://dx.doi.org/10.15506/JoG.1995.24.8.569.

Simonet C., Okundi S. and Masai P., 2000. General setting of coloured gemstone deposits in the Mozambique Belt of Kenya—Preliminary considerations. *Proceedings of the 8th and 9th Regional Conference on the Geology of Kenya*, Nairobi, November, 123–138.

Colour-zoned Green Beryl from Pakistan

During a buying trip to Pakistan in June 2016, gem dealer Dudley Blauwet obtained ~500 g of colourless beryl that showed distinctive green banding from a local miner/dealer. The beryl reportedly came from the Shandu Fangma mine, located on the ridge between Haiderabad and Baha, east of the Braldu River, in the Shigar Valley area of northern Pakistan. The crystals were hosted by a friable mica schist that fell apart when handled. Blauwet retained 25 of the best crystals to sell to mineral collectors, and assembled five parcels of rough material (totalling 297 pieces and weighing 199.5 g) to send to his cutting factory. He instructed the lapidaries to cut the various lots in different styles, including step cuts and elongate matched pairs to accentuate the colour zoning. He also had them facet some radiant emerald cuts to blend the colour zones into a more uniform pale emerald-green colour, and some cabochons to obtain cat's-eye gems from somewhat silky pieces. These latter two efforts did not prove successful, however, since the radiant cuts turned out pale blue with only slight green coloration, and the cabochons did not show chatoyancy. In total, the gems that were returned from the cutting factory totalled 434 pieces weighing 247.18 carats, and ranged from approximately 0.10 to 4.97 ct.

Blauwet loaned three faceted samples (0.83–4.97 ct) to authors CW and BW for examination (Figure 3). All of them were near-colourless with bluish green banding perpendicular to the length of the stones. The RIs were 1.572–1.579 (birefringence 0.007) and the SG was 2.68 (measured on the 4.97 ct stone), consistent with beryl. The samples were inert to standard long- and short-wave UV lamps (i.e. 365 and 254 nm, respectively); however, the bluish green bands did fluoresce moderate pink to 375 nm LED illumination (Figure 4). No reaction was observed with the Chelsea colour filter. The polariscope revealed that the optic axis of all the stones was oriented parallel to their length, and therefore the colour banding was parallel to the basal pinacoid. Viewed with the dichroscope, the green bands showed bluish green and yellowish green pleochroism, while the near-colourless areas appeared very pale blue and yellow.

Microscopic examination revealed growth tubes oriented parallel to the c-axis in all three stones (Figure 5). Some of the tubes appeared flattened with a feathery texture (Figure 5, left). While some tubes were colourless, others were filled with a dark substance; those that were open to the surface of the stones contained polishing residues with a different appearance than the dark matter mentioned above. Most of the growth tubes had abrupt terminations, in some instances where they encountered minute colourless mineral inclusions (Figure 5, right).

Figure 3: These beryls from Pakistan (0.83–4.97 ct) show distinct colour bands oriented parallel to the basal pinacoid. Photo by C. Williams.

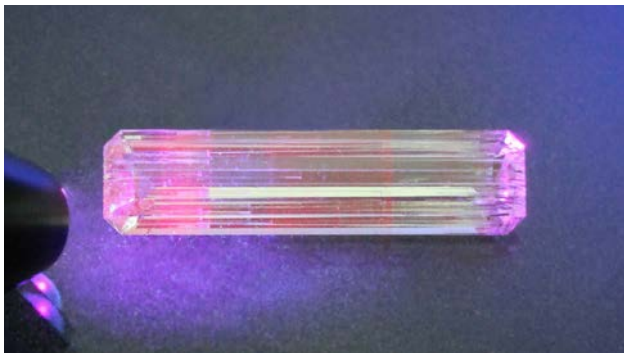


Figure 4: Moderate pink fluorescence is displayed by the bluish green colour bands in the 4.97 ct beryl when illuminated with a 375 nm LED torch. Photo by Dean Brennan.

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with an Amptek X123-SDD instrument showed significant Fe, minor Cr and Cs, and a trace of V; relatively higher amounts of these elements were found in the bluish green bands as compared to the near-colourless areas. In addition, standard-based chemical analysis done with scanning electron microscopy-energy dispersive spectroscopy of another sample of this beryl was performed by authors AUF and WBS using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The rough sample was ground down slightly and

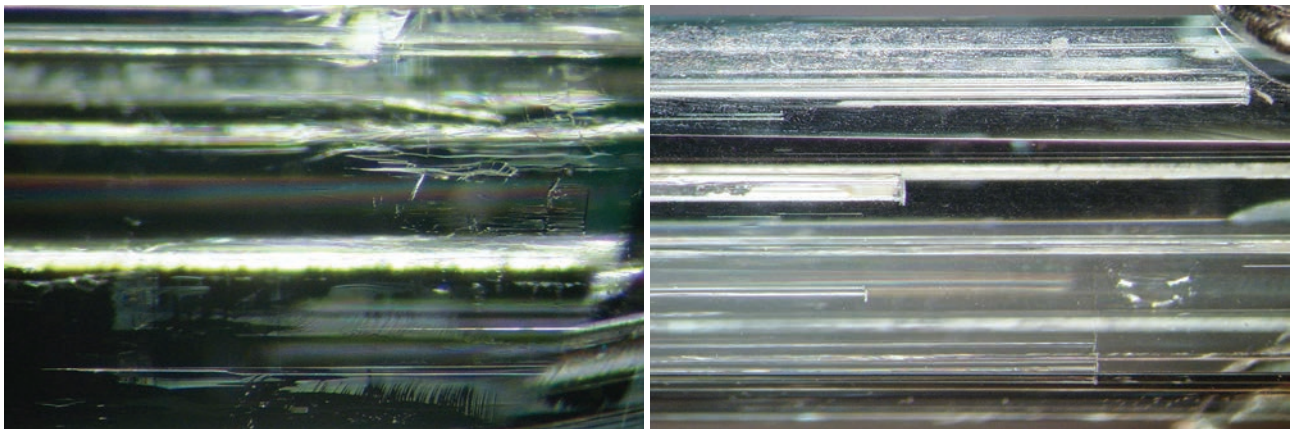


Figure 5: Growth tubes form conspicuous inclusions in the Pakistan beryls. Some of them show a feathery appearance (left, magnified 20×), and the tubes commonly terminate at colourless mineral inclusions (right, magnified 35×). Photomicrographs by C. Williams.

then polished before the analysis. Overall, it contained 0.3–0.6 wt.% FeO, 0.22–0.31 wt.% MgO and 0.14–0.20 wt.% Na_2O. In addition, contents of V_2O_5 ranged from below the detection limit up to 0.02 wt.%, with no relation to colour, whereas Cr_2O_3 was undetectable in the near-colourless areas and up to 0.05 wt.% in the darker green zones.

Blauwet has occasionally encountered limited quantities of this beryl in Pakistan since approximately mid-2011, and it was commonly offered to him as 'emerald'. Its colour banding and growth tubes are similar to those shown by colour-zoned beryl from Torrington and Emmaville in eastern Australia (e.g. Brown, 1998). However, the Australian beryls contained less Fe, and more Cr and V, than the Pakistan stones documented here.

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

Alexander U. Falster and
Dr William B. 'Skip' Simmons
Maine Mineral & Gem Museum
Bethel, Maine, USA

Brendan M. Laurs FGA

Reference

Brown G., 1998. Les gisements d'émeraudes en Australie. In D. Giard, Ed., *L'émeraude—Connaissances Actuelles et Prospectives*. Association Française de Gemmologie, Paris, France, 201–204.

Coloration of Green Dravite from the Commander Mine, Tanzania

A recent Gem Note by Williams et al. (2017) documented green/brown dravite from the Commander mine, Simanjiro District, north-eastern Tanzania. A crystal fragment that was studied for that report was subsequently analysed further by the present author to investigate the nature of its green coloration.

The green portion of the sample was sliced into a piece measuring 3 mm thick that was slightly darker at the rim and lighter in the interior. The dichroic colours of the rim were very light bluish green (E∥c) and greenish yellow (E⊥c), while the inner region was pale yellow (E∥c) to light yellow (E⊥c).

Visible-near infrared (Vis-NIR) spectroscopy with a silicon-diode array microspectrometer showed absorption bands at ~444 nm (more intense in the E∥c direction) and at ~606 nm (more intense in the E⊥c direction; Figure 6). An overtone of the OH bands occurred at 979 nm in the E∥c direction. These spectra are very similar to those of the V-Cr tourmalines (olenite, uvite and dravite) reported by Ertl et al. (2008). In addition, there is a close resemblance to the spectrum of green dravite from Tanzania (GRR 1719 with V>Cr) available at http://minerals.gps.caltech.edu/manuscripts/2008/V_Olenite/Index.html. The primary difference is the lack of a spin-forbidden

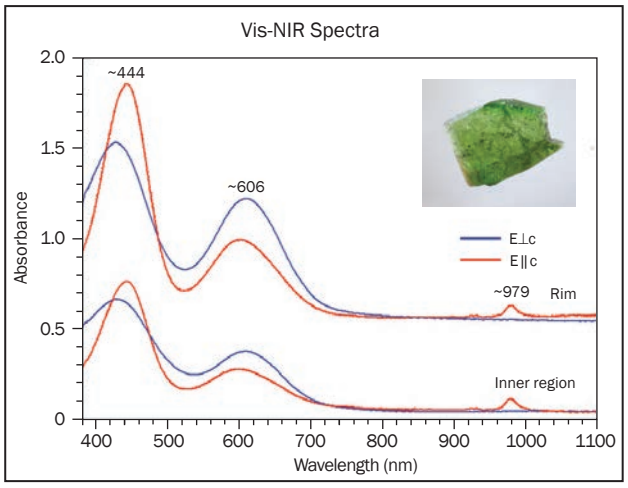


Figure 6: Polarized Vis-NIR spectra of the green dravite recorded absorption bands at ~444 and ~606 nm that are related to vanadium. In addition, an overtone of the OH bands occurred at 979 nm in the E∥c direction. The spectra for the rim are offset vertically for clarity. Inset photo by G. R. Rossman.

chromium band near 700 nm in the Commander mine sample, suggesting a lower Cr content.

This was corroborated by EDXRF chemical analysis using an INAM Expert 3 instrument, which indicated that vanadium is the primary chromophore. The outer darker green rim contained 0.25 wt.% V, 0.044 wt.% Cr and 190 ppm Fe, while the inner, more yellow region had 0.17 wt.% V, 0.036 wt.% Cr and 122 ppm Fe. In addition, both zones contained ~0.40 wt.% Ti.

From Figure 4 in Ertl et al. (2008), the position of the lowest-energy electronic absorption band at 606 nm corresponds to a ratio of V/(V+Cr) of approximately 82% for the darker green rim. This provides good agreement with the EDXRF analyses, which gave V/(V+Cr) ratios of 86% for the rim and 83% for the inner region of the sample. These results clearly indicate that this sample is coloured primarily by vanadium, as is typically the case for 'Cr-tourmaline' from East Africa (Schmetzer and Bank, 1979).

Dr George R. Rossman (grr@gps.caltech.edu)
California Institute of Technology
Pasadena, California, USA

References

Ertl A., Rossman G.R., Hughes J.M., Ma C., Brandstätter F., 2008. V^{3+}-bearing, Mg-rich strongly disordered olenite from a graphite deposit near Amstall, Lower Austria: A structural, chemical and spectroscopic investigation. *Neues Jarhbuch für Mineralogie*, **184**(3), 243–253, http://dx.doi.org/10.1127/0077-7757/2008/0100.

Schmetzer K. and Bank H., 1979. East African tourmalines and their nomenclature. *Journal of Gemmology*, **16**(5), 310–311, http://dx.doi.org/10.15506/jog.1979.16.5.310.

Williams C., Williams B., Laurs B.M., Falster A.U. and Simmons W.B., 2017. Gem Notes: Tourmaline (dravite) from Simanjiro District, Tanzania. *Journal of Gemmology*, **35**(6), 481-482.

Enstatite from Emali, Kenya

In September 2014, gem dealer Dudley Blauwet obtained a parcel of rough yellowish green enstatite from an East African supplier. The material reportedly came from the Emali area, located ~160 km northwest of the Taita Hills in southern Kenya. The parcel contained 65 pieces weighing a total of 45.7 g, and some of the stones had a black 'skin' on their surface, which the cutters were instructed to remove before faceting. Due to this, and the irregular shape of the rough, the cutting yield was relatively low: 82 faceted stones weighing a total of 29.4 carats were returned from Blauwet's cutting factory in April 2015. Blauwet loaned the author four faceted samples of this enstatite (Figure 7) for examination.

The stones consisted of one cushion and three oval cuts that weighed 1.18–1.49 ct. The cushion and one of the oval cuts (left two stones in Figure 7) showed saturated colours: respectively a dark strong green and a medium dark, moderately strong, slightly yellowish green. The other two stones were a very dark, slightly greyish, slightly yellowish green; abundant inclusions reduced their transparency.

Figure 7: These enstatites from Emali, Kenya (1.18–1.49 ct), range from a well-saturated green to a dark 'olive' green. Photo by J. C. Zwaan.

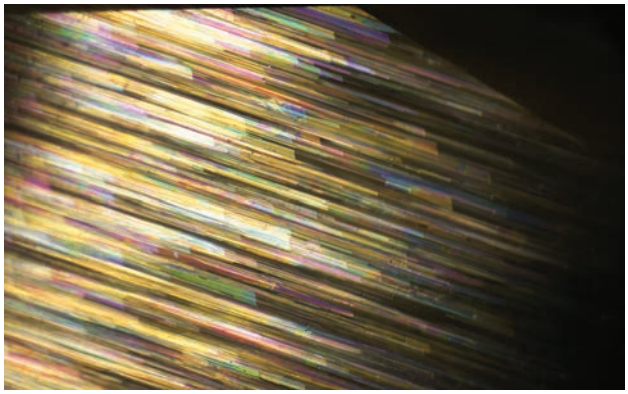


Figure 8: Viewed face-up with the microscope, iridescent colours were seen in one dark enstatite (1.49 ct), related to the presence of dense, parallel needles. Photomicrograph by J. C. Zwaan, oblique fibre-optic lighting; image width 3.7 mm.

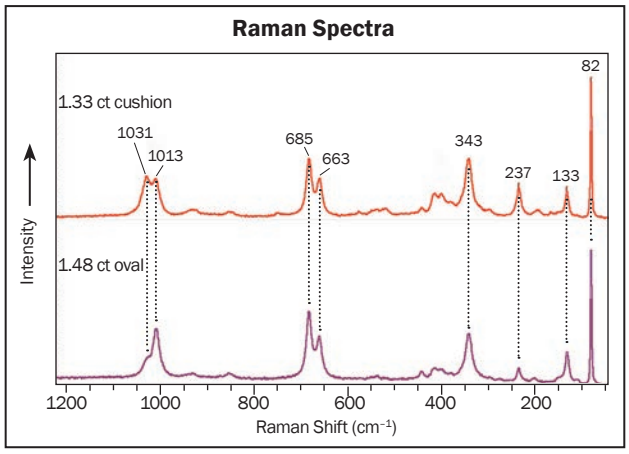


Figure 9: Representative unpolarized spectra taken at random orientations on two of the stones show the diagnostic Raman bands for orthoenstatite at 685 (Si-O-Si bending vibrations), 663 and 82 cm^{-1}, and also demonstrate that the intensity of the Si-O stretching vibrations at wavenumbers greater than 1000 cm^{-1} (here, at 1031 and 1013 cm^{-1}) are sensitive to orientation.

RIs varied from 1.661 to 1.672, yielding birefringence values of 0.008–0.011. The optic character was biaxial positive. Average hydrostatic SG values were 3.26–3.29. Using a calcite dichroscope, green and yellow-green pleochroism was observed in the lighter samples, while the very dark stones showed yellowish green and brown, or green and yellowish brown pleochroism. The prism spectroscope revealed two absorption lines at approximately 505 nm (clearly visible) and 550 nm (weak to very weak) in all four stones. The gems were inert to both long- and short-wave UV radiation.

The described properties are consistent with enstatite. Hypersthene, an orthopyroxene with intermediate composition between the end-members enstatite ($MgSiO_3$) and ferrosilite ($FeSiO_3$), need not be confused with enstatite, because hypersthene is biaxial negative and has higher RI values, between 1.686 and 1.772, with a greater birefringence of 0.015–0.017. It also has a higher SG of around 3.45 (cf. Deer et al., 1992; Dedeyne and Quintens, 2007).

The dark green cushion-shaped stone was relatively clean; it showed subparallel very fine needle-like inclusions or growth tubes, some of which appeared to be filled and thus looked like multiphase inclusions. It also contained a small liquid feather near the girdle. In the yellowish green oval stone, the fine parallel needles locally caused a slight silkiness, while in the very dark stones, the abundance of these needles not only imparted silkiness but also reduced their transparency. In one of those samples, dense parallel needles produced iridescent colours when viewed with oblique fibre-optic illumination (Figure 8).

Chemical analyses were obtained by EDXRF spectroscopy with an EDAX Orbis Micro-XRF Analyzer on the tables of the four stones, using a spot size of 300 µm. Apart from the main elements Mg and Si, the analyses showed 2.6–3.0 wt.% FeO and 0.30–0.57 wt.% CaO.

All four stones showed similar Raman spectra (e.g. Figure 9), which were collected with a Thermo Fisher Scientific DXR Raman microscope using 532 nm laser excitation. The Si-O-Si bending doublet at 685–663 cm^{-1} and the lowest-lying mode at 82 cm^{-1} confirmed the identity of these stones as orthoenstatite, easily distinguished from two other common polymorphs of enstatite: low-clinoenstatite (lowest mode at 118 cm^{-1}) and protoenstatite (high-temperature polymorph with no doublet but a single peak at 673 cm^{-1}; cf. Reynard et al., 2008). The intensities of the Si-O stretching vibrations above 1000 cm^{-1} are sensitive to orientation, while the intensities of the diagnostic peaks at 685 and 663 cm^{-1} are not (Reynard et al., 2008).

Similar yellowish green enstatite from an alluvial deposit in the Mairimba Hill region of southern Kenya, located south of the Taita Hills, was described by Schmetzer and Krupp (1982). However, that enstatite had lower RI (1.652–1.662) and SG (3.23) values, and its colour was attributed to a combination of iron and chromium, whereas no Cr was detected in this Emali enstatite.

Dr J. C. (Hanco) Zwaan FGA
(hanco.zwaan@naturalis.nl)
Netherlands Gemmological Laboratory
National Museum of Natural History 'Naturalis'
Leiden, The Netherlands

References

Dedeyne R. and Quintens I., 2007. *Tables of Gemstone Identification*. Glirico, Gent, Belgium, 309 pp.

Deer W.A., Howie R.A. and Zussman J., 1992. *An Introduction to the Rock-Forming Minerals*, 2nd edn. Longman Scientific & Technical, New York, New York, USA, 696 pp.

Gübelin E.J. and Koivula J.I., 2008. *Photoatlas of Inclusions in Gemstones*, Vol. 3. Opinio Publishers, Basel, Switzerland, 672 pp.

Reynard B., Bass J.D. and Jackson J.M., 2008. Rapid identification of steatite–enstatite polymorphs at various temperatures. *Journal of the European Ceramic Society*, **28**(13), 2459–2462, http://dx.doi.org/10.1016/j.jeurceramsoc.2008.03.009.

Schmetzer K. and Krupp H., 1982. Enstatite from Mairimba Hill, Kenya. *Journal of Gemmology*, **18**(2), 118–120, http://dx.doi.org/10.15506/JoG.1982.18.2.118.

Grossular from Tanga, Tanzania

Grossular—particularly the yellow-orange to brownish orange variety known as hessonite—commonly displays a roiled graining appearance in the microscope called 'treacle' (O'Donoghue, 2006, p. 215). Recently we encountered two examples of slightly brownish yellow grossular that showed this effect, but that also contained other interesting features. Both stones were loaned for examination by gem dealer Dudley Blauwet, who obtained the rough material at the February 2017 Tucson gem shows in Arizona, USA. According to his East African supplier, the two alluvial pebbles came from Tanga, Tanzania. Faceting of the 7.43 and 5.81 g pieces yielded an 11.75 ct cushion cut and a 10.13 ct pear cut (Figure 10).

Figure 10: These grossular gemstones from Tanga, Tanzania, show interesting features resulting from an intense treacle effect (left, 11.75 ct) and from dark green colour patches (right, 10.13 ct). Photo by Robison McMurtry, © GIA.

The larger stone displayed a particularly intense treacle effect (Figure 11), so pronounced that it made the stone appear oily. The treacle appearance was much less pronounced in the smaller stone, which was notable for containing two dark green patches, located on either end of the pear cut. Microscopic examination by author NDR revealed that the green areas were associated with inclusion clusters characterized by transparent, dark coloured, irregular spots that had an RI similar to that of the host garnet (Figure 12). Also present were irregular transparent colourless birefringent crystals with a lower RI

Figure 11: The strong treacle effect displayed by the 11.75 ct grossular is shown here, and is superimposed over the facet pattern of the stone's pavilion. Photomicrograph by N. D. Renfro, © GIA; image width 5.8 mm.

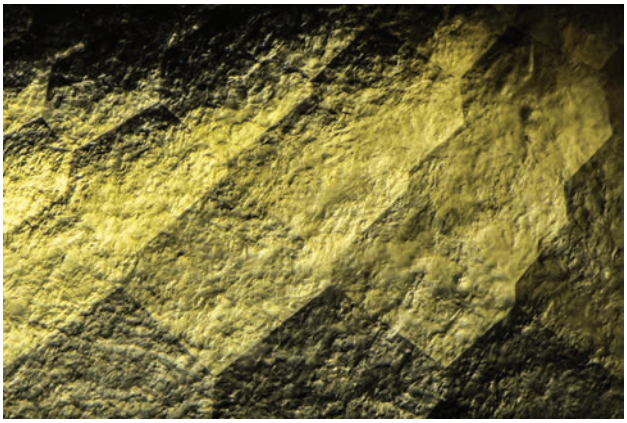
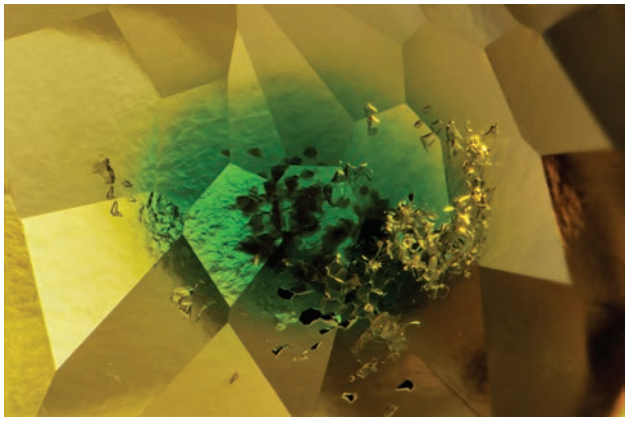


Figure 12: This green colour patch in the 10.13 ct grossular is associated with a cluster of colourless and dark inclusions. Photomicrograph by N. D. Renfro, © GIA; image width 4.1 mm.



than that of the host garnet. Raman spectroscopy of the inclusions yielded poor-quality spectra that we could not conclusively match with any in our database. The origin of the V and/or Cr that is inferred to have caused the tsavorite-like green patches in this grossular is unknown. The coloration might result from V- and/or Cr-bearing inclusions that subsequently underwent alteration, releasing the chromophores into the surrounding grossular.

Brendan M. Laurs FGA and Nathan D. Renfro FGA

Reference

O'Donoghue M., Ed., 2006. *Gems*, 6th edn. Butterworth-Heinemann, Oxford, 873 pp.

Natrolite from Portugal

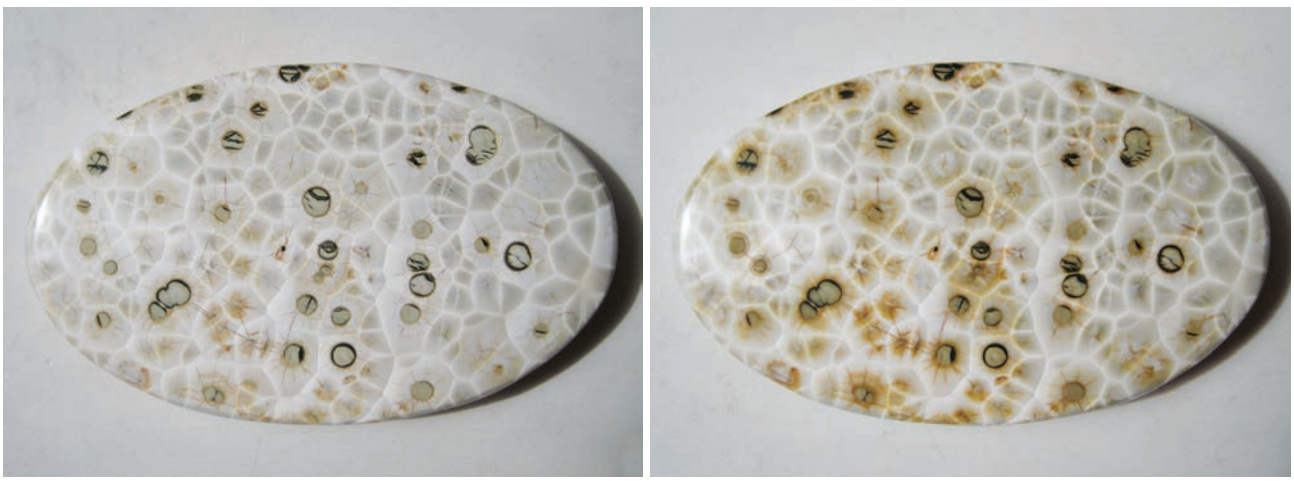
Natrolite ($Na_2Al_2Si_3O_{10} \cdot 2H_2O$) is a zeolite mineral with a Mohs hardness of 5–5½ that commonly forms compact radial aggregates of fine needles. Natrolite crystals are rarely thick and transparent enough for faceting, although rare colourless gems weighing up to 8.70 ct have been reported (e.g. Wight, 1996).

At the February 2016 Tucson gem shows, Dr Marco Campos Venuti (Seville, Spain) had cabochons composed of radial aggregates of natrolite from Portugal. In June 2015, he obtained ~2 kg of rough material from Spanish mineral dealer Alberto Ledo Lopez, who reported the source as a basalt quarry near Sintra on Portugal's west coast. Zeolites and other minerals are well-known from quarries in this area (Inácio Martins, 2013).

Figure 13: These natrolite veins from Portugal (up to 9.7 cm long) have been partially sawn away from their basalt matrix in preparation for cutting. Photo by M. Campos Venuti.

The rough pieces consisted of vein fillings 1–2 cm thick and up to 20–40 cm long (e.g. Figure 13). Campos Venuti cut ~50 cabochons that were oriented perpendicular to the width of the veins, which displayed interesting cellular patterns that were created by the radiating crystal clusters. The cabochons ranged from ~2 to 10 cm in maximum dimension (e.g. Figure 14); smaller pieces did not show enough of the pattern and were discarded. Campos Venuti noted

Figure 14: The cellular pattern in this natrolite cabochon is accentuated after it has been soaked in water for 10 seconds. In addition, its weight has increased from 229.21 to 231.85 ct. Photos by M. Campos Venuti.



that the pattern becomes darker and more accentuated after the cabochons are soaked in water (again, see Figure 14).

Campos Venuti kindly donated one natrolite cabochon (2.8 × 2.0 cm) to Gem-A. Microscopic examination by one of the authors (NDR) showed distinct colour zoning in some of the radial aggregates (Figure 15), but Raman analysis revealed only the presence of natrolite, regardless of the area that was analysed. This suggests that the darker cores are due to staining, perhaps originating from the adjacent matrix material that was removed before cutting.

Brendan M. Laurs FGA and Nathan D. Renfro FGA

Figure 15: The radial aggregates in this natrolite cabochon (gift of Marco Campos Venuti) contain yellowish brown cores. Photomicrograph by N. Renfro, © GIA; image width 11.05 mm.

References

Inácio Martins A.M., 2013. Zeolites@Portugal. Mindat.org, www.mindat.org/article.php/1608/Zeolites%40Portugal, posted 4 December.

Wight W., 1996. The gems of Mont Saint-Hilaire, Quebec, Canada. *Journal of Gemmology*, **25**(1), 24–44, http://dx.doi.org/10.15506/jog.1996.25.1.24.

Large Matrix Opal Carving

In April 2017, L. Troy Hatch (Galaxy Gems Brazil, Newcastle, Washington, USA) showed this author a carved matrix opal from Andamooka, Australia, which was significant for its large size (Figure 16). Weighing 8.15 kg and measuring 38.1 cm long and 20.3 cm tall, the piece was carved on both sides and exhibited play-of-colour in red, orange, yellow, green and violet. The intensity of the colours shifted with changes in the viewing angle to the piece. The carving was done over a period of 11 days in March 2017 by Dalan Hargrave (GemStarz Jewelry, Spring Branch, Texas, USA). After the carving process was complete, the piece was 'sugar-treated' and then coated with a thin layer of resin to increase its lustre. Several Chinese-themed motifs are displayed on the piece: two cranes (left side), a penjing tree (centre), butterflies (top), lotus flowers (bottom left), cherry blossoms (upper right), the Great Wall of China (top edge) and

Figure 16: This carved matrix opal from Andamooka, Australia, measures 38.1 cm long and 20.3 cm tall. Photo by B. M. Laurs.

Figure 17: Orange, red and violet play-of-colour mingle with various elements of the carved matrix opal. Photo by B. M. Laurs; image width ~11 cm.

a dragon (back side). Figure 17 shows a closer view of some of the butterfly and cherry blossom motifs.

It is unusual to encounter large pieces of matrix opal that show play-of-colour over a widespread area, and carved pieces of this material commonly range up to just a few centimetres in maximum dimension (e.g. Brown, 1991). The large size and wide distribution of the play-of-colour make this matrix opal carving quite unusual.

Brendan M. Laurs FGA

Reference

Brown G., 1991. Treated Andamooka matrix opal. *Gems & Gemology*, **27**(2), 100–106, http://dx.doi.org/10.5741/gems.27.2.100.

Update on Sapphires from Tigray, Northern Ethiopia

Following the discovery of sapphires in the Chila area of Tigray Province in late 2016 (Laurs, 2017; Vertriest et al., 2017), mining and trading activities in northern Ethiopia are now well underway. In collaboration with Ethiopia's Ministry of Mines, this author visited the sapphire mines and markets in the Tigray region for one week in late May to early June 2017.

Sapphire mining was actively taking place in the region surrounding the town of Chila (Figure 18), which is also a focal point for sapphire trading. The deposits are all alluvial (Figure 19) and extend north of the town of Aksum (or Axum) toward the Eritrean border. The original sapphire discovery occurred near Chila (14°16'23.94"N, 38°38'4.26"E), and a second mining area was subsequently discovered several kilometres west-north-west of Chila (14°19'58.48"N, 38°36'4.86"E). Additional deposits were then found east toward the town of Rama and also to the west of Chila. In June 2017, new finds of higher-quality material were made southeast of Chila toward Aksum University.

According to a geological map published by the Geological Survey of Ethiopia (1999), the region hosting the sapphire deposits is underlain mostly by Neoproterozoic basement rocks. They are locally covered to the south by Paleozoic to Mesozoic sediments as well as Tertiary volcanic rocks—particularly in the Aksum area but also locally around Chila (again, see Figure 18). The Tertiary units consist of stratified basaltic rocks that have been mapped as the Koyetsa Volcanics, as well as the Adwa Trachyte and Phonolite. Their presence as isolated hills in the region indicates that they erupted over a larger area before being eroded (Tadesse, 1999). Since the sapphires have properties consistent with a magmatic origin, it seems likely that these alluvial deposits are associated with the weathering of the Tertiary volcanic rocks of the Aksum area. Geochemically, some of these rocks are correlative with volcanic suites in central and south-eastern Eritrea (Hagos et al., 2010).

As reported previously (Laurs, 2017), only a small proportion of the Tigray sapphires are of gem quality. Their coloration falls within the typical dark-toned blue-yellow-green series that is commonly associated with basaltic-origin sapphires with relatively high Fe content (Figure 20a,b). In addition, a small amount (approximately 5%) of the gem-quality production appears lighter in colour and is therefore inferred to contain relatively less Fe. Such stones display a pleasing intense medium blue colour, and they are keenly sought after by international rough sapphire buyers.

Since the rough material typically has a slightly pale green dichroism, it has to be carefully oriented during faceting to yield the most attractive pure blue coloration. In general, the darker blue sapphires tend to occur in larger sizes, while the lighter ones are smaller (i.e. typically up to 4–5 g). Interestingly, stones from the new 'University Block' area near Aksum often show a desirable

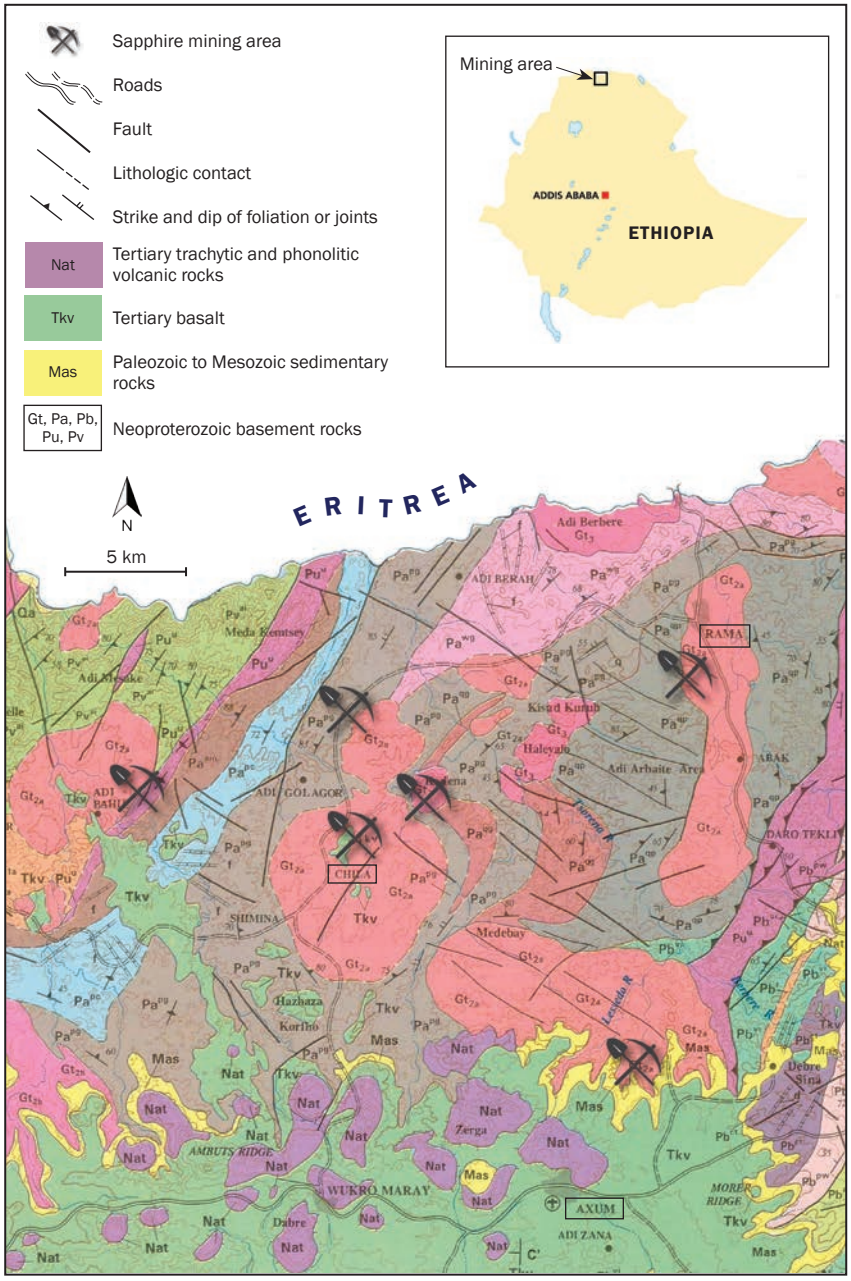


Figure 18: Sapphire mining areas in Tigray Province, northern Ethiopia, are shown on a portion of a geological map produced by the Geological Survey of Ethiopia (1999). Various Neoproterozoic basement rocks (mainly granitoids [Gt], metamorphic rocks [Pa, Pb and Pv] and mafic intrusives [Pu]) are overlain in the southern portion of the map area by Paleozoic to Mesozoic sediments (Mas) and Tertiary volcanic rocks (Tkv and Nat). Boxes surround the names of towns mentioned in the text.

blue colour without the greenish dichroism, and they commonly occur in cleaner pieces than typical Tigray sapphires (Figure 20c).

The heat treatment of Tigray sapphires has met with mixed success. While some of the material can be successfully lightened with high-temperature heat treatment, a portion of the darker material behaves unpredictably, and several treatment facilities in Chanthaburi (Thailand) took considerable financial losses exploring its viability as a commercial product. Generally, those facilities having longstanding experience with basaltic-type sapphires from Australia, Diego Suarez (Madagascar), Shandong (China) and Nigeria are

Figure 19: The sapphires are hosted by alluvial deposits along active or formerly active watercourses. The miners dig shallow pits with simple hand tools. Photo by S. Bruce-Lockhart.

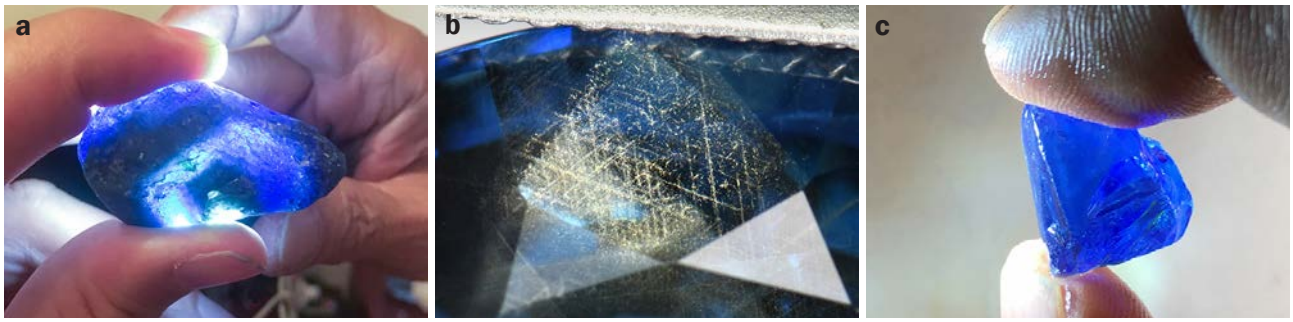


Figure 20: Shown here are some examples of different types of unheated Tigray sapphires: (a) an ~50 g very dark stone that is strongly backlit to show zones containing abundant black silk, (b) a relatively dark 18.56 ct faceted sapphire with 'golden'-coloured silk and (c) a lighter 4.85 g sapphire (which has been oiled) showing the particularly attractive blue colour of fine stones from the 'University Block' area near Aksum. Photos by S. Bruce-Lockhart.

enjoying the most success with Tigray sapphires. The main challenges are avoiding an increase in undesirable greenish coloration during the heating process and removing dense clouds of rutile 'silk'. The Thai heaters have had to deploy specific processes for each of the three types of silk present in these Ethiopian sapphires, which consist of: (1) silk that will disappear with heating; (2) denser silk that can be heated only to produce semi-transparent or opaque star stones; and (3) dark, very dense silk known locally as *MaaHin* (e.g. Figure 20a), which, when heated, will result in valueless, dark, almost opaque corundum. The very dense silk is cut away from the stones before heating to prevent the darkness from spreading into adjacent gem-quality areas.

Unlike other gem rushes in Africa, the Tigray sapphire mines have not received a huge influx of migrant workers from other regions of Ethiopia or other countries. No hastily constructed shanty towns were seen around the mines, as the diggers consist of local farmers who commute to the mines daily from their homes. Labour shortages inevitably lead to production declines when the local population is engaged with agricultural obligations during various times of the year (e.g. most recently during the first half of July).

According to a senior Ministry of Mines official, about 35 kg of sapphires were exported in June 2017. Compared to the official export figure of 0.03 kg for November 2016, this represents a considerable increase. The Tigray sapphires have made their way from Ethiopia to the gem-heating centres of Thailand and Sri Lanka, and from there have entered the global faceted-sapphire markets (Figure 21). Many gem labs have knowingly or unknowingly encountered these sapphires, and their potential as a commercially important gem material is starting to be understood by treaters and lapidaries.

Figure 21: These stones (~3–10 ct) show the typical colour range of the heated darker blue sapphires from the Tigray region of northern Ethiopia. Photo by S. Bruce-Lockhart.

Simon Bruce-Lockhart FGA DGA
(simonlockhart@yahoo.com)
Chanthaburi, Thailand

References

Laurs B.M., 2017. Gem Notes: New sapphire deposit in northern Ethiopia. *Journal of Gemmology*, **35**(6), 478–479.

Geological Survey of Ethiopia, 1999. Axum. Geological map (scale 1:250,000) to accompany Memoir No. 9, Addis Ababa, Ethiopia.

Hagos M., Koeberl C., Kabeto K. and Koller F., 2010. Geochemical characteristics of the alkaline basalts and the phonolite-trachyte plugs of the Axum area, northern Ethiopia. *Austrian Journal of Earth Sciences*, **103**(2), 153–170.

Tadesse T., 1997. *Geology of the Axum Area*. Memoir No. 9, Geological Survey of Ethiopia, Addis Ababa, 184 pp.

Vertriest W., Weeramonkhonlert V., Raynaud V. and Bruce-Lockhart S., 2017. Gem News International: Sapphires from northern Ethiopia. *Gems & Gemology*, **53**(2), 247–260.

Gem-quality Whewellite from the Czech Republic

Two mineral species that are suitable for faceting can be found in coal basins of the northwestern Czech Republic. One of them is marcasite, from which rose cuts were made at the beginning of 20th century, mostly for silver jewels. The other is whewellite, a monoclinic calcium oxalate ($CaC_2O_4 \cdot H_2O$) with a Mohs hardness of 2½–3.

The first whewellite samples were discovered in 1897 during excavation work at the Venuše mine in Konobrže, near the city of Most. Grey-white samples in the form of radial aggregates were found in clay layers at 110–120 m depth (Becke, 1898). Significantly better-quality whewellite was recovered after 1899 from the Julius II mine in Kopisty (~2 km from the Venuše mine). Smaller crystals also were found after 1910 in the closed Guttmann mine near Most (Ježek, 1911). A large amount of yellow whewellite, in aggregates or crystals up to 6 mm, was recovered from septarian nodules at the Bílina mine between 1987 and 2000. Most recently, in 1996–2008, whewellite of facetable quality was discovered at the Ležáky mine in Kopisty (e.g. Figure 22). This locality has been mined out and was flooded by a lake during restoration, so no additional production is expected from there in the future.

The gem-quality whewellite was recovered from pelosiderite cavities within septarian nodules that ranged from 20 cm to 1 m in maximum dimension. (Pelosiderite consists of siderite contaminated with an admixture of clay.) The pelosiderite nodules mostly occurred in pelitic sediments near coal banks. Whewellite formed after sedimentation (i.e. during diagenesis), in cracks and cavities where various minerals crystallized from residual fluids, and also within the nodules during the final phases of diagenesis. The crystals are often mistaken for calcite or other carbonates showing irregular crystal growth. The whewellite crystals typically do not exceed 2 cm, although specimens ranging up to 4 cm rarely have been found. Whewellite often forms acicular or radial aggregates (Dvořák et al., 2012), rather than blocky crystals that could be faceted. The presence of dickite reduces the transparency of the crystals and imparts a grey colour. At the Ležáky mine, the crystals are commonly twinned, and this causes problems during faceting. Brittleness also makes faceting difficult.

Thirty faceted specimens of whewellite (0.05–2.21 ct, e.g. Figure 23) from the Ležáky mine were characterized by the author for this report, and the following properties were obtained: colour—colourless to slightly yellow; RI—1.489–1.649; birefringence—0.160; hydrostatic SG—2.21–2.23; fluorescence—intense white to long-wave and very weak whitish to short-wave UV radiation; phosphorescence—white after exposure to long-wave UV; and no absorption features visible with a desk-model spectroscope. Microscopic examination revealed

Figure 22: These two specimens of pale yellow whewellite on dolomite crystals are from the Ležáky mine at Kopisty, near Most, Czech Republic. The crystal on the left is 8 mm wide, and the one on the right is 3 mm in longest dimension. Photos by P. Fuchs.

Figure 23: These faceted whewellites, weighing 0.81 and 0.66 ct (left) and 2.21 ct (right), are also from the Ležáky mine. Photos by R. Hanus.

fractures as well as fluid inclusions along partially healed cleavage planes (Figure 24).

Whewellite has a special position among collector's stones because it was formed by biogenic processes.

Acknowledgement: The author thanks Zdeněk Dvořák for his proofreading.

Dr Radek Hanus (kakt@centrum.cz)
e-gems.cz, Prague, Czech Republic

References

Becke F., 1898. Whewellit vom Venustiefbau bei Brüx. *Lotos*, **48**, 93–97.

Dvořák Z., Svejkovský J., Janeček O. and Coufal P., 2012. *Minerály severočeské hnědouhelné pánve* [Minerals of the North Bohemian Lignite Basin]. Granit, Prague, Czech Republic, 160 pp.

Ježek B., 1911. Whewellit z Lomu (Bruch) u Duchcova. *Rozpravy Ceske Akademie Cisare Frantiska Josefa,* **20**(2), 1–9.

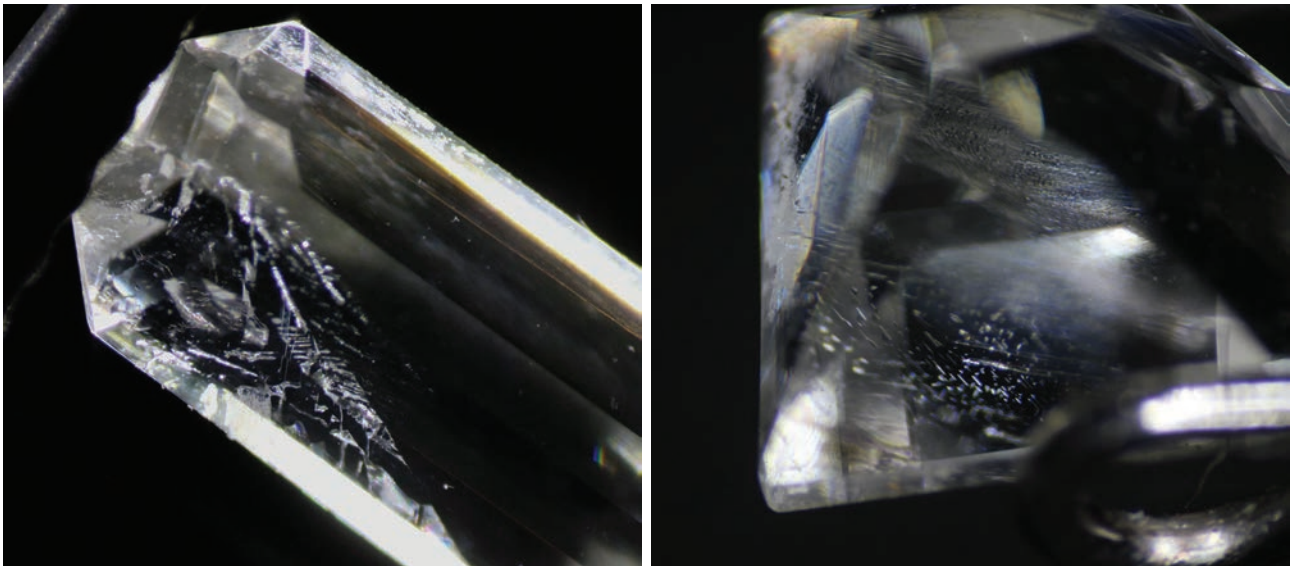


Figure 24: The whewellite on the left contains fractures that demonstrate the material's very good cleavage. The sample on the right contains fluid inclusions along partially healed cleavages. Photomicrographs by R. Hanus; magnified 40× (left) and 20× (right).

INCLUSIONS IN GEMS

Inclusions in Sunstone Feldspar from Norway

Aventurescent feldspar, commonly called *sunstone* in the gem trade, is known from various localities, mainly Tanzania and India (oligoclase with hematite inclusions) and Oregon, USA (labradorite with copper inclusions), although various other occurrences have been reported (O'Donoghue, 2006,

Figure 25: This sawn piece of rough sunstone from Norway (32 × 30 × 23 mm) displays attractive schiller and is bordered by dark layers of biotite-rich gneiss. Photo by Mauro Pantò.

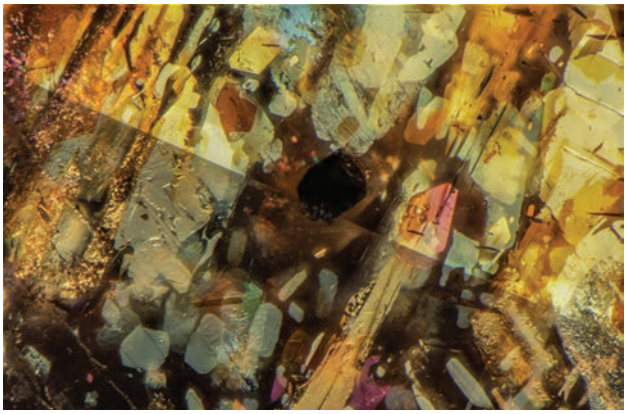
Figure 26: This 0.62 ct sunstone from Norway contains a noticeable cluster of black inclusions that were identified as biotite. Gift of Mauro Pantò; photo by Robison McMurtry, © GIA.

pp. 277–281). Southern Norway may be the first-known sunstone locality (Weibye, 1848), and although deposits in this area have not yielded large quantities of material for the gem trade, the oligoclase sunstone has been extensively characterized mineralogically (e.g. Copley and Gay, 1978, 1979).

Today it is rare to encounter Norwegian sunstone in the gem trade, but during the February 2016 Tucson gem shows, Mauro Pantò (The Beauty in the Rocks, Sassari, Italy) had several cut stones. He reported that the rough material (e.g. Figure 25) came from the original Norwegian sunstone locality (Østerådalen, Østerå, Tvedestrand, Aust-Agder), and about 75% of it displayed schiller. However, the pieces were heavily fractured, so it was difficult to facet large stones without cracks. He cut approximately 15 gems ranging from ~1 to 3 ct each.

Pantò kindly donated one of the faceted sunstones to Gem-A (Figure 26), and microscopic examination by author NDR showed a locally dense network of orange platy inclusions (Figure 27). As expected, Raman analysis identified these platelets as hematite. In addition, a group of conspicuous dark inclusions in the stone were identified as biotite. The presence of biotite in this sunstone is not surprising, since the rough material is associated with a biotite-bearing gneissic host rock that commonly envelops the sunstone (again, see Figure 25).

Figure 27: The interior of the 0.62 ct Norwegian sunstone is dominated by an oriented network of hematite inclusions. Photomicrograph by N. D. Renfro using oblique fibre-optic illumination, © GIA; image width 3.8 mm.



Brendan M. Laurs FGA and
Nathan D. Renfro FGA

References

Copley P.A. and Gay P., 1978. A scanning electron microscope investigation of some Norwegian aventurine feldspars. *Norsk Geologisk Tidsskrift*, **1**, 93–95.

Copley P.A. and Gay P., 1979. Crystallographic studies of some Norwegian aventurinised feldspars by optical, X-ray, and electron optical methods. *Norsk Geologisk Tidsskrift*, **3**, 229–237.

O'Donoghue M., Ed., 2006. *Gems*, 6th edn. Butterworth-Heinemann, Oxford, 873 pp.

Weibye P.C., 1848. Beiträge zur topograpischen Mineralogie Norwegens. *Archiv für Mineralogie, Geognosie, Bergbau und Hüttenkunde*, **22**, 465–544.

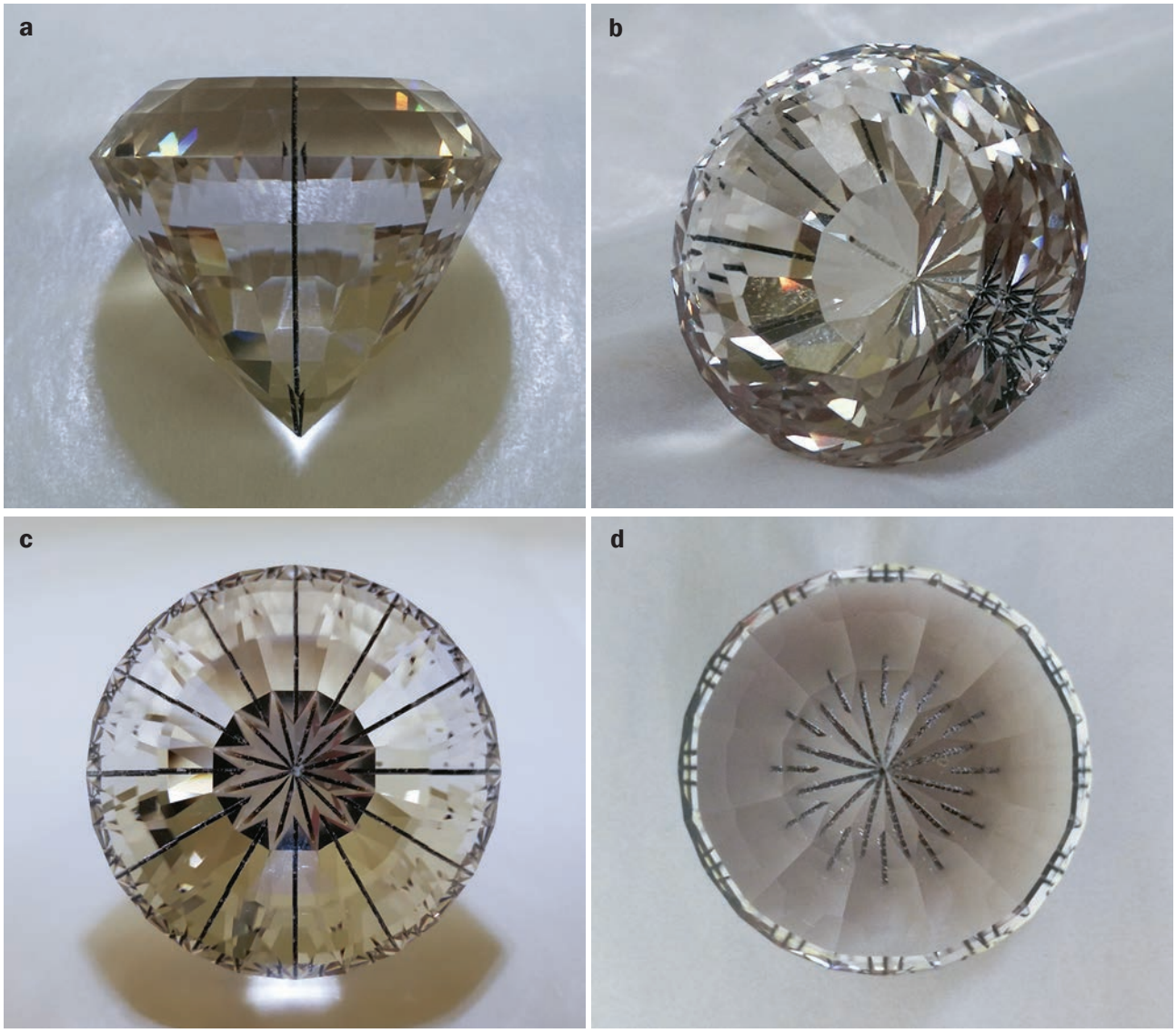
Quartz with Outstanding Black Tourmaline 'Pinwheel' Inclusion

Although inclusions in transparent gemstones are generally avoided, some of them are highly prized due to their attractive appearance or interesting nature (e.g. insects in amber, 'horsetail' inclusions in demantoid, etc.).

Inclusions of black tourmaline (schorl) in quartz are commonly encountered as aggregates of needles (e.g. Gübelin and Koivula, 2005, pp. 639–640). Rough material containing a single isolated needle of tourmaline (or another conspicuous acicular inclusion) may be carefully faceted with the inclusion extending from the culet to the centre of the table, so that when viewed face-up, the stone displays multiple reflections of the inclusion that create a spoke-like appearance (e.g. Koivula, 1986; Gübelin and Koivula, 2005, p. 549; and www.palagems.com/inclusions). Such gems are commonly referred to as having a 'pinwheel' or 'wagon-wheel' appearance.

An excellent example of this phenomenon is shown by the 50.55 ct rock crystal quartz from Madagascar in Figure 28. The stone measures 22.6 mm in diameter and has a total height of 19.6 mm; it contains a single needle of black tourmaline that is reflected with 12-fold rotational symmetry. The gem was faceted to have three steps of crown fac-

Figure 28: The 50.55 ct 'Time Quartz', cut by Y. Guazzini and from the collection of P. Entremont, contains a single black tourmaline needle that is perfectly oriented perpendicularly from the centre of the table to the culet, so that it reflects uniformly in the gemstone with 12-fold rotational symmetry. The photos show the stone from the side (a), obliquely from the top (b), directly from the top (c) and from the back (d). Photos by T. N. Bui.



ets consisting of one row of 12 mains and two rows of 24 break facets near the girdle (which is also faceted). The pavilion has three steps composed of 12 main facets, 12 star facets and 24 break facets at the girdle. In total, there are 157 facets. The gem is referred to by its owner (author PE) as 'Time Quartz', in reference to the 12-fold symmetry of the reflection pattern.

When the stone is viewed face-up (Figure 28c), the schorl reflections appear discontinuous from the centre to the girdle due to the positioning of the pavilion star facets, which are angularly shifted from all the main facets by 15°. The outer reflections of the schorl extending to the girdle are created by the crown and pavilion mains that are cut in the three rows. The gradual step angles forming the main facets in the crown and pavilion induce an overlap of the schorl reflections, resulting in the appearance that each 'needle' is continuous along its length. The triple duplication of the culet seen through the crown when the stone is viewed obliquely (Figure 28b) confirms this assertion.

When the gemstone is observed through the pavilion, the tourmaline needle is reflected only by the pavilion star facets and the first two rows of the pavilion mains (Figure 28d). The end of the reflected schorl, located at the second row of the pavilion mains, corresponds physically to the needle's intersection with the table. The discontinuous reflected image of the schorl is then virtually 'compressed' by the quartz medium.

Creating such a pinwheel appearance in gemstones is not limited to schorl in quartz, but the black colour of the inclusion does offer good contrast against the colourless quartz. This 'Time Quartz' gemstone is a demonstration of the high cutting skill achievable by lapidaries. Such pieces will likely remain uncommon, not only because of the cutting expertise needed to produce them, but also due to the rarity of finding suitable rough material (i.e. a large clean piece of transparent quartz containing only one isolated acicular schorl crystal), since tourmalinated quartz generally hosts aggregates of such needles, as well as other inclusions and fractures.

Thanh Nhan Bui (tnhan93@gmail.com)
Université catholique de Louvain
Louvain-la-Neuve, Belgium

Yves Guazzini
Gem cutter, Thiers, France

Pascal Entremont and Jean-Pierre Gauthier
Centre de Recherches Gemmologiques
Nantes, France

References

Gübelin E.J. and Koivula J.I., 2005. *Photoatlas of Inclusions in Gemstones*, Vol. 2. Opinio Publishers, Basel, Switzerland, 829 pp.

Koivula J.I., Ed., 1986. Gem News: Wagon-wheel quartz. *Gems & Gemology*, **22**(2), 114.

Illuminating Different Sets of Acicular Inclusions in 12-rayed Star Sapphires

Star sapphires with 12 rays are somewhat rare or very rare in most of the world's known deposits (Hughes, 2017, Chapter 12). Asterism in corundum (and in other minerals) is caused by the presence of oriented acicular inclusions. If one type of needle exists in one crystallographic direction in the basal pinacoid, it also will be found in the other two equivalent directions due to the ternary axial symmetry of the host corundum, leading to a six-rayed star. When observing the regularly spaced arms forming a 12-rayed star, one must conclude that this appearance is due to the presence of two sets of needles angularly rotated by 30° to one another. The authors' recent research (see below) has focused on whether these inclusions are of the same or a different nature.

What is already known about acicular inclusions in natural star sapphires? As early as 1878, Tschermak suggested that rutile was responsible for the asterism. In 1982, Sahama confirmed this. But rutile is not the only mineral that can form acicular inclusions in sapphire. In black star sapphires from Thailand, Weibel and Wessicken (1981) found the presence of hematite, but Saminpanya (2001) leant rather toward a phase of the hematite-ilmenite series. In 'Gold Sheen' sapphires from Kenya, Bui et al. (2015) identified the acicular inclusions as an intergrowth of hematite and ilmenite. In a 12-rayed black star sapphire from Ban Kha Cha, Thailand, Schmetzer and Glas (2001) noted a colour difference in the two stars turned by 30°, one bluish white due to rutile inclusions and the other 'golden' yellow due to an undetermined phase close to hematite. In similar Thai sapphires, Bui et al. (2017b) showed that rutile also might cause the six-rayed star in

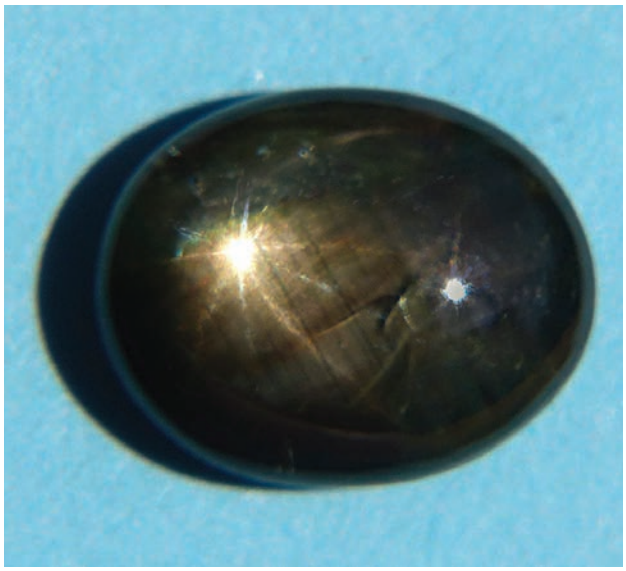
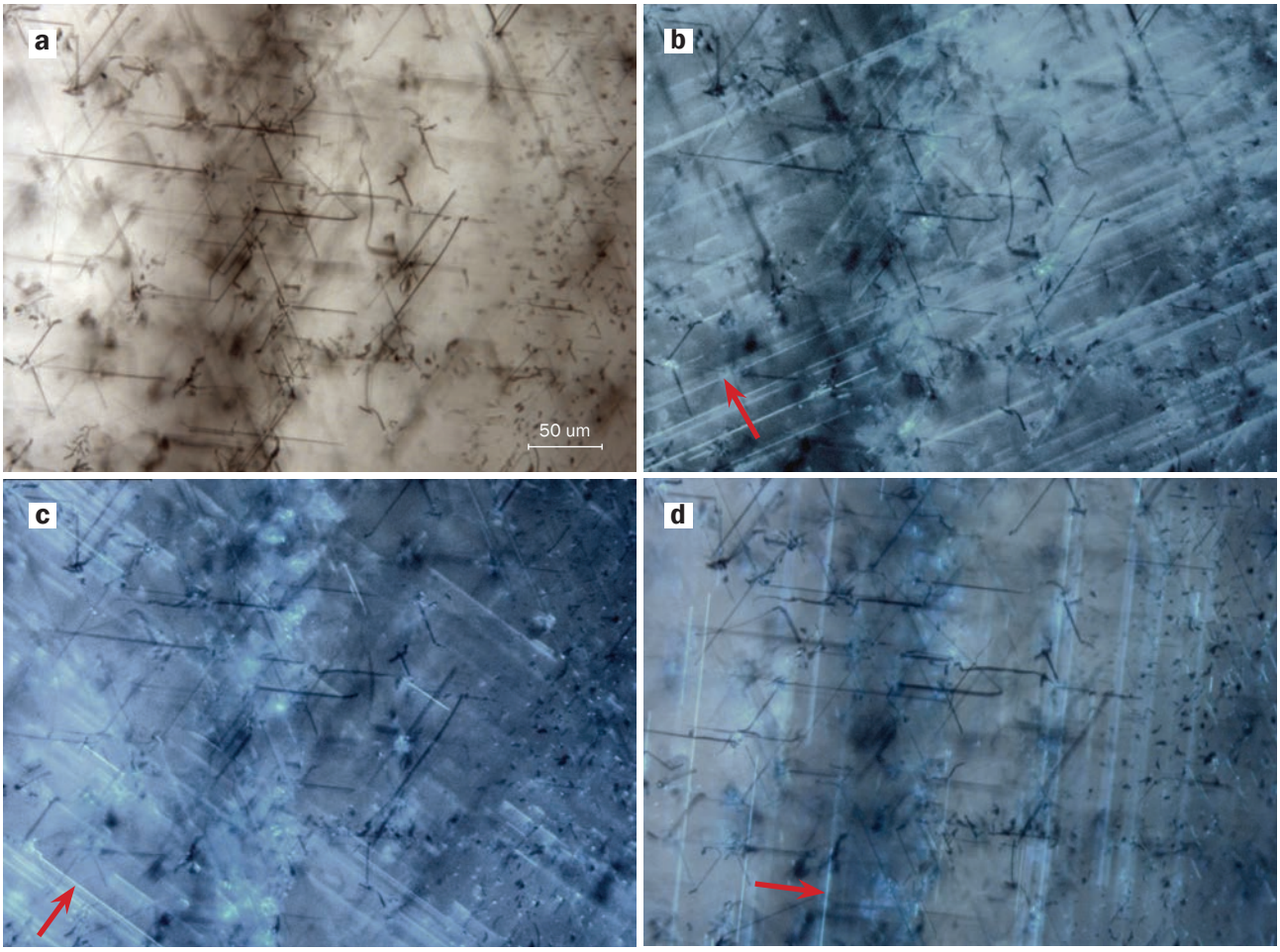


Figure 29: This 1.60 ct black star sapphire from Ban Kha Cha, Thailand, displays 12-rayed asterism and was studied for this report. Photo by J.-P. Gauthier.

one domain, whereas adjacent needles could be of the hematite-ilmenite series, yielding another six-rayed star turned by 30°. In a 12-rayed star sapphire from Sri Lanka, Bui et al. (2017a) identified both domains of acicular inclusions as ilmenite. Pearson (1990) analysed a 12-rayed Australian sapphire and found two kinds of needles: rutile and a 'ferrilmenite'-type phase.

We recently examined a few dozen 12-rayed black star sapphires from Ban Kha Cha (e.g. Figure 29) with an optical microscope at relatively high magnification (initially around 250×). Although they all displayed 12-rayed asterism, we could observe only three sets of opaque, relatively short needles perpendicular to growth zones, and these are inferred to be of the hematite-ilmenite type owing to their orientation, 'golden' brown colour and shortness compared to rutile needles (Figure 30a). Rutile inclusions seemed to be absent, un-

Figure 30: The sapphire in Figure 29 displays various acicular inclusions, as shown in these four images of the same area within the sample. (a) Transmitted lighting reveals only the opaque inclusions of hematite-ilmenite. (b,c,d) Reflected lighting oriented tangential to the surface of the cabochon in different directions shows three sets of rutile inclusions that are illuminated in succession. The arrows point to each set of rutile inclusions and show the lighting directions used to illuminate them. Photomicrographs by J.-P. Gauthier.



like in other star sapphires, such as those from Sri Lanka (Gübelin and Koivula, 2008a, p. 350 and 2008b, p. 287) or Myanmar (Hughes, 2017, p. 182), in which the rutile needles are visible within the range of magnification typically used in gemmology. In the present stones, it turns out that due to the transparency of the rutile needles in the corundum matrix and their very narrow dimension, they were not visible with our setup using transmitted lighting. We therefore tried different illumination directions, although we could not light the sample from directly overhead because the microscope objective was positioned too close to the cabochon. Instead, we used a penlight to provide reflected illumination tangentially. Thus, by orienting the light beam from various oblique directions, different sets of rutile needles were successively revealed. When directing the lamp parallel to one set of hematite-ilmenite needles, only the rutile needles perpendicular to this set were visible (Figure 30b). By changing the light azimuth by 120° and 240°, the second and third sets of rutile needles were illuminated in succession (Figure 30c,d).

Optical microscopy at higher magnification (500×; not pictured) revealed that the diameter of the rutile needles was approximately 1 µm, while that of the hematite-ilmenite needles was two to three times broader. Thus the diameter of the highlighted rutile inclusions was of the same order of magnitude as the hematite-ilmenite needles, but they were much longer (by several times). Because of the low density of the rutile inclusions, the branches of the star they caused were much less intense than those due to hematite-ilmenite.

This selective lighting method, previously used on an unusual six-rayed blue star sapphire from Tanzania (Entremont et al., 2016), is here shown to be particularly valuable for distinguishing both types of inclusions in 12-rayed star sapphires.

Jean-Pierre Gauthier and Thanh Nhan Bui

References

Bui T.N., Deliousi K., Malik T.K. and De Corte K., 2015. From exsolution to 'Gold Sheen': A new variety of corundum. *Journal of Gemmology,* **34**(8), 678–691, http://dx.doi.org/10.15506/JoG.2015.34.8.678.

Bui T.N., Entremont P. and Gauthier J.-P., 2017a. Large 12-rayed black star sapphire from Sri Lanka with asterism caused by ilmenite inclusions. *Journal of Gemmology*, **35**(5), 430–435, http://dx.doi.org/10.15506/JoG.2017.35.5.430.

Bui T.N., Solyga A., Deliousi K. and Gauthier J.-P., 2017b. Astérisme pivotant et changeant de couleur dans des saphirs noirs étoilés thaïlandais. *Revue de Gemmologie A.F.G.*, No. 199, 4–6.

Entremont P., Gauthier J.-P. and Bui T.N., 2016. Gem Notes: Unusual star sapphire from Tanzania. *Journal of Gemmology*, **35**(3), 199–201.

Gübelin E.J. and Koivula J.I., 2008a. *Photoatlas of Inclusions in Gemstones*, Vol. 1, 5th edn. Opinio Publishers, Basel, Switzerland, 532 pp.

Gübelin E.J. and Koivula J.I., 2008b. *Photoatlas of Inclusions in Gemstones*, Vol. 3. Opinio Publishers, Basel, Switzerland, 672 pp.

Hughes R.W., 2017. *Ruby & Sapphire: A Gemologist's Guide*. RWH Publishing/Lotus Publishing, Bangkok, Thailand, 816 pp.

Pearson G., 1990. Multiple chatoyancy in Australian sapphire. *Australian Gemmologist*, **17**(8), 296–298.

Sahama T.G., 1982. Asterism in Sri Lankan corundum. *Schweizerische Mineralogische und Petrographische Mitteilungen*, **62**(1), 15–20.

Saminpanya S., 2001. Ti-Fe mineral inclusions in star sapphires from Thailand. *Australian Gemmologist*, **21**(3), 125–128.

Schmetzer K. and Glas M., 2001. Zwölftstrahliger Sternsaphir aus Bang-kha-cha, Thailand. *Lapis*, **26**(11), 40–42, 54.

Tschermak G., 1878. Optisches Verhalten von Korund-Krystallen. *Mineralogische und Petrographische Mittheilungen*, **1**(4), 362–364.

Weibel M. and Wessicken R., 1981. Hämatit als Einschluß im schwarzen Sternsaphir. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **30**(3–4), 170–176.

Topaz from Sri Lanka with an Interesting Inclusion

Topaz may host a variety of interesting internal features, but recently these authors encountered an unusual inclusion that we believe was unlike those reported previously. The 4.79 ct very light brown topaz was purchased in July 2015 by gem dealer Dudley Blauwet in the local market at Ratnapura, Sri Lanka. It was reportedly cut from rough material found in Sri Lanka, and it contained a rather large pyramid-shaped inclusion that was readily visible through the table of the stone (Figure 31). Closer

Figure 31: This 4.79 ct topaz from Sri Lanka contains a pyramid-shaped inclusion under the table that was identified as fluorite. Photo by Robison McMurtry, © GIA.

examination showed that the inclusion formed a half-octahedron and was locally surrounded by narrow tension fractures (Figure 32). Raman analysis by author NDR identified the inclusion as fluorite.

Fluorite inclusions are well-known in topaz, particularly from Nigeria, in which they typically show various forms such as the cube and octahedron or a combination of these and/or the rhombic dodecahedron (Hornytzkyj, 1982). In the present case, it appears that only half of the fluorite octahedron crystallized.

Brendan M. Laurs FGA and Nathan D. Renfro FGA

Reference

Hornytzkyj S., 1982. Fluorite inclusions in topaz from Nigeria. *Journal of Gemmology*, **18**(2), 131–137, http://dx.doi.org/10.15506/jog.1982.18.2.131.

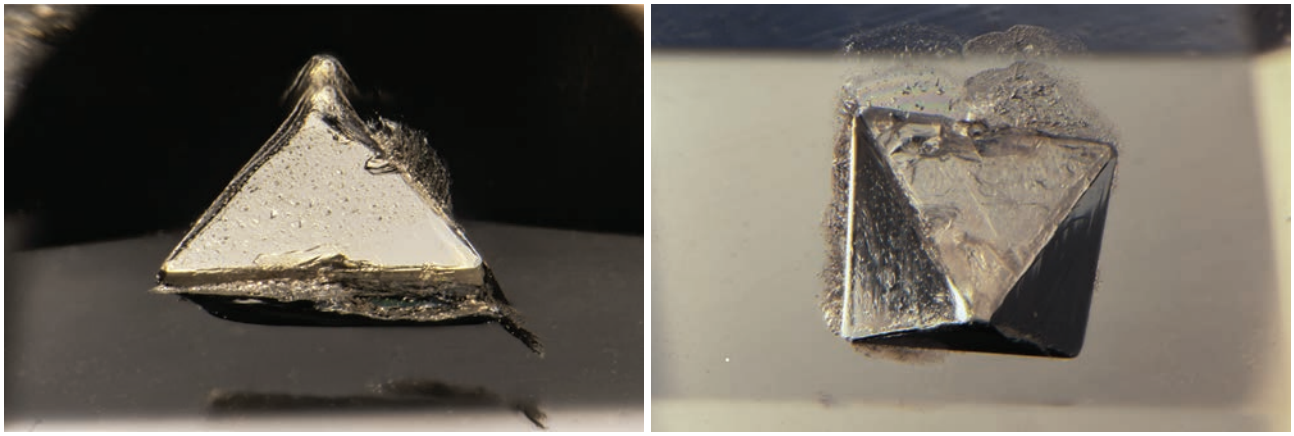


Figure 32: Two views of the fluorite inclusion reveal its pyramidal or half-octahedron shape. The inclusion is surrounded in places by small tension fractures. Photomicrographs by N. D. Renfro, © GIA; image width 3.0 mm (left) and 3.8 mm (right).

PEARLS

Black Non-Nacreous Natural Pearls from *Pteria* sp.

The Bahrain Institute for Pearls & Gemstones (DANAT), Manama, recently received a 5.70 ct black pearl (9.49–9.51 × 8.75 mm) and an 11.84 ct black and brown pearl (13.63–13.71 × 9.55 mm), both of button shape (Figure 33). Viewed with the microscope, the samples showed hexagonal-like cellular patterns linked with calcite columnar structures, similar to those observed on non-nacreous pearls of similar colour (Sturman et al., 2014). The brown part of the larger sample showed a nacreous appearance. EDXRF chemical spectroscopy revealed Sr/Mn>>12, characteristic of saltwater pearls.

Digital X-microradiographs of the samples in three orientations, taken perpendicular to one another, are shown in Figure 34. Lighter tones indicate materials with higher density such as calcium carbonate, and darker tones represent lower-density materials such as organic matter or cracks. Both samples presented radial structures, as well as concentric structures pronounced toward the rim and a darker centre (mainly observed in the larger sample; see middle and right radiographs at the bottom row of Figure 34), characteristic of natural pearls. The fully non-

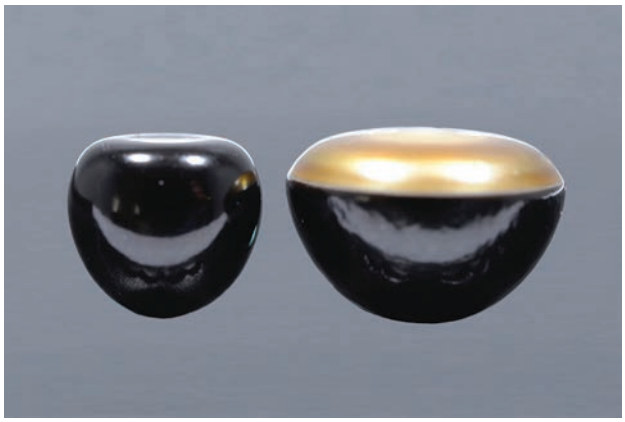


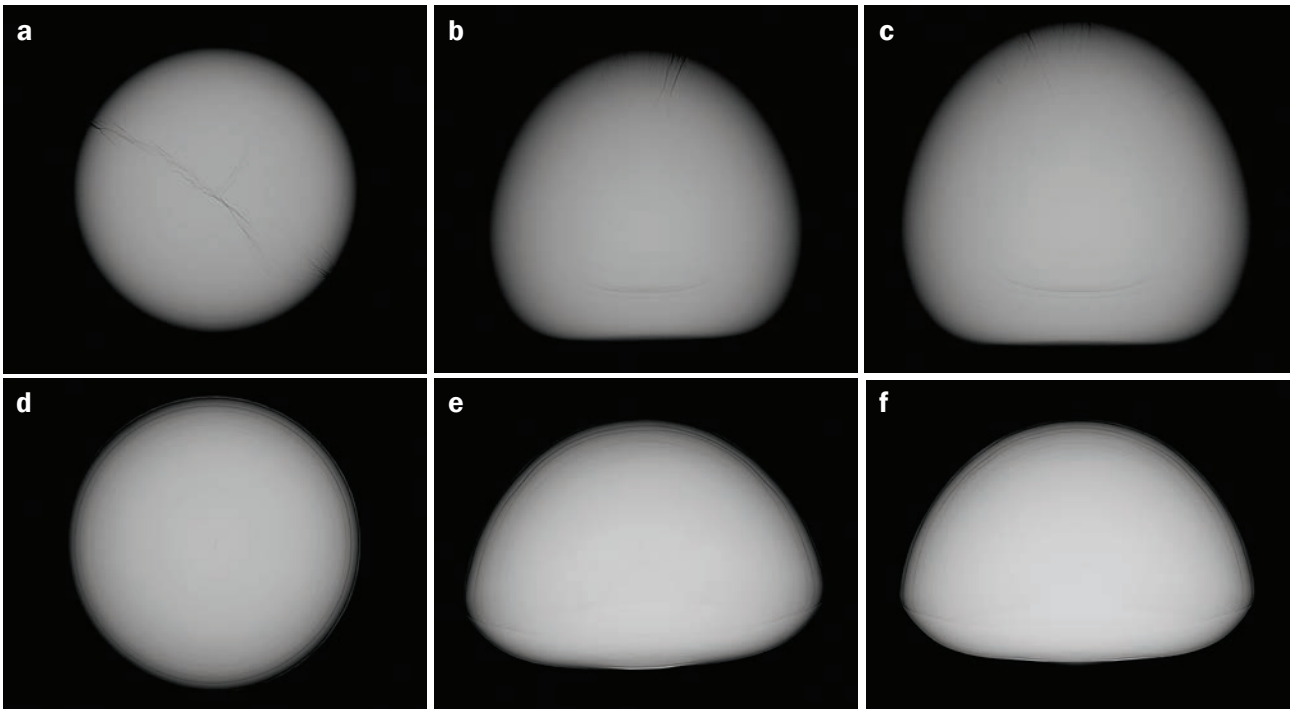
Figure 33: A 5.70 ct black pearl (left; 9.49–9.51 × 8.75 mm) and a 11.84 ct black and brown pearl (right; 13.63–13.71 × 9.55 mm) were recently examined at DANAT. Both pearls are of button shape, with the one on the left being non-nacreous and the one on the right showing areas that are non-nacreous (black part) and nacreous (brown part). Photo by H. Abdulla, © DANAT.

nacreous pearl also showed some cracks, mainly visible in the radiograph taken along the longest dimension (Figure 34a). Small cracks also were visible in the centre of the other sample (Figure 34d). It is worth noting that cracks in non-nacreous calcitic pearls are commonly observed along their columnar structures.

Under long-wave UV radiation (365 nm, 6 watt), both samples exhibited orangey red fluorescence (Figure 35), similar to that observed in pearls from *Pteria* sp. (Kiefert et al., 2004). Under short-wave UV radiation (254 nm, 6 watt), both samples luminesced a very weak yellowish green. A similar fluorescence reaction, which is linked with a kind of porphyrin, was observed for a partially non-nacreous and nacreous pearl from a *Pteria penguin* bivalve when viewed with the microscope using 300–410 nm excitation (Hainschwang et al., 2013). A porphyrin-type pigment also has been identified in natural and cultured pearls from other molluscs (e.g. *Pinctada margaritifera*); however, samples from *Pteria* sp. present orange-red fluorescence to long-wave UV. Thus, even though black-coloured non-nacreous pearls are found in different molluscs (e.g. from the Pinnidae family, also known as pen shells, which commonly show chalky yellow fluorescence to long-wave UV; Sturman et al., 2014), the fluorescence of these two samples leads us to the conclusion that they originated from *Pteria* sp.

Dr Stefanos Karampelas (Stefanos.Karampelas@danat.bh) and Hasan Abdulla
Bahrain Institute for Pearls & Gemstones (DANAT)
Manama, Bahrain

Figure 34: Digital X-radiographs are shown in three different directions for the 5.70 ct sample (top row) and the 11.84 ct sample (bottom row). The contrast has been adjusted to reveal features that the authors consider most insightful. Depending on the contrast used, the X-radiographs showed subtle features characteristic of natural pearls, including radial and concentric structures with a darker centre (note that these features may only be visible in the original hardcopy of this issue, and not in the PDF version).



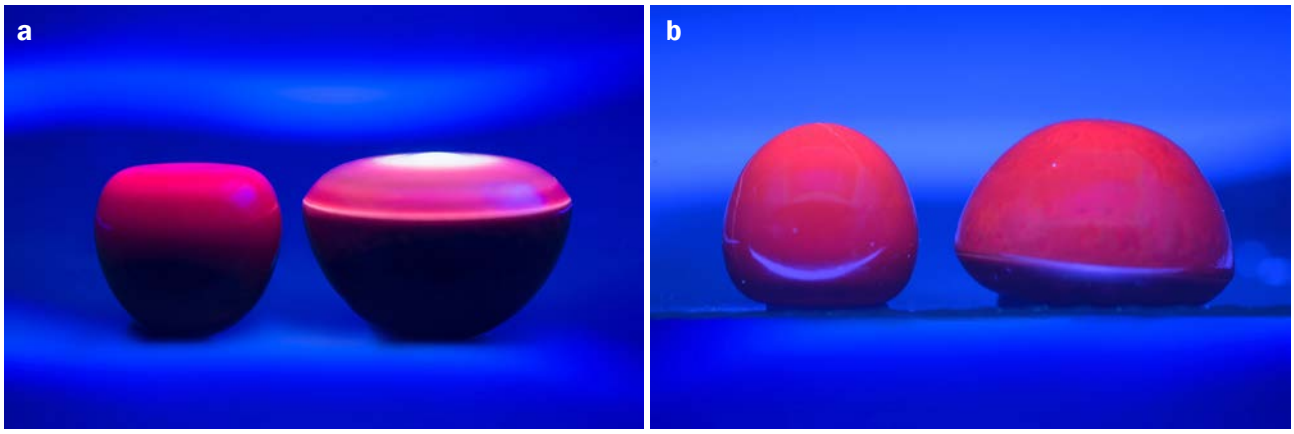


Figure 35: The samples show orangey red luminescence to long-wave UV radiation, on both their top and bottom sides, as is characteristic of pearls from Pteria *sp. Photos by H. Abdulla, © DANAT.*

References

Hainschwang T., Karampelas S., Fritsch E. and Notari F., 2013. Luminescence spectroscopy and microscopy applied to study gem materials: A case study of C centre containing diamonds. *Mineralogy and Petrology*, **107**(3), 393–413, http://dx.doi.org/10.1007/s00710-013-0273-7.

Kiefert L., Moreno D.M., Arizmendi E., Hänni H.A. and Elen S., 2004. Cultured pearls from the Gulf of California, Mexico. *Gems & Gemology*, **40**(1), 26–38, http://dx.doi.org/10.5741/gems.40.1.26.

Sturman N., Homkrajae A., Manustrong A. and Somsaard N., 2014. Observations on pearls reportedly from the Pinnidae family (pen pearls). *Gems & Gemology*, **50**(3), 202–214, http://dx.doi.org/10.5741/gems.50.3.202.

SYNTHETICS AND SIMULANTS

Pink Synthetic Spinel with an Unusually Large Negative Crystal

Recently, a pink octagonal step cut weighing 12.56 ct (Figure 36) was submitted for identification to the Gem Testing Laboratory, Jaipur, which drew attention for various reasons. First, it had an unusually large elongated tubular inclusion; second, this elongated inclusion contained a bend; and third, it hosted a group of parallel 'bomb-shaped' gas bubbles—all visible to the unaided eye. Since bomb-shaped gas bubbles are typically associated with synthetic gems grown by the flame-fusion process (e.g. Gübelin and Koivula, 1997, pp. 476–477, 501, 515), their presence, along with the large bent elongated tubular inclusion, also with different orientation, was intriguing.

Figure 36: This 12.56 ct pink flame-fusion synthetic spinel coloured by iron is unusual for its large bent tubular inclusion (negative crystal/bubble), which is visible to the unaided eye in the lower right here. Also note the group of parallel 'bomb-shaped' gas bubbles in the upper portion of the gem, which are oriented in a different direction than the large inclusion. Photo by G. Choudhary.

The large elongated inclusion also appeared to be a bomb-shaped gas bubble or a negative crystal (terms used interchangeably in synthetics; again see, e.g., Gübelin and Koivula, 1997, p. 515). It displayed complex growth consisting of several sections: a main tubular body, a tail, a pseudo-hexagonal head and a pyramidal top (Figure 37). Pseudo-hexagonal negative crystals in flame-fusion synthetics have been reported by the above-mentioned authors as well as by Kiefert (2003). The head and its top were bent at ap-

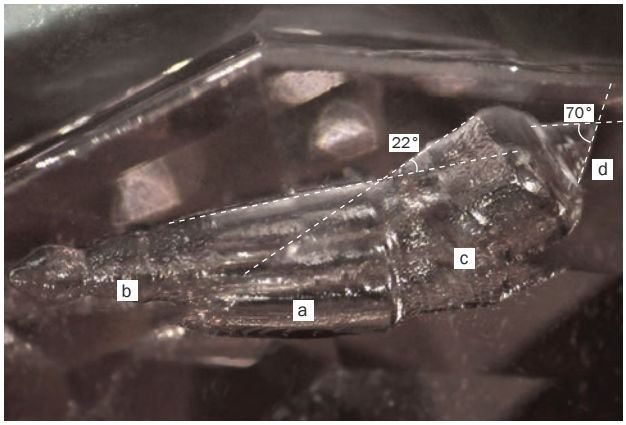
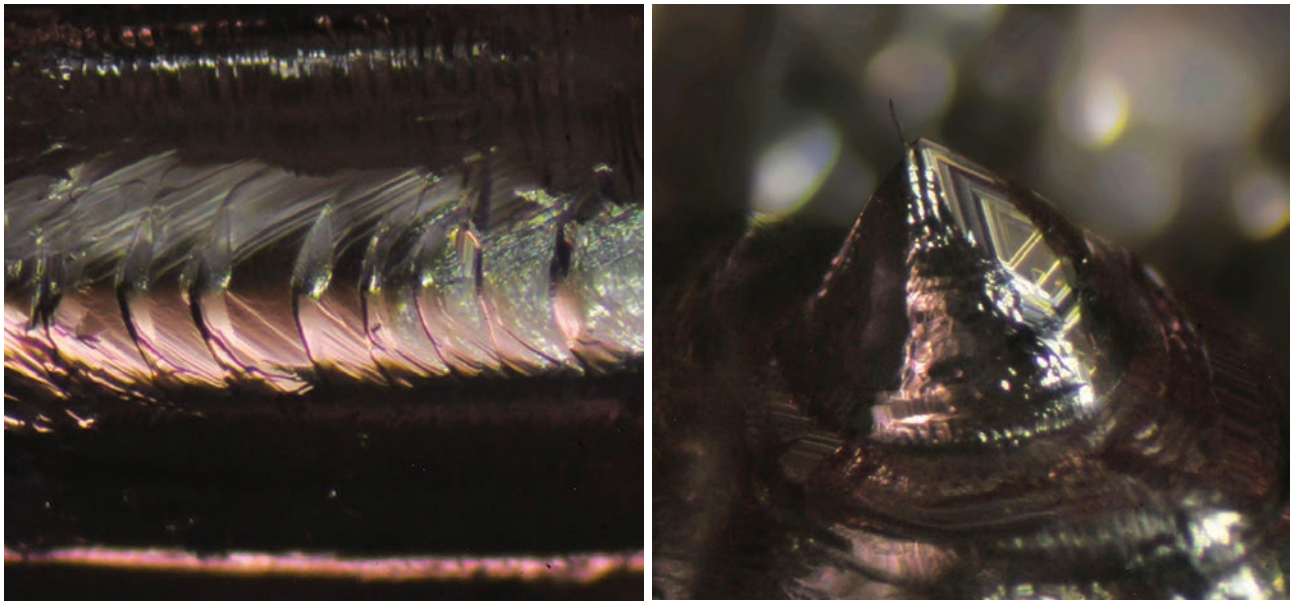


Figure 37: The large negative crystal or bomb-shaped bubble has a complex growth structure consisting of a main tubular body (a), a tail (b), a pseudo-hexagonal head (c) and a pyramidal top (d). As suggested by the interfacial angle of ~70°, the faces of the pyramidal top appear to be following octahedral directions. Photomicrograph by G. Choudhary; image width 8.0 mm.

proximately 22° from the main tubular section, while the faces of the pyramidal top intersected at approximately 70°; all these sections displayed different patterns of growth markings, controlled by the growth and symmetry of the host crystal. The main tubular body displayed striations or growth planes in two directions (Figure 38, left), giving the impression of pyramidal faces, intersecting each other at approximately 70°/110°. The pseudo-hexagonal head displayed a highly complex pattern of striations that could not be resolved properly, while the pyramidal top displayed triangular features suggesting three-fold symmetry, such as that associated with octahedral and rhombohedral faces (Figure 38, right).

Standard gemmological testing revealed a single RI value of ~1.727 and a hydrostatic SG of 3.57. Between crossed polarizers, strong anomalous birefringence (strain) was visible. Weak absorption features were seen in the blue-green and yellow-orange regions with a desk-model spectroscope, and the sample was inert to long- and short-wave UV radiation. The RI value and strong anomalous birefringence suggest synthetic spinel, although the SG value was relatively low (possibly due to the presence of the large negative crystal). Further, as compared to typical pink spinel coloured by chromium (in our reference collection as well as given in the literature, e.g. O'Donoghue, 2006, pp. 171–172), this specimen displayed neither any UV reaction nor Cr-related absorption lines in the desk-model spectroscope. Interestingly, qualitative EDXRF chemical analysis revealed traces of only Fe; no V, Cr, Co, Zn or Ga was detected. The ultraviolet-visible absorption spectrum displayed a broad band at ~553 nm with an associated weak shoulder

Figure 38: The main tubular body displays growth striations or planes in two directions, giving the impression of pyramidal faces intersecting each other at approximately 70°/110° (left). However, the angle also suggests their alignment with octahedral faces. The pyramidal top shows triangular features or hillocks (right), as commonly seen on octahedral faces of natural spinel. Photomicrographs by G. Choudhary; image width 4.6 mm for each.



at 525 nm; weak absorptions at ~442, 473 and 615 nm; and a cut-off at 400 nm. The overall properties are consistent with those reported by Krzemnicki and Lefèvre (2007) for a pink flame-fusion synthetic spinel coloured by iron.

This is the first time that our laboratory has encountered such a synthetic spinel. We could not find any reports of a synthetic gem containing negative crystals or bomb-shaped gas bubbles that display a bend or a series of complex growth markings. The growth markings on the main tubular inclusion can be related to the octahedral faces, as the angle of their intersection, as well as that of the faces of the 'pyramidal' top, is approximately 70°, which is quite close to that of the interfacial angle of octahedral faces at 70°31'44" (e.g. Ford, 2005). While the bend appears to have formed as a result of disturbances during growth, determining its exact cause would just be speculation at this stage. Any insights on this from the readers are welcome.

Gagan Choudhary FGA (gagan@gjepcindia.com)
Gem Testing Laboratory, Jaipur, India

References

Ford W.E., 2006. *Dana's Textbook of Mineralogy (with Extended Treatise Crystallography & Physical Mineralogy)*, 4th edn. CBS Publishers & Distributors, New Delhi, India, 851 pp.

Gübelin E.J. and Koivula J.I., 1997. *Photoatlas of Inclusions in Gemstones*, 3rd edn. ABC Edition, Zurich, Switzerland, 532 pp.

Kiefert L., 2003. Gem News International: Synthetic spinel with unusual inclusions. *Gems & Gemology*, **39**(3), 239–240.

Krzemnicki M.S. and Lefèvre P., 2007. Gem News: Pink synthetic spinel colored by iron. *Gems & Gemology*, **43**(2), 178–179.

O'Donoghue M., Ed., 2006. *Gems*, 6th edn. Butterworth-Heinemann, Oxford, 873 pp.

TREATMENTS

Filled Phosphosiderite

Recently 13 pendants of purple 'jade' (Figure 39) were submitted to the National Gemstone Testing Center Laboratory in Beijing, China. The samples' spot RIs (ranging from 1.69 to 1.71), SG (approximately 2.76), and infrared and Raman spectra confirmed their identity as phosphosiderite, $FePO_4 \cdot 2H_2O$ (Wang et al., 1987; Pei et al., 2012).

The samples were observed using Gemolite microscopes with magnifications ranging up to 40× and with various illuminations. With diffused light and a fibre-optic illuminator, we could see white spots on the surfaces of all the samples. Brightfield lighting showed the samples' coarse granular texture. With reflected lighting, the cracks and pits on the surfaces of 11 of the samples were seen to be filled with a material that obviously had a different lustre than the phosphosiderite; the other two samples did not show this characteristic.

Diffuse-reflectance Fourier-transform infrared (FTIR) spectroscopy of all samples was performed with a Nicolet 6700 spectrometer in the 4000–400 cm^{-1} range, at a resolution of 4.0 cm^{-1} and 32 scans. We applied a Kramers-Kronig transformation to remove distortions in the spectra (Zhang, 2006, pp. 120–121). In addition to identifying the samples as phosphosiderite (Wen, 1989), the FTIR

Figure 39: These 13 samples of purple 'jade' (from 14 x 13 mm to 31 x 14 mm) were found to be phosphosiderite. All but two of them (at the lower right) were filled with an epoxy resin. Photo by X. Feng.

spectra of the suspected filled samples showed a line at 1510 cm^{-1} (Figure 40a). Significantly, 1510 cm^{-1} is the major band of epoxy resin (González et al., 2012). To confirm that these samples had been filled with artificial resin, we carried out more detailed testing. With the client's permission, a minute amount of powder was scraped from each sample, and attenuated total reflectance (ATR) infrared spectroscopy showed a result consistent

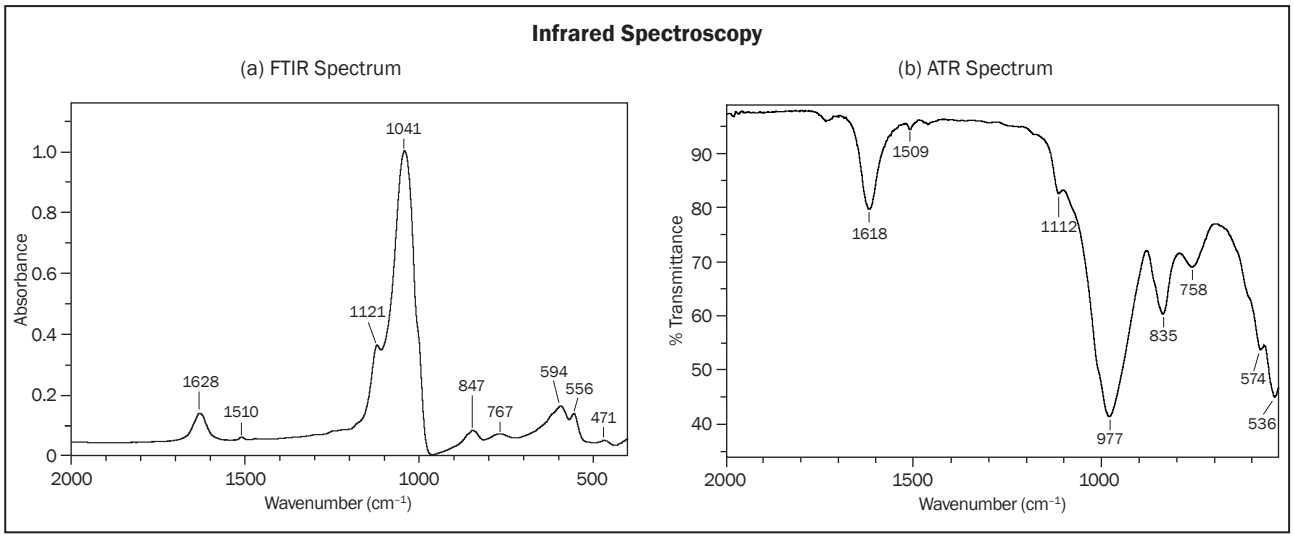


Figure 40: (a) FTIR spectroscopy (after Kramers-Kronig transformation) of the purple 'jade' pendants revealed features typical of phosphosiderite, plus a line at 1510 cm^{-1} in the filled samples that is indicative of epoxy resin. (b) ATR spectroscopy confirmed the FTIR results, including the epoxy resin feature at 1509 cm^{-1} in the filled samples.

with the diffuse-reflectance FTIR spectra: While all the samples had the characteristic bands of phosphosiderite, the filled ones had an extra line at 1509 cm^{-1} (Figure 40b).

Raman spectra of all samples were obtained at liquid-nitrogen temperature using a Renishaw In-Via Reflex laser Raman spectrometer with 532 nm excitation in the range 4000–400 cm^{-1} (at a resolution of 2.0 cm^{-1} and one scan). As expected, the main Raman peaks (1004, 984, 846, 489 and 456 cm^{-1}) confirmed that the purple 'jade' was phosphosiderite (Xi et al., 1984). The filled samples had several additional peaks at 3068, 1608, 1184 and 1110 cm^{-1} (Figure 41) that are mainly attributed to epoxy resin (Yu et al., 2004).

On the basis of microscopic observation combined with infrared and Raman spectroscopy, we concluded that 11 of the phosphosiderite samples were filled, while two of them were untreated. Although phosphosiderite is relatively common on the Chinese market today, filled phosphosiderite is much rarer.

Shanshan Du (mnshanshan0624@163.com), Xiaoyan Feng and Jun Su
National Gemstone Testing Center Laboratory, Beijing, China

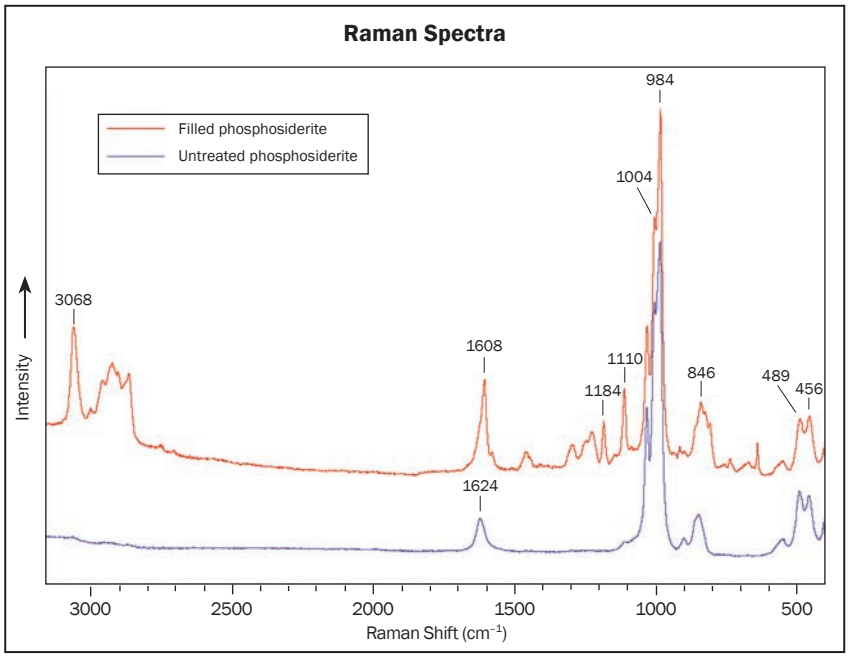


Figure 41: Raman spectra representative of the filled samples are compared to the untreated phosphosiderite. The features shown by the filled sample at 3068, 1608, 1184 and 1110 cm^{-1} are typical of epoxy resin.

References

González M.G., Cabanelas J.C. and Baselga J., 2012. Applications of FTIR on epoxy resins – Identification, monitoring the curing process, phase separation and water uptake. In T. Theophile, Ed., *Infrared Spectroscopy—Materials Science, Engineering and Technology*, InTech, Rijeka, Croatia, 261–284.

Pei J., Xie H. and He Z., 2012. Study on gemmological and mineral characteristics of phosphosiderite. *Journal of Gems & Gemmology*, **14**(4), 40–43 (in Chinese with English abstract).

Wang P., Pan Z. and Weng L., 1987. *Systematic Mineralogy*. Mineralogy Publishing, Beijing, China (in Chinese).

Wen L., 1989. *Mineral Infrared Spectroscopy*. Chongqing University Publishing, Chongqing, China (in Chinese).

Xi S., Lan S. and Zeng G., 1984. Raman and infrared spectra of rare-earth pentaphosphate. *Spectroscopy and Spectral Analysis*, **4**(1), 8–15 (in Chinese).

Yu B., Chen B. and Qiu Z., 2004. Application of instrumental testing methods in identification of treated jadeite jades. *Jewellery Science and Technology*, **55**(3), 37–49 (in Chinese with English abstract).

Zhang B., 2006. *Systematic Gemmology*, 2nd ed. Gemology Publishing, Beijing, China, 120–121.

MISCELLANEOUS

54th Myanmar Jade and Gems Emporium

On 2–11 August 2017, the 54th Myanmar Jade and Gems Emporium took place in Nay Pyi Taw. This author visited on opening day, when a large crowd gathered inside and outside of the facility due to a visit by Myanmar's vice president, U Henry Van Thio. This year's Emporium occurred in grand style with lots of security and many gem and jewellery shops open for business. In addition, the inaugural Gems and Jewellery Day was celebrated on 3 August.

Open tender bidding took place 5–10 August, and was attended by 3,466 foreign merchants and 1,845 local buyers. Of the 326 Gems lots that were offered, 105 of them sold for a total of US$3,643,809. Of the 5,500 Jade lots offered, 4,282 sold for a total of US$535,920,497.

This year the author was pleased to see good-quality rubies and sapphires, as well as some rare stones such as johachidolite, jeremejevite, serendibite, edenite and danburite. In addition, some noteworthy pieces consisted of: (1) lot no. 78, a 7.1 ct faceted ruby with a reserve price of €2,600,000; (2) lot no. 89, a 42 ct sapphire pendant set with diamonds that had a reserve price of €12,900,000; and (3) lot no. 243, an 11.82 ct pale bluish green johachidolite with a reserve price of €50,000. In total, the rubies on offer included 96 rough lots, 20 cut lots and 22 rough parcels (of Mong Hsu material), while the sapphires consisted of 30 rough lots and 58 cut lots.

Figure 42: Various colours of jadeite decorate these three beds that were offered at the 54th Emporium. Photo by T. Hlaing.

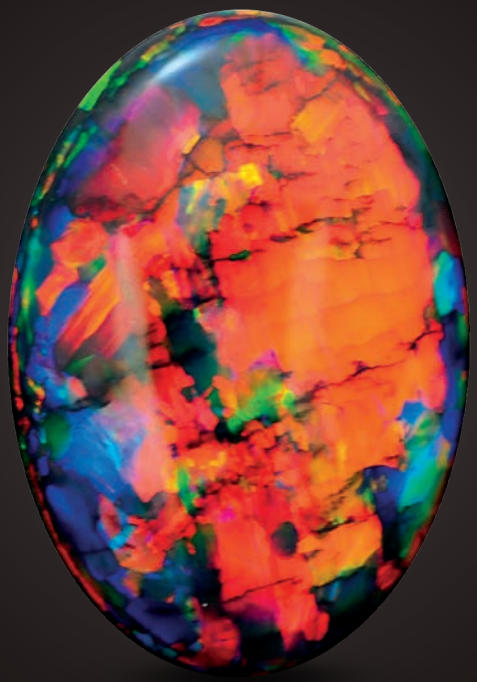
The most unusual offering at this year's Emporium consisted of three beds decorated with jadeite (Figure 42). Variously coloured jadeite tiles were used to embellish the headboards, footboards and sides of the beds, and jadeite beads were sewn together to create the bedspreads and pillowcases.

Dr U Tin Hlaing (p.tinhlaing@gmail.com)
Dept. of Geology (retired)
Panglong University, Myanmar

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD



Black Opal 15.7 Carats

Suppliers of Australia's finest opals to the world's gem trade.

CODY OPAL

Level 1 - 119 Swanston Street Melbourne Australia

T. +61 3 9654 5533 E. INFO@CODYOPAL.COM

WWW.CODYOPAL.COM

INTERNATIONAL COLORED GEMSTONE ASSOCIATION MEMBER

JOG

The Linkage Between Garnets Found in India at the Arikamedu Archaeological Site and Their Source at the Garibpet Deposit

Karl Schmetzer, H. Albert Gilg, Ulrich Schüssler, Jayshree Panjikar, Thomas Calligaro and Patrick Périn

The archaeological site of Arikamedu, located in Tamil Nadu State on the east coast of India, was the centre for many centuries of a significant bead-producing industry. Beads were made of both glass and stone, including garnet, but the source of the garnet rough material has not been confirmed. To probe this question, garnet beads found at Arikamedu were compared with rough material from the Garibpet deposit, located approximately 640 km away in Telangana State, east of the city of Hyderabad, India. Samples from the two localities exhibited substantial correlation with respect to average composition, trace-element contents, chemical zoning of major and minor elements, inclusion assemblages and zoning of inclusions between the rims and cores of the crystals. Chemically, the stones were almandine rich (averaging 81.0% almandine, 11.5% pyrope, 3.3% spessartine and 1.5% grossular), with pronounced zoning for Mn and Mg. Zoning of trace elements also was observed, especially for Y, P and Zn. The most characteristic aspects of the inclusion pattern were sillimanite fibres that were concentrated in a zone between an inclusion-rich core and an inclusion-poor rim. In combination, the microscopic observations, identification of the inclusion assemblage, and chemical analyses established that the rough material used historically in the Arikamedu area to produce garnet beads originated from the Garibpet deposit. Furthermore, the results suggest that existing schemes for classifying historical garnets require additional refinement.

The Journal of Gemmology, **35**(7), 2017, pp. 598–627, http://dx.doi.org/10.15506/JoG.2017.35.7.598

Introduction

During the Hellenistic and Roman eras, garnets in the red-to-purple colour varieties were one of the most appreciated and expensive gem minerals. Principal uses spanned from functional to aesthetic: They were both engraved as seals and set in jewellery pieces. In the ancient world, the extensive use of garnet—*anthrax* in Greek; *carbunculus* in Latin—can be traced from approximately 300 BC to the end of the western Roman Empire (5th century AD). Usage continued in the Early Middle Ages (5th–7th century AD or even

Table I: Various nomenclature schemes used for classifying historical garnets.

Calligaro et al., 2002	Type I	Type II	—	—	Type III	Type IV	Type V
Gilg et al., 2010; Gilg and Gast, 2012	Cluster B	Cluster A	Cluster C	Cluster Z	Group X	Cluster D	Cluster E
Chemical characteristics	Mn-, Cr- and Y-poor almandine	Mn-, Cr- and Y-rich almandine	Ca- and Mg-rich almandine	Ca-rich, Mg-poor almandine	Intermediate pyrope-almandine	Cr-poor pyrope	Cr-rich pyrope

somewhat later, e.g. in Scandinavia), with garnet becoming the dominant gem mineral in jewellery. The setting of flat, doubly polished garnet plates into a metal framework (see photo on the cover of this issue) is one form of the so-called cloisonné work used in the past (*cloisonné* is French for 'partitioned'). In central Europe, the extensive use of garnets in personal jewellery then decreased throughout the course of the 6th century AD and disappeared almost entirely in the 7th century, a period associated with a suspected closure of sea routes to India by the Sasanians and later by the Muslim Arab invasion (Rupp, 1937; Whitehouse and Williamson, 1973; Roth, 1980; Sidebotham, 1991; von Freeden et al., 2000; Lennartz, 2001). The causative relationship, however, has been questioned, and other factors—including changes in fashion and/or burial habits concomitant with Christianization—may have contributed to the decline in garnet use (Calligaro et al., 2006–2007; Gilg et al., 2010; Drauschke, 2011; Sorg, 2011). Summarizing the various periods in which garnet played an important role in glyptic and jewellery, Adams (2011) referred to the span from 300 BC to AD 700 as the 'garnet millennium'.

The origin of the primary garnet material used in the ancient world and the Early Middle Ages, and correlation with information found in texts penned by the authors of classical antiquity (primarily Theophrastus and Pliny the Elder), was a matter of largely unsupported speculation for decades. The initial examinations used physical and structural properties (e.g. SG, RI or unit cell dimensions obtained by X-ray diffraction analysis), but interpretations were highly ambiguous in the absence of chemical data. A major step forward was achieved when scientists began to apply nondestructive analytical techniques that measured the complete chemical composition of garnet samples found in early medieval jewellery or excavated at historical sites. Moreover, such results could then be compared with data obtained for garnets from modern sources (e.g. Löfgren, 1973; Rösch et al., 1997; Farges, 1998; Greiff, 1998; Quast and Schüssler, 2000; Calligaro et al., 2002).

Classification Schemes for Historical Garnets

Building on the advancements mentioned above, Calligaro et al. (2002) subdivided early medieval garnets into five different types primarily by means of major- and trace-element composition, with a smaller contribution coming from the identification of inclusions in a limited number of samples. As shown in Table I, these subdivisions comprised two types of almandine with different Mn, Ca, Cr and Y contents (Types I and II), two types of pyrope with different Cr levels (Types IV and V) and one intermediate pyrope-almandine type with variable composition (Type III). Further studies refined the five types (Calligaro et al., 2006–2007; Périn and Calligaro, 2007; Calligaro et al., 2009; Gast et al., 2013; Bugoi et al., 2016), and the scheme was applied, in general, to additional groups of early and even late medieval garnets by other researchers (e.g. Mathis et al., 2008; Greiff, 2010; Horváth and Bendö, 2011; Šmit et al., 2014).

Nonetheless, despite the foregoing progress, problems remain in any attempt to assign historical garnets to various types or groups. As noted, Calligaro et al. (2002) performed the main subdivision of garnets into different types by means of spot chemical analysis, and for a small number of samples inclusions also were identified by micro-Raman spectroscopy. Because pyropes are largely free of diagnostic inclusions, the 2002 study identified mineral inclusions in just five samples (one Type I almandine and four Type II almandines). Hence, although the large chemical data set of Calligaro et al. (2002)—as expanded in follow-up studies using the AGLAE proton probe at the Louvre in Paris, France (see references cited

above)—continues to be the best resource on garnet chemistry available to date, only a statistically insignificant amount of information on inclusions was provided by these studies. Consequently, the assignment of garnets to different types is at present still based mainly on chemical data, and no 'typical' inclusion patterns derived from a similarly large number of examined samples have been offered to assist in classifying Type I to Type V garnets. Furthermore, these studies did not indicate the number of stones that could not be definitely assigned to a specific type of garnet.

Such drawbacks were highlighted when Gilg et al. (2010) observed that the two types of almandines showed fairly consistent inclusion characteristics, and the intermediate pyrope-almandines (Type III) had extremely variable inclusion assemblages. Thus, the latter could not be considered a 'type', but rather were a group of different types. Gilg et al. (2010) therefore used a somewhat different nomenclature, subdividing the samples into Clusters A through E and Group X (again, see Table I). Four of the clusters paralleled four of Calligaro's types, and one, Cluster C, incorporated a new chemically distinct group for Scandinavian stones as characterized in previous studies (Löfgren, 1973; Mannerstand and Lundqvist, 2003). The remaining garnets formed the larger intermediate Group X, which corresponded broadly to Calligaro's pyrope-almandine type but likely included multiple more discrete types or clusters.

Thoresen and Schmetzer (2013) then compiled and compared properties of 37 garnets from the ancient Greek and Roman eras with those of early medieval samples. In that study, garnets were found with compositions close to four of Calligaro's types: the two different types of early medieval almandines (Type I/Cluster B and Type II/Cluster A), Cr-poor pyrope (Type IV/Cluster D) and the large group of intermediate pyrope-almandine (Type III/Group X). Conversely, no Cr-rich pyropes were discovered. In addition, the investigations identified, among the Greek and Roman samples, a third type of almandine that to date has not been seen in early medieval jewellery. These almandines were distinguished by their high Ca and Mn but very low Mg contents. A small group of Greek and Roman stones yielding a similar composition already had been denominated Cluster Z by Gilg and Gast (2012; see Table I). Still, notwithstanding such work, the statistical data set for Greek and Roman jewellery has remained small, and information about inclusions or trace-element contents was not available for all of these samples.

Thus, in summary, no clear and fully supported boundaries for the different types or clusters of historical garnets have yet been published. In most studies, only average chemical compositions and standard deviations for the types and groups, or hand-drawn compositional fields in binary plots, were provided for characterization. Ideally, data dealing with major-, minor- and trace-element compositions; with solid and fluid inclusion assemblages; and with zoning of such chemical components and inclusions—all taken from a sufficiently large number of samples—should be utilized to define a type or cluster. Such complete data sets, however, do not yet exist or have not yet been published. Consequently, for samples with overlapping chemical compositions, the need persists to find additional well-defined criteria or establish definite inclusion patterns, in order to support and better define the classification of historical garnets into types, clusters or groups. In the process, for each group of examined samples, the number of stones which cannot be definitively assigned to a specific type of garnet should be indicated.

Determining Geographic Origin of Historical Garnets

Shortcomings also affect efforts to take the next step beyond type classification and to correlate garnet types with supposed geographic origins. Many studies have pointed to large countries (India, Sri Lanka), Indian states (Rajasthan, Orissa) or regions (Bohemia) as the possible or probable source of a certain garnet type, cluster or group. Such assignments often have been based only on similarities in chemical composition and have not considered or presented adequate comparative inclusion data. Moreover, a detailed discussion of other geologically related and thus chemically similar occurrences has rarely been offered. For example, gem-quality Cr-poor pyropes with chemical compositions identical to those assigned to Type IV/Cluster D garnets have been mentioned from at least three places that were accessible in ancient and medieval times (Monte Suimo, Portugal; possibly the Jos Plateau, Nigeria [Garamantic garnets]; and Elie Ness, Scotland), the first two of which

Figure 1: These faceted garnet beads were collected by local farmers from the Arikamedu site. The samples constitute some of those studied for this report (i.e. group B1) and measure ~4.5–5.5 mm in diameter. Photo by K. Schmetzer.

apparently even relate to sources mentioned in ancient texts (Gilg et al. 2010). A further occurrence of pyrope (Mount Carmel, Israel; Mittlefehldt, 1986) has, to the knowledge of the present authors, been considered as a possible source of historical garnets only briefly by Gilg et al. (2010).

Such challenges are magnified in the case of India, where, aside from the basic problem that a specific source might have been completely exhausted and thus be presently unknown as a gem locality, the pertinent time span can be extensive and poorly documented. More than a millennium stretched between the last written record in late antiquity and the beginning of mineralogical research in India in the first part of the 19th century. Yet available recent summaries of gem garnet localities in India that might have supplied raw material for ornamental or jewellery purposes mostly repeat older references and do not provide primary data (e.g. Brown and Dey, 1955; Wadia, 1966; Jyotsna, 2000). Likewise, recent summaries of possible trade routes in antiquity (see, e.g., Borell-Seidel, 2017; Larios, 2017; Seland, 2017; Thoresen, 2017) present only generalized overviews, without referring to specific localities in detail.

Consequently, the most promising strategy, and the one employed here, is to take a more comprehensive approach: After considering the potential sources mentioned in the literature, gem-quality material is obtained from likely localities for examination and comparison with properties of the historical garnets in question, incorporating a large number of samples and multiple criteria.

The current study presents for the first time a thorough chemical and mineralogical characterization of garnets found at the Arikamedu archaeological site in southern India (e.g. Figure 1), using high-quality major- and trace-element data in conjunction with detailed inclusion studies. The authors then demonstrate a remarkable correlation with recently mined garnets from Garibpet in Telangana State, India—approximately 640 km away or 760 km distant by road—as the source of origin. Potential relationships of the Arikamedu and Garibpet garnets to those excavated at additional localities and to engraved samples, as well as a discussion of possible trade routes, will be the subjects of future publications.

Background

The Arikamedu Site and Its Connection to Garnet Beads

Arikamedu is a highly significant historical location in India and has sparked great interest within the archaeological community. The site is situated on the banks of the Ariyankuppam River, approximately 4 km south of the town of Pondicherry (Puducherry), in the state of Tamil Nadu in southeast India (Figure 2). Arikamedu was discovered in the 1930s and was excavated by British-Indian (R. E. M. Wheeler, campaign of 1945), French (J.-M. Casal, campaigns of 1947–1950) and American-Indian archaeological teams (V. Begley, campaigns of 1989–1992). These excavations unearthed numerous archaeological artefacts of Roman origin and led to Arikamedu being initially portrayed as a Roman settlement (Wheeler et al., 1946; Casal 1949; Wheeler, 1954). Continued research, however, has shifted modern theories toward interpreting Arikamedu as an important Indian trading centre and harbour, connecting the east coast of India with the Western world from the 1st century BC to the 7th century AD (Begley, 1983, 1993; Begley et al., 1996, 2004). Various trade routes from the Indian east coast (Coromandel Coast) to the west coast (Malabar Coast) have been established. These included both land routes using the Palghat Gap and sea routes via the Palk Strait between India and Sri Lanka with smaller vessels or, later, circumnavigating Sri Lanka with larger craft. The Indian west coast was then linked with Mediterranean society by means of major harbours, for example Muziris (Ray, 1994; Smith, 2002; Deloche, 2010; Rajan, 2011; Gurukkal, 2013).

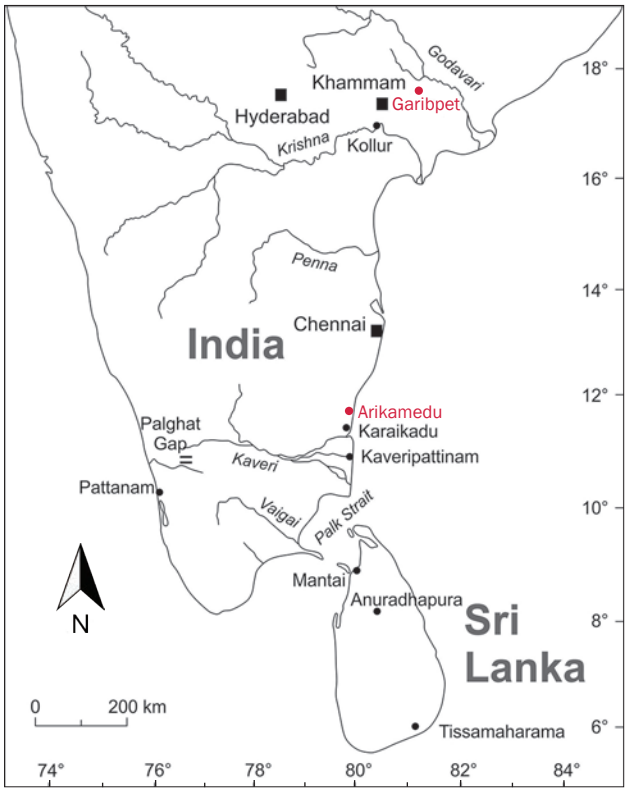


Figure 2: This map of southern India shows the locations of Arikamedu and Garibpet on the subcontinent. The Arikamedu site is located adjacent to the Ariyankuppam River, near the town of Pondicherry (neither of which are shown at the scale of this map).

Arikamedu has been equated with the harbour of Podouke (Podukê) mentioned in the *Periplus Maris Erythraei* (Periplus of the Erythraean Sea), a sailing guide written by an anonymous author in the 1st century AD (Raman, 1991). Another important ancient harbour also located on the Coromandel Coast, south of Arikamedu, was named Kaveripattinam (Rao, 1991a,b; Gaur and Sundaresh, 2006; Sundaresh and Gaur, 2011). The Kaveripattinam port has been associated with the Kaberis Emporium cited by Ptolemy (Raman, 1991) and with a locality denominated 'Caber' in a text by the traveller and merchant Cosmas Indicopleustes, written in the mid-6th century and known as *Christian Topography* (Banaji, 2015; see also Winstedt, 1909 and Schneider, 2011). It has been speculated that the text mentioning "Caber which exports alabandenum" refers to shipment of almandine garnet (Roth, 1980; Kessler 2001). After the decline in trade with the West, Arikamedu trading activities focused on the East, as demonstrated by the Chinese ceramics excavated at the site (Begley et al., 1996, 2004). In the 19th and 20th centuries, even after the archaeological importance of the site had been recognized, Arikamedu and surrounding regions continued to be used for agriculture. Only in 2006 was the land purchased by the government from private landowners and designated a protected historical site (Suresh, 2007).

In addition to its functions as port and trading centre, Arikamedu served as one of the main bead-producing localities in India. The unearthing of several thousand stone and glass beads during the archaeological excavations attests to this fact. Wheeler et al. (1946) mentioned "more than two hundred beads of various materials found in the excavations" but did not refer specifically to garnets. Casal (1949) depicted a limited number of garnets along with other beads. Detailed information describing the material excavated by Begley and her team in the 1989–1992 campaigns was published by Francis (2002, 2004), who had joined in the archaeological work. It was noted that garnets were the second-most prevalent among the stone beads after the quartz varieties. Francis (2004) listed about 3,500 pieces of glass beads and bead-making waste that were excavated in the 1989–1992 campaigns together with 200 stone beads, including 29 garnets. Numerous unworked garnet pebbles were mentioned as well, exceeding the number of finished beads.

The Pondicherry Museum houses 50,000 beads of multiple kinds, catalogued in a 'bead census' by Francis (1986). This enormous number far surpasses the several hundred beads excavated by Wheeler and Casal. Francis (1987) surmised that "the material was picked up on the surface over the last 200 years or so" by villagers living near Arikamedu. Garnet beads account for 10.1% of the Pondicherry Museum holdings of stone beads (Francis, 2002). Francis (1991, 2001, 2004) assumed that beads were produced in Arikamedu for over 2,000 years. Bead production remained on-going in the region for centuries and was only abandoned in the early 17th century. A period when the site was uninhabited followed thereafter for some time, with the area then seeing agricultural use in the 19th and 20th centuries (S. Suresh, pers. comm., 2017). Francis (1993) indicated that "the almandine garnets at Arikamedu were doubtless from lower Andhra Pradesh", but he offered no definitive proof for this conclusion.

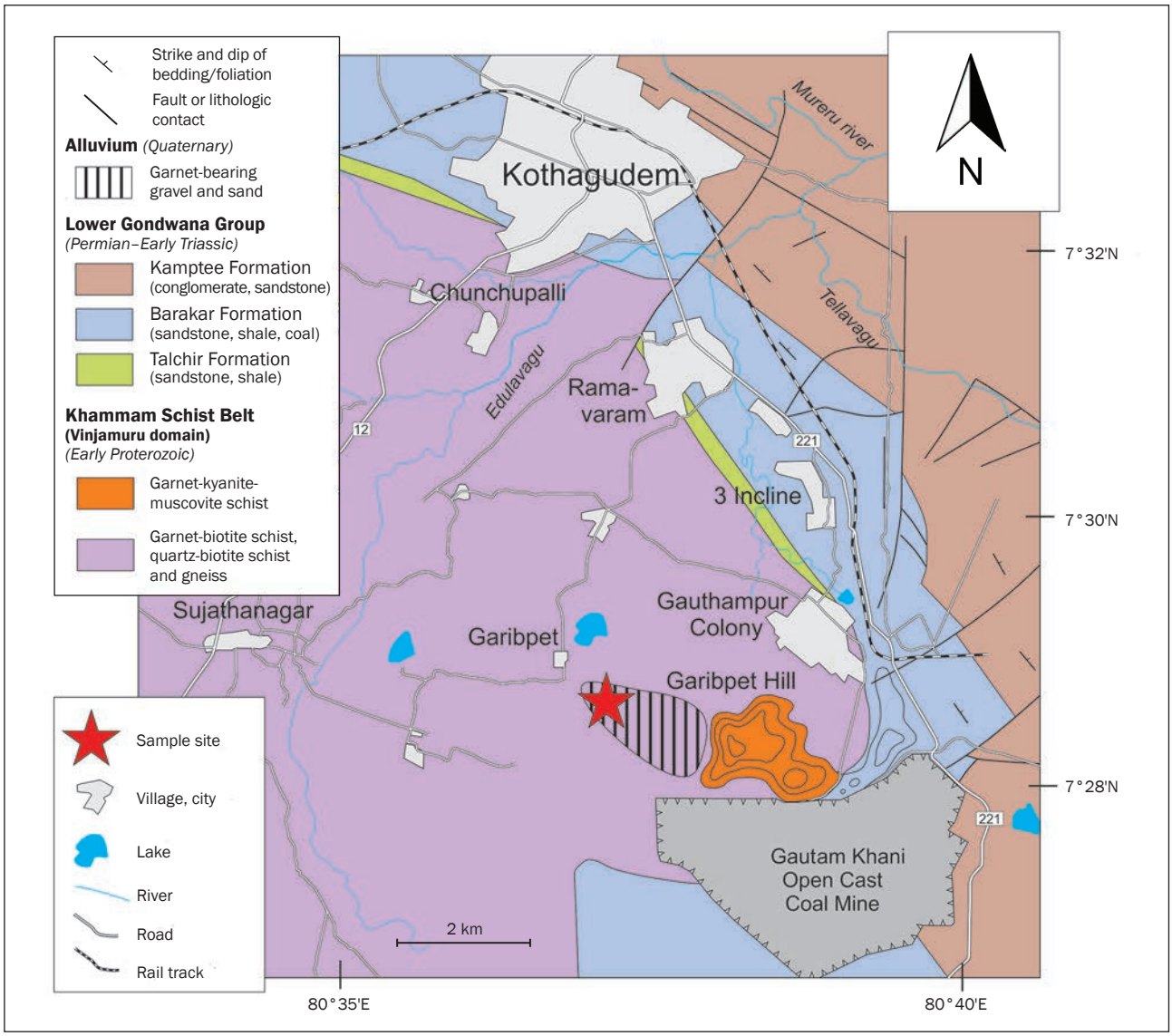


Figure 3: The locations of Garibpet Hill and Garibpet village can be seen in this geological map, south of the municipality of Kothagudem in the Khammam District, Telangana State, India. The Garibpet samples characterized in this study came from the alluvial garnet deposit associated with Garibpet Hill. After Phani (2014b).

Although stone beads were mentioned in all major excavation reports for Arikamedu (Wheeler et al., 1946; Casal, 1949; Wheeler, 1954; Begley et al., 1996, 2004), only very limited information about the garnet mineral species and composition is available. The sole source of chemical data exists in the form of a summary published twice by Francis (2002, p. 240; 2004, p. 480) of a microprobe analysis performed by C. Rösch at the University of Würzburg, Germany. The garnet, a surface find from Francis's collection, was determined to be composed of 83% almandine and 12% pyrope, with spessartine and grossular being subordinate. Unfortunately, the full analytical data underlying the summary are no longer available (C. Weinfurter, née Rösch, pers. comm., 2014). Thus, with the possibilities offered by modern scientific instruments and methods, further investigation of Arikamedu garnets may help answer heretofore unresolved questions of historical significance. In particular, correlating Arikamedu samples with medieval garnets could corroborate or disprove origin theories and could confirm ancient trade routes, as hinted at by the suggested association of the 'alabandenum' from Caber with almandine.

Garibpet—History and Geology

Garibpet Hill is located south of the modern city of Kothagudem in the Khammam District, Telangana State, and southeast of the village of Garibpet (Figures 2 and 3; see also Master Plans India, 2014). *Garibpet*, *Gharibpeth*, *Gharibpet*, *Gareeb-*

pet and several other variants of the name are mentioned in the literature. Sometimes the locality is also referred to as *Palunsha* or *Paloncha*, now part of the modern city of Palvoncha, situated northeast of Kothagudem. Telangana State was separated in 2014 from the neighbouring Indian state of Andhra Pradesh.

The Garibpet locality was first described as a secondary deposit and garnet mine by Voysey (1833), the 'Father of Indian Geology' (Murty, 1982). Many subsequent studies referred to this short note by Voysey (e.g. Walker, 1841; Newbold, 1843), and Walker also indicated that the material was cut in Hyderabad. Bauer (1896) mentioned Garibpet as a secondary occurrence of better-quality gem garnets. Mirza (1937) then reported production figures covering the period from 1910 to 1929. In addition to discussing primary sources, Mirza observed that "precious garnets are also reported in the water courses draining the hills composed of garnetiferous rocks" (see again Figure 3). The production figures reflect that the most extensive mining activity during this period evidently occurred from 1915 to 1919, as follows (converted from pounds to kilograms): 6,205 kg from 1910 to 1914, 105,513 kg from 1915 to 1919, 28,358 kg from 1920 to 1924, and 12,902 kg from 1925 to 1929.

Researchers of the current era still recognize the productive nature of the geology, with a recent publication remarking that garnet-bearing schist "constitutes an entire hill at Garibpet, in the Khammam district" of Telangana State (Phani, 2014a). Phani (2014a) further stated that in the Kothagudem area "crystals of transparent to translucent almandine variety of garnet occur in situ as well as float ore". The garnets have been used both as an abrasive and as a gem material (Kothagudem City, 2014). An analysis of Kothagudem garnet revealed a composition of 85.0% almandine, 9.5% pyrope and 0.9% spessartine (Kumar et al., 1992).

Garibpet is situated in the western part of the Proterozoic Eastern Ghats Belt, close to the north-west–south-east trending Permo-Triassic Godavari Rift (Subbaraju, 1976; Phani, 2014b). The Eastern Ghats Belt experienced two orogenic episodes as a result of collisions between the Archean Dharwar, Bhandara (Bastar) and Singhbum cratons in the west and cratonic areas of Antarctica in the east. The late Paleoproterozoic Krishna orogeny (~1.65 to 1.55 billion years [Ga]) occurred during the formation of the Columbia supercontinent (Zhao et al., 2002), while the late Mesoproterozoic to Neoproterozoic Grenvillian orogeny started ~1.1 Ga during the assembly of Rodinia (e.g. Dobmeier and Raith, 2003; Mukhopadhyay and Basak, 2009; Dasgupta et al., 2013). The Paleoproterozoic metamorphism prevails in the western part of the Eastern Ghats Belt, the so-called Krishna Province that is subdivided into the western Nellore-Khammam schist belt and the eastern granulite-facies Ongole domain (Dobmeier and Raith, 2003). The Nellore-Khammam schist belt comprises the upper, low-grade Udayagiri domain and the lower, moderate-grade Vinjamuru domain. The Kothagudem-Garibpet area is located in the Vinjamuru domain of the Khammam schist belt and consists of Paleoproterozoic moderate-grade (and partly migmatitized) metasediments and metavolcanics with minor mafic and granitic intrusives (Subbaraju, 1976).

Figure 4: (a) Shallow pits mark the locations of artisanal mining activities in this secondary deposit of garnet-bearing gravel in the Garibpet area. Garibpet Hill is visible in the background. Photo by P. Périn, 2012. (b) The gravels consist mainly of garnet pebbles (mostly ~0.5-1.5 cm in diameter). Photo by T. Calligaro, 2012.

Figure 5: This schematic map of the Arikamedu archaeological site indicates where garnet beads in the form of faceted bicones, typically broken, were found. The arrow indicates the location of the site shown in Figure 6. The inset shows a sign marking the boundary of the Arikamedu site. Photo by J. Panjikar; map after Begley et al. (1996).

The conspicuous Garibpet Hill is formed of garnet-kyanite-muscovite schist and is surrounded by biotite schist and gneiss. The adjacent Godavari Rift hosts clastic rocks composed of Lower Gondwana sediments, including the Early Permian terrestrial Talchir and Barakar Formations and the Late Permian to Early Triassic Kamptee Formation. The upper part of the Barakar Formation contains significant coal seams that make up the Kothagudem Coal Field, with several underground workings and the large Gautam Khani (or Goutham Khani) open-cast mine located to the south of Garibpet Hill (Figure 3).

The alluvial gem quality garnet-bearing gravels occur on the west-north-western side of Garibpet Hill and are derived from the weathering of the garnet-bearing schist (again, see Figure 3). The gravels are less than 1 m thick and consist mostly of garnet pebbles (Figure 4). They continue to be worked by local artisanal miners.

Figure 6: Various types of beads, including garnets, were found on the surface at the Arikamedu archaeological site. Many beads were discovered in the roots of trees and along the banks of the Ariyankuppam River. Photo by J. Panjikar, 2014.

Materials and Methods

Sample Collection

In March 2014 one of the authors (JP) visited Arikamedu, together with a local guide (Panjikar, 2014). During a walk across the site, beginning at the 'French mission house', the guide found various beads on the surface at several places. The locations of these surface finds are shown in Figure 5. Some beads were found in the roots of fallen trees (e.g. Figure 6), while others were seen in the sand along the banks of the Ariyankuppam River. A preliminary examination at the Pangem

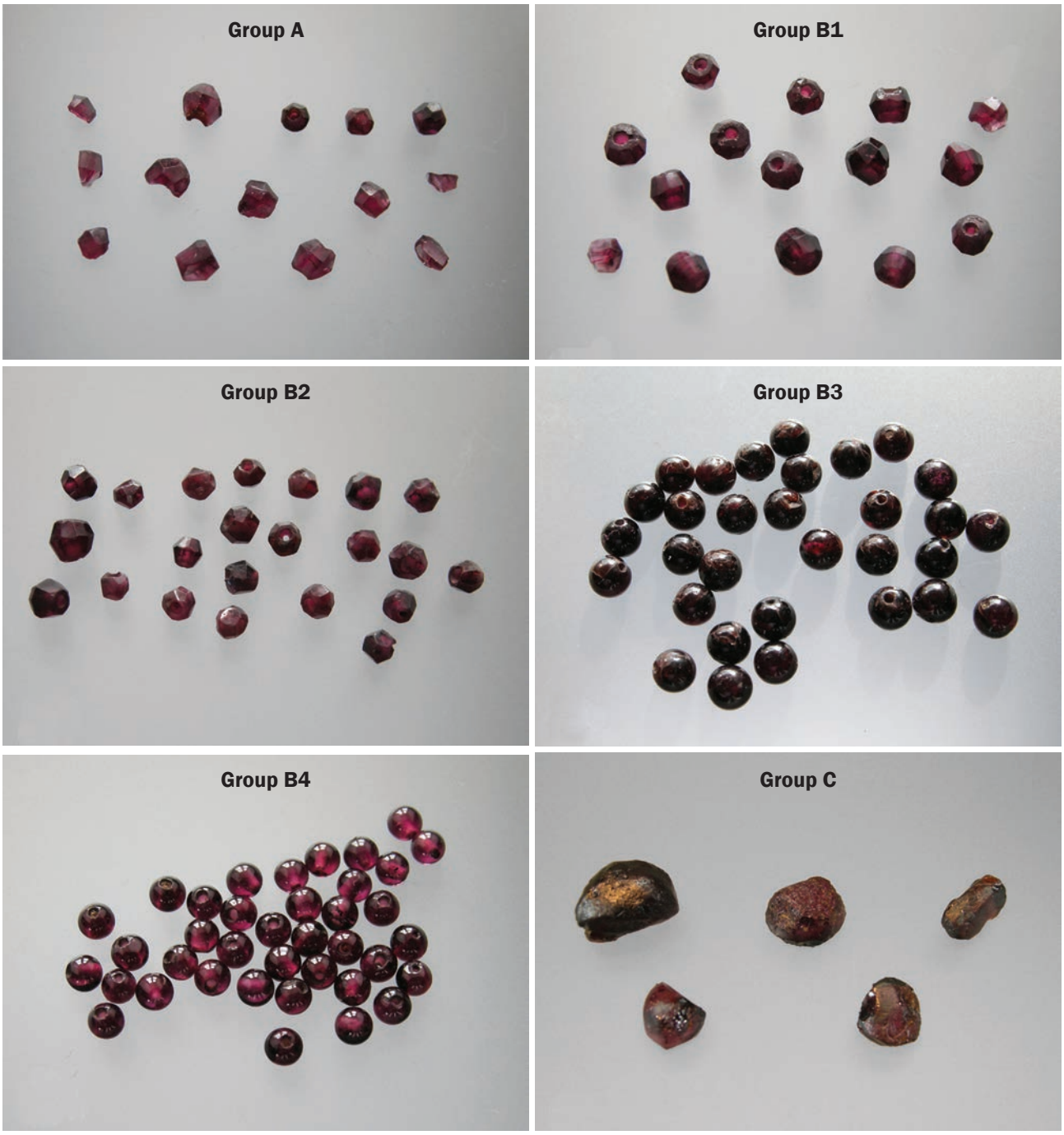


Figure 7: These photos show the garnet samples from Arikamedu that were assembled for the present study and from which selected samples were characterized. Group A: faceted bicones found at the archaeological site in 2014, with the largest measuring ~4 mm in diameter. Groups B1 and B2: transparent faceted bicones collected by local farmers, with B1 samples measuring ~4.5–5.5 mm in diameter and B2 samples being ~2.8–3.2 mm in diameter. Groups B3 and B4: translucent and transparent spherical beads collected by local farmers, with B3 samples measuring ~5.2 mm in diameter and B4 samples being ~3.2 mm in diameter. Group C: garnet fragments collected by P. Francis and archived at the American Museum of Natural History, New York, USA, with the sample at top left measuring 9.0 × 6.8 mm. Photos by K. Schmetzer.

Testing Laboratory in Pune, India, revealed that four different kinds of beads had been collected: blue glass, green glass, red to brownish red glass and garnet. The garnet beads consisted of broken and complete faceted samples, and 22 of these were sent to Germany for further examination. All garnets of this group, designated group A in the following text, were faceted in the form of barrel-shaped bicone beads and were mainly broken (Figure 7, upper left).

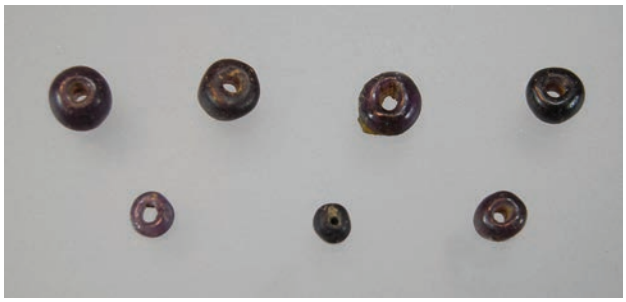


Figure 8: These red-to-purple glass beads from Arikamedu were collected by P. Francis and archived at the American Museum of Natural History, New York, USA. The sample at top left measures 3.6 mm in diameter. Photo by K. Schmetzer.

Figure 9: These garnet pebbles (~0.5–1.5 cm in diameter and coated by a weathered crust) were recovered from a secondary deposit in the Garibpet area. Photo by T. Calligaro, 2012.

During her visit to Arikamedu, author JP was informed by her guide that members of his family possessed numerous similar beads that had been unearthed in past decades during agricultural work at or near the fenced archaeological site, and a particularly substantial find had been made when local farmers were digging a well. A portion of the garnets so discovered had been kept within the guide's family for at least two generations. Ultimately, 314 such beads were obtained from the family members and supplied for examination. They are here designated group B (Figure 7) and were visually sorted into four subgroups: faceted barrel-shaped bicones (groups B1 and B2, identical in appearance to group A) and smooth spherical beads (groups B3 and B4). Group B1 consisted of 69 larger bicones ranging from ~4.5 to 5.5 mm, and group B2 contained 55 smaller bicones of ~2.8–3.2 mm. Group B3 consisted of 60 larger translucent spherical beads with a diameter of ~5.2 mm, and group B4 comprised 130 smaller transparent spherical beads of ~3.2 mm in diameter.

Although garnet samples from the Pondicherry Museum were not available for non-destructive analyses and microscopic examination, the authors were nonetheless able to obtain access through an alternate channel to material that had been collected by Peter Francis Jr. at Arikamedu. After his death in 2002, bead research materials remaining in Francis's possession in the USA were donated to the American Museum of Natural History in New York (see www.TheBeadSite.com). Upon request, all samples in the red-to-violet colour range within the container labelled 'Arikamedu', and thus potentially consisting of garnets, were made available for study. In total, 31 samples were examined. Of those, 22 were red-to-purple glass beads (e.g. Figure 8), one was an amethyst and eight were garnets. The eight garnets, designated group C for this project (Figure 7), were all rough, primarily irregularly shaped pieces without drill holes. As for the glass beads, their visual appearance was such that, without thorough gemmological examination, some could be mistaken for garnets.

For comparative purposes, the study also incorporated rough material recently obtained from the known garnet locality in Garibpet, India. Because initial research suggested that the properties of such samples correlated extremely well with those of Arikamedu material, data on Garibpet stones was obtained to investigate the possibility of this deposit being a source of garnets for the Arikamedu bead-making enterprise. The garnet samples were collected in 2012 by two of the authors (TC and PP) from a secondary deposit in the Kothagudem-Garibpet area (again, see Figure 4) and are here designated group E. These water-worn pebbles had somewhat rounded and irregularly shaped surfaces, and were generally covered by a weathered crust (Figures 9 and 10). Although some of the samples were transparent (group E1), most were only translucent at best (group E2).

Sample Selection, Preparation and Analytical Techniques

The garnets were initially examined with an immersion microscope to provide information on internal features and to guide selection of samples for more thorough investigation and analysis.

Figure 10: Among the garnet pebbles from the secondary deposits in the Garibpet area, it is possible to find transparent samples of facetable quality. The pebbles range up to ~1.5 cm in diameter. Photo by T. Calligaro, 2012.

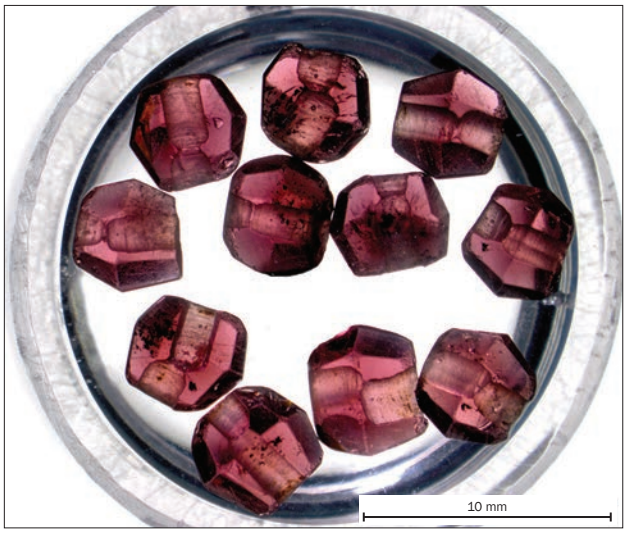


Figure 11: Faceted garnet bicones from Arikamedu were cut in half and polished for microprobe analysis. Two drill holes meet approximately in the centre of each sample. Photo by H. A. Gilg.

From the transparent Arikamedu beads (groups A, B1, B2 and B4; see Figure 7), 41 were chosen for electron microprobe analyses and detailed inclusion examination, including identification by micro-Raman spectroscopy. These examples covered all the different types of inclusion patterns seen in the various beads. For the primarily broken bicones (group A), smaller faceted bicones (group B2) and smaller transparent spherical beads (group B4), a single flat face was polished on each sample for microprobe analysis. From the larger faceted bicones (group B1), 11 beads were cut in half using a diamond wire saw, and the sawn surfaces of both halves were polished for analysis (Figure 11). The same sawing procedure was employed for five translucent spherical beads that contained opaque veinlets of foreign material (group B3). Six irregularly shaped samples from the Francis collection at the American Museum of Natural History (group C) were analysed on a suitable rough surface without preparatory cutting or polishing. A similar method had previously been used successfully for the garnet beads excavated at Tissamaharama, Sri Lanka (Schüssler et al., 2001). From the water-worn pebbles collected at Garibpet, 15 samples were sliced in half, and both resultant surfaces were polished. Seven of these garnets (group E1) were comparable with the transparent samples from Arikamedu (groups A, B1, B2, B4 and C), and the other eight (group E2) contained opaque polycrystalline seams or veinlets comparable with the translucent Arikamedu samples (group B3). The analysed garnets of the different groups are listed in Table II.

Electron microprobe analysis was carried out using a JEOL JXA 8800L instrument equipped with wavelength-dispersive spectrometers. Analytical conditions were as follows: 15 kV accelerating voltage, 20 nA beam current, 1 µm beam diameter and counting times of 20 s for peak positions and 20 s for background. Natural and synthetic silicate and oxide mineral standards or pure-element standards supplied by Cameca were used for calibration (i.e. andradite for Si and Ca, hematite for Fe, Cr_2O_3 for Cr, corundum for Al, $MnTiO_3$ for Mn and Ti, and MgO for Mg). *K*α radiation was utilized in the process, and matrix correction was performed by a ZAF procedure. Under these conditions, the detection limit was ~0.05 wt.% for most elements, and the analytical precision was better than 1% relative for all major elements.

For all samples from Arikamedu with the exception of the garnets from group C, from four to 12 single point analyses were performed on their cut/polished surfaces. Appropriate locations were selected on the rough fragments of group C for a similar number of single point analyses per stone. Additionally, for two faceted beads (group B1) and two spherical beads (group B3), detailed line-scans consisting of 29–49 point analyses per scan were obtained. For the samples from Garibpet (without drill holes), complete line-scans were performed across the cut and polished surfaces of all 15 garnets, consisting of 12–53 point analyses within a single scan. In summary, a total

Table II: Samples and techniques for microprobe analyses of garnets from Arikamedu and Garibpet, India.

Designation	Description	No. of drill-holes	No. of analysed samples	Cut and/or polished for analysis	Analysis technique[a]	No. of point analyses
Arikamedu Group A	Faceted transparent bicones, mostly broken	2	10	Yes	1	60
Arikamedu Group B1	Larger faceted transparent bicones	2	11	Yes	1, 3 (for two samples)	123[b] + 60[c]
Arikamedu Group B2	Smaller faceted transparent bicones	2	4	Yes	1	24
Arikamedu Group B3	Larger translucent spherical beads	1	5	Yes	1, 3 (for two samples)	58[b] + 80[c]
Arikamedu Group B4	Smaller transparent spherical beads	1	16	Yes	1	96
Arikamedu Group C	Irregularly shaped fragments, transparent	None	6	No	2	24
Garibpet Group E1	Irregularly shaped water-worn transparent pebbles	None	7	Yes	3 (for all samples)	192
Garibpet Group E2	Irregularly shaped water-worn translucent pebbles	None	8	Yes	3 (for all samples)	137

[a] 1 = several point analyses on a cut and/or polished face; 2 = several point analyses on a flat rough surface; 3 = continuous scans across a cut and polished face.
[b] Number of individual point analyses.
[c] Number of point analyses within continuous scans across cut and polished faces.

of 854 point analyses were acquired from the Arikamedu and Garibpet samples for this study (see again Table II).

Trace elements in the garnets were analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) using a short-pulsed (<4 ns) UP193Fx argon-fluoride fast-excimer laser ablation system (New Wave Research Inc.) inductively coupled to an Agilent 7300c plasma quadrupole mass spectrometer system with an He-Ar carrier gas mixture. Single-spot ablation (30–50 µm spot size) was conducted with a laser frequency of 20 Hz, an irradiance of 0.69 GW/cm² and a fluence of 3.41 J/cm². Data reduction was carried out using Glitter 4.4.4 software, with Si measured by the electron microprobe as an internal standard. The glass standard NIST SRM 612 (Pearce et al., 1997) was used for external calibration. Four large faceted bicones and two larger spherical beads from Arikamedu (groups B1 and B3) and seven garnets from Garibpet (groups E1 and E2) were selected for scans consisting of three to eight spot analyses from centre to rim.

A Leica DM LM polarising microscope with transmitted and reflected light sources and an Olympus DX stereomicroscope, both equipped with an Olympus DP25 digital camera and Olympus Stream Motion software, were used for microscopic investigation and documentation of inclusions. All mineral phases were additionally identified by micro-Raman spectroscopy by means of a Horiba Jobin Yvon XploRA PLUS confocal Raman microscope. The spectrometer was equipped with a frequency-doubled Nd:YAG laser (532 nm, with a maximum power of 22.5 mW) and an Olympus 100× long working-distance objective with a numerical aperture of 0.9.

Results

Arikamedu Garnets—Visual Appearance

The garnets from Arikamedu comprised both beads (groups A, B1, B2, B3 and B4) and irregularly shaped fragments (group C). The beads were either faceted bicones or smooth spheres. The bicones, all transparent, showed two parallel planar facets, on opposite ends, into which the holes through the beads had been drilled (Figures 12 and 13). The holes had been made from each end, meeting approximately in the centres of the bicones, and were cylindrical in shape (Figures 11 and 14). The bead surfaces sloped outward from each flat end, creating a rounded

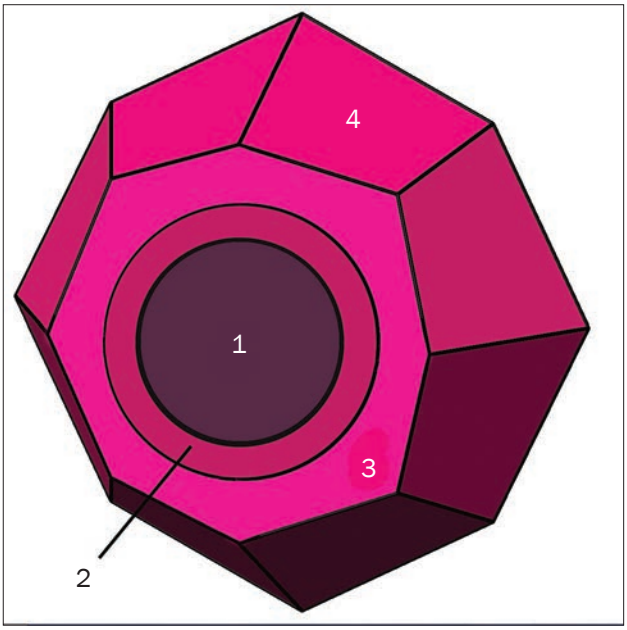


Figure 12: This schematic drawing of a faceted bicone from Arikamedu shows various features: (1) drill hole, (2) planar unpolished facet used as a base for the drill hole, (3) somewhat rounded area and (4) polished facet. Drawing by K. Schmetzer.

area, followed by two rows of facets around the sides. The two angled rows of facets intersected to form the widest diameter of the bicone beads. Measurements at these widest points versus those between the drilled planar facets reflected ratios such as 5.0/4.2 mm, 4.1/3.6 mm or 3.4/3.1 mm.

The number of polished facets in each of the two rows ranged from between 8 and 10 on the larger beads to between 7 and 9 on the smaller beads (Figure 13). Typically, the total count of facets per row for any particular bead was identical (e.g. 9/9 or 8/8), but some beads exhibited different numbers of facets within their two rows (e.g. 7/8 or 7/9). The alignment of facets within the two rows could be mirrored across the centre junction, forming a more-or-less straight sequence of edges around the cross-sections of the beads. Conversely, where the facets in the two rows varied in position or number, a zigzag pattern of edges was seen around the centre circumference (again, see Figure 13).

The spherical beads comprised either smaller transparent stones (Figure 14) or larger translucent samples (Figure 15). In detail, the larger garnets contained some transparent areas interspersed with opaque polycrystalline veins of foreign materials (Figure 15). Both the smaller and the larger spherical beads showed only a single, conically shaped drill hole.

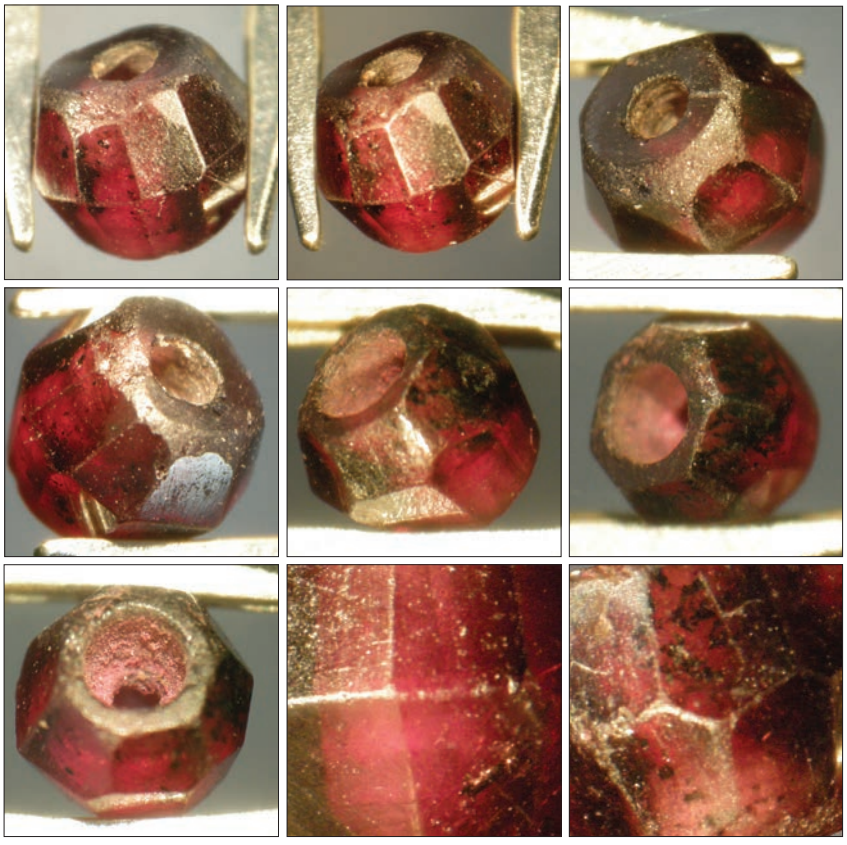


Figure 13: Shown here are various faceted bicones from Arikamedu. Each sample has planar unpolished facets serving as a base for the drill holes, and a somewhat rounded area between these planar surfaces and the rows of polished facets. If the alignment of facets in the two rows is mirrored across the centre junction, a straight sequence of edges is formed around the bicones (bottom row, centre); if the alignment or the number of facets in the two rows differs, a zigzag pattern of edges is found around the circumference (bottom row, right). The beads measure 2.8–5.5 mm in diameter. Photos by K. Schmetzer.

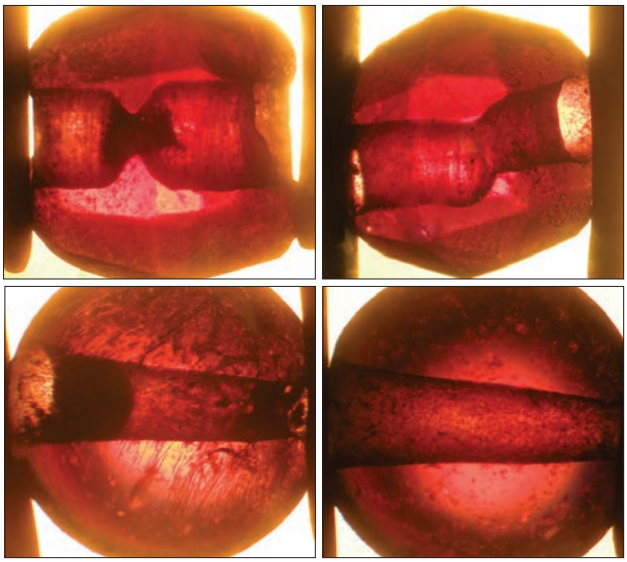


Figure 14: All faceted garnet beads from Arikamedu show two cylindrical drill holes meeting approximately at the centre (top row, ~5 mm in diameter). In contrast, spherical garnet beads from Arikamedu show only a single slightly tapered drill hole (bottom row, ~3.2 mm in diameter). Photos by K. Schmetzer.

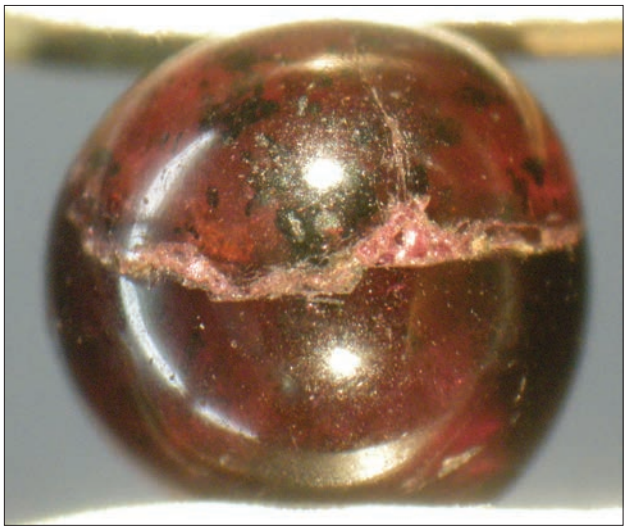


Figure 15: An irregular fracture is present in this translucent spherical garnet bead from Arikamedu. The sample measures ~5.2 mm in diameter. Photo by K. Schmetzer.

The contrast shown by the drill holes within the faceted bicones versus the spherical beads indicated different drilling techniques. According to Gwinnett and Gorelick (1987) and Gorelick and Gwinnett (1988), conically shaped drill holes are commonly observed in Asian material and are made by various simple tools. Cylindrically shaped drill holes, on the other hand, are produced by diamond drills, most likely by the so-called twin diamond drills. Analogous observations with respect to drilling methods have also previously been made in connection with an Arikamedu sample (Gwinnett and Gorelick, 1988), thus supporting the proposed manufacturing techniques.

The remaining samples from Arikamedu consisted of rough, irregularly shaped pieces without drill holes. The fragments were primarily transparent. In visual appearance, they resembled the excavated garnets depicted by Casal (1949).

All samples from Arikamedu, regardless of group, were homogeneous purplish red to reddish purple, occasionally with a slightly brownish modifier, and without any colour zoning discernible to the unaided eye.

Garibpet Garnets—Visual Appearance

The material from Garibpet (groups E1 and E2) consisted of waterworn pebbles covered by a weathered crust and, prior to preparation for testing, had not undergone further processing or fashioning. After being cleaned or polished on the surface, the diaphaneity of the gem-quality samples examined varied from translucent to fully transparent. Their colour appeared identical to that of the garnets from Arikamedu, and no colour zoning was observed with the unaided eye.

Chemical Properties

Compositional Fields and End-Member Percentages: The great majority of analysed samples from Arikamedu, including both beads and fragments (groups A, B and C), and the rough stones from Garibpet (group E) proved to be garnets with high almandine content. Microprobe data revealed almandine in the range of 77–84 mol%, with minor components of pyrope, spessartine and grossular. Calculations based on some of the 854 point analyses indicated the presence of a small andradite (Fe^{3+}) component of up to 2.0%; other garnet end members were negligible. Table III summarizes the results of the chemical analyses by electron microprobe.

A ternary plot of the molecular percentages of the garnet end members pyrope and almandine and the sum of spessartine + grossular showed that the studied garnets plotted within a relatively small compositional range (Figure 16a). This outcome was seen even more clearly when only a small portion of the full ternary diagram was drawn with an extended scale (Figure 16b). Various binary diagrams representing the

Table III: Microprobe analyses of garnets from Arikamedu and Garibpet, India.[a]

Locality	Arikamedu			Garibpet	
Group	A, B1, B2, B4	B3	C	E1	E2
Description	Transparent faceted bicones or spherical beads	Translucent spherical beads	Transparent irregularly shaped fragments	Transparent pebbles	Translucent pebbles
Composition (wt.%)					
SiO_2	35.42–37.03	35.96–37.28	34.58–37.79	34.74–36.84	35.18–36.72
TiO_2	nd–0.05	nd–0.05	nd–0.05	nd–0.06	nd–0.07
Al_2O_3	21.02–22.28	21.66–22.22	21.46–22.75	20.55–22.24	21.10–21.97
Cr_2O_3	nd–0.08	nd–0.08	nd–0.05	nd–0.08	nd–0.09
Fe_2O_3[b]	0.29–3.25	0.59–2.73	0.29–4.64	0.42–3.48	0.45–2.91
MnO	0.41–2.32	0.75–1.43	0.59–1.37	0.50–2.38	0.51–2.58
MgO	2.52–3.37	2.83–3.57	2.96–3.27	2.42–2.99	2.37–2.99
CaO	0.34–0.90	0.60–0.93	0.47–0.82	0.47–0.73	0.48–0.73
FeO[b]	34.50–37.20	35.05–36.90	34.08–37.33	34.05–37.20	0.45–2.91
FeO_{total}	36.38–38.76	36.41–38.33	36.92–39.03	36.39–38.88	36.30–39.21
Mol% end members[c]					
Almandine	77.6–83.5	77.7–82.3	77.4–81.9	79.4–83.4	79.2–84.0
Pyrope	10.2–14.2	11.3–14.1	11.8–13.0	9.8–12.0	9.6–12.0
Spessartine	0.9–5.3	1.7–3.2	1.3–3.1	1.1–5.5	1.2–5.9
Grossular	0.9–2.5	1.6–2.5	1.3–2.5	0.6–2.1	1.1–2.1

[a] The composition of two anomalous samples from Arikamedu (see Figure 16a) are not included here, since they apparently represent garnets from different primary sources. Abbreviation: nd = not detected.
[b] FeO and Fe_2O_3 were calculated from FeO_{total} by stoichiometry.
[c] Small andradite contents (up to 2.0 mol%) are not included.

main cations replacing one another within the solid-solution series pyrope-almandine-spessartine-grossular (i.e. Mg-Fe-Mn-Ca; Figure 17) also were helpful in elucidating the relatively small compositional range and the overlap of chemical properties for samples from Arikamedu and Garibpet.

The compositional fields for all but one of the transparent Arikamedu samples obtained by author JP at the archaeological site and from local residents (groups A, B1, B2 and B4) showed a complete overlap and, hence, are not reported separately. The compositions of the larger translucent garnet beads from Arikamedu containing veinlets of iron oxides and hydroxides as weathering products (group B3) were found to be in the same range, as were five of the six analysed garnets from the Francis collection (group C). The samples from Garibpet, both transparent (group E1) and translucent (group E2), likewise evidenced substantial overlap in compositional fields. No differences in chemical composition were found between 'clean' samples and those with veins filled by secondary weathering and oxidation processes, regardless of whether the material was from Arikamedu or Garibpet.

Thus, the compositional fields for the two major groups considered here (i.e. samples from Arikamedu and Garibpet) were in close proximity and overlapped to a large extent, as demonstrated in Figures 16 and 17. Neglecting the small andradite percentages, the compositional ranges for the two localities were:

- Arikamedu: 77.4–83.5% almandine, 10.2–14.2% pyrope, 0.9–5.3% spessartine, 0.9–2.5% grossular
- Garibpet: 79.2–84.0% almandine, 9.6–12.0% pyrope, 1.1–5.9% spessartine, 0.6–2.1% grossular

Notably, these almandine contents are in the upper range or even slightly above the values typically observed for gem-quality almandine from other modern localities (Stockton and Manson, 1985).

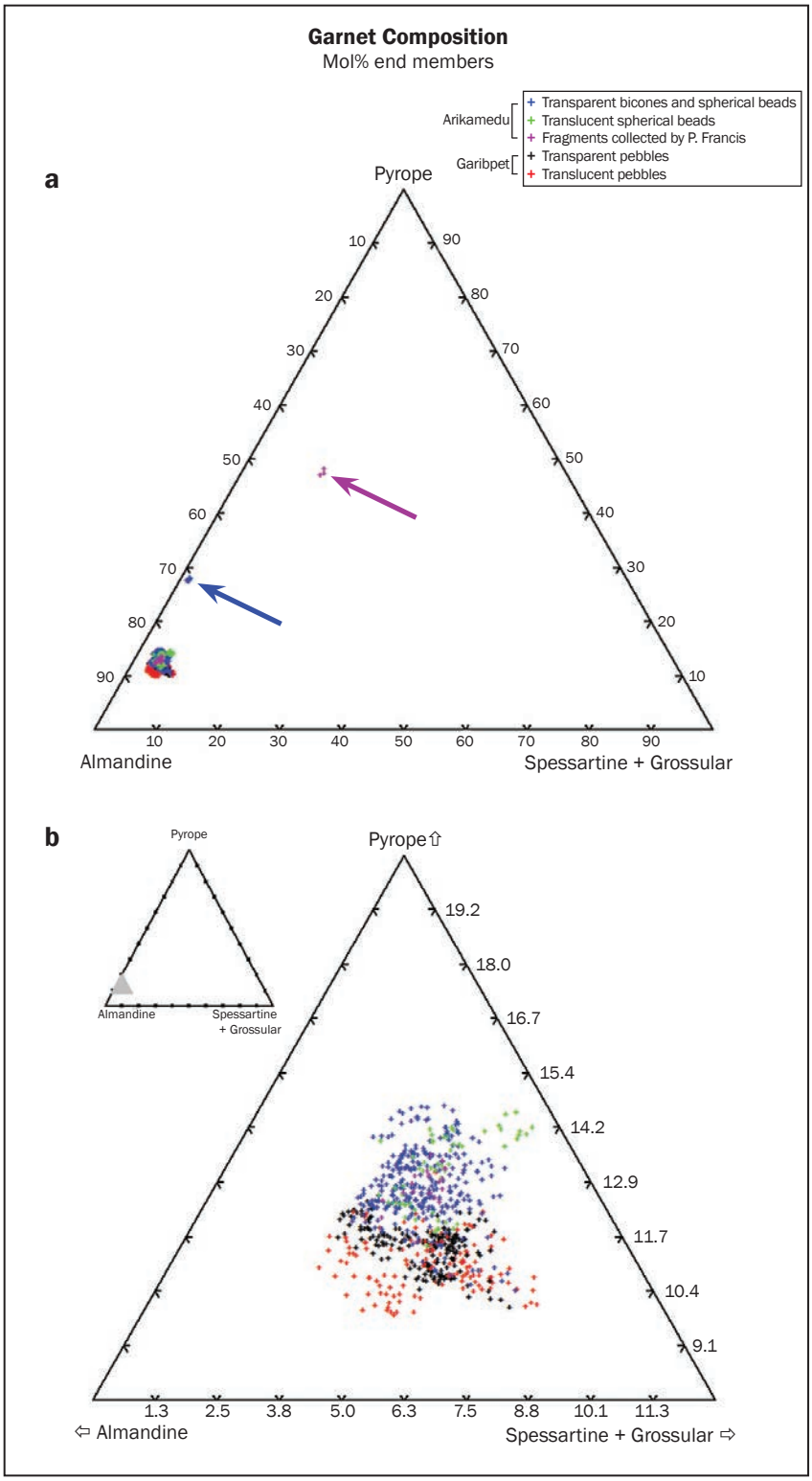


Figure 16: (a) This ternary diagram shows the chemical composition of garnets from Arikamedu and Garibpet calculated for the molecular end-members pyrope, almandine and spessartine + grossular. The compositions plot in a concentrated area, except for two anomalous Arikamedu samples (blue and purple arrows) that fall outside the main compositional field, which are inferred to be from different sources. (b) An enlarged detail of the main compositional field for the Arikamedu and Garibpet garnets corresponds to the area defined by the grey triangle in the inset. Note the extensive overlap in the composition of garnets from Arikamedu and Garibpet.

Oxide weight percentages further revealed that the average MgO content in Arikamedu samples was slightly higher than in Garibpet garnets (Figure 17a–c). The average CaO value was also slightly higher for garnets from Arikamedu (Figure 17a). In contrast, the average MnO content was slightly greater in Garibpet samples and slightly lower in garnets from Arikamedu (Figure 17b,d). Nonetheless, it should be emphasized that, although the average compositions were slightly different, samples from Arikamedu and Garibpet cannot be separated using a single point analysis, due to the wide overlap in the compositional ranges for both groups.

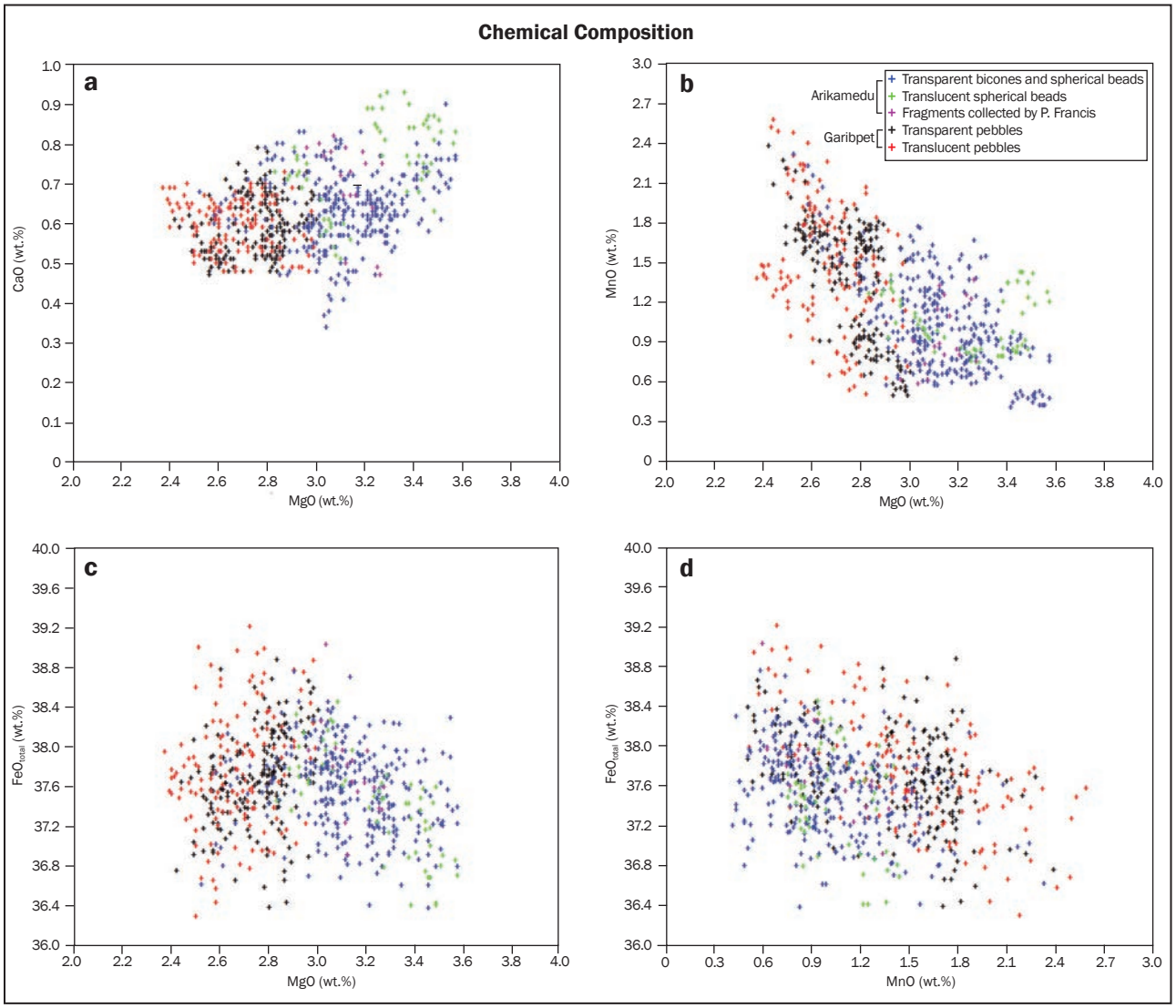


Figure 17: Various binary plots show the chemical composition of Arikamedu and Garibpet garnets, calculated as MgO, CaO, MnO and FeO weight percentages. Again, the plots show extensive overlap in the compositions for garnets from Arikamedu and Garibpet.

There were also two exceptions to the above typical composition, and they were found amongst the samples from Arikamedu (see Figure 16a). One of the beads from group A consisted of 68.4% almandine, 27.1% pyrope, 0.5% spessartine and 1.1% grossular, and one garnet from the Francis collection showed 38.9% almandine, 45.8% pyrope, 2.5% spessartine and 10.4% grossular. Given the notable divergence from the compositional ranges for the vast majority of the Arikamedu and Garibpet stones, these two garnets most likely represent samples from other primary sources, and they presumably came to Arikamedu from localities other than Garibpet.

For general interest, some of the 22 purplish red glass beads from Arikamedu that had been collected by Francis were analysed as well. These samples contained unusually high manganese contents in the range of 4.5 wt.% MnO and relatively low iron percentages of 0.9 wt.% FeO.

Chemical Zoning of Major and Minor Elements: Additional chemical detail was obtained from analytical traverses across the undrilled water-worn pebbles from Garibpet. All of these line-scans showed a decrease in Mn from core to rim of the garnet crystals, which correlated with an increase in Mg (Figure 18). Prominent Mn zonation is characteristic of prograde garnet growth (e.g. Spear, 1995), and such zoning has been reported from several locations (e.g. Lanzirotti, 1995; Borghi et al., 2000). Calcium zoning was less pronounced but still frequently observed. Calcium levels decreased slightly from the core

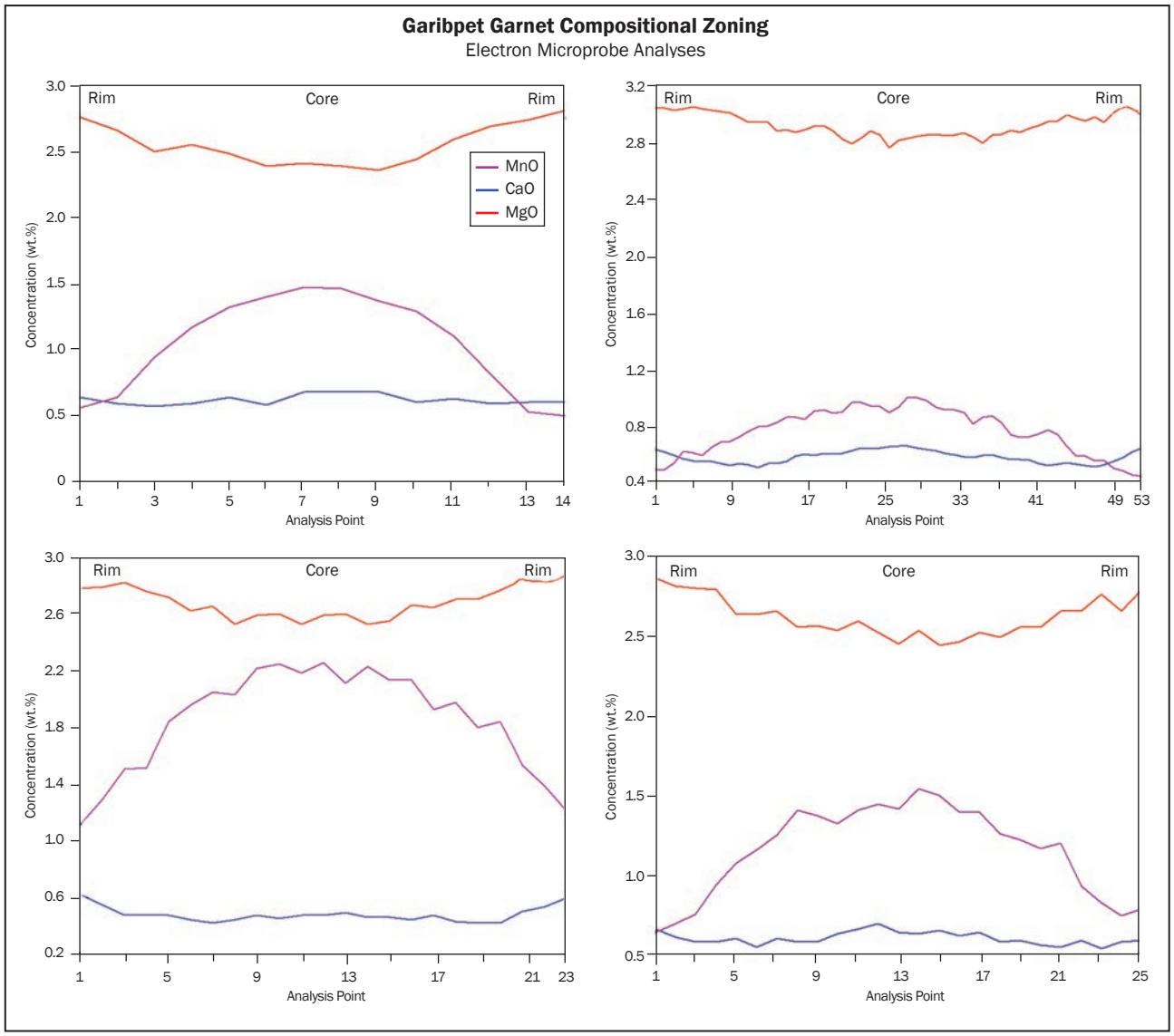


Figure 18: Line-scans by electron microprobe across four garnet samples from Garibpet show chemical zoning of MnO, CaO and MgO. From the core to the rim, MnO decreases and MgO increases; CaO exhibits a subtle but more complex pattern.

outwards and, after a minimum, then reversed direction to increase slightly toward the outermost rim (again, see Figure 18). In some scans, only a portion of the patterns depicted in Figure 18 was apparent, as expected when examining samples derived from secondary deposits in the form of water-worn pebbles, since some of the crystals were broken or abraded and did not represent the complete as-grown garnets.

The four line-scans performed across samples from Arikamedu (two faceted bicones and two spherical beads) revealed the same basic chemical zoning as the Garibpet samples. Again, however, because these beads consisted of only a part of the original as-grown crystals, the scans corresponded merely to a portion of the full area from core to rim and back. More specifically, the scans across the two spherical beads represented an area that could be described as the core plus inner rim, while the scan across one faceted bicone represented an area from core to rim and the scan across the other bicone represented an area from the rim to the core and then to the inner rim.

Crystal Chemistry: Upon plotting the atomic proportions of the main bivalent cations Mg (representing pyrope), Fe (representing almandine), Mn (representing spessartine) and Ca (representing grossular), an inverse correlation between Mg and Mn (Figure 19a) and between Mg and Fe (Figure 19b) was observed. Again, comparing the samples from Garibpet and Arikamedu, slightly

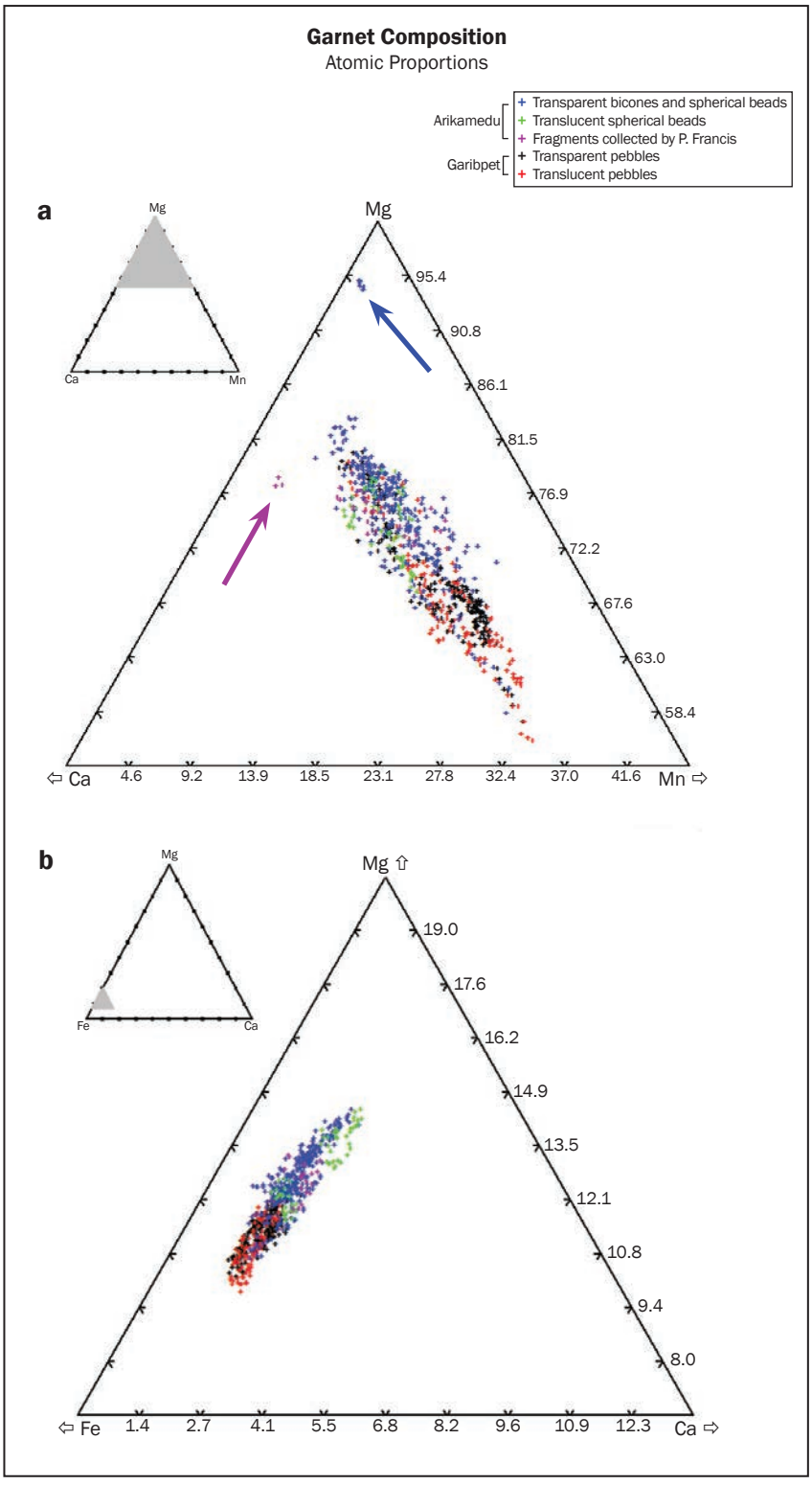


Figure 19: These ternary diagrams show the chemical composition of garnets from Arikamedu and Garibpet, calculated according to atomic proportions for: (a) Mg, Ca and Mn; and (b) Mg, Fe and Ca. Both plots display enlarged details of the full triangular diagrams, as shown by the grey triangles in the insets. The data show an inverse correlation between Mg and Mn (a) and between Mg and Fe (b).

elevated Mg (pyrope) contents were found in Arikamedu garnets, with higher Fe (almandine) and Mn (spessartine) proportions seen in garnets from Garibpet. As previously noted, the compositional ranges for the Arikamedu samples obtained on author JP's visit and those from the Francis collection were substantially equivalent, and the overlap with the Garibpet garnet chemistry was extensive. The results exhibited for both the Arikamedu and the Garibpet garnets were consistent with an isomorphic replacement of Mg by Mn, which was dominant, and a replacement of Mg by Fe, which was subordinate. This isomorphic substitution can be represented by the gen-

Table IV: LA-ICP-MS analyses of garnets from Arikamedu and Garibpet, India.

Locality	Arikamedu			Garibpet		
No. samples	6			7		
No. analyses	30			31		
Element (ppmw)	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Li	22	16	27	22	15	28
P	232	154	371	227	122	313
Ca	3454	2652	4414	3308	2746	5055
Sc	95	74	125	79	55	112
Ti	39	17	61	38	18	55
V	29	19	43	28	17	44
Cr	64	28	198	55	25	255
Mn	8747	3422	17456	11494	3451	19494
Co	33	23	56	33	19	41
Ni	0.5	0.3	1.0	0.6	0.3	1.1
Zn	129	88	159	107	77	129
Y	261	88	548	213	45	401
Zr	6	1	17	4	1	11

eral scheme Mg ↔ (Mn, Fe), applicable to all of the Arikamedu and Garibpet samples. For crystal chemistry considerations, Ca was correlated with Mn in the core of the samples and with Mg in the rim (Figure 18). This leads to a replacement scheme of Mg ↔ (Mn, Fe, Ca) for the core and (Mg, Ca) ↔ (Mn, Fe) for the rim of the garnets. Thus, in general, the small changes in Ca values representing slightly different grossular components were negligible.

Trace Elements: Trace-element contents yielded by LA-ICP-MS are summarized in Table IV. Both the compositional averages and the ranges demonstrated by the analyses were nearly identical for the Arikamedu and Garibpet garnets. A similar relationship was noted for lanthanide rare-earth elements (not shown in Table IV). Several samples from Arikamedu and Garibpet also showed chemical zoning for some trace elements, such as Y, P and Zn. Levels of certain other trace elements were nearly constant within the scans.

Considering in detail both trace and other elements as measured by LA-ICP-MS, chemical zoning between core and rim was strong for Mn and significant for Ca, largely consistent with the results of microprobe analyses. The continuously decreasing Mn contents within scans from core to rim correlated with an increase in Ca and Zn and a systematic decrease in P. Yttrium levels varied but typically in a random way, displaying only minor, and often no, systematic variation between core and rim (Figure 20). The relatively high Y concentrations in the Arikamedu and Garibpet garnets are indicative of a temperature range of ~550–600°C during formation, if buffered by xenotime (Pyle and Spear, 2000). Titanium levels were low (17–61 ppm) and showed a moderate decrease from core to rim.

Inclusions

Insofar as all investigated garnets from Arikamedu had inclusion characteristics identical to those seen in the Garibpet samples, the results are presented together here. The garnets exhibited a very typical zonation with an inclusion-rich core and a rather inclusion-poor rim (Figures 21a,b and 22). The cores reached a diameter of ~2–3 mm, while the rims had a maximum width of ~3–4 mm. Consequently, the small beads and fragments sometimes displayed inclusion features corresponding only to the core or the rim, but not both. The proto- to syngenetic inclusions in the cores comprised, with decreasing abundance: apatite, quartz, ilmenite, rutile, monazite, zircon, graphite and fluid inclusions. The elongated inclusions at times showed a preferential orientation, marking in part a wavy schistosity inherited

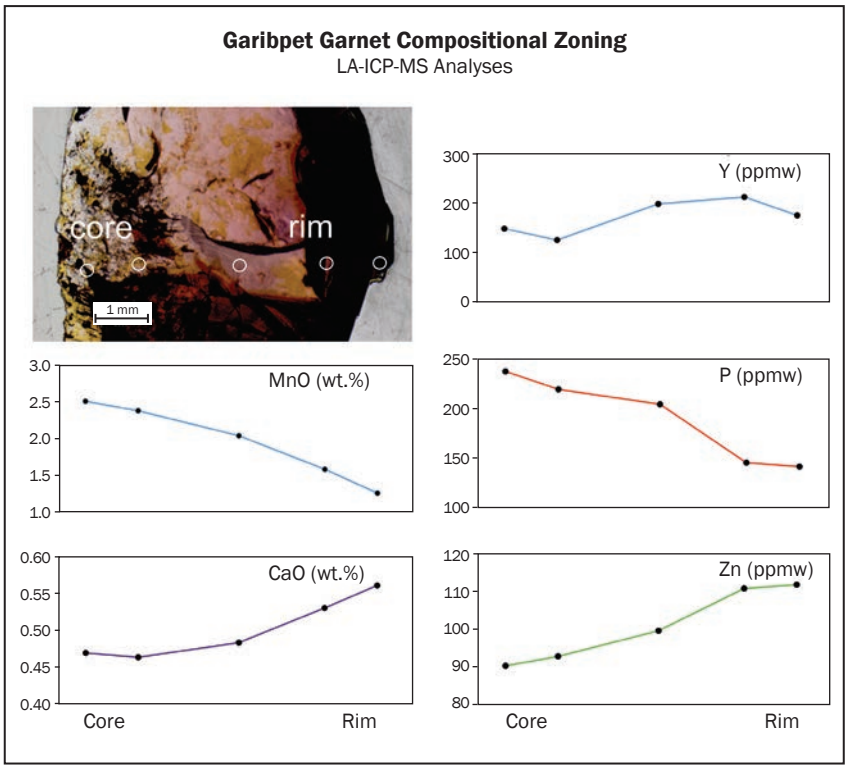


Figure 20: LA-ICP-MS analyses show chemical zoning between the core and rim in a garnet from Garibpet. Variations are seen in two primary garnet compositional elements, Mn and Ca (left), and in the trace elements Y, P and Zn (right). The analysis points are shown by the circles on the photo of the sample. Photomicrograph by H. A. Gilg.

from the metamorphic host rock. At the core-rim boundary, a very characteristic layer of fibrous sillimanite bundles was observed. The sillimanite fibres in some instances reached far into the inclusion-poor rims. Isolated zircon, monazite and quartz crystals also were found occasionally in the rims. The garnets were often cut by brownish-yellowish fractures coated by various generations of goethite or other iron oxides-hydroxides.

Apatite (Figure 21c,d) occurred as elongated, sometimes segmented, euhedral prismatic crystals up to 600 µm long and 60 µm in diameter, with subrounded tips. The apatite was colourless and contained characteristic flaky rounded opaque inclusions up to 20 µm in diameter that Raman microspectroscopy identified as graphite. Apatite was not observed in the inclusion-poor rims of the garnets.

Quartz (Figure 21e,f) was found as rounded to subrounded isometric and elongate transparent grains, as well as occasional polycrystalline aggregates with straight grain boundaries. The aggregates were more common in the inclusion-poor rims and were up to 1 mm long. Also observed was an unusual ring-shaped quartz inclusion.

Sillimanite (Figure 21g,h) was mainly seen at the core-rim boundaries. The fibrous curved aggregates of colourless needles exhibited a diameter of less than 10–30 µm (Figure 23) but reached a length of more than 1 mm. Some acicular sillimanite crystals also continued to grow into the inclusion-poor rims of the garnets (Figure 24).

Monazite (Figure 25a,b) was observed as short prismatic crystals, easily recognizable by their brownish halos, rounded shapes and inclusion-rich nature. The inclusions consisted of opaque phases, identified by Raman analyses as graphite, as well as high-relief colourless rutile crystals. Anhedral monazites up to 60 µm were seen. The monazite inclusions only exceptionally induced fractures in the host garnets.

Zircon (Figure 25c,d) was found as euhedral prismatic crystals and was primarily colourless. In contrast to the monazite inclusions, zircon almost always produced tension fractures.

Ilmenite (Figure 25e,f) often formed rounded, or more rarely subhedral, opaque flakes of up to 300 µm in diameter. These flakes occurred within the cores of the garnet crystals in groups frequently recognizable with the unaided eye. In rare cases, highly irregular shapes were found. With reflected light (Figure 25g,h), the internal structure of the opaque flakes was visible on cut surfaces and showed many rounded inclusions up to 20 µm in diameter. Raman spectroscopy identified these inclusions as quartz.

Rutile (Figure 26a,b) occurred mostly in the form of a three-dimensional network of extreme-

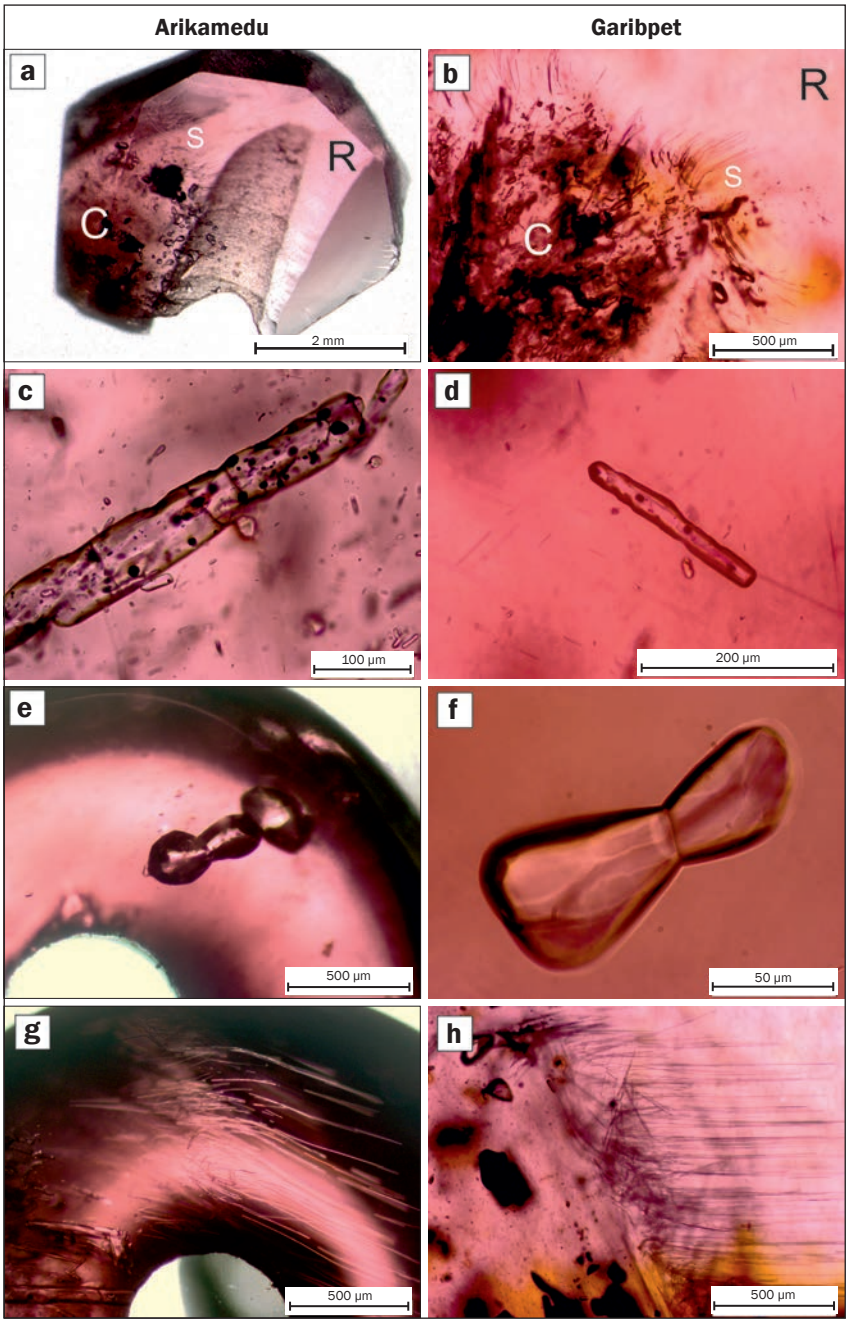


Figure 21: A comparison of the inclusion pattern found in garnets from Arikamedu (left) and Garibpet (right) revealed very similar features which include: (a,b) zoning of inclusions in the core 'C' and rim 'R' of the samples, with 's' representing a zone enriched in tiny sillimanite fibres; (c,d) apatite; (e,f) quartz; and (g,h) sillimanite fibres. Photomicrographs by H. A. Gilg.

ly thin needles oriented along [110] or [111] directions of the host, found exclusively in the cores of the zoned garnets. The distribution of the oriented needles was, however, quite patchy, and many inclusion-rich cores lacked such a rutile network. More rarely a second type of rutile was found as brownish translucent euhedral overgrowth rims on opaque ilmenite cores (Figure 26c,d).

Fluid inclusions (Figure 26e,f) were present in planar arrays along healed fractures, thus indicating their secondary nature. They always displayed a very rugged, irregular surface. Their visual aspect suggested either textural re-equilibration or retrograde reactions with the host, synchronous to the formation of colourless Fe-rich chlorite crystals. Some fractures appeared to have monophase inclusions without vapour bubbles, while others exhibited a vapour bubble filling approximately 40% of the inclusion's volume.

Secondary fractures (Figure 26g,h) were filled with polycrystalline material. Raman microspectroscopy identified them as primarily iron oxides and hydroxides (see also Figure 15).

The complete inclusion pattern just demonstrated has not yet been described for any historical garnet. However, it should be emphasized

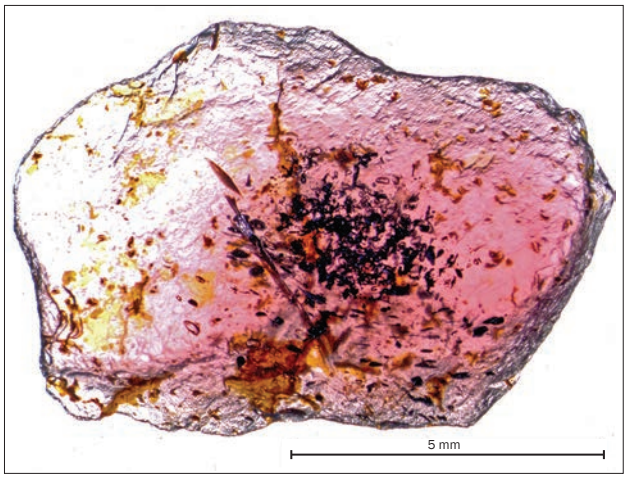


Figure 22: Zoning of inclusions in a garnet pebble from Garibpet shows a heavily included core and a more transparent rim. In the transition area is a zone enriched with a high concentration of tiny sillimanite fibres (visible at higher magnification; see, e.g., Figure 23). Photomicrograph by H. A. Gilg.

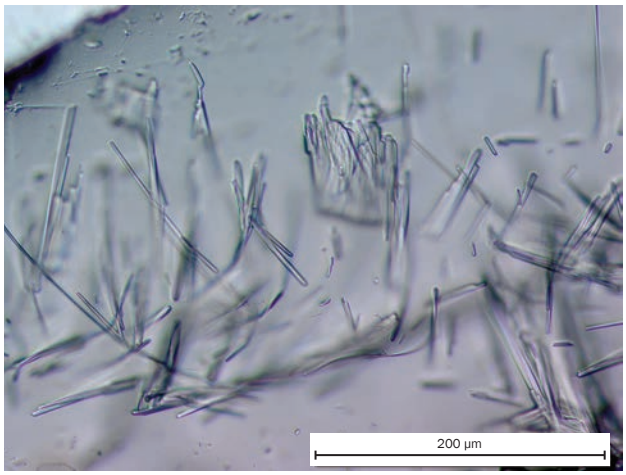


Figure 23: Tiny sillimanite fibres are shown here at high magnification in a transparent garnet bead from Arikamedu. Black-and-white photomicrograph by H. A. Gilg.

that the most characteristic feature—the zone of fine sillimanite fibres—while rare among garnets in general, is not unique. A similar rim of sillimanite fibres surrounding a core with numerous inclusions such as biotite, ilmenite and rutile was described recently from north-eastern Connecticut, USA (Axler and Ague, 2015).

Discussion and Conclusions

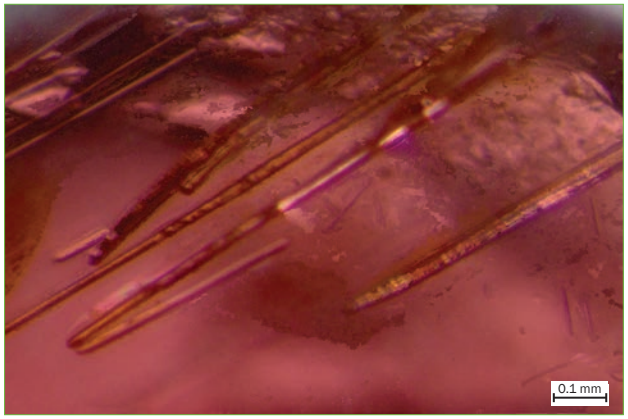
Garnets found at Arikamedu, historically one of the most important bead-producing locations in India, were characterized and compared to samples collected from an alluvial deposit in the Garibpet area, located approximately 640 km north of Arikamedu. In particular, six criteria were considered to evaluate whether the Arikamedu garnets were originally sourced from Garibpet:

1. Chemical composition, namely in terms of the percentage of garnet end members
2. Chemical zoning for major and minor elements within the crystals from core to rim
3. Trace-element contents
4. Zoning of trace elements from core to rim
5. General inclusion assemblage
6. Distribution and zoning of inclusions

The authors suggest that such criteria are key in any endeavour to establish a common source for groups of gem samples, including historical material. In applying these criteria to garnets from Arikamedu and Garibpet, the following results were obtained:

a. Broad overlap in the population fields for the chemical composition of samples from both localities, with a nearly identical average and only small differences
b. An identical scheme of chemical zoning from core to rim for major and minor elements
c. The same group of trace elements in essentially identical percentage ranges
d. A consistent situation with respect to zoning of trace elements with insignificant variability for most elements and distinct zoning for some others (e.g. Y, P and Zn in several samples)
e. The same general assemblage of inclusions, incorporating numerous specific minerals (mainly apatite, quartz, ilmenite, rutile, monazite, zircon and sillimanite)

Figure 24: Coarse acicular sillimanite needles were observed in a small number of the garnets from Arikamedu. Photomicrograph by H. A. Gilg.



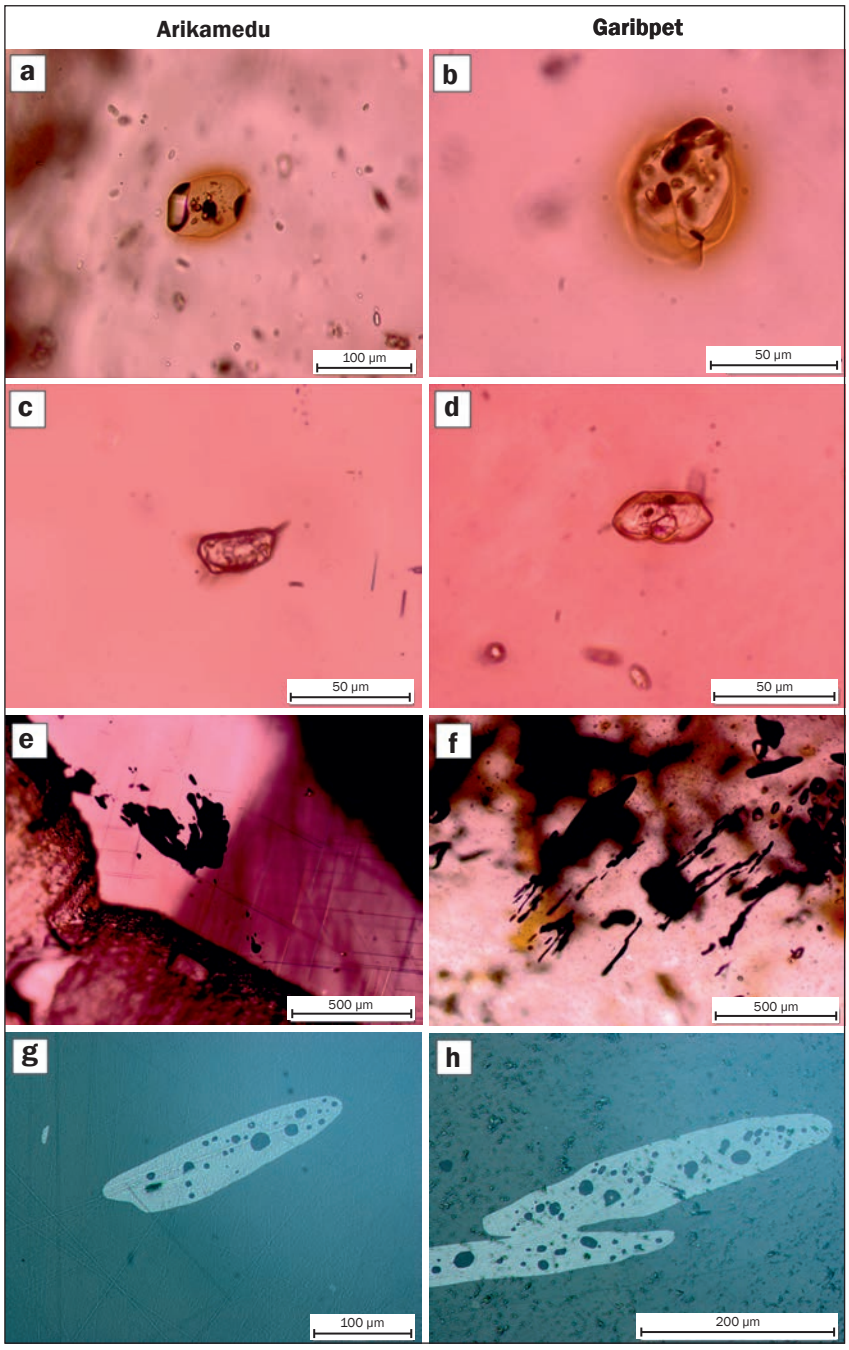


Figure 25: Very similar inclusion patterns are seen in garnets from Arikamedu (left) and Garibpet (right), including: (a,b) monazite with graphite and rutile inclusions; (c,d) zircon with tension cracks; (e,f) ilmenite flakes; and (g,h) ilmenite flakes with quartz inclusions. Photomicrographs by H. A. Gilg in transmitted light (a–f) and reflected light (g,h).

f. A consistent zoning of inclusions between core and rim, with the boundary separating these two zones being enriched with fibrous sillimanite needles

Given the detailed consistency of features listed above for the chemical criteria 2, 3 and 4, and very similar properties related to end-member composition populations (criterion 1), the authors are convinced that the garnets worked at the bead-making site of Arikamedu originated from the Garibpet area. The small differences observed in the average chemical compositions can probably be explained by the fact that the Garibpet samples were collected from one secondary source within a large garnet-bearing area (which includes the primary source of Garibpet Hill) and, therefore, are not entirely representative of the Garibpet rough material used for bead production at Arikamedu. However, neither detailed data for garnets collected at various places within the extensive Garibpet area, nor a comparison of samples found within the secondary garnet-bearing gravels and the primary garnet-bearing host rock, is presently available.

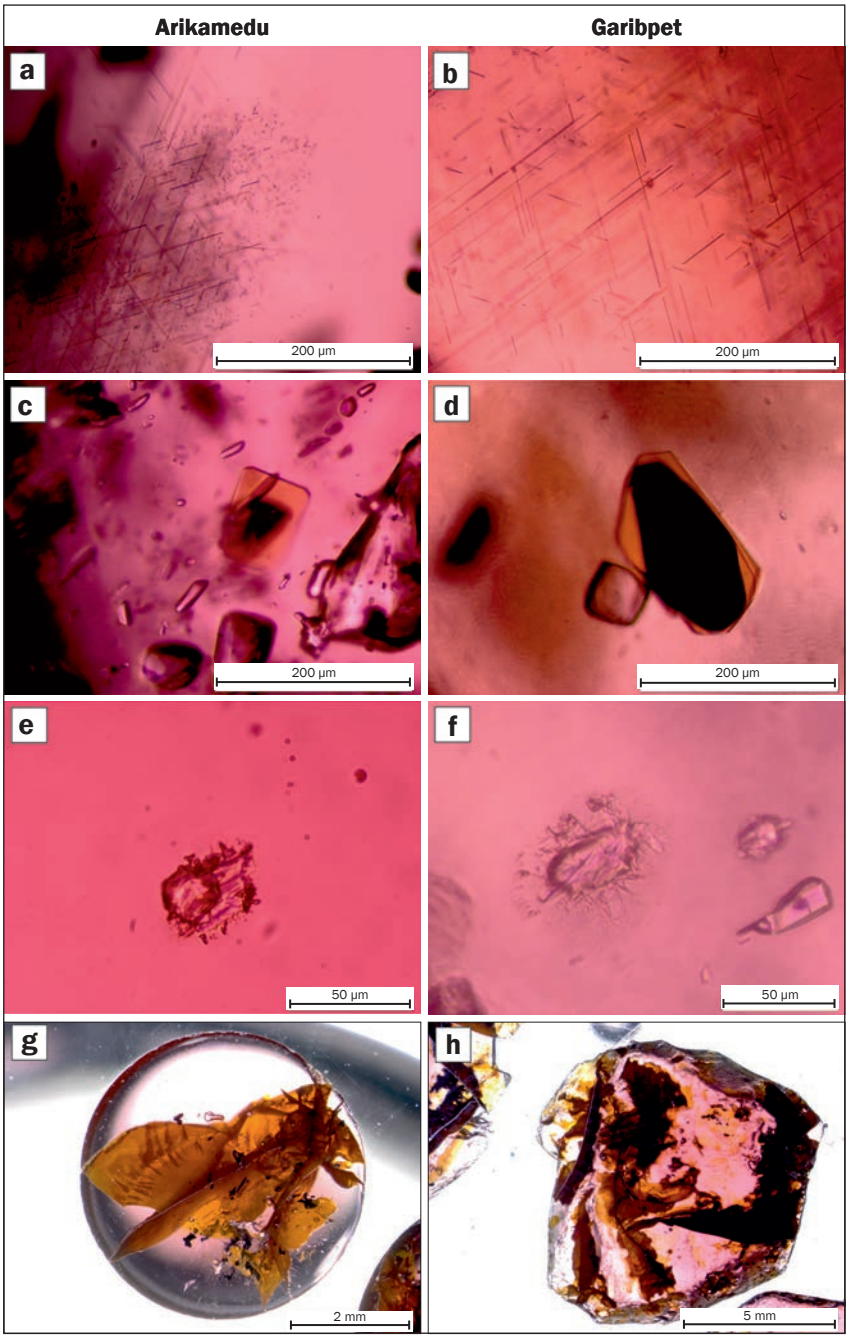


Figure 26: Additional characteristic inclusion patterns in garnets from Arikamedu (left) and Garibpet (right) include: (a,b) networks of rutile needles; (c,d) transparent rutile overgrowth on opaque ilmenite crystals; (e,f) fluid inclusions; and (g,h) secondary fractures filled with polycrystalline material, primarily iron oxides and hydroxides. Photomicrographs by H. A. Gilg.

The Arikamedu-Garibpet garnets characterized in this study plot—according to chemical composition and depending on the type of plot and the elements selected—within or close to one of the major types or clusters of garnets established for early medieval samples, namely within Type I of Calligaro et al. (2006–2007) or Cluster B of Gilg et al. (2010). However, they are distinguishable by their higher Mn, Cr and Y concentrations. This scenario suggests a potential problem of excessive breadth in the existing definitions circumscribing the types or clusters. Such breadth, in turn, calls into question the usefulness of these categories, not only for understanding relationships amongst historical and/or contemporary samples but also for guiding origin determination. The overlap is mostly due to the poor quality of some (but not all) chemical analyses (H. A. Gilg, unpublished research). Indeed, by considering only good-quality analyses (i.e. those with a garnet composition and formula close to ideal or at least acceptable garnet stoichiometry), there is a reduction in overlap and a better definition of garnet types or clusters.

With respect to the general inclusion assemblage and inclusion zoning (criteria 5 and 6), the data for the Arikamedu and Garibpet samples are

quite consistent, thereby supporting the relationship indicated by their composition. Conversely, no inclusion pattern similar to that described for the Arikamedu/Garibpet samples has been seen by the authors to date in garnets from numerous recent productive localities in India and Sri Lanka.

Again, however, it must be emphasized that a particular group of inclusions alone should not be relied upon as sufficient for origin determination. For instance, samples excavated in Unterhaching, Bavaria, which plot chemically in the Type II/Cluster A compositional field, display an inclusion pattern consisting of rutile needles, zircon, quartz, sillimanite and ilmenite (Gast et al., 2013). This clearly demonstrates the possibility of similar and partly overlapping inclusion assemblages among garnets from different origins and dictates that all features of such inclusion patterns should be considered. To give an illustrative example, the characteristic graphite-bearing apatite inclusions found in Garibpet and Arikamedu garnets are absent from Type II/Cluster A garnets.

Hence, the authors suggest that the results of the present study should prompt a re-evaluation, at least partly, of the established types or clusters. On a general level, it has become apparent that some of the types or clusters might consist of several subgroups and should be split accordingly. More specifically, in doing so, the methodology should perhaps be refined beyond a simple narrowing of compositional ranges. Because it remains possible, and even likely, that there will be samples from different origins with overlapping or similar chemical compositions, regardless of the ranges chosen, the following two queries should be considered. First, how many criteria should be used to define the types or clusters? Second, how many such criteria would any given sample need to fulfil before being assigned to a particular type or cluster? In some cases, it may be feasible only to offer probabilities of assignments.

The authors are of the opinion that the traditional practice of using mainly chemical composition, occasionally supplemented by identification of a few inclusions (not a complete pattern incorporating any possible zoning), is deficient. As one example of the shortcomings of the current method, two garnets set in a Hellenistic gold earring described by Gartzke (2004) plot within the same compositional field as the Arikamedu-Garibpet samples (for further details, see Thoresen and Schmetzer, 2013). Without considering multiple additional features, however, it is clear that such information offers only minimal support for drawing any conclusions regarding the provenance of these two Hellenistic garnets. Thus, we feel that a more detailed correlation of properties is necessary to assign a sample to an established type or cluster of garnets. Stated otherwise, only samples which fulfil more than one, or preferably more than two, criteria (taking into account the concentrations of all measured main, minor and trace elements as well as the type, shape and distribution of inclusions) should be assigned to a particular garnet type or cluster. Conversely, any proposed assignment of samples that correspond only in one feature (e.g. in chemical composition) should be indicated as not assigned with certainty.

Some of the early medieval garnets classified as Type I/Cluster B, with the underlying analyses derived mostly from excavated jewellery pieces, overlap in chemical composition with the range determined for the Arikamedu-Garibpet samples. Other criteria pertaining to the early medieval samples, however, are unavailable or vague. Hence, at a minimum, further detailed inclusion studies would be necessary to establish whether the same inclusion assemblage, and especially the zoning of inclusions with a sillimanite-enriched boundary, is present in the medieval garnets. Such examinations could go far in proving or disproving whether stones from the Garibpet deposit were used for early medieval cloisonné metalwork jewellery.

In forthcoming studies, the results described in this article will be compared with those derived for garnets from other excavations—such as stones from Tissamaharama, Sri Lanka—and with properties of engraved early medieval samples. As a harbinger of such future work, the authors would highlight that a Byzantine garnet, engraved with a Christian motif and dated to the end of the 6th or beginning of the 7th century AD, has shown consistency with the Garibpet material in average chemical composition, chemical zoning, inclusion assemblage and inclusion zoning. This, in turn, could have significant implications for establishing whether the text of Cosmas Indicopleustes (see Banaji, 2015), written in the mid-6th century AD, refers to the shipment of Garibpet garnets from harbours located on the Coromandel Coast at or close to Arikamedu.

References

Adams N., 2011. The garnet millennium: The role of seal stones in garnet studies. In C. Entwistle and N. Adams, Eds., *'Gems of Heaven': Recent Research on Engraved Gemstones in Late Antiquity, c. AD 200–600,* British Museum Research Publication 177, The British Museum, London, 10–24.

Axler J.A. and Ague J.J., 2015. Oriented multiphase needles in garnet from ultrahigh-temperature granulites, Connecticut, U.S.A. *American Mineralogist*, **100**(10), 2254–2271, http://dx.doi.org/10.2138/am-2015-5018.

Banaji J., 2015. 'Regions that look seaward': Changing fortunes, submerged histories, and the slow capitalism of the sea. In F.D. Romanis and M. Maiuro, Eds., *Across the Ocean: Nine Essays on Indo-Mediterranean Trade*, Brill, Leiden, The Netherlands, 114–126.

Bauer M., 1896. *Edelsteinkunde*. Chr. Herm. Tauchnitz, Leipzig, Germany, 711 pp.

Begley V., 1983. Arikamedu reconsidered. *American Journal of Archaeology*, **87**(4), 461–481, http://dx.doi.org/10.2307/504104.

Begley V., 1993. New investigations at the port of Arikamedu. *Journal of Roman Archaeology*, **6**, 93–108, http://dx.doi.org/10.1017/s104775940001148x.

Begley V., Francis Jr. P., Mahadevan I., Raman K.V., Sidebotham S.E., Slane K.W. and Will E.L., 1996. *The Ancient Port of Arikamedu. New Excavations and Researches 1989–1992*, Vol. 1. Centre d'Histoire et d'Archéologie, École Française d'Extrême-Orient, Pondicherry, India, 400 pp.

Begley V., Francis Jr. P., Karashima N., Raman K.V., Sidebotham S.E., and Will E.L., 2004. *The Ancient Port of Arikamedu. New Excavations and Researches 1989–1992*, Vol. 2. École Française d'Extrême-Orient, Paris, France, 644 pp.

Borell-Seidel B., 2017. Gemstones in Southeast Asia and beyond: Trade along the maritime networks. In A. Hilgner, S. Greiff and D. Quast, Eds., *Gemstones in the First Millennium AD—Mines, Trade, Workshops and Symbolism*, Römisch-Germanisches Zentralmuseum Mainz, RGZM-Tagungen, Mainz, Germany, 21–44.

Borghi A., Agnella D., Belluso E., Cossio R. and Ruffini R., 2000. Multiple electron beam analyses applied to eclogite from the western Alps. *Microchimica Acta*, **132**(2–4), 479–487, http://dx.doi.org/10.1007/s006040050097.

Brown J.C. and Dey A.K., 1955. *India's Mineral Wealth: A Guide to the Occurrences and Economics of the Useful Minerals of India, Pakistan and Burma*, 3rd edn. Oxford University Press, Bombay, India, 761 pp.

Bugoi R., Oanţă-Marghitu R. and Calligaro T., 2016. IBA investigations of loose garnets from Pietroasa, Apahida and Cluj-Someşeni treasures (5th century AD). *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **371**, 401–406, http://dx.doi.org/10.1016/j.nimb.2015.09.038.

Calligaro T., Colinart S., Poirot J.-P. and Sudres C., 2002. Combined external-beam PIXE and μ-Raman characterisation of garnets used in Merovingian jewellery. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **189**(1–4), 320–327, http://dx.doi.org/10.1016/s0168-583x(01)01078-3.

Calligaro T., Périn P., Vallet F. and Poirot J.-P., 2006–2007. Contribution á l'étude des grenats mérovingiens (Basilique de Saint-Denis et autres collections du Musée d'Archéologie Nationale, diverses collections publiques et objects de fouilles récentes). *Antiquités Nationales*, **38**, 111–144.

Calligaro T., Périn P. and Sudres C., 2009. À propos du 'trésor de grenats de Carthage', attribué à l'époque vandale. *Antiquités Nationales*, **40**, 155–165.

Casal J.-M., 1949. *Fouilles de Virampatnam-Arikamedu: Rapport de l'Inde et de l'Occident aux Environs de l'Ere Chretienne*. Imprimerie Nationale, C. Klincksieck, Paris, France, 71 pp.

Dasgupta S., Bose S. and Das K., 2013. Tectonic evolution of the Eastern Ghats Belt, India. *Precambrian Research*, **227**, 247–258, http://dx.doi.org/10.1016/j.precamres.2012.04.005.

Deloche J., 2010. Roman trade routes in South India: Geographical and technical factors (c. 1st cent. BC–5th cent. AD). *Indian Journal of History of Science*, **45**(1), 33–46.

Dobmeier C.J. and Raith M.M., 2003. *Crustal Architecture and Evolution of the Eastern Ghats Belt and Adjacent Regions of India*. Geological Society of London, Special Publications, **206**(1), 145–168, http://dx.doi.org/10.1144/gsl.sp.2003.206.01.09.

Drauschke J., 2011. *Zwischen Handel und Geschenk – Studien zur Distribution von Waren im östlichen Merowingerreich*. Verlag Marie Leidorf, Rahden, Germany, 565 pp.

Farges F., 1998. Mineralogy of the Louvres Merovingian garnet cloisonne jewelry; origins of the gems of the first kings of France. *American Mineralogist*, **83**(3–4), 323–330, http://dx.doi.org/10.2138/am-1998-3-416.

Francis Jr. P., 1986. The Arikamedu bead census: Wide implications for bead studies. *The Margaretologist*, **1**(3), 3–5.

Francis Jr. P., 1987. *Bead Emporium: A Guide to the Beads from Arikamedu in the Pondicherry Museum*. The Pondicherry Museum, Government of Pondicherry, India, 34 pp.

Francis Jr. P., 1991. Beadmaking at Arikamedu and beyond. *World Archaeology*, **23**(1), 28–43, https://doi.org/10.1080/00438243.1991.9980157.

Francis Jr. P., 1993. South Indian stone beadmaking. *The Margaretologist*, **6**(2), 3–6.

Francis Jr. P., 2001. Final report on Arikamedu, India. *The Margaretologist*, **13**(2), 3–12.

Francis Jr. P., 2002. *Asia's Maritime Bead Trade: 300 BC to the Present*. University of Hawaii Press, Honolulu, Hawai'i, USA, 305 pp.

Francis Jr. P., 2004. Beads and selected small finds from the 1989–92 excavations. In V. Begley, P. Francis Jr.,

N. Karashima, K.V. Raman, S.E. Sidebotham and E.L. Will, Eds., *The Ancient Port of Arikamedu. New Excavations and Researches 1989–1992,* École Française d'Extrême-Orient, Paris, France, 447–604.

Gartzke E., 2004. *Methoden zur materialkundlichen Untersuchung antiker Schmuckstücke*. Master's thesis, Institut für Archäologie, Universität Würzburg, Germany, 196 pp.

Gast N., Calligaro T., Gilg H.A., Macknapp K., Schmahl W.W. and Stark R., 2013. Die Funde: Farbige Einlagen. In B. Haas-Gebhard and H. Fehr, Eds., *Unterhaching. Eine Grabgruppe der Zeit um 500 n. Chr. bei München*, Abhandlungen und Bestandskataloge der Archäologischen Staatssammlung München, Germany, 50–74.

Gaur A.S. and Sundaresh, 2006. Onshore and near shore explorations along the southern Tamilnadu coast: With a view to locating ancient ports and submerged sites. In P.C. Reddy, Ed., *Mahasenasiri: Riches of Indian Archaeological and Cultural Studies*, Sharada Publishing House, New Delhi, India, 122–130.

Gilg H.A. and Gast N., 2012. Naturwissenschaftliche Untersuchungen an Granatgemmen der Sammlung James Loeb. In F. Knauß, C. Weiss, J. Loeb and P. Arndt, Eds., *Die Gemmen der Sammlung James Loeb. Forschungen der Staatlichen Antikensammlungen und Glyptothek, Supplement zu Band 1*, Kunstverlag Josef Fink, Lindenberg im Allgäu, Germany, 48–57, 62–63.

Gilg H.A., Gast N. and Calligaro T., 2010. Vom Karfunkelstein. In L. Wamser, Ed., *Karfunkelstein und Seide: Neue Schätze aus Bayerns Frühzeit (Bayerische Geschichte)*, Graf. Großbetrieb Friedrich Pustet, Munich, Germany, 87–100.

Gorelick L. and Gwinnett A.J., 1988. Diamonds from India to Rome and beyond. *American Journal of Archaeology*, **92**(4), 547–552, http://dx.doi.org/10.2307/505249.

Greiff S., 1998. Naturwissenschaftliche Untersuchungen zur Frage der Rohsteinquellen für frühmittelalterlichen Almandingranatschmuck rheinfränkischer Provenienz. *Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz*, **45**(2), 599–646.

Greiff S., 2010. Zur Herkunft der roten Granate an Schmuckobjekten des Erfurter Schatzfundes. In S. Ostritz, Ed., *Die mittelalterliche jüdische Kultur in Erfurt Band 2: Der Schatzfund: Analysen – Herstellungstechniken – Rekonstruktionen*, Verlag Beier & Beran, Langenweißbach, Germany, 482–487.

Gurukkal R., 2013. Classical Indo-Roman trade: A historiographical reconsideration. *Indian Historical Review*, **40**(2), 181–206, http://dx.doi.org/10.1177/0376983613499670.

Gwinnett A.J. and Gorelick L., 1987. Experimental evidence for the use of a diamond drill in Sri Lanka ca. AD 700–1000. *Archaeomaterials*, **1**(2), 149–152.

Gwinnett A.J. and Gorelick L., 1988. A possible lapidary training piece from Arikamedu, India. *Archaeomaterials*, **2**(2), 187–193.

Horváth E. and Bendő Z., 2011. Provenance study on a collection of loose garnets from a gepidic period grave in northeast Hungary. *Archeometriai Mühely*, **2011**(1), 17–32.

Jyotsna M., 2000. *Distinctive Beads in Ancient India*. BAR International Series 864, British Archaeological Reports, Oxford, 122 pp.

Kessler O., 2001. Der spätantik-frühmittelalterliche Handel zwischen Europa und Asien und die Bedeutung des Almandins als Fernhandelsgut. *Archäologisches Zellwerk: Beiträge zur Kulturgeschichte in Europa und Asien*, Verlag Marie Leidorf, Rahden, Germany, 113–128.

Kothagudem City, 2014. *Geology and Mineral Resources of Khammam District, Telangana*. www.kothagudemcity.com/latest/mineral-reserves-khammam.

Kumar K.K., Balaram V. and Sirdeshmukh L., 1992. Characterization and dielectric properties of almandine-pyrope garnet. *Bulletin of Materials Science*, **15**(3), 279–284, http://dx.doi.org/10.1007/bf02927506.

Lanzirotti A., 1995. Yttrium zoning in metamorphic garnets. *Geochimica et Cosmochimica Acta*, **59**(19), 4105–4110, http://dx.doi.org/10.1016/0016-7037(95)00320-y.

Larios B., 2017. Elusive gemstone mines: The red garnet industry in contemporary Rajasthan. In A. Hilgner, S. Greiff and D. Quast, Eds., *Gemstones in the First Millennium AD—Mines, Trade, Workshops and Symbolism*, Römisch-Germanisches Zentralmuseum Mainz, RGZM-Tagungen, Mainz, Germany, 7–19.

Lennartz A., 2001. Die Rolle Ägyptens im mediterranen Fernhandel vom Ende des 6. Jahrhunderts bis zu seiner arabischen Eroberung. *Archäologisches Zellwerk: Beiträge zur Kulturgeschichte in Europa und Asien*, Verlag Marie Leidorf, Rahden, Germany, 267–280.

Löfgren J., 1973. Die mineralogische Untersuchung der Granaten von Paviken auf Gotland. *Early Medieval Studies*, **6**(9), 78–96.

Mannerstrand M. and Lundqvist L., 2003. Garnet chemistry from the Slöinge excavation, Halland and additional Swedish and Danish excavations—Comparisons with garnet occurring in a rock context. *Journal of Archaeological Science*, **30**(2), 169–183, http://dx.doi.org/10.1006/jasc.2000.0583.

Master Plans India, 2014. *Development Plan for Kothagudem*. www.masterplansindia.com/telangana/khammam/kothagudem-base-map.

Mathis F., Vrielynck O., Laclavetine K., Chêne G. and Strivay D., 2008. Study of the provenance of Belgian Merovingian garnets by PIXE at IPNAS cyclotron. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **266**(10), 2348–2352, http://dx.doi.org/10.1016/j.nimb.2008.03.055.

Mirza K., 1937. *A Brief Outline of the Geological History of Hyderabad State with a Reference to its Mineral*

Resources. Hyderabad Geological Series Bulletin No. 2, Hyderabad-Deccan, India, 39 pp.

Mittlefehldt D.W., 1986. Petrology of high pressure clinopyroxenite series xenoliths, Mount Carmel, Israel. *Contributions to Mineralogy and Petrology*, **94**(2), 245–252, http://dx.doi.org/10.1007/bf00592941.

Mukhopadhyay D. and Basak K., 2009. The Eastern Ghats Belt – a polycyclic granulite terrain. *Journal of the Geological Society of India*, **73**(4), 489–518, http://dx.doi.org/10.1007/s12594-009-0034-8.

Murty K.S., 1982. Geological sciences in India in the 18th–19th century. *Indian Journal of History of Science*, **17**(1), 164–178.

Newbold F.R.S., 1843. Mineral resources of southern India. No. 7. Corundum, ruby, and garnet localities. *Journal of the Royal Asiatic Society of Great Britain & Ireland*, **7**(14), 219–225, http://dx.doi.org/10.1017/s0035869x00155881.

Panjikar J., 2014. Ancient Roman bead-makers of Arikamedu, south India. *ICGL Newsletter*, No. 2, 2–3.

Pearce N.J.G., Perkins W.T., Westgate J.A., Gorton M.P., Jackson S.E., Neal C.R. and Chenery S.P., 1997. A compilation of new and published major and trace element data for NIST SRM 610 and NIST SRM 612 glass reference materials. *Geostandards and Geoanalytical Research*, **21**(1), 115–144, http://dx.doi.org/10.1111/j.1751-908X.1997.tb00538.x.

Périn P. and Calligaro T., 2007. Neue Erkenntnisse zum Arnegunde Grab. Ergebnisse der Metallanalysen und der Untersuchungen organischer Überreste aus Sarkophag 49 aus der Basilika von Saint-Denis. *Acta Praehistorica et Archaeologica*, **39**, 147–179.

Phani P.R., 2014a. Mineral resources of Telangana State, India: The way forward. *International Journal of Innovative Research in Science, Engineering and Technology*, **3**(8), 15450–15459, http://dx.doi.org/10.15680/ijirset.2014.0308052.

Phani P.R.C., 2014b. Sedimentological studies and palaeoenvironment of lower Gondwana strata, north of GKOC mine, Kothagudem coalfields, Telangana, India. *International Journal of Advancement in Earth and Environmental Sciences*, **2**(2), 31–38.

Pyle J.M. and Spear F.S., 2000. An empirical garnet (YAG) – xenotime thermometer. *Contributions to Mineralogy and Petrology*, **138**(1), 51–58, http://dx.doi.org/10.1007/pl00007662.

Quast D. and Schüssler U., 2000. Mineralogische Untersuchungen zur Herkunft der Granate merowingerzeitlicher Cloisonnéarbeiten. *Germania*, **78**(1), 75–96.

Rajan K., 2011. Emergence of early historic trade in peninsular India. In P.-Y. Manguin, A. Mani and G. Wade, Eds., *Early Interactions Between South and Southeast Asia*, Institute of Southeast Asian Studies Publishing, Singapore, 177–196.

Raman K.V., 1991. Further evidence of Roman trade from coastal sites in Tamil Nadu. In V. Begley and R.D. De Puma, Eds., *Rome and India: The Ancient Sea Trade*, University of Wisconsin Press, Madison, Wisconsin, USA, 125–133.

Rao S.R., 1991a. Marine archaeological explorations of Tranquebar-Poompuhar region on Tamil Nadu coast. *Journal of Marine Archaeology*, **2**(July), 5–20.

Rao S.R., 1991b. Underwater exploration of submerged towns near Tranquebar (Tarangambadi) on Tamilnadu coast. In S.R. Rao, Ed., *Recent Advances in Marine Archaeology: Proceedings of the Second Indian Conference on Marine Archaeology of Indian Ocean Countries*, Society for Marine Archaeology, National Institute of Oceanography, Goa, India, January 1990, 60–64.

Ray H.P., 1994. The western Indian ocean and the early maritime links of the Indian subcontinent. *Indian Economic and Social History Review*, **31**(1), 65–88.

Rösch C., Hock R., Schüssler U., Yule P. and Hannibal A., 1997. Electron microprobe analysis and X-ray diffraction methods in archaeometry: Investigations on ancient beads from the Sultanate of Oman and from Sri Lanka. *European Journal of Mineralogy*, **9**(4), 763–783, http://dx.doi.org/10.1127/ejm/9/4/0763.

Roth H., 1980. Almandinhandel und -verarbeitung im Bereich des Mittelmeeres. *Allgemeine und vergleichende Archaeologie*, **2**, 309–335.

Rupp H., 1937. *Die Herkunft der Zelleneinlage und die Almandin-Scheibenfibeln im Rheinland. Rheinische Forschungen zur Vorgeschichte, Band 2*. Ludwig Röhrscheid Verlag, Bonn, Germany, 144 pp.

Schneider H., 2011. *Kosmas Indikopleustes, Christliche Topographie. - Textkritische Analysen. Übersetzung. Kommentar*. Brepols Publishers, Turnhout, Belgium, 298 pp.

Schüssler U., Rösch C. and Hock R., 2001. Beads from ancient Sri Lanka – First results of a systematic material analysis. In H.-J. Weisshaar, H. Roth and W. Wijeyapala, Eds., *Ancient Ruhana: Sri Lankan-German Archaeological Project in the Southern Province I*, Verlag Philipp von Zabern, Mainz am Rhein, Germany, 227–242.

Seland E.H., 2017. Gemstones and mineral products in the Red Sea/Indian Ocean trade of the first millennium. In A. Hilgner, S. Greiff and D. Quast, Eds., *Gemstones in the First Millennium AD—Mines, Trade, Workshops and Symbolism*, Römisch-Germanisches Zentralmuseum Mainz, RGZM-Tagungen, 45–58.

Sidebotham S.E., 1991. Ports of the Red Sea and the Arabia-India trade. In V. Begley and R.D. De Puma, Eds., *Rome and India: The Ancient Sea Trade*, University of Wisconsin Press, Madison, Wisconsin, USA, 12–38.

Šmit Ž., Fajfar H., Jeršek M., Knific T. and Lux J., 2014. Analysis of garnets from the archaeological sites in Slovenia. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **328**, 89–94, http://dx.doi.org/10.1016/j.nimb.2014.02.121.

Smith M.L., 2002. The role of local trade networks in the Indian subcontinent during the early historic period. *Man and Environment*, **27**(1), 139–151.

Sorg M., 2011. Byzanz als Drehscheibe des merowingerzeitlichen Handels zwischen Ost und West. Das Beispiel Granat. In B.J. Nemes and A. Rabus, Eds., *Vermitteln – Übersetzen – Begegnen: Transferphänomene im europäischen Mittelalter und der frühen Neuzeit. Interdisziplinäre Annäherungen*, Vandenhoeck & Ruprecht Unipress, Göttingen, Germany, 137–165, http://dx.doi.org/10.14220/9783847098409.137.

Spear F.S., 1995. *Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths*, 2nd edn. Mineralogical Society of America, Washington DC, USA, 799 pp.

Stockton C.M. and Manson D.V., 1985. A proposed new classification for gem-quality garnets. *Gems & Gemology*, **21**(4), 205–218, http://dx.doi.org/10.5741/gems.21.4.205.

Subbaraju M., 1976. Some aspects of the schistose rocks of Khammam District, Andhra Pradesh. *Indian Mineralogist*, **16**, 35–42.

Sundaresh and Gaur A.S., 2011. Marine archaeological investigations on Tamil Nadu coast, India: An overview. In M. Staniforth et al., Eds., *Proceedings of the 2011 Asia-Pacific Regional Conference on Underwater Cultural Heritage*, Asian Academy for Heritage Management, Manilla, Philippines, 8–12 November, 233–248.

Suresh S., 2007. *Arikamedu: Its Place in the Ancient Rome-India Contacts*. Development Cooperation Office, Embassy of Italy, New Delhi, India, 126 pp.

Thoresen L., 2017. Archaeogemmology and ancient literary sources on gems and their origins. In A. Hilgner, S. Greiff and D. Quast, Eds., *Gemstones in the First Millennium AD—Mines, Trade, Workshops and Symbolism*, Römisch-Germanisches Zentralmuseum Mainz, RGZM-Tagungen, Mainz, Germany, 155–218.

Thoresen L. and Schmetzer K., 2013. Greek, Etruscan and Roman garnets in the antiquities collection of the J. Paul Getty Museum. *Journal of Gemmology*, **33**(7–8), 201–222, http://dx.doi.org/10.15506/JoG.2013.33.7.201.

von Freeden U., Richter E.-L. and Härlin H., 2000. Das Ende engzelligen Cloisonnés und die Eroberung Südarabiens durch die Sasaniden. *Germania*, **78**(1), 97–124.

Voysey H.W., 1833. Second report on the geology of Hyderabad. *Journal of the Asiatic Society of Bengal*, **2**(18), 392–405.

Wadia M.D.N., 1966. *Minerals of India*. National Book Trust, New Delhi, India, 199 pp.

Walker A.M., 1841. Notes and observations, in continuation, from Dr. Walker, Madras Medical Service, on a tour in H. H. the Nizam's Territories. *Journal of the Asiatic Society of Bengal*, **10**(117), 725–735.

Wheeler M., 1954. *Rome Beyond the Imperial Frontiers*. G. Bell and Sons Ltd., London, 192 pp.

Wheeler R.E.M., Ghosh A. and Deva K., 1946. Arikamedu: An Indo-Roman trading-station on the east coast of India. *Ancient India—Bulletin of the Archaeological Survey of India*, No. 2, 17–124.

Whitehouse D. and Williamson A., 1973. Sasanian maritime trade. *Iran*, **11**, 29–49, http://dx.doi.org/10.2307/4300483.

Winstedt E.O., 1909. *The Christian Topography of Cosmas Indicopleustes*. Cambridge University Press, Edinburgh, 376 pp.

Zhao G., Cawood P.A., Wilde S.A. and Sun M., 2002. Review of global 2.1–1.8 Ga orogens: Implications for a pre-Rodinia supercontinent. *Earth-Science Reviews*, **59**(1–4), 125–162, http://dx.doi.org/10.1016/s0012-8252(02)00073-9.

The Authors

Dr Karl Schmetzer
85238 Petershausen, Germany
Email: SchmetzerKarl@hotmail.com

Prof. Dr H. Albert Gilg
Lehrstuhl für Ingenieurgeologie, Technische Universität München, 80333 Munich, Germany

Prof. Dr Ulrich Schüssler
Institut für Geographie und Geologie, Universität Würzburg, 97074 Würzburg, Germany

Dr Jayshree Panjikar FGA
Panjikar Gem Research & Tech Institute, Pune 411001, India

Dr Thomas Calligaro
Centre de Recherche et de Restauration des Musées de France, 75001 Paris, France

Patrick Périn
Directeur honoraire du Musée d'Archéologie Nationale, 08220 Rubigny, France

Acknowledgements

The authors are grateful to Lorann S.A. Pendleton and Dr David H. Thomas (Division of Anthropology, American Museum of Natural History, New York, New York, USA) for the loan of garnet and glass samples collected at Arikamedu by Peter Francis, Jr. Prof. Dr Peter Gille (Department of Earth and Environmental Sciences, Ludwig-Maximilians-University, Munich, Germany) assisted in sawing the beads examined for this study, and Vladimir Ruttner (Engineering Geology, Technical University of Munich) prepared the polished sections. Dr Helene Brätz (Geo-Center of Northern Bavaria, Erlangen, Germany), is thanked for measurement and evaluation of the LA-ICP-MS analyses. Prof. S. Suresh (Chennai, India) provided helpful information about the history of Arikamedu.

Simultaneous X-Radiography, Phase-Contrast and Darkfield Imaging to Separate Natural from Cultured Pearls

Michael S. Krzemnicki, Carina S. Hanser and Vincent Revol

The separation of natural from cultured pearls is mainly based on the interpretation of their internal structures, which traditionally have been visualized by X-radiography and more recently by X-ray computed microtomography (micro-CT). In this study, the authors present a new analytical approach using a grating interferometer, which simultaneously generates an X-radiograph, a phase-contrast image and a small-scale scattering or darkfield image. The latter two additional images provided by this technique offer detailed and complementary information, as they are especially sensitive for visualizing tiny material inhomogeneities in pearls such as fissures, organic layers and cavity structures. Using seven selected natural and cultured pearl samples and a strand of non-beaded freshwater cultured pearls, the authors demonstrate that this new analytical approach offers versatile and rapid pearl identification possibilities, especially as it is possible to analyse not only single loose pearls but also entire strands and necklaces. Compared to micro-focus digital radiography and micro-CT, certain limitations in resolution still remain with the described prototype setups, and as such this new methodology should be considered a helpful complementary technique to the classical radiography of pearls.

The Journal of Gemmology, **35**(7), 2017, pp. 628–638, http://dx.doi.org/10.15506/JoG.2017.35.7.628

Introduction

One of the main duties of gemmological laboratories working for the pearl trade is to distinguish natural (Figure 1) from cultured pearls. This separation, as well as the identification of pearl treatments, is commonly based on a combination of testing methods, among them visual (microscopic) observation, ultraviolet-visible reflectance spectroscopy (Elen, 2002; Karampelas et al., 2011), Raman spectroscopy (Barnard and de Waal, 2006; Karampelas et al., 2007), X-ray luminescence (Hänni et al., 2005), X-ray diffraction (i.e. Lauegrams; Hänni, 1983) and trace-element analysis (e.g. energy-dispersive X-ray fluorescence [EDXRF] spectroscopy; Gutmannsbauer and Hänni, 1994).

However, for decades by far the most important approach to identifying natural and cultured pearls has been X-radiography and, in more recent years, micro-CT (Anderson, 1932; Farn, 1986; Kennedy, 1998; Scarratt et al., 2000; Schlüter et al., 2005; Hänni, 2006; Strack, 2006; Wehrmeister et al., 2008; Sturman, 2009; Karampelas et al., 2010;

Figure 1: This seven-strand pearl necklace contains 543 saltwater natural pearls (4.55–9.90 mm in diameter) of exceptionally matching shape and lustre. The length of the strands varies from approximately 43.5 to 57.0 cm (including the clasp), and the total declared weight of the pearls is 1,006 ct. The necklace is from the Hussein Alfardan pearl collection and was tested and analysed at the Swiss Gemmological Institute SSEF. Photo by Luc Phan, SSEF.

Krzemnicki et al., 2010; Cartier and Krzemnicki, 2013; Rosc et al., 2016). Both methods enable the visualization and interpretation of internal features in pearls such as cavities, ring structures, dehydration fissures and bead structures.

Here the authors describe a new and promising complementary method to visualize internal structures in pearls: simultaneous X-ray differential phase-contrast imaging and small-angle scattering (or darkfield imaging). The technique was initially presented by Krzemnicki et al. (2015), and the current article provides a gemmological description and interpretation of analysed pearl structures for a range of natural and cultured samples. As such, it follows a more general introduction into phase-contrast and darkfield imaging for pearl testing by Revol et al. (2016). Initially developed using synchrotron light (David et al., 2002; Momose et al., 2003), this imaging technology is nowadays usable with standard X-ray tubes (Pfeiffer et al., 2006) and—coupled with an improved design of X-ray interferometers—is characterized by a considerably enlarged field of view and range of usable X-ray energies (Revol et al., 2011). Phase-contrast imaging and darkfield imaging are based on the interaction of X-rays with pearls, similar to classical radiography, but they offer additional information and/or sensitivity to minute internal features. This technology is especially useful for detecting small structural inhomogeneities such as organic matter in the calcium carbonate matrix of a pearl. Both single pearls and entire strands can be analysed, and the technique is thus capable of rapid and versatile non-destructive pearl characterization.

Figure 2: The X-ray phase contrast and darkfield imaging prototype EVITA, developed and installed at the CSEM research facility in Switzerland, was one of the instruments used in this study. Photo © V. Revol, CSEM Switzerland.

Principles of X-ray Phase-Contrast and Darkfield Imaging

Classical radiography is based on the attenuation (decrease of intensity via absorption and scattering) of X-rays passing through an object. This happens as the X-rays interact with the electrons of the atoms in the specimen. The amount of attenuation correlates to the atomic weight of the elements present (i.e. their atomic number), thus heavier elements will absorb X-rays more effectively. As a consequence, dense calcium carbonate appears light, whereas organic matter and voids within pearls appear dark in X-radiographs.

Phase-contrast imaging relies on the phase shift of radiation (e.g. X-rays) propagating through an object. For our study, a grating interferometer was used (e.g. Figure 2), which enabled us to transform the phase shift caused by the sample

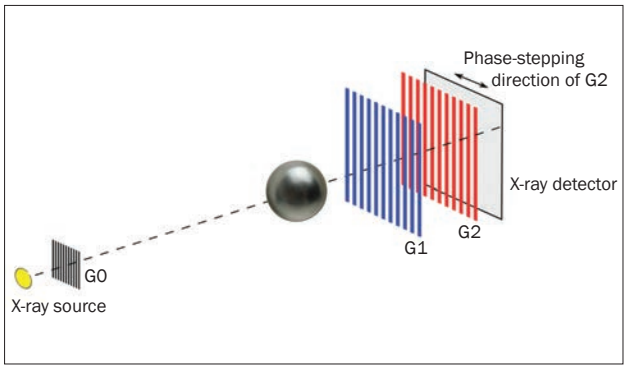


Figure 3: In this schematic diagram of the grating interferometer, the pearl sample is placed between the gratings G0 and G1, while grating G2 is moved in a direction perpendicular to the X-ray beam while recording the resulting intensity with the detector. After Revol et al. (2016).

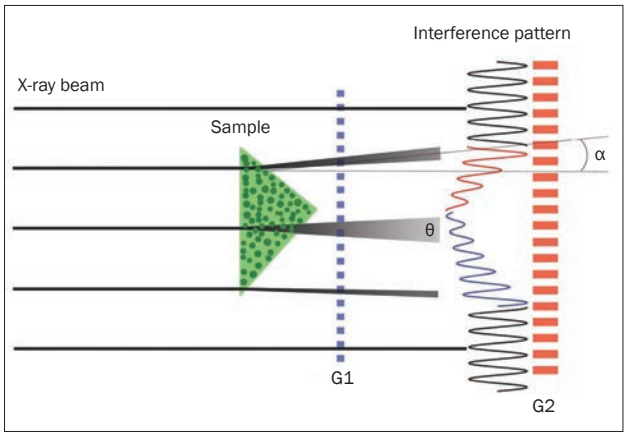


Figure 4: This diagram shows the principle of the X-ray grating interferometer for measuring a differential phase-contrast image (angular deflection α) and a darkfield image (scattering power θ). Depending on the gradient of the index of refraction, α changes from a positive to a negative angle, as illustrated by the red and blue sections of the interference pattern.

into variations in intensity, which could then be recorded by a conventional digital X-ray detector. The principle of the grating interferometer is explained extensively in the literature (Pfeiffer et al., 2008; Revol et al., 2010). As illustrated in Figure 3, the radiation emitted from an X-ray tube first passes through a source grating (G0), which is an aperture mask with transmitting slits that create an array of X-ray 'line sources' that are directed toward the sample. The phase grating (G1) behind the sample splits the beam array by imprinting periodic phase modulations, resulting in interference (intensity modulations) of the split rays in the plane of the final analyser grating (G2) through the Talbot effect (Weitkamp et al., 2005; Pfeiffer et al., 2008; Zhu et al., 2010). In the presence of a sample, the phase front is distorted, which leads to a change in the intensity, position and amplitude of the interferences, as illustrated in Figure 4. The change in the interferences can be recovered by using the phase-stepping approach presented in Weitkamp et al. (2005). It consists of moving one of the grids (e.g. G2 in our setup) perpendicular to the beam while recording the intensity with the detector. For each pixel, the resulting intensity variations are compared to a reference measurement made without a sample to extract the average intensity, position and amplitude of the interferences (Pfeiffer et al., 2008; Zhu et al., 2010).

The method allows the simultaneous generation (using the same instrumental parameters) of three images: a conventional X-ray absorption image (radiograph), a differential phase-contrast image and a darkfield image. As illustrated in Figure 4, the phase-contrast image is related to the deflection angle by the gradient of the phase shift. The darkfield image is a measurement of the ultra-small-angle scattering of the beam induced by inhomogeneities in the sample at the microscopic scale. This method thus gathers otherwise inaccessible structural information below the resolution limit of the X-ray detector. (For more on the experimental setup, see Revol et al., 2011.)

Pearls are especially suitable for this type of analysis because the organic matter and void/cavity/fissure features within their carbonate matrix provide inhomogeneities that can result in strong phase contrasts compared to conventional attenuation-based imaging (Revol et al., 2016).

Materials and Methods

To illustrate both the capabilities and limitations of X-ray phase-contrast and darkfield imaging, we selected seven natural and cultured pearls (Table I) from the molluscs *Pinctada maxima, P. margaritifera, P. radiata, Hyriopsis cumingii* and *Strombus gigas*, ranging from 3.68 to 25.30 ct. These specimens included three natural pearls (saltwater) and four cultured pearls (one non-beaded freshwater cultured pearl, one non-beaded saltwater cultured pearl and two beaded saltwater cultured pearls). In addition, we analysed an entire strand of 44 colour-treated (by silver salt) non-beaded freshwater cultured pearls. Previously, we had fully characterized all of these

Table I: Natural and cultured pearl samples analysed for this study.

Sample no.	Type	Species	Origin	Weight (ct)	Size (mm)	Colour
NP-2e	Saltwater natural pearl	*P. radiata*	Bahrain	6.49	10.3	Light cream
P14-11	Saltwater natural pearl	*P. maxima*	Northern Australia	3.68	8.2	White
NP-2j	Natural conch pearl	*Strombus gigas*	Caribbean Sea	6.58	14.3	Light pink
CP-2d	Beaded saltwater cultured pearl	*P. maxima*	Indonesia	25.30	15.4	Yellow
CP-2e2	Beaded saltwater cultured pearl	*P. margaritifera*	French Polynesia	12.76	12.1	Black
CP-2m	'Keshi' non-beaded saltwater cultured pearl	*P. margaritifera*	French Polynesia	8.14	13.9	Black
CP-1b	Non-beaded freshwater cultured pearl	*Hyriopsis cumingii*	China	9.92	13.0	White
CP-54	Non-beaded freshwater cultured pearl strand (44)	*Hyriopsis cumingii*	China	~3.5 each	~7.5 each	Dark grey (silver treated)

samples (and confirmed their species identification) using X-ray luminescence, radiography, micro-CT (except for the cultured pearl strand) and EDXRF (including three selected cultured pearls in the strand), among other techniques.

We used two different grating interferometer setups: a research prototype (S50-4) and, in a second round, an improved prototype (EVITA), both installed at the Centre Suisse d'Electronique et de Microtechnique (CSEM) research facilities in Switzerland. This instrumentation is currently under commercial development and is not yet available for purchase. The characteristics of each setup and the corresponding measurement parameters are listed in Table II. The X-ray gratings were produced at CSEM from 100 or 150 mm-diameter silicon wafers by photolithography, wet etching and electroplating. The sample holder could accommodate up to ~30 loose pearls, or a complete pearl strand/necklace. Further details of the setup and analytical conditions are described in Hanser (2015) and Revol et al. (2016).

The images were reconstructed with the help of the phase-stepping approach using the translation of the G2 grating (Weitkamp et al., 2005) by employing proprietary algorithms developed at CSEM. For pearls, the phase-contrast image results in a virtual surface topography, with highly absorbing zones appearing slightly elevated and the sample virtually illuminated from the side

Table II: Characteristics of the grating interferometers used in this study.

Parameter	S50-4 setup	EVITA setup
Design energy	50 keV	40 keV
X-ray source	60 kVp, 16.65 mA, focal spot 1 × 1 mm², 0.8 mm beryllium window	60 kVp, 10 mA, focal spot 0.4 × 0.4 mm², 0.8 mm beryllium window
Filter	No filtering	No filtering
Detector	2048 × 1024, 48 µm pixel size	3072 × 1944, 75 µm pixel size
Distance G0–G1	161.3 cm	107.5 cm
Distance G1–G2	40.3 cm	21.5 cm
Grating size	7 × 5 cm	10 × 10 cm
Magnification	1.3	1.4
Effective pixel size in the image	37 µm	54 µm
Number of phase steps	9	19
Exposure time per phase step	6 s	0.7 s
Averaging	10	10
Total exposure time	9.0 min	2.2 min

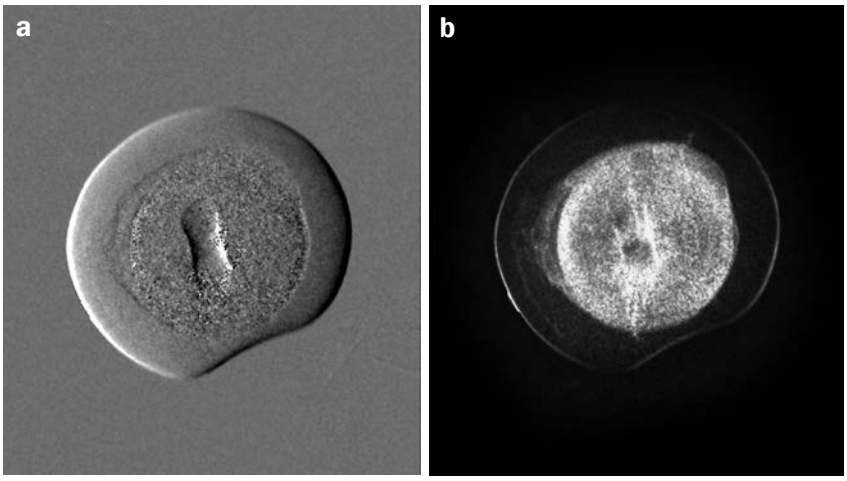


Figure 5: (a) Differential phase-contrast imaging of a natural pearl (9.5 mm in diameter) reveals an enriched amount of organic material in its core (pixelated with lower relief) as compared to its nacre rim, which appears to be slightly elevated. (b) Darkfield imaging of the same pearl shows a high amount of small-angle scattering in the organic-rich core (appearing bright); the outline of the pearl is also marked by a bright line as a result of scattering at the pearl's surface. The distinct columnar structure in the centre of each image corresponds to the slightly inclined drill hole. Images by V. Revol.

(Figure 5a). Zones of intense inhomogeneities (and scattering) appear strongly pixelated. The darkfield image is more similar to a classical X-radiograph, but it displays bright areas and streaks in the zones where small-angle scattering at material inhomogeneities occurs in great number. As such, the organic-rich heterogeneous zones in pearls (e.g. the core zone in particular) usually appear brighter than the very densely packed layers of nacre, which is contrary to the appearance of an X-radiograph. The outline of the investigated sample is also displayed, as small-angle scattering occurs at the pearl/air interface (Figure 5b). To improve such images, a built-in band-pass filter using ImageJ software was used uniformly to filter out structures larger than 10 pixels (equivalent to 577 µm). Some of the images were further enhanced by applying Adobe Photoshop functions such as gamma correction, exposure, line sharpening and colouring.

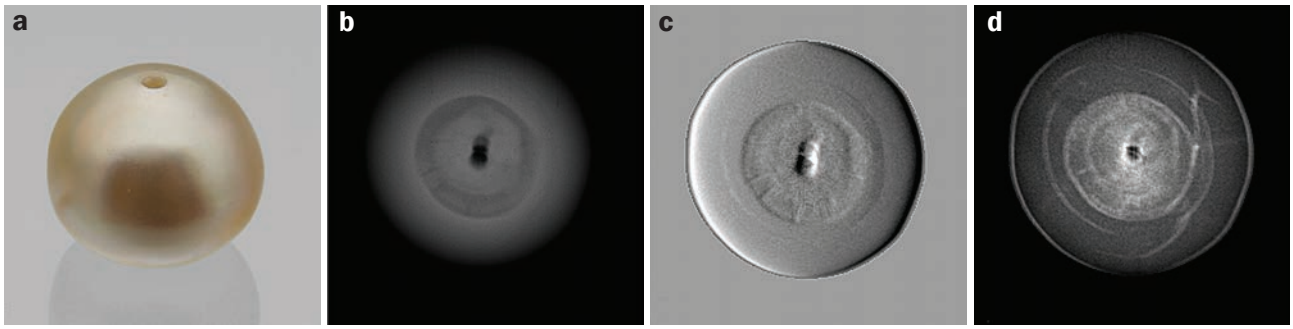
Results

The samples in this study were selected for the presence of internal features commonly encountered in natural and cultured pearls. The interpretation of their structures is based on both the presented images and detailed analyses by micro-CT. For each of the following five examples, we present X-radiographs, phase-contrast images and darkfield images, all obtained simultaneously with the EVITA setup (see Table II).

Natural Pearl with a Core Enriched in Organic Matter

The X-radiograph of saltwater natural pearl NP-2e (*P. radiata*, Figure 6a) is characterized by a grey nacre layer of ~3 mm thickness surrounding a darker grey core consisting of radially arranged calcite prisms interlayered with organic matter (Figure 6b). The outermost part of the core appears distinctly darker as a result of an enrich-

*Figure 6: A sequence of images is shown for saltwater natural pearl NP-2e (*P. radiata *from Bahrain), which weighs 6.49 ct and measures 10.3 mm in diameter. The photograph (a) was taken from the side, while the radiograph (b), phase-contrast (c) and darkfield (d) images were taken from above. This pearl is characterized by an organic-rich core of radially arranged calcite prims surrounded by an approximately 3 mm-thick nacre layer. The prominent structure in the centre of images b–d corresponds to the drill hole. Pearl photo by Carina Hanser and other images by V. Revol.*



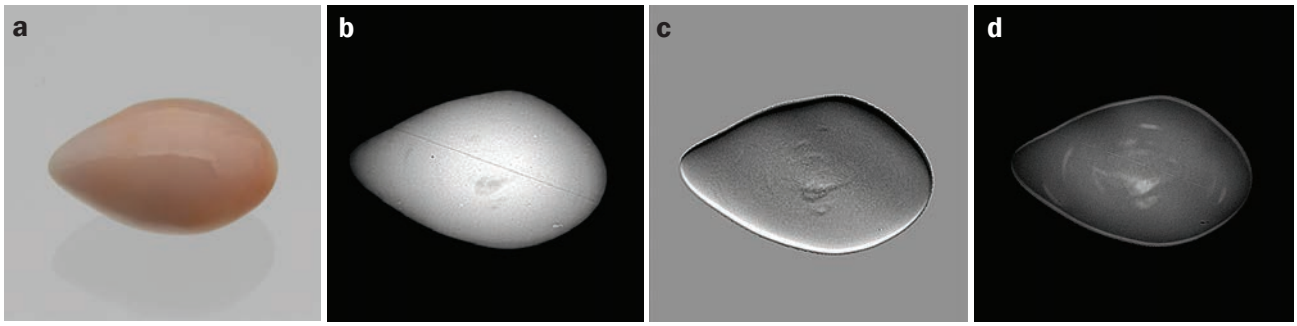


Figure 7: (a) This natural pearl (sample NP-2j from the H. A. Hänni reference collection at SSEF) is from the queen conch Strombus gigas *and was collected from the Caribbean Sea in the early 1990s; it weighs 6.58 ct and is 14.3 mm long. The radiograph (b), phase-contrast (c) and darkfield (d) images reveal an irregularly shaped cavity structure, not to be mistaken as an indication of cultured origin. The diagonal line (which is particularly visible in the radiograph) is an instrumental artefact. Pearl photo by Carina Hanser and other images by V. Revol.*

ment of organic matter. The phase-contrast image (Figure 6c) of the same pearl shows a marked contrast between the organic-rich core and the quasi-uniform rim of nacre, apparent as a 'quasi'-surface topography. Within the nacre are weak ring structures typical of nacre layers in pearls. The organic-rich outer portion of the core shows a number of radial fractures. In the darkfield image (Figure 6d), the core appears distinctly brighter because of an increased amount of small-angle scattering in this calcium-carbonate (calcite) zone enriched in organic matter. The darkfield image further reveals the complex structures of fine fissures and cracks in the nacre layer, which were not discernible or only barely visible in the radiograph and phase-contrast images.

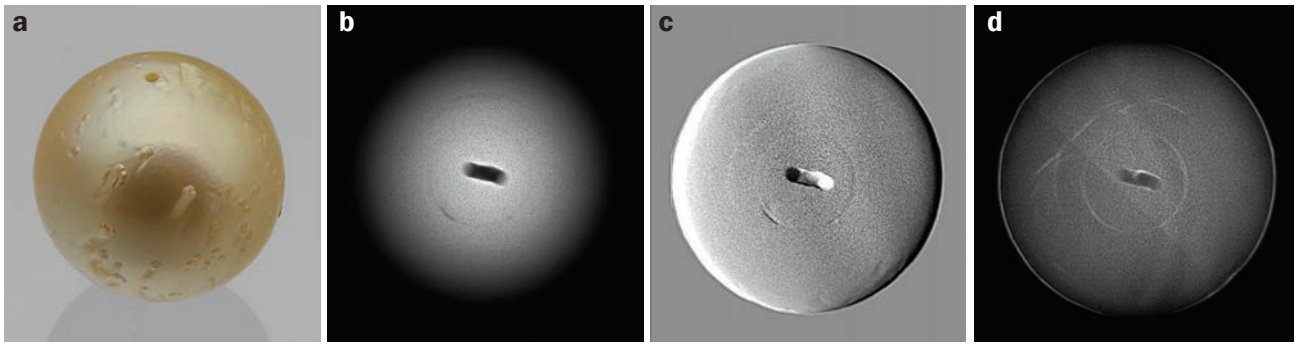
Natural Conch Pearl with Cavity Structure

Conch pearls from marine gastropods such as *Strombus gigas* (e.g. sample NP-2j; Figure 7a) often show no to very weak internal structures in radiographs (Figure 7b). The irregularly shaped cavity and additional weak surrounding growth rings in this natural conch pearl are evident in the phase-contrast and darkfield images (Figure 7c,d). Such cavity structures are occasionally seen in natural pearls from marine gastropods and should not, or only cautiously, be interpreted as an indication of a cultured formation without additional evidence such as a bead structure. This is in contrast to pearls from bivalve molluscs, where similar cavities are commonly encountered, especially in non-beaded cultured pearls (e.g. from *P. maxima* or *Hyriopsis cumingii*), and as such provide a strong indication of cultivation (see below).

Beaded Saltwater Cultured Pearl

The beaded saltwater cultured pearl CP-2d (*P. maxima*, Figure 8a) reveals rather weak structures in the radiograph, indicating a small bead (~5 mm) surrounded by a thick and nearly unstructured nacre layer (Figure 8b). As a result of

*Figure 8: (a) This beaded saltwater cultured pearl CP-2d (*P. maxima *from Indonesia; side view) weighs 25.30 ct and is 15.4 mm in diameter. The radiograph (b), phase-contrast (c) and darkfield (d) images were taken from above. It contains a rather small bead overgrown by a thick layer of nacre (about 5 mm), best seen in the phase-contrast and darkfield images. The columnar structure in the centre of each image corresponds to the slightly inclined drill hole. Pearl photo by Carina Hanser and other images by V. Revol.*



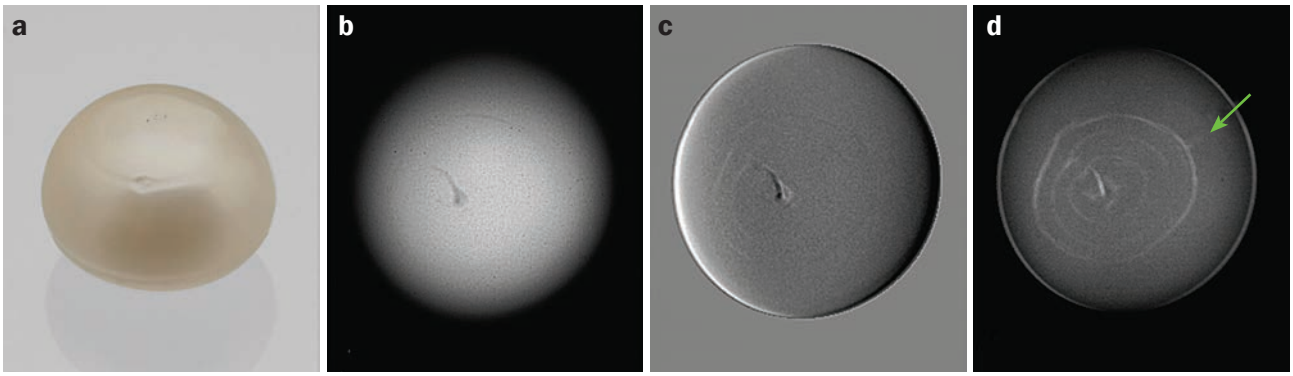


*Figure 9: (a) This non-beaded freshwater cultured pearl CP-1b (*Hyriopsis cumingii *from China; side view) weighs 9.92 ct and is 13.0 mm in diameter. The radiograph (b), phase-contrast (c) and darkfield (d) images were taken from above. It reveals a small irregular (comma-shaped) cavity surrounded by ring structures and a small crack (green arrow) that is only seen in the darkfield image. Pearl photo by Carina Hanser and other images by V. Revol.*

the thick nacre overgrowth, the commonly observed difference in brightness between the bead (made from a freshwater shell) and the nacre overgrowth (slightly more transparent to X-rays and thus slightly darker) is barely visible in the radiograph. In the phase-contrast image and, especially, in the darkfield image (Figure 8c,d), the perfectly round bead is more discernible, as are growth circles and dehydration fissures in the nacre overgrowth. Both features were also observed in micro-CT images of this sample.

Non-Beaded Freshwater Cultured Pearl

The non-beaded freshwater cultured pearl CP-1b (*Hyriopsis cumingii*, Figure 9a) exhibits a small central cavity structure in the X-radiograph (Figure 9b), highly characteristic for this type of cultured pearl. The phase-contrast and darkfield images (Figure 9c,d) add even more detail to the internal structures, with additional fine growth rings and a small crack only seen in the darkfield image. This crack was not visible in micro-CT images of this sample.

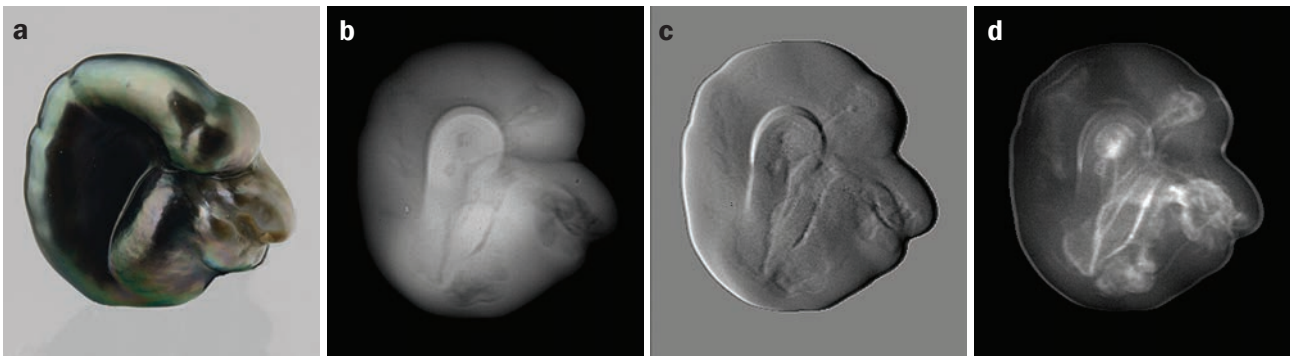
'Keshi' Non-Beaded Saltwater Cultured Pearl

The non-beaded saltwater cultured pearl CP-2m (*P. margaritifera*, Figure 10a) has a baroque shape, characteristic of cultured pearls formed within a collapsing pearl sac after ejection of the bead that had been inserted for second-generation cultured pearl production. This is also known as a second-generation 'keshi' cultured pearl. The complex structure of the large organic-rich cavity can be observed equally well in the X-radiograph, phase-contrast and darkfield images (Figure 10a–c). The darkfield image again delivers the most detailed insight, strongly highlighting the complexly folded internal structure of the sample (compare with Figure 15 of Sturman, 2009). This is due to the small-angle scattering effects (appearing bright in the darkfield image) at these material inhomogeneities.

Entire Strand of Cultured Pearls

Because of the large field of view afforded by the instrumentation, it is possible to analyse entire

*Figure 10: (a) This 'keshi' non-beaded saltwater cultured pearl CP-2m (*P. margaritifera *from French Polynesia) weighs 8.14 ct and is 13.9 mm in diameter. The complex spatial structure of the large cavity in its core is discernible in great detail in the radiograph (b), phase-contrast (c) and darkfield (d) images. Pearl photo by Carina Hanser and other images by V. Revol.*



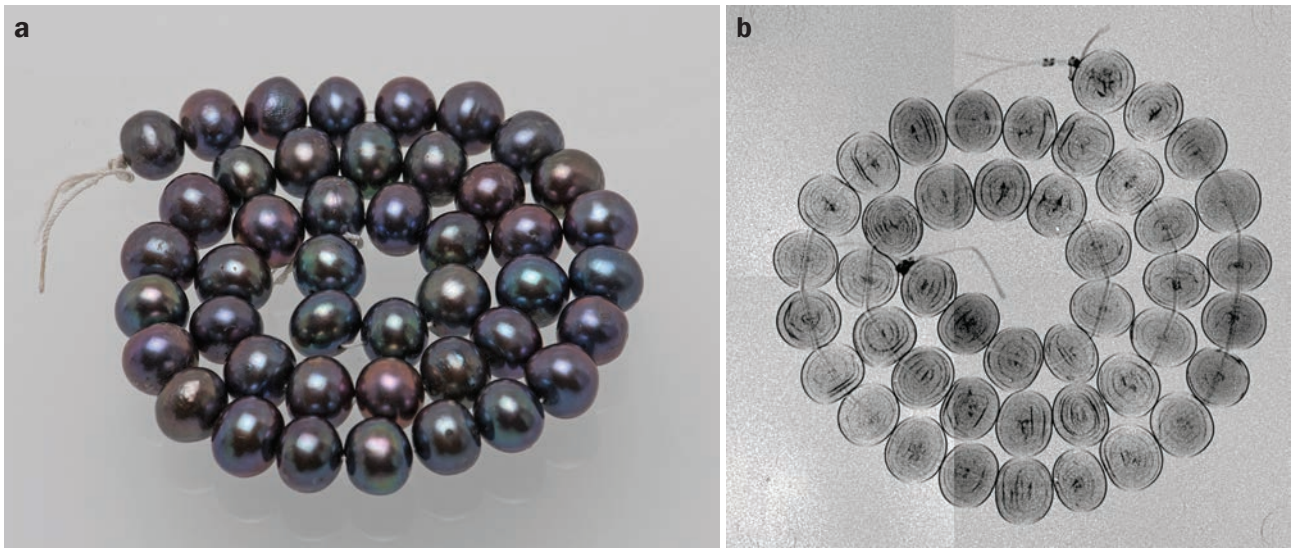


Figure 11: A strand of dyed non-beaded freshwater cultured pearls from China (sample CP-54, ~7.5 mm in diameter each) is shown in a photograph (a; photo by Vito Lanzamfame, SSEF) and in an inversed darkfield image (b; image by V. Revol). The latter view shows a central cavity structure in each pearl that is characteristic of culturing; these features are readily displayed in greater detail than with traditional radiography.

strands/necklaces at once, a prerequisite for rapid and reliable routine analysis in a gemmological laboratory. The darkfield image of the strand of non-beaded freshwater cultured pearls in Figure 11a was acquired with the S50-4 setup (see Table II). Owing to the relatively limited field of view of this setup, four images were stitched together to obtain the final image displayed in Figure 11b. As also shown by Figure 11b, the black-and-white tones in darkfield images can be inverted for a more straightforward comparison with conventional X-radiographs.

Discussion

As described above, X-ray phase-contrast and darkfield imaging offer simultaneous complementary information to 'classical' radiography, all in one analytical run. However, it should be noted that the current setup and instrumental limitations provide X-radiographs at lower resolution and contrast than state-of-the-art digital radiography units (e.g. Yxlon Cougar). Figure 12 compares such X-radiographs. This drawback is compensated by the additional information simultaneously delivered by phase-contrast and darkfield imaging. However, this makes it a complementary analytical approach rather than a full replacement of 'classical' radiography at this time.

By using a rotating sample stage, it is also possible to obtain three-dimensional tomographic reconstructions of a pearl with the grating interferometer setup. This is shown for natural pearl P14-11, which is characterized by several dehydration fissures along the nacre growth rings and

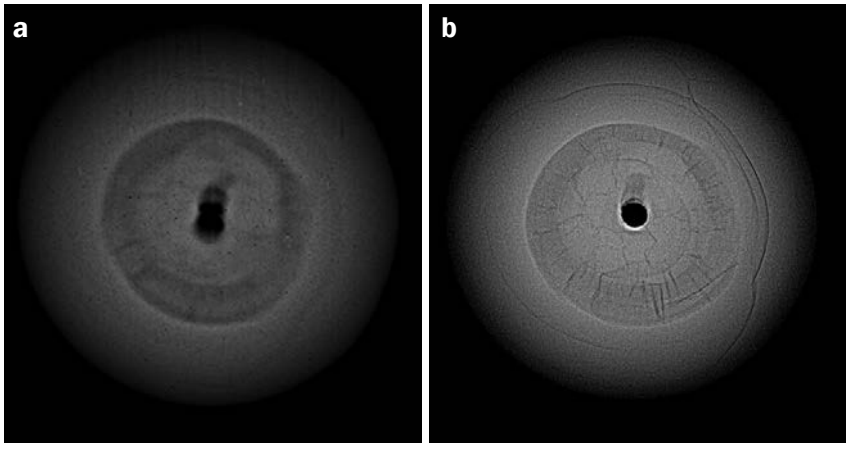


Figure 12: A significant difference in resolution is seen here in the X-radiographs of natural pearl NP-2e (10.3 mm in diameter) that were obtained with a grating interferometer (left, image by V. Revol) and a Yxlon Cougar micro-focus X-ray inspection system (right, image by J. Braun, SSEF).

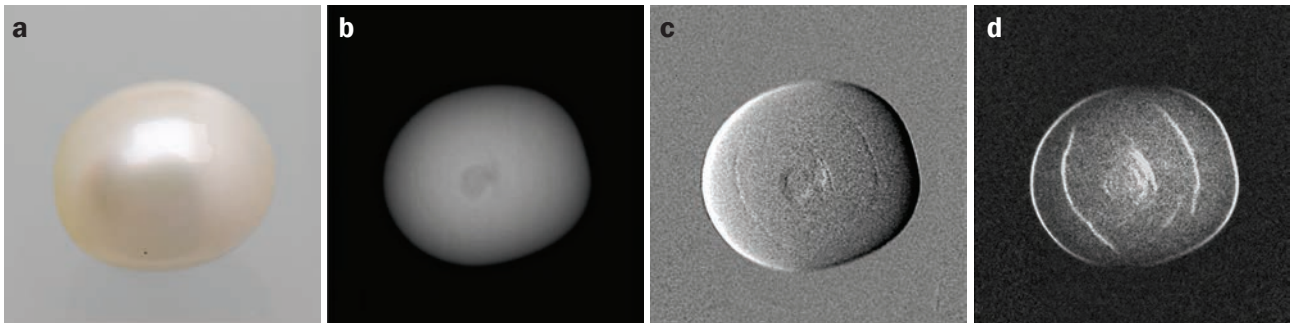


*Figure 13: (a) This saltwater natural pearl P14-11 (*P. maxima *from northern Australia) weighs 3.68 ct and measures 8.2 mm in diameter. The radiograph (b), phase-contrast (c) and darkfield (d) images reveal its internal features. Pearl photo by Carina Hanser and other images by V. Revol.*

a roundish centre zone slightly enriched in organic matter (Figures 13 and 14). These internal structures are best illustrated by darkfield tomography, and the three-dimensional reconstruction offers insights into the shell-like shape of the fissures on each side of the pearl, together with the spherical outline of the organic-rich core.

Additional possibilities with these digitally registered images are to study internal features along a line-scan (see, e.g., Revol et al., 2016), or to overlay X-radiographs with the simultaneously registered phase-contrast and darkfield images for better visualization (see, e.g., Hanser, 2015).

As demonstrated with the natural and cultured pearls studied here, X-ray phase-contrast imaging is useful for visualizing aspects such as cores containing an enrichment of organic matter. Darkfield imaging is particularly powerful, as it offers valuable and complementary information to traditional radiography. The small-angle scattering in darkfield images reveals even tiny and thin material inhomogeneities at high contrast, such as fine fissures within the bead of a cultured pearl (Figure 15) or small central cavity structures that are especially characteristic of non-beaded freshwater cultured pearls from China.

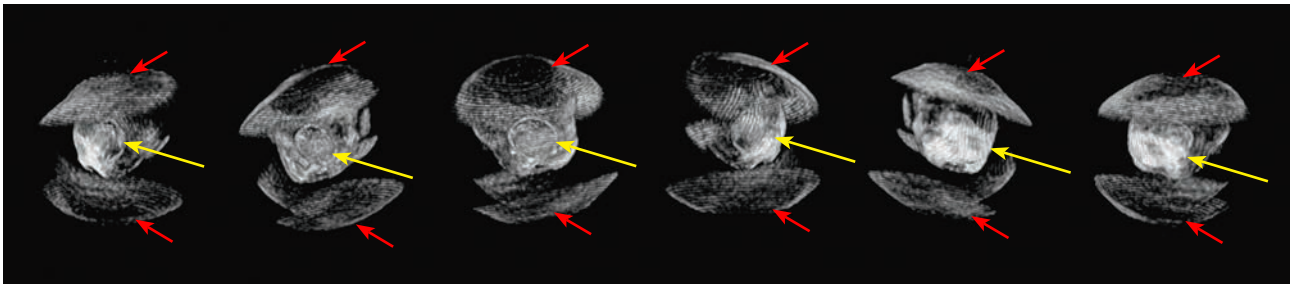
The authors did not observe any colour modification of the samples after imaging them with either analytical setup. Although the possibility that such colour changes may occur in rare cases cannot be excluded completely, the same applies to classical radiography (which has a similar range of exposure time and energy).

The main disadvantage of this new analytical technique at this stage is the low resolution of the simultaneously registered X-radiograph compared with state-of-the-art digital radiography (and micro-CT). The authors are currently working on this aspect with the aim to considerably improve the resolution of the X-radiographs in the near future.

Conclusion

The separation of natural from cultured pearls greatly relies on the interpretation of their internal structures. This study shows that X-ray differential phase-contrast imaging and X-ray darkfield imaging provide detailed information for pearl analysis that is complementary to traditional X-radiography. By using a grating interferometer coupled with a standard industrial micro-focus X-ray tube, it is possible to simultaneously generate

Figure 14: A sequence of video still images shows a full rotation of a darkfield tomographic reconstruction of saltwater natural pearl P14-11. Its internal features consist of an interlocked and shell-like arrangement of dehydration fissures (red arrows) in the nacre layer and a spherical organic-rich zone in the core (yellow arrow). The orientation of the pearl is rotated by 90° compared to that shown in Figure 13. Images by V. Revol.



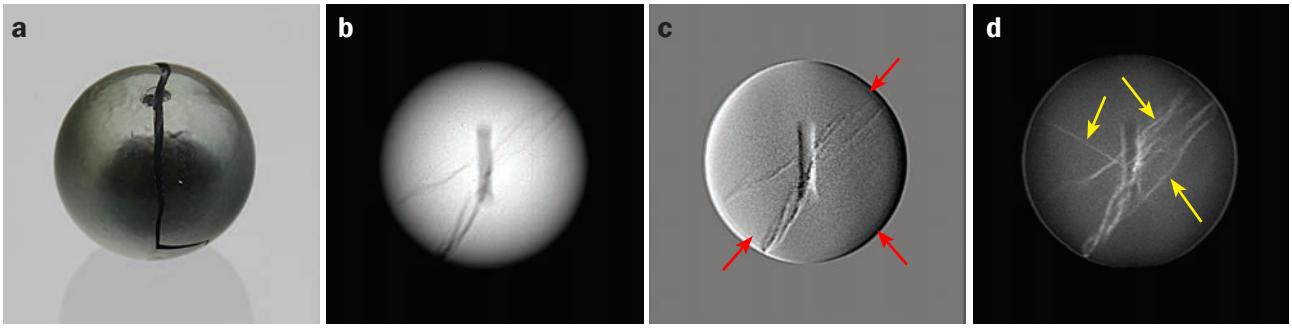


Figure 15: Fissures that develop in the bead of a cultured pearl during the drilling process are a major problem for both pearl farmers and the trade, as they can result in cracking of the pearl—as happened here for sample CP-2e2 during analytical manipulation (a; 12.1 mm in diameter). Compared to the radiograph (b), phase-contrast (c) and darkfield (d) imaging are both very useful for visualizing such fine structures of fracturing (yellow arrows), even at an incipient stage. The sample only has a thin layer of nacre over the large bead; the red arrows mark the boundary between the bead and the nacre overgrowth. Pearl photo by Carina Hanser and other images by V. Revol.

X-radiographs along with differential phase-contrast and darkfield images of pearls within a few minutes. There is no need to sequentially analyse a sample to obtain these three complementary images. Moreover, the ability to analyse not only single pearls but entire strands and necklaces makes this a rapid and versatile new approach, which in the authors' opinion has great potential for pearl characterization in the near future.

References

Anderson B.W., 1932. The use of X rays in the study of pearls. *British Journal of Radiology*, **5**(49), 57–64, http://dx.doi.org/10.1259/0007-1285-5-49-57.

Barnard W. and de Waal D., 2006. Raman investigation of pigmentary molecules in the molluscan biogenic matrix. *Journal of Raman Spectroscopy*, **37**(1–3), 342–352, http://dx.doi.org/10.1002/jrs.1461.

Cartier L.E. and Krzemnicki M.S., 2013. New developments in cultured pearl production: Use of organic and baroque shell nuclei. *Australian Gemmologist*, **25**(1), 6–13.

David C., Nöhammer B., Solak H.H. and Ziegler E., 2002. Differential X-ray phase contrast imaging using a shearing interferometer. *Applied Physics Letters*, **81**(17), 3287–3289, http://dx.doi.org/10.1063/1.1516611.

Elen S., 2002. Identification of yellow cultured pearls from the black-lipped oyster *Pinctada margaritifera*. *Gems & Gemology*, **38**(1), 66–72, http://dx.doi.org/10.5741/gems.38.1.66.

Farn A.E., 1986. *Pearls: Natural, Cultured and Imitation*. Butterworths Gem Books, London, 150 pp.

Gutmannsbauer W. and Hänni, H.A., 1994. Structural and chemical investigations on shells and pearls of nacre forming salt- and fresh-water bivalve molluscs. *Journal of Gemmology*, **24**(4), 241–252, http://dx.doi.org/10.15506/JoG.1994.24.4.241.

Hänni H.A., 1983. The influence of the internal structure of pearls on Lauegrams. *Journal of Gemmology*, **18**(5), 386–400, http://dx.doi.org/10.15506/JoG.1983.18.5.386.

Hänni H.A., 2006. A short review of the use of 'keshi' as a term to describe pearls. *Journal of Gemmology*, **30**(1–2), 51–58, http://dx.doi.org/10.15506/JoG.2006.30.1.51.

Hänni H.A., Kiefert L. and Giese P., 2005. X-ray luminescence, a valuable test in pearl identification. *Journal of Gemmology*, **29**(5–6), 325–329, http://dx.doi.org/10.15506/JoG.2005.29.5.325.

Hanser C., 2015. Comparison of Imaging Techniques for the Analysis of Internal Structures of Pearls. Master's thesis, University of Freiburg, Germany, 137 pp.

Karampelas S., Fritsch E., Mevellec J.-Y., Gauthier J.-P., Sklavounos S. and Soldatos T., 2007. Determination by Raman scattering of the nature of pigments in cultured freshwater pearls from the mollusk *Hyriopsis cumingi*. *Journal of Raman Spectroscopy*, **38**(2), 217–230, http://dx.doi.org/10.1002/jrs.1626.

Karampelas S., Michel J., Zheng-Cui M., Schwarz J.-O., Enzmann F., Fritsch E., Leu L. and Krzemnicki M.S., 2010. X-ray computed microtomography: Methodology, advantages, and limitations. *Gems & Gemology*, **46**(2), 122–127, http://dx.doi.org/10.5741/gems.46.2.122.

Karampelas S., Fritsch E., Gauthier J.-P. and Hainschwang T., 2011. UV-Vis-NIR reflectance spectroscopy of natural-color saltwater cultured pearls from *Pinctada margaritifera*. *Gems & Gemology*, **47**(1), 31–35, http://dx.doi.org/10.5741/gems.47.1.31.

Kennedy S.J., 1998. Pearl identification. *Australian Gemmologist*, **20**(1), 2–19.

Krzemnicki M.S., Friess S.D., Chalus P., Hänni H.A. and Karampelas S., 2010. X-ray computed microtomography: Distinguishing natural pearls from beaded and non-beaded cultured pearls.

Gems & Gemology, **46**(2), 128–134, http://dx.doi.org/10.5741/gems.46.2.128.

Krzemnicki M.S., Revol V., Hanser C., Cartier L., Hänni H.A., 2015. X-ray phase contrast and X-ray scattering images of pearls. *34th International Gemmological Conference*, Vilnius, Lithuania, 26–30 August, 117–120.

Momose A., Kawamoto S., Koyama I., Hamaishi Y., Takai K. and Suzuki Y., 2003. Demonstration of X-ray Talbot interferometry. *Japanese Journal of Applied Physics*, **42**, Part 2, No. 7B, L866–L868, http://dx.doi.org/10.1143/jjap.42.l866.

Pfeiffer F., Weitkamp T., Bunk O. and David C., 2006. Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources. *Nature Physics*, **2**(4), 258–261, http://dx.doi.org/10.1038/nphys265.

Pfeiffer F., Bech M., Bunk O., Kraft P., Eikenberry E.F., Brönnimann C., Grünzweig C. and David C., 2008. Hard-X-ray dark-field imaging using a grating interferometer. *Nature Materials*, **7**(2), 134–137, http://dx.doi.org/10.1038/nmat2096.

Revol V., Kottler C., Kaufmann R., Straumann U. and Urban C., 2010. Noise analysis of grating-based X-ray differential phase contrast imaging. *Review of Scientific Instruments*, **81**(7), article 073709, 7 pp., http://dx.doi.org/10.1063/1.3465334.

Revol V., Jerjen I., Kottler C., Schütz P., Kaufmann R., Lüthi T., Sennhauser U., Straumann U. and Urban C., 2011. Sub-pixel porosity revealed by X-ray scatter dark field imaging. *Journal of Applied Physics*, **110**(4), article 044912, 5 pp., http://dx.doi.org/10.1063/1.3624592.

Revol V., Hanser C. and Krzemnicki M., 2016. Characterization of pearls by X-ray phase contrast imaging with a grating interferometer. *Case Studies in Nondestructive Testing and Evaluation*, **6**, 1–7, http://dx.doi.org/10.1016/j.csndt.2016.06.001.

Rosc J., Hammer V.M.F. and Bruner R., 2016. X-ray computed tomography for fast and non-destructive multiple pearl inspection. *Case Studies in Nondestructive Testing and Evaluation*, **6**, 32–37, https://doi.org/10.1016/j.csndt.2016.08.002.

Scarratt K., Moses T.M. and Akamatsu S., 2000. Characteristics of nuclei in Chinese freshwater cultured pearls. *Gems & Gemology*, **36**(2), 98–109, http://dx.doi.org/10.5741/gems.36.2.98.

Schlüter J., Lohmann M. and Metge J., 2005. Diffraction enhanced imaging: A new X-ray method for detecting internal pearl structures. *Journal of Gemmology*, **29**(7–8), 401–406, https://doi.org/10.15506/jog.2005.29.7.401.

Strack E., 2006. *Pearls*. Ruhle-Diebener-Verlag, Stuttgart, Germany, 696 pp.

Sturman N., 2009. The Microradiographic Structures of Non-bead Cultured Pearls. Gemological Institute of America, Bangkok, Thailand, 20 August, 23 pp., www.gia.edu/gia-news-research-NR112009.

Wehrmeister U., Goetz H., Jacob D.E., Soldati A., Xu W., Duschner H. and Hofmeister W., 2008. Visualization of the internal structures of cultured pearls by computerized X-ray microtomography. *Journal of Gemmology*, **31**(1–2), 15–21, http://dx.doi.org/10.15506/JoG.2008.31.1.15.

Weitkamp T., Diaz A., David C., Pfeiffer F., Stampanoni M., Cloetens P. and Ziegler E., 2005. X-ray phase imaging with a grating interferometer. *Optics Express*, **13**(16), 6296–6304, http://dx.doi.org/10.1364/opex.13.006296.

Zhu P., Zhang K., Wang Z., Liu Y., Liu X., Wu Z., McDonald S.A., Marone F. and Stampanoni M., 2010. Low-dose, simple, and fast grating-based X-ray phase-contrast imaging. *Proceedings of the National Academy of Sciences*, **107**(31), 13576–13581, http://dx.doi.org/10.1073/pnas.1003198107.

The Authors

Dr Michael S. Krzemnicki FGA
Swiss Gemmological Institute SSEF
Aeschengraben 26, 4051 Basel, Switzerland
Email: michael.krzemnicki@ssef.ch

Carina S. Hanser
Albert Ludwig University of Freiburg, Institute of Earth and Environmental Sciences, Albertstrasse 23b, Freiburg im Breisgau, Germany

Dr Vincent Revol
Centre Suisse d'Electronique et de Microtechnique (CSEM), Untere Gründlistrasse 1, 6055 Alpnach Dorf, Switzerland

Acknowledgements

The authors thank Peter and Michael Bracher (Paspaley, Darwin and Sydney, Australia), Andy Müller (Hinata Trading Ltd., Kobe, Japan), Hussain Alfardan (Alfardan Group, Qatar), Thomas Faerber (Faerber Collection, Geneva, Switzerland) and José Casares (Shanghai Gems SA, Geneva) for the kind donation of natural and cultured pearl samples. We also thank three anonymous reviewers for their constructive comments.

MAYER & WATT

We *Deal* in inspiration...Naturally.

Download the Mayer and Watt
App for iOS/Droid.

US#: 606.564.3400

www.mayerandwatt.com

Follow us on Instagram : #mayerandwatt Facebook : @Gempornapp

Camels, Courts and Financing the French Blue Diamond: Tavernier's Sixth Voyage

Jack Ogden

The memoirs of the French gem merchant and traveller Jean-Baptiste Tavernier (1605–1689) are well known and shed much light on the European gem trade with India during the 17th century. A surviving factum (a submitted summary of a legal case) provides some supplementary information, as it details a claim made by Tavernier against the children and heirs of Parisian jeweller Daniel Chardin following his sixth trip to the East. We learn something of Tavernier's practical problems regarding extortionate Ottoman customs-duty demands and how he financed his trade. The diamonds he purchased in India were bought and sold by him on behalf of a syndicate of French merchants and investors, all of whom received a share of the profits. The royal goldsmith Jean Pitan (or Pitau), who received a brokerage fee for their sale, was a close relative by marriage to Tavernier. One of the stones brought back to France by Tavernier on this sixth and final voyage was a large blue diamond of slightly over 115 metric carats, which he sold to King Louis XIV in 1669. It was recut in 1673 as 'the blue diamond of the crown' or French Blue, and ultimately became what we know as the Hope Diamond in the Smithsonian National Museum of Natural History, Washington DC, USA. A letter dated early 1668 between British diplomats in the region provides a tantalizing hint that Tavernier might have purchased this large blue diamond in Isfahan, Persia, for the equivalent then of £7,000, and also sheds some light on Tavernier's competitor, David Bazu.

The Journal of Gemmology, **35**(7), 2017, pp. 640–650, http://dx.doi.org/10.15506/JoG.2017.35.7.640

Introduction

Jean-Baptiste Tavernier's memoires, *Les Six Voyages de J. B. Tavernier*, first published in Paris in 1676, are perhaps the best-known historical record of a gem dealer (Tavernier, 1676a,b). They recount in detail his six journeys to the East in the mid-1600s and provide a wealth of information, from the mining of diamonds to the trade routes to the Mughal court. The title page of the 1678 Amsterdam edition of Tavernier's *Voyages* in Figure 1 shows Tavernier buying diamonds at a mine in India (Tavernier, 1678). Extracts of his work are quoted in almost every study relating to the gem trade in the past, and the *Voyages* even form

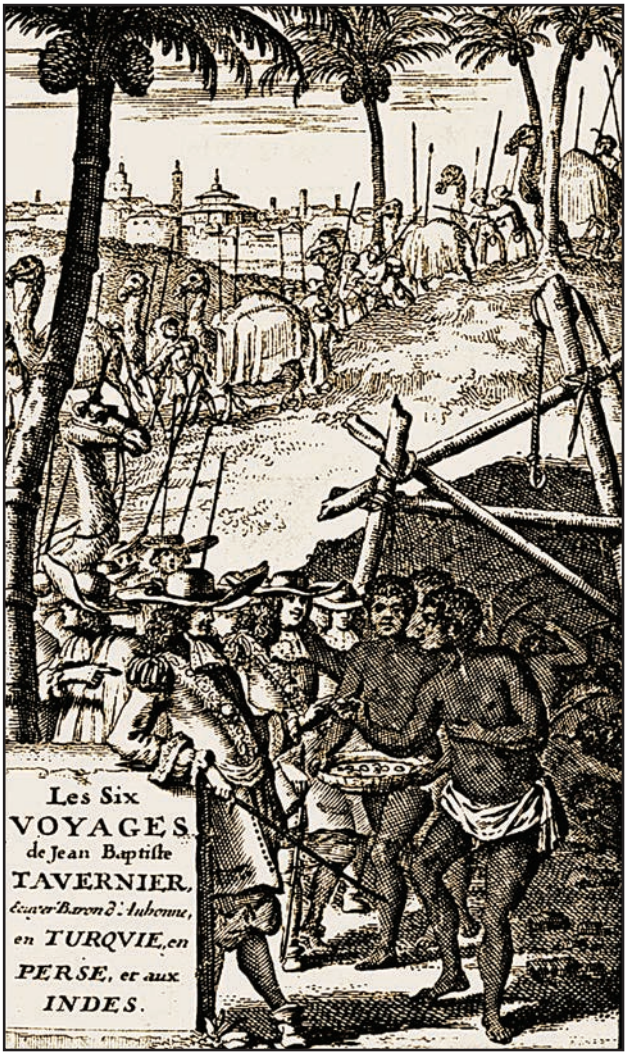


Figure 1: The title page of the 1678 Amsterdam edition of Tavernier's Voyages *shows him being offered diamonds at a mine site in India, with a caravan of camels in the background.*

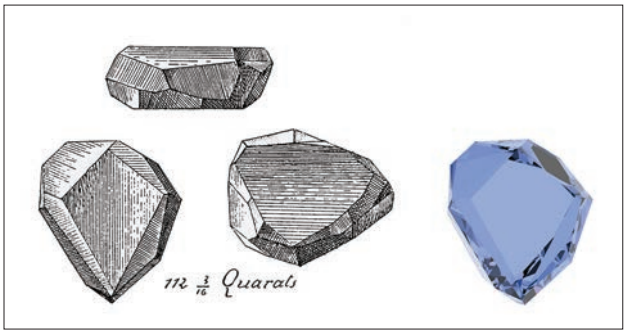


Figure 2: A drawing of three views of Tavernier's large blue diamond, as published in most editions of his Voyages, *is shown together with a modern three-dimensional computer rendering of the stone prepared by the author.*

Figure 3: This CZ replica of the French Blue diamond was faceted by Scott Sucher (The Stonecutter, Tijeras, New Mexico, USA), and represents the stone as it was cut by Pitan. Photo by Scott Sucher.

the basis of an engaging historical novel (Wise, 2009). Tavernier provides us with information on the diamond trade in India in the 1600s and on some of the renowned diamonds mined there, including what was perhaps the Koh-i-Noor and the Great Mughal, the latter probably equivalent to the Orlov (Malecka, 2016).

However, the stone that Tavernier is best associated with is a large blue diamond of 112$^{3}/_{16}$ old carats (115.28 metric carats) that he obtained on his sixth trip (Figure 2) and sold to the French King Louis XIV. It had been roughly cut, perhaps as what we would term a preform to best show off its colour. It was soon recut for the king into what we know as the French Blue (cf. Figure 3), a kite-shaped brilliant of 67$^{1}/_{8}$ old carats (68.9 metric carats) according to the 1691 inventory of the king's jewels (Bapst, 1889, p. 374). The French Blue was confiscated and then stolen during the French Revolution, only to turn up, recut to 44.5 old carats (45.7 metric carats), for sale in London in 1812, where it was described and accurately drawn by the mineralogist James Sowerby (Ogden, in prep.). It passed into the gem collection of Henry Philip Hope and has retained the name 'The Hope Diamond' in the Smithsonian National Museum of Natural History, now weighing 45.52 ct. The meticulous research to prove that the Hope Diamond is indeed the French Blue recut, and a summary of its history, appears in Farges et al. (2009).

Despite Tavernier's extensive writing, we know little of the business and monetary aspects of his dealings, such as prices, how he was financed and his customers. This is understandable; few gem

dealers today would wish to publish such information. Supplementary documentation to fill these gaps is sadly sparse, but there is some to be found in various archives. Of his customers in Europe, we know of only two major ones by name: Louis XIV, of course, and Louis' younger brother the Duke of Orleans. We learn of the latter from a 1668 letter from Benjamin Lannoy of the British Consul in Aleppo, Syria, to Sir Heneage Finch, Third Earl of Winchilsea, Charles II's Ambassador to the Ottoman Empire in Constantinople (modern Istanbul), where Tavernier is described as "a person who hath often bin sent [to India] by the Duke of Orleans and others to gather rarities for them" (Finch, 1913, p. 439).

Most informative about Tavernier's financing is a document of which at least three copies survive, although they are not well known: a *factum*, or summary of a legal case, prepared by Tavernier's legal advisor Procurator Marpon.[1] It is a claim against the children and heirs of French jeweller Daniel Chardin and his wife, and although its text sheds considerable light on Tavernier's dealings and although it has been mentioned by some writers in the context of Chardin's travels in the East (e.g. van der Cruysse, 1998), it seems little known in the gem world. The first page of this four-page factum is shown in Figure 4.

Factums were an interesting feature of the old French legal system. Cases were played out in written submissions and judgements rather than being debated in court. The factum discussed here gives some unique insights into the trade in diamonds in the 1600s, and it links three well-known figures in jewellery history: Jean-Baptiste Tavernier, Daniel Chardin (the Parisian jeweller mentioned above) and Jean Pitan (or Pitau), the court jeweller to King Louis XIV who is best known for recutting the large blue diamond into the French Blue.[2]

Background

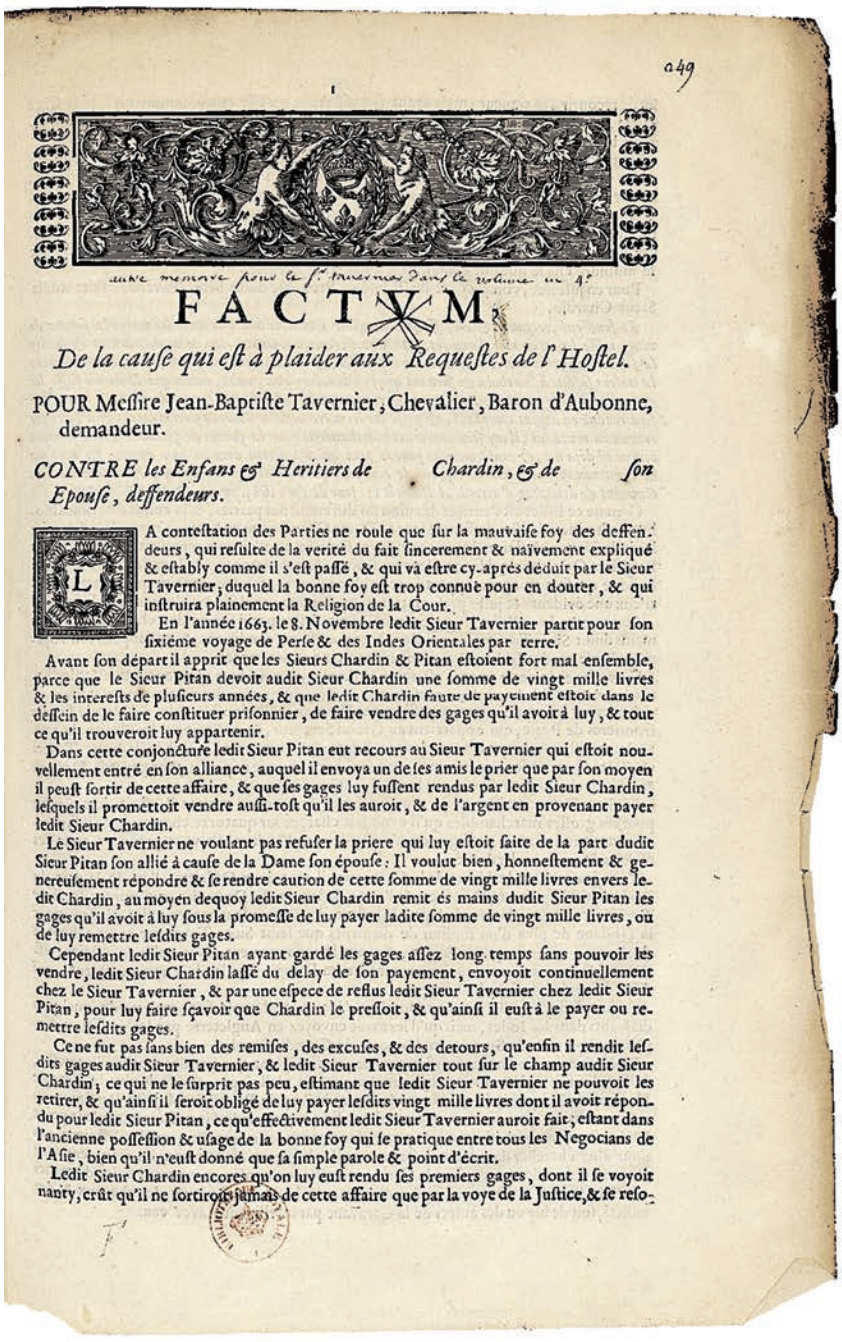
Prior to Tavernier's departure on his sixth voyage to the East in 1663, he learned that there was animosity between Daniel Chardin and Jean Pitan. Pitan owed Chardin 20,000 livres[3], as well as several years' interest. Chardin had goods as security from Pitan and was threatening to sell these and anything else of his he could get his hands on. Pitan approached Tavernier and begged him to help, assistance which Tavernier felt obliged to offer because of what the factum calls his 'new alliance' with Pitan. This alliance was one of marriage. In 1662, in his late fifties, Tavernier had married Madeleine Goisse, the daughter of another Parisian jeweller, Jean Goisse, and his wife Elisabeth, formerly Elisabeth Pitan. The anonymous author of the introduction to the 1713 Paris edition of Tavernier's *Voyages* (and some subsequent editions) notes that he accepted Madeleine as wife in gratitude for the many services rendered to him by her father, a "jeweller-diamond cutter" (translated from Tavernier, 1713, Foreword). He added that he didn't look so good but had many merits, and that she was too old and could not give him an heir. She is sometimes referred to as Jeanne-Madeleine Goisse. This was not the only association of the families; Tavernier's older brother Melchior had married a Pitan (Joret, 1886, p. 161), and as early as 1619 Melchior was described as a brother-in-law at the time he and Jean Pitan were among the witnesses of an inventory made when Jean's brother, the painter Géral Pitan, died (Guiffrey, 1915, p. 103). So royal jeweller Jean Pitan—who cut the French Blue—was the brother of Tavernier's mother-in-law.

The factum explains that Pitan promised that, if Tavernier arranged to have the goods on pledge

[1] The three copies of this factum of which this author is aware are all in the Bibliothèque nationale de France (BnF): Two copies are bound together in BnF manuscript Clairambault 1182 and the third is BnF manuscript Z THOISY-87 (f. 249). The latter can be obtained online at http://gallica.bnf.fr/ark:/12148/bpt6k3120071/f1.item.zoom. These are also the only three versions of this factum that are noted in Corda (1902, p. 27).

[2] Mentions of this diamond's recutting usually give the cutter's family name as Pitau, although it is clearly shown as Pitan in the factum. In 17th-century French handwriting, such as in a document relating to the recutting of the blue diamond by Pitan (described later in this article), the letters 'u' and 'n' are often indistinguishable, but this is probably not the root of the discrepancy. Jean was originally from a Flemish family, and it seems likely that Pitan (sometimes spelled Pittan, e.g. Guiffrey, 1872, p. 165) was the Flemish spelling. The spelling changed to how it sounded in French—'Pitau'—as he and his family assimilated into Parisian society. Certainly, when his son Nicolas, an artist, engraved a portrait of Louis XIV in 1670 it included the printed legend: *N. Pitau sculpsit 1670*. Since Tavernier, also from a Flemish family, refers to the royal jeweller as Jean Pitan, this is the spelling used in this article.

[3] It is not easy to suggest a modern equivalent value, but in Tavernier's time there were approximately 10 livres to the British pound and each livre was equal to around 12 g of silver. The debt of 20,000 livres was thus about £2,000, the equivalent of 240 kg of silver then (or £100,000 at current silver prices).



a49

FACTVM

De la cauſe qui eſt à plaider aux Requeſtes de l'Hoſtel.

POUR Meſſire Jean-Baptiſte Tavernier, Chevalier, Baron d'Aubonne, demandeur.

CONTRE les Enfans & Heritiers de Chardin, & de ſon Epouſe, deffendeurs.

A conteſtation des Parties ne roule que ſur la mauvaiſe foy des deffendeurs, qui reſulte de la verité du fait ſincerement & naïvement expliqué & eſtably comme il s'eſt paſſé, & qui va eſtre cy-aprés déduit par le Sieur Tavernier; duquel la bonne foy eſt trop connuë pour en douter, & qui inſtruira plainement la Religion de la Cour.

En l'année 1663. le 8. Novembre ledit Sieur Tavernier partit pour ſon ſixiéme voyage de Perſe & des Indes Orientales par terre.

Avant ſon départ il apprit que les Sieurs Chardin & Pitan eſtoient fort mal enſemble, parce que le Sieur Pitan devoit audit Sieur Chardin une ſomme de vingt mille livres & les intereſts de pluſieurs années, & que ledit Chardin faute de payement eſtoit dans le deſſein de le faire conſtituer priſonnier, de faire vendre des gages qu'il avoit à luy, & tout ce qu'il trouveroit luy appartenir.

Dans cette conjoncture ledit Sieur Pitan eut recours au Sieur Tavernier qui eſtoit nouvellement entré en ſon alliance, auquel il envoya un de ſes amis le prier que par ſon moyen il peuſt ſortir de cette affaire, & que ſes gages luy fuſſent rendus par ledit Sieur Chardin, leſquels il promettoit vendre auſſi-toſt qu'il les auroit, & de l'argent en provenant payer ledit Sieur Chardin.

Le Sieur Tavernier ne voulant pas refuſer la priere qui luy eſtoit faite de la part dudit Sieur Pitan ſon allié à cauſe de la Dame ſon épouſe: Il voulut bien, honneſtement & genereuſement répondre & ſe rendre caution de cette ſomme de vingt mille livres envers ledit Chardin, au moyen dequoy ledit Sieur Chardin remit és mains dudit Sieur Pitan les gages qu'il avoit à luy ſous la promeſſe de luy payer ladite ſomme de vingt mille livres, ou de luy remettre leſdits gages.

Cependant ledit Sieur Pitan ayant gardé les gages aſſez long-temps ſans pouvoir les vendre, ledit Sieur Chardin laſſé du delay de ſon payement, envoyoit continuellement chez le Sieur Tavernier, & par une eſpece de reflus ledit Sieur Tavernier chez ledit Sieur Pitan, pour luy faire ſçavoir que Chardin le preſſoit, & qu'ainſi il euſt à le payer ou remettre leſdits gages.

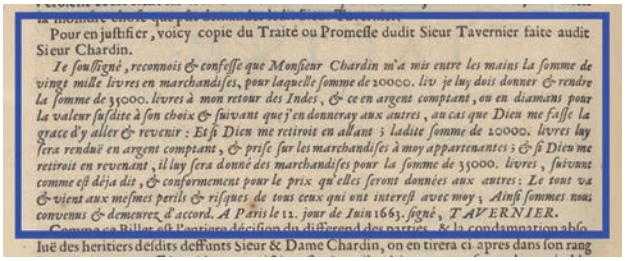
Ce ne fut pas ſans bien des remiſes, des excuſes, & des detours, qu'enfin il rendit leſdits gages audit Sieur Tavernier, & ledit Sieur Tavernier tout ſur le champ audit Sieur Chardin; ce qui ne le ſurprit pas peu, eſtimant que ledit Sieur Tavernier ne pouvoit les retirer, & qu'ainſi il ſeroit obligé de luy payer leſdits vingt mille livres dont il avoit répondu pour ledit Sieur Pitan, ce qu'effectivement ledit Sieur Tavernier auroit fait; eſtant dans l'ancienne poſſeſſion & uſage de la bonne foy qui ſe pratique entre tous les Negocians de l'Aſie, bien qu'il n'euſt donné que ſa ſimple parole & point d'écrit.

Ledit Sieur Chardin encores qu'on luy euſt rendu ſes premiers gages, dont il ſe voyoit nanty, crût qu'il ne ſortiroit jamais de cette affaire que par la voye de la Juſtice, & ſe reſo-

Figure 4: Shown here is the first page of the factum describing Jean-Baptiste Tavernier's case against the children and heirs of Daniel Chardin. Bibliothèque nationale de France, manuscript Z THOISY-87; © BnF.

returned to him, he could sell them quickly and pay Chardin back. So Tavernier "plainly and generously" (translated from p. 1 of the factum) acted as guarantor for the 20,000 livres Pitan owed Chardin, received back the goods and gave them to Pitan to sell. Unfortunately, Pitan had been overly optimistic and was unable to sell them quickly, but Chardin was impatient for his money. To resolve things, Tavernier volunteered to take the goods with him on his upcoming sixth voyage to the East, sell them in Persia or India, and on his return, give the proceeds to Chardin "without taking any profit or interest therein for his pains" (p. 2). Tavernier would take the merchandise to the value of 20,000 livres from Chardin and bring him back 35,000 livres in cash or diamonds, whichever Chardin preferred. There was also a specific clause in the agreement that all the risks involved would fall to Chardin. This was fair and "the least thing that Sieur Tavernier could ask" (p. 2), but it caused problems later, as we will see.

The agreement, signed by Tavernier on 12 June 1663, is quoted in the factum, as shown in Figure 5. We know little specific information about the nature of the goods that Tavernier carried east, other than he had some diamonds with him (Tav-



Pour en justifier, voicy copie du Traité ou Promesse dudit Sieur Tavernier faite audit Sieur Chardin.

Ie soussigné, reconnois & confesse que Monsieur Chardin m'a mis entre les mains la somme de vingt mille livres en marchandises, pour laquelle somme de 20000. liv je luy dois donner & rendre la somme de 35000. livres à mon retour des Indes, & ce en argent comptant, ou en diamans pour la valeur susdite à son choix & suivant que j'en donneray aux autres, au cas que Dieu me fasse la grace d'y aller & revenir : Et si Dieu me retiroit en allant ; ladite somme de 20000. livres luy sera renduë en argent comptant, & prise sur les marchandises à moy appartenantes ; & si Dieu me retiroit en revenant, il luy sera donné des marchandises pour la somme de 35000. livres, suivant comme est déja dit, & conformement pour le prix qu'elles seront données aux autres : Le tout va & vient aux mesmes perils & risques de tous ceux qui ont interest avec moy ; Ainsi sommes nous convenus & demeurez d'accord. A Paris le 12. jour de Juin 1663. signé, TAVERNIER.

Comme ce Biller est l'entiere décision du different des parties, & la condamnation absolue des heritiers desdits deffunts Sieur & Dame Chardin, on en tirera ci-apres dans son rang

Figure 5: This section of the factum cites the 12 June 1663 agreement between Chardin and Tavernier. It includes the former's agreement to cover the cost of the involved "perils and risks" of his expedition to the East. Bibliothèque nationale de France, manuscript Z THOISY-87; © BnF.

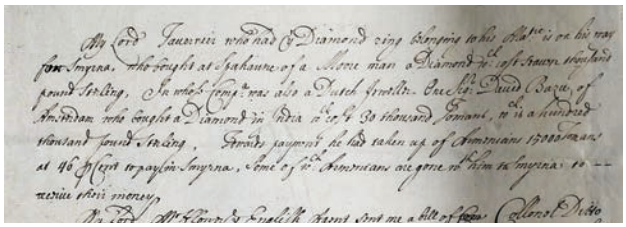


Figure 6: This portion of a 1668 letter from Consul Lannoy in Aleppo to the Earl of Winchilsea in Constantinople explains that Tavernier, then in a caravan heading to Smyrna, had bought a diamond in Isfahan in Persia for £7,000. Source: The Record Office for Leicestershire, Leicester & Rutland, Finch MSS p. 493/1.

ernier, 1676a, p. 96), as well as a gold ring set with a diamond engraved with the coat-of-arms of the King of England (Tavernier, 1676a, p. 484). Letters from Consul Lannoy in Aleppo to the Earl of Winchilsea in Constantinople and from the Earl of Winchilsea to Lord Arlington, who was then in charge of foreign affairs for Charles II, also refer to this engraved diamond (summarized in Finch, 1913, pp. 477, 482, 493, 509). Part of the original text of one of these letters is shown in Figure 6, which describes it as the "Diamond ring belonging to his Ma[j]esty". George Kunz, however, argues that this cannot have been the British monarch's ring because there were later documents of the king that were impressed with this seal (Kunz, 1917, p. 154).

The Journey

Having obtained Chardin's agreement to the details, Tavernier set out on his sixth trip. The factum says he left Paris on 8 November 1663, yet the date given in Tavernier's *Voyages* is 27 November (Tavernier, 1676a, p. 253). The reason for the date discrepancy is unknown. He went via Lyon, down to Livorno in Italy and then sailed to Smyrna (modern Izmir) in Turkey, where he waited for more than a month to join a caravan. He then set off to Yerevan in Armenia and down to Isfahan in Persia, where he arrived on 14 December 1664 after more than a year of travelling. He took with him gems, goldwork and other objects totalling 400,000 livres in value to sell to the Persian Shah and the Indian Mughal emperor (Tavernier, 1676a, p. 253). This selling of precious objects brought from Europe to the Persian Shah is corroborated in various sources. A letter written from Bandar Abbas in Persia to the East India Company in Surat, India, dated 10 April 1665, notes that Tavernier was on his way, sailing to Surat "having sold the King [the Shah] to the value of 4000 tomands and upwards in jewells and other rarities brought with him out of Europe" (Foster, 1925, p. 16). The *toman* was the Persian currency, and the 1668 letter in Figure 6 conveniently tells us that 30,000 tomans were then the equivalent of £100,000. So Tavernier's sale to the Persian Shah was for the equivalent of just over £13,000. If we link this to current gold prices, it represents about £5 million today.

Tavernier arrived in Surat on 2 May 1665 (Foster, 1925, p. 15), with three or four Dutchmen, en route to the Mughal Court to sell the rest of his goods on which he had "allready made extraordinary proffit" (Foster, 1925, p. 16). It is unclear who these Dutch were. They did not include Tavernier's competitor from Amsterdam, David Bazu (see below), who arrived in Surat on the following ship (Foster, 1925, p. 16). Tavernier does tell us in his *Voyages* that he left Paris with eight companions with useful professional skills (Tavernier, 1676a, p. 253). The first edition of the *Voyages* does not name or describe these people, but we know one was a surgeon who is mentioned several times elsewhere in the work (e.g. Tavernier, 1676a, p. 20). Another was probably the young painter whose many engravings of 'courtesans' proved popular (Tavernier, 1676a, p. 151), and there were two described as a horologist and a goldsmith who died during the trip (Tavernier, 1676a, p. 267).

In the 'Corrections and Notes' at the end of the 1713 French edition of the *Voyages* we find information that was supposedly brought to light

after the rest of the volume had been printed (Tavernier, 1713). This includes a description of Tavernier's eight companions: his nephew; an Armenian valet named Antoine; Destremeau, a surgeon; Kernel, a Dutch diamantaire; Pitan, Tavernier's 'parent' and a goldsmith; Calvet, a goldsmith from Castres in southern France; Bizot, an horologist; and Deslandes, who was "the only Catholic among the Huguenots". It is unclear from where this more complete list was compiled or how reliable it is. With regards to Pitan, the term 'parent' had a slightly wider meaning than just father. The goldsmith who died from a disease on the trip must have been Calvet and not Pitan, judging from Tavernier's fleeting mention of this tragic event. Nor can Pitan the goldsmith have been Jean Pitan himself unless he travelled only part of the way, because just a year after they all set off Jean Pitan is recorded as selling a gem-encrusted sword to the French king for 264,566 livres (Bapst, 1889, pp. 357 and 396). That the list of companions in the 1713 edition of the *Voyages* is not completely fanciful is shown by the presence among them of Deslandes. This was André Daulier Deslandes (1621–1715) who later, in his own report, expressed his disappointment that Tavernier sold a major part of the goods brought from Paris to Shah ʿAbbās II in Isfahan without involving him in the negotiations (Deslandes, 1673; Yarshater, 1996). Tavernier describes his dealings with the Shah in Book 4, Chapter 15 of his *Voyages* (Tavernier, 1676a, pp. 464–476).

Customs Demands

Having explained the background, the factum fast-forwards to Tavernier's homeward journey from the East in 1667–1668. After leaving Surat he travelled to 'Urzeron' (Erzurum), a large city in what is now eastern Turkey. Erzurum was an important Ottoman centre on the frontier with Persia, and the place where merchants paid the customs duties on goods they brought into the Ottoman Empire from the East, although in his *Voyages* Tavernier is not very flattering about the city itself (Tavernier, 1676a, p. 17). Tavernier and his caravan remained in Erzurum for three weeks, so that the relevant duties could be paid and provisions obtained for the onward journey. Tavernier paid the customs duties required for the merchandise, which he had loaded on to 14 camels.[4] The factum notes that if a traveller there had no merchandise to declare, he would be taken for a spy and mistreated.

Then, three days before the caravan set off again, two men approached Tavernier—one on behalf of the governor of the city, who took a share of the customs revenues, and the other a customs official. They placed him under house arrest where he was staying, demanding 30,000 piastres[5] in customs duties on more than a million piastres worth of diamonds. These diamonds, they said, had been brought from India by Tavernier; they had learned of them from a Dutchman called 'Bazur', who claimed to have made the purchases. This was David Bazu, a diamond merchant and cutter who Tavernier says cleaved a large but flawed diamond that no other dealer in India would risk money on and made a loss. Bazu was travelling in the same caravan as Tavernier and inadvertently or deliberately let the officials know about the diamonds. In his edition of Tavernier's *Voyages in India*, Valentine Ball notes that on his return to Europe, Bazu "sold a number of diamonds and pearls to Louis XIV" (Ball, 1889, p. 99). This is something of an understatement: Shortly after Tavernier sold his diamonds to Louis XIV, Bazu also sold the king diamonds and other objects for more than 500,000 livres, including one large Indian-cut diamond of 70 old carats which represented 110,000 livres, half the price of the French Blue (BnF MS Mèlanges de Colbert, Vol. 281, f. 14). Once recut, this might have been the cushion-shaped brilliant later set in Louis XV's Golden Fleece ornament, above the French Blue (Morel, 1988, pp. 223–224; Farges et al., 2009, p. 6).

Tavernier explained to the two Ottoman officials that he had bought many diamonds in India but had sent them by sea from Surat to England aboard an English ship. The officials were sceptical. 'Bazur', they said, had revealed that when the caravan had recently passed through Isfahan, the Persian king had wanted to buy a good number of Tavernier's diamonds, which supposedly was

[4] A camel load is about 200 kg, so Tavernier's 14 camels must have been carrying something in addition to his own belongings, most likely Indian textiles, a major French import.

[5] The fineness and purity of the Ottoman silver currency varied during the 17th century, but the officials' demand of 30,000 piastres was then the equivalent of about 450 kg of fine silver.

proof that he had them with him. The problem was that the Ottoman officials did not relish the thought of having to search through the merchandise on the "two thousand camels and four or five hundred horses and mules" (p. 2 of the factum) that comprised the entire caravan. This shows the huge size of such caravans, more particulars of which are detailed by Tavernier in Chapter 10 of the first book of his *Voyages* (Tavernier, 1676a). In the background of the title page of a 1678 edition (Figure 1), one can see a section of such a caravan (Tavernier, 1678). Tavernier's protestations that he had sent the diamonds by sea might have been true, and it was perhaps a safer way to transport his merchandise to Europe, but a letter dated 20 October 1667 from Lannoy in Aleppo, to the Earl of Winchilsea in Constantinople, after noting that Tavernier was travelling with a silk caravan, quoted a report from India that he and the Dutchmen in his company "had bought up in those parts vast quantities of jewelles, which they carry with them for Christendome" (Finch, 1913, p. 482).

The Turkish and Armenian merchants in the caravan supported Tavernier—the factum righteously explains that this was because "justice was wholly on the side of the said Sieur Tavernier" (p. 3 of the factum)—and they told the governor's functionary and customs official that no merchant should have to pay duty on goods he didn't have and which could not be found. This made little impression on the officials, and so the merchants appealed to the local Islamic scholars. These experts in Islamic jurisprudence decided that the officials were indeed wrong: The Koran expressly said that no rights shall be taken of things not made by man's hands, and thus customs duties could not be levied on diamonds, gems, gold, silver and other minerals that are found in the ground. In the face of this ruling, and the clamour from the other merchants, Tavernier was released on payment of 10,000 piastres rather than the 30,000 they originally had demanded. The factum describes this payment as an *avania*—the tax or fee, typically an extortionate one, imposed on foreigners by the Ottomans.

The factum notes that this outcome was actually a great favour for Tavernier because it is "constant and true" that the more one tries to avoid paying tax, the more it costs, and "reason has no place" (p. 3). But as the factum also points out, merchants returned from the East with goods, not money, so for Tavernier to raise this sum in cash was complex and expensive. When he finally reached Constantinople, and with the help of the French ambassador's interpreter and 800 piastres paid for 'presents' for the provincial governor and other officers, it was agreed that the money he had paid in Erzurum should be returned to him. But to achieve this he would have to go back to Erzurum accompanied by two members of the Ottoman cavalry and a representative of the Grand Vizier (the prime minister of the Ottoman Sultan), paying them for their services as well as the costs of the trip. The extra delay in his return to France would add considerably to his time and costs. Besides, the French ambassador confided that it might be unwise to trust the three Ottomans who would accompany him. Tavernier decided that his best option was to return home.

The Sale to the King

Back in France, Tavernier paid those who had put up goods for his voyage their capital investments and shares of the considerable profits. The factum specifically notes that these profits included the amount made on the diamonds sold to King Louis XIV. The investors also gave their word that, as per their original agreements, they would repay Tavernier their share of the unforeseen and unfortunate *avania* and associated costs once the calculations of this total amount, with relevant exchange rates, had been completed. This sum was found to be more than 48,000 livres in total, which we are told worked out that each of his investors was liable for 8% of their investment. This would suggest that the original investment was in excess of 600,000 livres, although Tavernier stated that he took goods worth 400,000 livres on his trip. The explanation for this discrepancy is unclear. In any case, all of the investors paid up apart from Daniel Chardin.

Tavernier could see no reason why Chardin should escape his obligations and requested payment many times, sometimes with witnesses present. The Chardins had the funds to pay and did not deny that the sum was due, but they thought it should be paid by Pitan. Their argument presumably was that they should not have to defray the costs involved in being paid back what was owed to them. Chardin fell ill and died while Tavernier himself was gravely ill for a long time and was in no state to press his case. Then, as one

accident typically follows another (as the factum sagely notes on page 4), Chardin's widow with whom Tavernier had taken up the case also died. So he had to turn to Chardin's children to get the refund of the *avania* and, mentioned now for the first time, 1½ percent extra for what we are told was the brokerage fee paid to Pitan on the sale of the diamonds. From this we might infer that Pitan, as the royal jeweller, played a facilitating role in the sale of the French Blue and the other diamonds to the king. The factum notes that the other investors had covered their shares of this brokerage. The Pitan heirs seemed to deny any involvement; the 35,000 livres debt had been paid back to Chardin, but not via their father, so they considered that they had no further liabilities or responsibilities. Recourse to the courts, and thus the drafting of the factum, was the only option left to Tavernier.

Tavernier was sure that if the record books of Chardin's business were made available (something he had often requested), the payments and the original agreement would be seen. This would provide clarification for the court, which would understand that it was not right for the Chardin heirs to take advantage of Tavernier's goodness and readiness to help, as had their father and mother. The factum concludes with the plea that the court will judge in his favour, not forgetting interest and expenses.

The Case

The factum is undated, but it must date to after 1675, since it was taken out against Chardin's children and heirs, and Pitan's heirs are also mentioned. Chardin died in 1672; the date of his wife's death is unknown. Jean Pitan, noted in the factum as deceased, died in 1675; he was described as goldsmith to the king and "one of the first who executed these presents so rich and so varied which Louis XIV presented to foreign ambassadors and to his entourage" (translated from Maze-Sencier, 1885, p. 63). The factum leaves a blank space for the first names of Chardin and his wife. It is hardly likely that Tavernier didn't know their names, so it suggests Tavernier had not given this information to his legal representative and was not readily available to furnish it. Possibly this means that the factum was not issued until after 1689 when Tavernier left France, but that would mean an extraordinarily long delay. The factum has the signatory 'Marpon, Proc'—i.e. Procureur (prosecutor) Philibert Marpon.

The detailed recounting of the Erzurum incident in the factum, even describing the number of camels in the caravan and the intervention of Islamic legal scholars, seems unnecessary in a French legal deposition, and one is tempted to think that this was partly intended to entertain the court and thus get it on Tavernier's side. The factum does, however, argue that it was unfair of Chardin and his heirs to deny him payment after he had undertaken "labours and risks which few people are capable of undertaking, and still less able to withstand and overcome" (p. 4). The copious details of the problems in Erzurum would provide the court with a clear idea of the perils involved in a business such as Tavernier's.

To date, the present author has not located court records that reveal whether Tavernier ever received his money from Chardin's heirs. Daniel Chardin and his wife Jeanne had several children. These included Jean, born in 1643, and Daniel, born in 1649. Jean worked with his father in the jewellery business and also travelled to the East. It has been suggested that he became a diamond dealer and travelled East as a replacement for Tavernier after the latter's business relationship with Danial Chardin "soured" (Baghdiantz McCabe, 2008, p. 108). However, Jean first travelled East while Tavernier was on his sixth trip, thus before the matter of non-payment of the *avania* arose, and the factum does not imply any bad feeling between Tavernier and Daniel Chardin before this. Jean Chardin settled in England after the persecution of Protestants in France began, becoming Crown Jeweller there, and was knighted as Sir John Chardin. Daniel Chardin the younger became a merchant in Madras (now Chennai), India, and a business partner to Jean. There were three other sons, two of whom had died, and one recorded sister.

We should be grateful for Jean Pitan's non-payment of his debt to Chardin, without which the factum and its insights into Tavernier's business and challenges would not exist. Pitan might have been an excellent goldsmith, but he seems to have been poor at managing his finances. In 1699 his heirs were acquitted of another of Pitan's debts dating back to 1673 (Guiffrey, 1896, col. 306)—proof that slow payment is not a preserve of the modern gem industry.

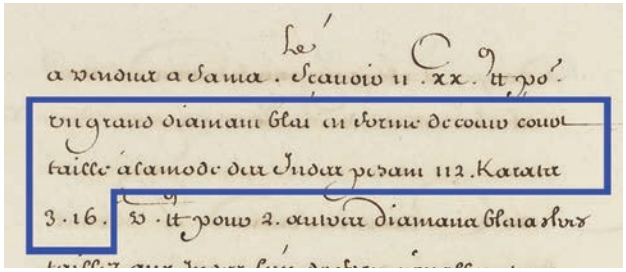


Figure 7: In this record of the 1669 payment to Tavernier for diamonds, the first stone listed is the large blue one. A translation of the outlined text says, "a large blue diamond in the form of a short heart cut in the Indian fashion weighing 112 3/16 carats". Detail of BnF MS Mèlanges de Colbert, Vol. 281, f. 14; © BnF.

The French Blue

The factum refers to the sale of diamonds, including the large blue one, to King Louis XIV, but it does not describe any of them individually or give the date of the sale. Nor does Tavernier say anything about the origin or purchase of the large blue diamond in his *Voyages*. The only possible clue to where he obtained it, of which this author is aware, is the letter of 31 January 1668 from Lannoy in Aleppo to the Earl of Winchilsea in Constantinople (Figure 6). This states that Tavernier, then on the way from Aleppo to Smyrna with the caravan, and travelling with "a Dutch jeweller One Sig[nor] David Bazu of Amsterdam", had purchased a diamond for the huge sum of £7,000 on his trip "at Spahaune [Isfahan] of a Moore man [i.e. an Arab merchant]" (Figure 6; also summarized by Finch, 1913, p. 493). The amount of £7,000 would have been around 70,000 livres. That is exactly the sort of price we might expect him to have paid for the large blue diamond that he sold to Louis XIV for 220,000 livres, according to its record of the payment, which survives today in the Bibliothèque nationale de France (BnF) in Paris among the collection documents of Jean-Baptiste Colbert, French Minister of Finance from 1665 to 1683 (Figure 7; BnF MS Mèlanges de Colbert, Vol. 281, f. 14). Of the other diamonds that he sold the king, the only one that would have shown a good profit on 70,000 livres was the third on his invoice, one of just over 51 old carats that he sold for 180,000 livres. On his invoice to the king he describes this rather lumpy table cut, and several others, as "cut in India", whereas the large blue diamond he describes more enigmatically as "cut in the Indian fashion"—not a description he applied to any of the others (Figure 7). The original invoice was quoted in full by Germain Bapst (1889, 403–405).

The possibility that Tavernier's large blue stone, now the Hope diamond, was the one purchased from an Arab merchant in Iran is intriguing, but it is impossible to corroborate unless further archive documentation comes to light. But if nothing else, the 1668 letter does reinforce the view that despite what Tavernier had told the officials in Erzurum, he took some diamonds with him on his journey home; not all had been sent off by sea.

There have been some suggestions over the years that Tavernier might actually have purchased his large blue diamond on an earlier trip, but it is unlikely that he would tie up significant capital for so long (Morel, 1988, p. 158). That it was one of the diamonds purchased on his sixth trip is also shown by his drawing of the 20 most important stones he sold to the king, which appeared in most editions of his *Voyages* and of which Figure 2 is a detail. In the first edition of his *Voyages*, this drawing is clearly described as the "representation of twenty diamonds which the author sold to the king on the return from his last [i.e. sixth] voyage to India" (translated from Tavernier, 1676b; see p. 336 and adjoining plate). The drawing was probably made around the time of the sale in 1669 and certainly seems to have been in circulation by 1670. When the London diamond merchant John Cholmley wrote to his brother Nathaniel in India in December 1670, he enclosed "the prints for the great Dyamond hee [Tavernier] brought with him the last time from India" (Cholmley and Cholmley, 1664–1693, f. 0147). It seems probable that this refers to the Tavernier drawing.[6]

With Tavernier making no comment about where he purchased the diamond, India would be the natural assumption. The date of the sale can be placed with some certainty to 1669, soon after his return from his final trip and the year he was able to purchase the Seigneury (feudal lordship) of Aubonne near Geneva, an honour granted to him by the king on account of his services. A margin note in the handwritten record of Tavernier's sale of the diamonds to the king—just

[6] The "Representation of a considerable number of excellent Diamonds, sold by one Monsieur Tavernier to his King" was also noted in Anonymous (1674). This author noted that the drawing had come into his hands 'some while since'.

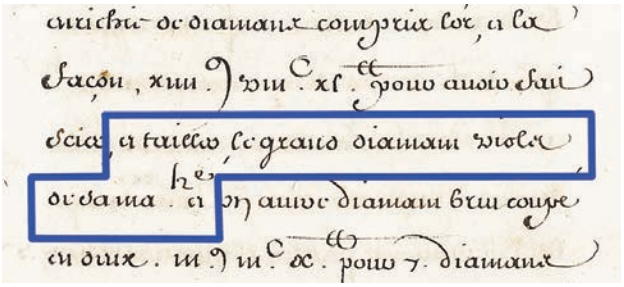


Figure 8: This shows a record of the payment to Jean Pitan for cutting the large blue diamond—"le grand diamant violet de sa ma[jesté]". Detail of BnF MS Mèlanges de Colbert, Vol. 291, f. 341; © BnF.

off to the side of the excerpt in Figure 7—confuses the issue because it places the purchase by the king in the year 1666. However, this annotation is in a later hand, and little reliance should be placed on it. This document, a copy of the invoice from Tavernier, lists all the diamonds with their sizes, prices paid and sometimes a description of their shape or cut. Thus, it provides us with the total price paid: 898,731 livres. The large blue stone is described as "a large blue diamond in the form of a short heart cut in the Indian fashion weighing 112$^{3}/_{16}$ carats" (Figure 7), and its price is given as 220,000 livres. At today's silver prices these would represent about £4.5 million and £1 million, respectively (considerably more if relative gold values are used).

The 1668 letter in Figure 6 also tells us that David Bazu of Amsterdam, then on his way with Tavernier from Aleppo to Smyrna, had "bought a Diamond in India wh[ich] cost 30 thousand Tomans, wh[ich] is a hundred thousand pounds Sterling" (also summarized in Finch, 1913, p. 493). He had raised 15,000 tomans of this by borrowing from Armenians at 46% interest, noting that "Some of wh[ich] Armenians are gone with him to Smyrna to receive their money" (again, see Figure 6). If this report is accurate, this diamond must have been truly exceptional—it was worth more than all the other diamonds that Tavernier sold to Louis XIV added together.

The Colbert documents also record the payment to Jean Pitan for cutting "the large violet diamond of his Majesty" (Figure 8; text translated from BnF MS Mèlanges de Colbert, Vol. 291, f. 341). In 1673 Pitan reduced it into a kite shape that was essentially a brilliant, a very early example of the form. It was listed second and described in an extensive 1691 inventory of the French Crown jewels as a "very large violet diamond very thick, cut in facets in the fashion of two sides, formed as a short heart of eight sides, very lively water and clear" (translated from Bapst, 1889, p. 374). At that time it weighed 67$^{1}/_{8}$ old carats, was set in a pin of gold with enamelled reverse and was estimated to be worth 400,000 livres. The first diamond listed in the inventory was the Sancy—weighing less at 53¾ old carats, but valued more at 600,000 livres. As John Fryer, a surgeon with the East India Company, observed just a few years later, a diamond "of a Blue, Brown, or Yellow Water, is not worth half the Price of a perfect Stone of a White Water" (Fryer, 1698, p. 213). Coloured diamonds at that time were clearly not held in high esteem.

Conclusion

The detail in the factum, along with other archive documents, adds to our understanding of the complexities and perils that impacted the gem trade in the 1600s and on Tavernier in particular. It also shows that even after his five previous trips, Tavernier remained reliant on fellow French merchants to provide the precious objects which he could sell in the East to finance his purchases. In particular, it indicates that his purchase of the French Blue and other diamonds was funded by selling jewelled objects in Persia and India that had been provided by a syndicate of French merchants and investors. The original value of the goods supplied by this syndicate was stated to be 400,000 livres—perhaps 600,000 livres, as noted above. If, as implied by the factum, the diamonds he sold to Louis XIV were all the diamonds he brought back, the profit was some 300,000–500,000 livres less the *avania* costs, Pitan's brokerage or commission fee ('courtage') and perhaps other expenses. That was a huge amount of money, but we do not know how large Tavernier's stakeholding was in this business, although his profit no doubt covered the 60,000 livres he paid for the Seigneury of Aubonne in 1669, when he became Baron Tavernier. The possibility that Tavernier purchased the large blue diamond that was to become the French Blue—eventually the Hope—at Isfahan in Persia from an Arab merchant adds a tantalizing new angle to the history of this celebrated gem, but it is for now just supposition.

References

Anonymous, 1674. A note about some unusual diamonds. *Philosophical Transactions*, **9**(101–111), 26, https://doi.org/10.1098/rstl.1674.0012.

Baghdiantz McCabe I., 2008. *Orientalism in Early Modern France: Eurasian Trade, Exoticism and the Ancien Regime*. Bloomsbury Academic, Oxford, 352 pp.

Ball V., 1889. *Travels in India, by Jean Baptiste Tavernier, Baron of Aubonne, Translated from the Original French Edition of 1676 with a Biographical Sketch of the Author, Notes, Appendices, etc.*, Vol. 2. Macmillan and Co., London, 496 pp.

Bapst G., 1889. *Histoire des Joyaux de la Couronne de France d'Après des Documents Inédits*. Librairie Hachette et Cie, Paris, France, 754 pp.

Cholmley N. and Cholmley J., 1664–1693. Nathaniel Cholmley Accounts and Letter Book, and John Cholmley Letter Book. Among Cholmley & Strickland of Whitby Papers in North Yorkshire County Record Office (Record Reference ZCG), Microfilm MIC 2554.

Corda A., 1902. *Catalogue des Factums et d'Autres Documents Judiciaires Anterieurs à 1790,* Vol. 6. Plon, Paris, France.

Deslandes A.D., 1673. *Les Beautés de la Perse, ou la Description de ce qu'il y a de Plus Curieux dans ce Royaume, Enrichie de la Carte du Pays, & de Plusieurs Estampes Dessinées sur les Lieux*. Gervais Clouzier, Paris, France, 20 pp.

Farges F., Sucher S., Horovitz H. and Fourcault J.-M., 2009. The French Blue and the Hope: New data from the discovery of a historical lead cast. *Gems & Gemology*, **45**(1), 4–19, http://dx.doi.org/10.5741/gems.45.1.4.

Finch A.G., 1913. *Report on the Manuscripts of Allan George Finch, Esq., of Burley-on-the-Hill, Rutland*, Vol. I. His Majesty's Stationery Office, London, 1,026 pp.

Foster W., 1925. *The English Factories in India 1665–1667*. Clarendon Press, Oxford, 354 pp.

Fryer J., 1698. *A New Account of East-India and Persia, in Eight Letters. Being Nine Years Travels*. Ri. Chiswell, London, 499 pp.

Guiffrey J., 1896. *Comptes des Bâtiments du Roi sous le Règne de Louis XIV. Tome Quatrième. Colbert de Villacerf et Jules Hardouin Mansard 1696–1705*. Imprimerie Nationale, Paris, France, 399 pp.

Guiffrey J., 1915. *Artistes Parisiens du XVIe et du XVIIe Siècles; Donations, Contrats de Mariage, Testaments, Inventaires, etc., Tirés des Insinuations du Châtelet de Paris*. Imprimerie Nationale, Paris, France, 414 pp.

Guiffrey J.J., 1872. Testament et inventaire des reliquaires de la reine Anne d'Austriche. In J. Guiffrey, Ed., *Nouvelles Archives de l'Art Français: Recueil de Documents Inédits*. Société de l'Histoire de l'Art Français, Paris, France, 261–274.

Joret P.L.C.R., 1886. *Jean-Baptiste Tavernier, Écuyer, Baron d'Aubonne, Chambellan du Grand Electeur, d'Après des Documents Nouveaux et Inédits*. Pion et Nourrit, Paris, France, 413 pp.

Kunz G.F., 1917. *Rings for the Finger, from the Earliest Known Times, to the Present, with Full Descriptions of the Origin, Early Making, Materials, the Archaeology, History, for Affection, for Love, for Engagement, for Wedding, Commemorative, Mourning, etc*. J. B. Lippincott Co., Philadelphia, Pennsylvania, USA, and London, 536 pp.

Malecka A., 2016. The Great Mughal and the Orlov: One and the same diamond? *Journal of Gemmology*, **35**(1), 56–63, http://dx.doi.org/10.15506/JoG.2016.35.1.56.

Maze-Sencier A., 1885. *Le Livre des Collectionneurs 1885*. Librairie Renouard, Paris, France, 902 pp.

Morel B., 1988. *The French Crown Jewels: The Objects of the Coronations of the Kings and Queens of France, Followed by a History of the French Crown Jewels from François I up to the Present Time*. Fonds Mercator, Antwerp, Belgium, 417 pp.

Ogden J., in prep. *Out of the Blue: The Hope Diamond in London*. [New research into the Hope in London during 1812–1832.]

Tavernier J.-B., 1676a. *Les Six Voyages de Jean Baptiste Tavernier, Ecuyer Baron d'Aubonne, qu'il a fait en Turquie, en Perse, et aux Indes (...)*, Vol. 1. Gervais Clouzier et Claude Barbin, Paris, France, 702 pp.

Tavernier J.-B., 1676b. *Les Six Voyages de Jean Baptiste Tavernier, Ecuyer Baron d'Aubonne, qu'il a fait en Turquie, en Perse, et aux Indes (...)*, Vol. 2. Gervais Clouzier et Claude Barbin, Paris, France, 527 pp.

Tavernier J.-B., 1678. *Les Six Voyages de Tavernier en Turquie, en Perse et aux Indes (...)*, Vol. 1. J. van Someren, Amsterdam, The Netherlands, 792 pp.

Tavernier J.-B., 1713. *Les Six Voyages de Jean Baptiste Tavernier, Ecuyer Baron d'Aubonne, qu'il a fait en Turquie, en Perse, et aux Indes (...),* Vol. 1. Pierre Ribou, Paris, France, 501 pp.

van der Cruysse D., 1998. *Chardin le Persan*. Fayard, Paris, France, 568 pp.

Wise R.W., 2009. *The French Blue*. Brunswick House Press, Lenox, Massachusetts, USA, 589 pp.

Yarshater E., Ed., 1996. *Encyclopaedia Iranica*. Vol. VII, Fasc. 2, 127–128, www.iranicaonline.org/articles/daulier-deslandes (accessed 17 July 2017).

The Author

Dr Jack M. Ogden FGA
Striptwist Ltd., 55 Florin Court,
Charterhouse Square, London EC1M 6EU
E-mail: jack@striptwist.com

PAUL WILD

EXCELLENCE IN
GEMSTONE INNOVATION

MORGANITE

Loved for its subtle colours and dazzling brilliance,
morganite is known as a symbol of eternal love and affection.

MINING • CUTTING • CREATION

PAUL WILD OHG • AUF DER LAY 2 • 55743 KIRSCHWEILER • GERMANY
T: +49.(0)67 81.93 43-0 • F: +49.(0)67 81.93 43-43 • E-MAIL: INFO@PAUL-WILD.DE • WWW.PAUL-WILD.DE

VISIT US AT

The Munich Show
Mineralientage München
World of Minerals, Gems, Jewellery & Fossils

THE Gemworld
MUNICH – Brilliant Creators

MUNICH SHOW BOOTH NO. B6. 431
OCTOBER 27 – 29, 2017

Counterfeiting Gems in the 16th Century: Giovan Battista Della Porta on Glass 'Gem' Making

Annibale Mottana

Glass simulants of gemstones were long produced with little or no prejudice against their use. However, their making is poorly documented due to the secretiveness imposed by glassmaking guilds, despite the presence of some late medieval manuscripts that have recently appeared. They reveal glass composition and fabrication recipes in accordance with the trend launched by 16th-century 'writers of secrets', who revealed technological developments to the public. Giovan Battista Della Porta was the first to publish in print recipes for making glass simulants of gems, in addition to information on the enhancement of natural gem materials. His *Magiae Naturalis* (1558), originally written in Latin to appeal to upper-class amateurs, enjoyed vernacular translations in several European languages. The second, vastly improved edition (Della Porta, 1589), again in Latin, did not enjoy the same popularity—possibly because the first one had saturated the market or, alternatively, because the Catholic Church had enforced rules that made alchemy a forbidden practice, and even the title *Magiae* became suspect. In spite of such restrictions, both editions contributed to making glass 'gems' popular decorative objects and to increasing their trade. During Baroque times, interest in glass 'gem' making reached an acme, and Della Porta's treatise was even translated into English in 1658.

The Journal of Gemmology, **35**(7), 2017, pp. 652–666, http://dx.doi.org/10.15506/JoG.2017.35.7.652

Introduction

Opening the 37th book of his *Naturalis Historia* (Natural History), Pliny the Elder stated in the 1st century AD that people admire gemstones and seek after them more passionately than anything else: "*...gemmae supersunt et in artum coacta rerum naturae maiestas, multis nulla parte mirabilior*" (Corso et al., 1988, 37.1). However, they also may make them factitiously, and "no kind of fraud is practised by which larger profits are made" ("*neque enim est ulla fraus vitae lucrosior*"; Corso et al., 1988, 37.197). With such concise but highly poignant words, Pliny summarized almost two millennia of vitreous paste and glassmaking with the goal of simulating gemstones, starting from Mesopotamian and Egyptian times to his own era. He

did not refrain from stressing the negative implications of such activities, and concluded with a statement that he would avoid describing the full glass-making methodology. To further stress his disdain, he pointed out that Romans used such glass gem simulants only for the rings of lowest-class people: "*fit et ipsum e creta admixtis vitreis gemmis e volgi anulis*" (Corso et al., 1988, 35.48).[1] Yet the majority opinion was never as severe as Pliny's, as long as the simulants possessed properties that would make them attractive as 'gems'. High-quality natural stones occur too rarely and are thus too valuable as not to induce unscrupulous dealers from faking them. While the most common fraud was (and perhaps still is) swindling the customer with an imitation composed of a natural stone but of a cheaper type, gem simulants were also commonly made from glass. Even the elite would tolerate the manufacture of glass gem imitations as being a sound practice; indeed, there was a widespread understanding among cultivated people that producing something which had properties either very close or at times even superseding the natural version was a triumph for technology. Nevertheless, such activities were mostly severely repressed, exposing the forger to a penalty that could bring him as far as to death.[2]

The state of gem trading through Roman times and the Middle Ages has been widely studied and will not be repeated here (see, e.g., Zwierlein-Diehl, 2007). By contrast, glass 'gems' (e.g. Figure 1) have been the subjects of lesser studies, although they too have a long tradition with roots in late Roman imperial times. The availability of the information related to such glass objects has recently increased significantly due to thorough investigations of miscellaneous medieval codices preserved in library archives (e.g. Beretta, 2004, 2009; Cannella, 2006; Tosatti, 2006; Baroni et al., 2013). This was particularly the case for the 15th and 16th centuries, when Europe left the Dark Ages and entered Humanism and the Renaissance.

Renaissance scholars enjoyed wearing gemstones just as much as any other men of their time, despite being aware that they could be either enhanced or counterfeited. They could draw such information from sources spanning from late antiquity to the late Middle Ages.[3] However, only one author gave reliable information on glass gem simulants made in Roman times. This was Heraclius, who wrote when late Greco-Roman techniques were still alive. Heraclius' treatise *De Coloribus et Artibus Romanorum* consists of two parts. The first two books, which are in verse, were written in Italy during the 8th century, while the third is a prose paraphrase of the first two with many added explanations, written in northern France by a pseudo-Heraclius of the 12th century (Garzya Romano, 1996, p. xxi; Tosatti,

Figure 1: These 'emerald' and 'amethyst' glass eardrops in the Renaissance style were presumably assembled in the second half of the 16th century. The mounting is partially silvered copper. The green glass 'gems' are 6 mm in diameter. Courtesy of a private collection near Rome, Italy; photo by Carlotta Cardana.

[1] Properly, this refers to an artificial white (candidum) pigment used to colour plaster and added with ground glass splinters to obtain pleasant sparkling effects.

[2] In 1488, a forger named Zocolino, who had cheated the king of England by selling him a doublet at a very high price, was submitted by the duke of Milan to *debito supplicio* (i.e. put to death; Cardano, 1560, p. 642). However, later the same year, the duke had to relax his hold, as he realized that his revenues included substantial excise taxes from dealers of *contrafacte* (counterfeit) gems (Venturelli, 1996, p. 53).

[3] The oldest Latin recipes for making coloured glass derive from Greek and Oriental sources that date back to Pliny, or even older. They are reported in *Mappae Clavicula* (also known as *Compositiones lucentes*), a compilation resulting from an intricate process of addition and accumulation with contributions from various sources which developed from the 8th to the 12th centuries AD at various monastic sites (Baroni et al., 2013, pp. 27–35).

2006, pp. 37–46). In verse I.13 (i.e. in the oldest section), Heraclius recommends carving a hole in a lump of clay with the shape of the gemstone one wants to imitate, and filling it with ground glass of the appropriate colour. Then the clay block is fired so that the glass powder melts and completely fills the pre-shaped hole, thus obtaining a defect-free glass 'gem' of the right size and shape (Garzya Romano, 1996, pp. 5–63). Such a production technique continued to be used in many scattered places.[4] Implicitly, Heraclius points out that the most important aspects of a gemstone's appearance are its shape and colour; these two properties are directly determined by nature but can be duplicated by art. Therefore, the technical challenges to those creating gem simulants shifted from imitating gems[5] to glassmaking activities.

At that time, one could take advantage of various sources on glassmaking (see works by Beretta, 2004, 2009; Tosatti, 2006; Baroni et al., 2013). However, only one describes the technology in full: "*Le traité de Théophile reste à bien des regards atypique*" (Boulanger, 2004, p. 14). This unique source is the celebrated *De Diversis Artibus* written by 'Theophilus presbyter'.[6] His book is rooted in long tradition and its content ranges from very basic data on how to build a kiln to some final touches such as repairing broken vases. In between, Theophilus specifies how to make vitreous gems and polish them so that they shine. He instructs that 'gem' glass will become as shiny as rock crystal after rubbing and polishing ("*Lapides quoque eodem modo vitrei, quo cristallum, fricantur et poliuntur*"; Caffaro, 2000, Book III, Chapter 95, p. 416) using *tenax*, a concoction that was nothing more than brick powder mixed with pitch and wax.[7]

Three centuries later, in the technical environment preceding the Renaissance, a few new treatises appeared that referred to artificial 'gems' made of coloured glass according to a preparation method essentially following Theophilus' one. The best-known text is by Jean d'Outremeuse[8], written ca. 1390–1400 to inform high-class people of the Bourgogne court, but he also included what he had learned from old masters and had used successfully for a long time. This is why he wrote in vernacular French and did not spare practical details, mentioning both the good results and the bad ones.

In fact, all through the late Middle Ages glass had been used occasionally to simulate gems, but it was mostly in the form of polished shards (scrap from the window panes decorating cathedrals) and relics picked up among the debris of Roman towns (including mosaic *tesserae*) or in buried treasures. The glass 'gems' thus obtained did not have the required shape, but they had the appropriate colours, so that polishing, which was almost the only enhancement applied, made them bright and lustrous. Most of the genuine gemstones during this time consisted of crude 'cabochons', as the simplest cleavage cuts were then at their beginning.[9]

Short descriptions of glassmaking, mostly dealing with kiln operations but also with scattered information on the possibility of producing glass 'gems', are found in metallurgical treatises by Biringuccio[10] and Agricola.[11] They dealt with glass near the end of their descriptions of ore-dressing methods to extract met-

[4] It was still described in the *Sedacina*, an alchemical treaty by the Catalan monk Guillem Sedacer, who died ca. 1382–1383. A translation with extensive comments was given by Barthélemy (2002).

[5] A prominent example of imitating gems occurred in 1347, when during the manufacture of the Bohemian royal crown the artist inserted a rubellite to imitate the largest ruby.

[6] Possibly the pen name of the Benedictine monk Roger from Helmarshausen, who also operated as a goldsmith ca. 1140–1160 in the Cologne and Liège regions (Tosatti, 2006, p. 77), located in present-day Germany and Belgium.

[7] The texts mentioned in this and the two previous paragraphs represent the antigraphs for the entire science of glassmaking that developed in Europe during the early Middle Ages. Such sources might appear to be few, but consider that there were scattered recipes in even older books (e.g. *Mappae Clavicula*; see footnote 3). These recipes were repeatedly copied in more than 400 manuscripts, although in bits and pieces (Boulanger, 2004, p. 12; Cannella, 2006, pp. 72–103; Baroni et al., 2013, p. 134).

[8] Born 1338 in Liège, he was an officer in the court of the dukes of Bourgogne. He wrote *Trésorier de philosophie naturelle des pierres précieuses*, the fourth book of which is dedicated entirely to gems, both natural and fictitious (Cannella, 2006). He died in Liège in 1400.

[9] The first written information on cut diamonds ('rose cuts') dates to a note in the 1413 inventory of Jean de Berry, the brother of the king of France. A late example of this kind of enhancement is the Lyte Jewel, in which four large 'Burgundian-style' rose-cut diamonds surround the IR monogram (for Iacobus Rex) of King James Stuart VI of Scotland, made probably 1605–1610 after his accession as King James I of England and Ireland. However, shaping glass by grinding with emery dust and selling it as diamond was practised long before.

Figure 2: This portrait of Giovan Battista Della Porta at the age of 50 is from the title plate of the 1589 edition of his Magiae Naturalis.

als, because glass (which melts under fire) was considered by both to be a transparent and fragile kind of metal. Additional information on glass 'gems' appears in Cardano's *De Subtilitate* (1560)[12], whose entire Book VII concerns minerals, rocks and gem materials. At the end of Book VII, Cardano even proposed a practical method to distinguish a true gem from a glass one by using their reflective properties.

It was not until the full development of the Renaissance, in the mid-1500s, that a writer purposely gave the tedious details of the entire process of glass 'gem' making.[13] This author was Giovan Battista Della Porta.[14]

Della Porta's Contribution to Disclosing Gem Counterfeiting

Della Porta (1535–1615; Figure 2) was a Neapolitan polymath and a major representative of the 'writers of secrets'—those who, from around 1550 onward, made agreements with greedy printers to make public numerous practices and techniques long since kept secret by the artisan guilds and alchemists of the Middle Ages. Most of them wrote in Italian, as their target was the largest possible number of common people across Italy[15], but their teachings spread through translations into most European vernacular languages. Only a small number of them, including Della Porta, chose to write and print their books in Latin.[16] These authors had as their target not only the Italian cultivated class, which they considered to be fairly well informed on matters of natural science, but also well-to-do people from other countries, since Latin was the *lingua franca* of Europe.

---

[10] *De la Pirotechnia* (On the Firing Art, 1540) by Vannoccio Biringuccio (1480–1537), a mine engineer from Siena, Italy, is the first book on the matter in Italian and the first treatise published about the fire treatment of metal-bearing ores. It has only a few pages on gems. Moreover, *De la Pirotechnia* was the first Renaissance book to provide printed information on glass imitations of gem materials.

[11] Georg Pawer or Bauer (1499–1554; a German physician and mining scientist whose name was Latinised as Agricola) wrote in Latin and published his classification of minerals and rocks in *De Natura Fossilium* (On the Nature of Minerals; 1546), after which he prepared his major treatise, *De Re Metallica* (On Mining; 1556), in which he established mining and metallurgy on a solid scientific basis.

[12] Girolamo Cardano (1501–1576) was a polymath: inventor, mathematician, philosopher and astrologist. He wrote in Latin and first published *De Subtilitate* (On Subtlety) in 1550, almost doubled its size in 1554, and further enlarged it in 1560 (Cardano, 1560). His five-fold division of the mineral world was clearly influenced by Agricola, but he also introduced novel concepts and ideas.

[13] The thorough review of the Venetian Renaissance glass-making techniques and innovations by Marco Verità states precisely (and unfortunately) that "lead silica glass for the production of imitation gemstones, (is) not discussed in this paper" (Verità, 2014, p. 53, note 1).

[14] Della Porta is the name and surname given to him in the National Edition of all his works (currently in preparation). In the past, a variety of names and surnames have been used for him: Giambattista Porta was most common, and is reflected in the English translation as John Baptist(a) Porta.

[15] Their actual target was the *paterfamilias* (literally, 'family father'), so that he could be educated enough to face all the problems arising when managing his household. Indeed, most 'secrets' concerned how to cure sickness by concocting herbal medicines and also dealt with other health issues. Such works enjoyed almost numberless printings. The most famous one, written originally by a 'reverendo donno Alessio Piemontese' (pen name of Girolamo Ruscelli, 1518–1566), was published only three years before Della Porta's book and reprinted more than a hundred times (Eamon, 1984; Eamon, 1994, pp. 352–417).

[16] Della Porta was also a prolific author in Italian. He wrote poems, dramas and comedies, besides translating his own Latin books (Clubb, 1965).

Della Porta disclosed recipes that were mostly related to artisans' practical arts and experiments having affinity with alchemy.[17] Spreading information of this sort (which was not entirely new, as it was already available in the closed circles of craftsmen and of members of alchemical unions) contributed to the general development of science, because carrying out tests and experiments by hand was no longer considered a demeaning practice for gentlemen and other open-minded seekers of new information. Della Porta's most significant work was his *Magiae Naturalis* (Natural Magic, 1558). He translated it into Italian, using a pen name to avoid losing authority (since it was inconceivable at the time for a Neapolitan nobleman to write about scientific topics in a language other than Latin), and within a century of its original publication there were 58 printings: 16 in the Latin original, 25 in French, 14 in Italian, two in Dutch and one in German (Balbiani, 1999, p. 280; see also Orlandi, 2013).[18]

Della Porta never stated where he drew his 'secrets' from, but it is likely that he gathered most of them from craftsmen who did not refrain from sharing their practical knowledge with a young nobleman[19] who showed as much an appreciation for their empirical approach as he did for his own scholarly readings. Indeed, Della Porta's *modus operandi* was well known. For every secret he learned, he first checked for other possible sources by reading books by old masters, after which he tested the results by performing experiments in his home laboratory. He also took discreet advantage of the guidance from such alchemists as Leonardo Fioravanti and Domenico Pizzimenti when they stayed in Naples, as well as from clever local apothecaries such as Ferrante Imperato.[20]

Glassmaking was one process that could be performed with a rather simple apparatus (a kiln). Ordinary cloudy glass was widely available and, when broken, was often repaired by re-melting. By contrast, the preparation of certain special glasses (e.g. coloured ones suitable for simulating gems) involved knowledge that had been an artisan secret until it was released by Della Porta in his original 1558 edition of *Magiae Naturalis*. He also described glassmaking and glass 'gems' in a later edition that he published in 1589.

Magiae Naturalis *Edition of 1558*

In Book III of *Magiae Naturalis*, 1558, Della Porta wrote three chapters (16–18, pp. 136–140) related to glass that followed the descriptions of other chemical operations[21], such as sublimation, distillation, purification and melting, plus miscellaneous recipes on how to repair broken corals, pearls and gemstones. Then he added recipes on how to clean these gems using etching liquids and organic additives. Clearly, what he delivered as a 'secret' was a mixture of alchemical and artisanal craft. As for gems, it is worth stressing that he did not care to deal with how to make ordinary glass, but he proceeded directly to release the technicalities on how to prepare the special colourless glass that would be suitable for making coloured glass, so as to imitate gem materials.[22] In Chapter 16 he summarized the preliminaries, recommending the use of very finely ground silica mixed with fluxes such as tartar juice, salt or dried egg white[23], or even

---

[17] Alchemy—that is, the process by which man tried to reproduce natural wealth—was officially repressed (particularly by the church), but widely tolerated and even supported by some of the highest authorities, clerical as well as lay, at least as long it would not appear that their alchemists were incapable of reaching satisfactory results (Pereira, 2006; Principe, 2013).

[18] Della Porta (1589, Foreword) mentions a Spanish translation and another in Arabic, but neither one appeared in Balbiani's (1999) survey of the books preserved in European libraries, or in Orlandi's (2013) commented list.

[19] In the 'Praefatio ad lectores' (foreword to the readers) of his 1589 *Magiae Naturalis*, Della Porta claims that he wrote the original 1558 version when he was a youth, "*vix tum quintum & decimum annum agente*" (only 15 years old). However, this should be interpreted as the age when he started compiling information, since the edition was actually published when he was 23 years old.

[20] Della Porta's research practices as a youth were reported by Neapolitan writer Pompeo Sarnelli (1649–1724), who wrote Della Porta's biography (Sarnelli, 1677) and translated some of his Latin works to Italian. For additional information, see Eamon (1984, 1994), Fulco (1987, p. 113) and Perfetti (1997, pp. 173–176).

[21] "*Experimenta (…) quae vulgus vocat chymica*" (Proœmium section of Book III). In fact, most of the recipes were of the alchemical type, but even at this early date Della Porta avoided mentioning alchemy openly.

[22] He called it "*pro adulterandis gemmis vitrum fictitium*" (Chapter 16, p. 136).

[23] "*Multa ovorum albumina simul exagitabis (…), ac diu coqui sinas, detrahe, & per multos dies resiccare curabis (…) ut in vitri duritiem transeat*" (Chapter 16, p. 136). To the present author's knowledge, nobody else specified this flux material, nor did Della Porta mention it again except in the Italian translation of his book, which he released in 1560.

ash. In Chapter 17 he made a digression aimed at explaining how natural gem materials acquire their colours and shifted to recipes on enhancing colour by using various natural pigments ('black lead' [i.e. galena], orpiment, curcuma root, iron filings, etc.), by slowly diffusing them from the surface to the bulk of the gem under the slow action of fire. Then he returned to recipes intended to add weight to glass without modifying its hardness. In particular, he recommended adding lead to the already prepared colourless glass only while it melts, so as to increase its brilliance and weight. After another digression, he ended Chapter 18 with a series of explanations on how to obtain attractive 'gem' glass by carefully mixing colourless glass with pigments while it melts (the colouring agents being burnt copper, minium, tin and 'white lead'). The resulting gem simulants would resemble diamond, emerald, sapphire, pyrope, topaz, olivine, chalcedony, etc. The final recommendation was that the crucible containing the molten mix should be kept under close supervision, as excess heating would make the colour fade away.

Della Porta's description flowed rapidly, with little care for detail, as if the reader already might be familiar with the subject. Most likely, these few chapters are a summary of alchemical recipes that he had learned quickly and not investigated sufficiently. Nevertheless, the subject was such as to arouse a wide interest, so that the entire text was promptly translated into Italian, Spanish and French, and some years later, Dutch and German.[24] Moreover, the original Latin edition was widely read and taken into account in England, where the Elizabethan court was just as interested in jewels as any other royal court in Europe.[25]

Magiae Naturalis *Edition of 1589*

In 1589, Della Porta, by now a mature scientist, reworked his *Magiae Naturalis*, expanding it from four books to 20 (Figure 3). This overall increase transformed his work into a very curious treatise, comprising a mixture of useful recipes, half-told half-truths, observations and experiments by both the author and his fellow investigators[26], as well as quotations from classical writers who, however, were often in disagreement. The in-folio sized text dealing with gems grew from five ordinary pages to a complete Book VI encompassing 10 dense pages (117–126) and distributed over 13 chapters.[27] Actually, only Chapters 1 to 5 concern glass gem simulants (pp. 118–120), because Chapter 6 (p. 121) is on abstruse alchemical matters[28] and Chapters 7 to 13 (pp. 121–126) mostly concern the enhancement of gem materials. Everything is described in much greater detail than in the previous edition. Although the approach to the subject did not change substantially, a systematic decrease in fancy alchemical recipes[29] and a corresponding increase in technology are immediately appar-

[24] "*Italicam nempe, Gallicam, Hispanicam, & Arabicam*" (1589, Foreword). As for the translation into Arabic, there is no known trace of it (Balbiani, 1999, pp. 280–281).

[25] The most influential divulger of gemstone enhancement techniques during Elizabethan times was Hugh Plat (1552–1608), himself a 'writer of secrets'. His book *The Jewell House of Art and Nature* (1594) draws information of all sorts from two books by Alessio Piemontese (1555, 1567) as well as from Della Porta, including some on glass 'gems'. However, for the latter, he copied from the 1589 edition of *Magiae Naturalis* rather than the 1558 one.

[26] Della Porta twice organized in Naples groups of researchers on natural matters who formed academies called *Accademia dei Secreti* (secret) and *Accademia degli Otiosi* (lazy), the latter meaning that they had time to spend enjoying apparently useless experiments. One after the other, both academies were dissolved (in 1580 and 1584) by the Spanish authorities running Naples at that time, because their founder had been admonished by Pope Gregory XIII (Sarnelli, 1677; Valente, 1999). In 1610 Della Porta joined the *Accademia dei Lincei*, founded in 1604 by Federico Cesi in Rome, as its fifth member and the leader-to-be of a section to be established in Naples (Carutti, 1883, p. 24; Paolella, 2002, p. 514).

[27] The title of Book VI is "*Gemmas adulterare nititur*" (p. 117), which translates as "one makes efforts to adulterate gems". Therefore, the full aim was not only counterfeiting gemstones, but enhancing them too.

[28] Not only does he refer (p. 121) to a recipe by which rock crystal can be made using the decapitated head of a rooster with its neck and comb ("*crista galli capiatur, & intercisa galea, caput, & collum seruato…*"), but he also proposes a riddle regarding the philosopher's stone ("*philosophorum lapidem inde habeas*"). Thus, Price (1958, p. 2) was not entirely correct when, in editing the reprint of the English translation on the occasion of the book's 300-year anniversary, he wrote that "the full and expanded version of his book…includes much new material of a real scientific character and omits from the 1558 version some of the more blatant marvels."

[29] The exception is the abstruse 6th chapter; it comes as a real surprise and interrupts the regular flow of technical descriptions.

ent. The word *alchemy* is nowhere mentioned[30], and yet several alchemical practices survived, although disguised and spread throughout the text so as not to be conspicuous.[31]

Fluxes: After the introduction ('proœmium') to Book VI (p. 117), where Pliny's words are recalled—but his advice not to enter deeply into such a shameful practice is ignored—Della Porta began Chapter 1 (p. 118) with a careful description of the preparation of reagents for glass gem making, beginning with two fluxes. For the first one, the ashes of *kali herba*[32] are burned and then boiled with water for four hours in a copper cauldron, the ratio being one pound (0.45 kg) of ash to one firkin (4.9 L) of water. When the liquid decreases to one-third, the cauldron is withdrawn from the fire and the liquid is allowed to settle for 12 hours to become clear; then it is filtered through cloth and placed aside. This process is repeated three times and finally the concentrated liquid is placed in an earthen vase, warmed again and condensed first to a thick liquid and then to a dry salt, which has to be skimmed with an iron spoon. The output from five pounds of 'herb' was said to be one pound of pure salt; too much, possibly, such that this result implies some contamination by unknown impurities.

The second flux to be prepared is tartar ("*tartarum vocatur vulgò*"; p. 118). One collects old wine dregs and dries them in a reverberant hot oven. They will whiten and must be turned over using iron tongs until they stop fuming and the entire mass is calcined. The broken bits are quenched in water and ground to a powder, which is settled in water in a large jar until it is clear; then it is filtered through felt into another jar while the first jar is filled again with water and the operation is repeated three or four times. All the filtered waters are then transferred to a glass vase, which is warmed with charcoal until all the water evaporates and the dry salt deposits. Such a salt must be kept in a dry place; otherwise it absorbs moisture and alters into a kind of oil.

Silica Raw Material and Glassmaking: Della Porta begins Chapter 2 (p. 118) by recalling that silica is the main constituent of any glass gem. The raw silica can be either crystal or flint, or even round pebbles, the best of which are said to be those gathered from the river Thames.[33] Cobbles are first set into a reverberant oven where the flame is most intense. When red hot, they are taken out, fractured by dropping them into water, dried and then ground with a bronze mortar until reduced to a light powder. The powder is transferred to a large basin full of water, which is shaken by hand so that the finest part will float and can be transferred to another basin. The coarser part is shaken repeatedly until the bottom portion looks like a mud. This will contain any dirt and, in particular, the metal particles scraped off the mortar and the mill; these would contaminate the gem simulant and should be washed away. The finest powder is skimmed off by a spoon and set into clear water until it dries completely and can be stored away.

At this point, Della Porta proceeds to teach the reader how to "cook" *pastilli* (pastilles): "*His peractis docere decet quomodo pastilli coquantur*"

[30] Because of the word *Magiae* in the title and of some contents of the book that could be interpreted as affected by alchemy, in 1574 and 1580 Della Porta was summoned to Rome for questioning, his books were suspended *donec expurgantur* (till being cleared from what was wrong) and he himself was warned not to publish anything before receiving clearance by church authorities. He avoided a heavier punishment only because he could convince the Inquisition that his teaching contained no trace of the errors and superstitions inherent in *magia nera* (black magic), i.e. inspired by the devil (cf. Amabile, 1892; Valente, 1999). However, despite its preliminary expurgation, the 1589 edition of *Magiae Naturalis* was on the 1593 *Index Librorum Prohibitorum* (Index of Prohibited Books) at the suggestion of the French philosopher Jean Bodin (1530–1596).

[31] A full translation into English of the 1589 edition appeared in 1658 under the title *Natural Magick*. It is now freely available online at https://archive.org/details/naturalmagick00port. Here the present author attempts to give a summary translation that goes directly to the point and disregards the useless digressions and fancy descriptions so common in many texts of that era.

[32] "*Kali herbam in cinerem versam, sodam appellat vulgus*" (p. 118). The herb is likely *Salsola kali L.*, which is a common bush along the Italian coastline, particularly from Venice to Trieste, where long since it had been picked up to supply Murano glass works. Its ashes are rich in potassium carbonate, indistinguishable from sodium carbonate ("soda" *sensu stricto*) at that time.

[33] Stated as "*rotundi fluminum calculi, principem enim locum tenent, qui ad Temesim amnem albi, perspicui, ovi magnitudine*", translated as "those are the best which are taken up by the river Thames, white, clear, and of the bigness of an egge". This translation appeared in the 1658 English edition (p. 179) of Della Porta's 1589 *Magiae Naturalis*. The present author could not find any reference to the river Thames in Biringuccio's or Agricola's treatises, but the Latin name of the river occurs in several medieval church documents (e.g. Guardo, 2008).

Figure 3: The title page of Magiae Naturalis Libri XX*, 1589 edition, shows the titles of all 20 books composing this volume.*

(p. 118). The ingredients are tartar, soda and silica in the ratio 5:5:20. They are mixed very well, and wetted to make a paste lump, which is sun-dried first and then set in a reverberant oven for six hours while increasing the heat slowly until the lump becomes red hot. However, it should not be allowed to melt, and therefore it is recommended not to use bellows. After such pastilles cool down, they should be so hard as almost not to break under a hammer.

After describing the preparation of the main mixture, Della Porta takes great pains to describe in detail the furnace and the instruments to be used (Chapter 3). A furnace for making gem simulants (p. 119) is similar to the ordinary one used by glassmakers, but smaller. It is 2.4 m high and narrow on top but with a vent 30 cm wide, and two chambers. The lower chamber has walls about 37 cm thick and one small opening to add wood, while the upper chamber has several large openings on every wall to let workers insert the open crucibles[34], which should lay on top of the furnace divide. Slow heating under continuous control requires six hours to reach

[34] To properly describe these crucibles, Della Porta used two words—*catini* (Latin) and *padella* (Italian)—to make it clear that they must be low and wide (basins). He also specifies that they be made with clay from Valencia (Spain), which stands up best to a hot fire.

the required temperature. Then the pastilles, which were previously crushed to pieces the size of a walnut, are set one by one into the crucibles using iron tongs. Several pastilles are added to each crucible. When they reach the melting temperature, they release air and tend to swell, and the worker must prick them with iron forks to deflate them and prevent the glass from flowing over the rim. One day of work will fill each crucible with molten glass, which must be sampled and tested for brightness and transparency. When the glass is ready, the crucibles are first extracted and cooled in water, and then the glass is brought back to the furnace for two days, so that the final glass becomes free of air bubbles generated by the fluxes. As a further precaution, at the end certain artisans add some 'white lead'[35], which first turns to red and then, when fully dissolved, makes the glass become colourless and transparent. The bubble-free and transparent glass is now ready to acquire the various colours.

Pigment Preparation and the Glass Coloration Process: Chapter 4 teaches how to prepare pigments, taking advantage of the two idle days during which the colourless glass[36] matures in the furnace (p. 119). The first colour to be made is orange-red (*crocus*[37]), obtained from iron filings washed in a large basin to skim off any intermingled wood shavings coming from the bottom chamber. The iron filings are first dried and then transferred into a large glazed jar that is filled with strong vinegar, in the ratio of three or four pounds of filings to three or four firkins of vinegar.[38] The chemical reaction should go on for three or four weeks, and every day the mass should be stirred seven or eight times using an iron rod. After the mixture has settled somewhat, the supernatant liquid is transferred to a pan, and fresh vinegar is added to the jar to renew the reaction as many times as needed to consume all of the iron-rich mud-like deposit. The solution in the pan is set in the warm side of the furnace and evaporated until it becomes a dry dust: this is the *crocus*. It may also be prepared by scraping filings from red-hot iron nails and quenching them into a pot of vinegar, and by repeating this operation three or four times, after which the vinegar is evaporated and the *crocus* resting at the bottom of the pot is collected.

A blue pigment is made by converting *zaphara*[39] into powder, by using a case (probably made of clay) measuring one foot wide that is built over a small window on a side of the furnace. The fire enters through a hole and opposite it is another hole with a shutter, which is just large enough for the hand of the artisan. The case containing the *zaphara* is set inside and the shutter closed for six hours, after which it is taken out and quenched in water so that it breaks apart. Finally the *zaphara* is dried and milled to a very fine powder.

A pigment called *aes* was used for making aquamarine and olivine imitations, and it was derived from burning copper. The copper is first filed smooth and then mixed with salt in a ceramic pot and exposed to fire for a full day while being turned over every two or three hours with an iron rod so that it is strongly heated throughout. It is then removed from the furnace and divided into two portions: one is stored away, and the other is mixed with salt again and exposed to fire for half a day, and so on for three or four times to be sure that all is completely changed into powder. The fire must be hot but the copper should not be allowed to melt; it should only show a black crust.

---

[35] "*In catinos tantundem cerussae addunt, nam rubescit illico, max liquescit cum vitro, & perspicuum redditur*" (p. 119). It was known from Roman times that the addition of lead would produce a transparent glass. Della Porta's innovation was to specify when to add lead and in what form. Indeed, white lead (*cerussa*) is $(Pb[CO_3])_2{\cdot}Pb(OH)_2$. At high temperature, it first turns into red lead Pb_3O_4 (minium), which then dissolves completely into the melt, increasing its density and refractive index. The cerussa was produced artificially by exposing metallic lead in a closed pot to fumes arising from warm vinegar.

[36] Here he calls such a glass *crystallum*, a name then in use in Venice (Verità, 2014, p. 57, Figure 1).

[37] Properly, the colour of *Crocus sativus L.* (i.e. saffron), a common flower in Italy's Apennine Mountains.

[38] In modern terms, ~2 kg of metallic iron should be reacted with ~160 L of vinegar.

[39] The *zaphara*, also called *zaphara figlinorum* (p. 120)—in English *zaffer* or *zaffre*—was a deep blue pigment obtained by sublimation of the fumes arising while roasting silver- and cobalt-bearing lead sulphide ores to extract silver in the Saxon-Bohemian ore district. It consists of impure, partly amorphous varieties of either cobalt oxide Co_3O_4 or cobalt arsenate $Co_3[AsO_4]_2$. It was imported to Italy as a raw powder, which, when wetted, was appropriate to paint pottery and glaze it to a vitreous coating during the final firing.

Table I: Recipes for making glass 'gems', from the 1589 edition of Magiae Naturalis.

Glass 'gem'	Pigment(s)	Ratio pigment : glass*	Experimental details
Sapphirus (sapphire)	*Zaphara* (zaffre: impure cobalt)	2 *dragma* : 1 *libra*	6 hours' duration
Aqua marina (aquamarine)	*Aes* (burnt copper)	Indifferent (best 1 *dragma* : 1 *libra*)	None given
Amethystinus (amethyst)	*Manganese* (manganese oxide)	1 *dragma* : 1 *libra*	None given
Topacium (topaz)	*Crocus* + *minium* (saffron + 'red lead')	3 *uncia* 'red lead' + ¼ *uncia* saffron : 1 *libra*	Add 'red lead' first
Chrysolitus (chrysolite or olivine)	*Aes* (burnt copper)	*Pulvisculum* (dusting)	Use the topaz-type glass instead of colourless glass
Smaragdum (emerald)	*Crocus* (saffron)	Add ¼ *uncia* to the aquamarine glass and let it season for 6 hours, then add ⅛ uncia and season, and so on until the desired colour is attained.	

* In Renaissance Naples, *dragma* was a weighing unit for drugstores equivalent to 2.64 g, and *libra* was 320.76 g. An *uncia* is roughly equivalent to one ounce.

Chapter 5 is the core of the entire process. Indeed, it is titled "How gems are coloured" ("*Quomodo gemmae colorentur*"; p. 120). The pigments described above are blended with the previously prepared colourless glass while it is molten, so that they mix homogeneously. The recipes are summarized in Table I. There were no particular instructions given here, but Della Porta thought it best to add a series of tedious recommendations based on his own observations of glassmaker practices. For example, the glass used for a sapphire simulant should be coloured first, and as soon as the proper colour is reached it should be quickly removed from the fire, as otherwise the colour would fade and the glass turn clear. The addition of *zaphara* requires strong stirring from the bottom to top of the crucible using an iron rod; a little glass should be tested to check if the correct colour is reached. He also added some information not given previously: (1) The blue glass 'gem' called 'aquamarine'[40] is a variety of sapphire (*sic*) and, as in natural stones, may be either dark or light in colour; (2) the colour of amethyst-type glass is obtained by adding manganese[41]; (3) adding 'red lead' will enhance the brightness of topaz-type glass; and (4) the glass made to imitate topaz can be further used to simulate chrysolite (olivine), because the latter gem has a similar colour except that it ranges into a shade of green.

The recipe for glass used to simulate emerald is given last, because this preparation requires a long exposure to fire, as the burnt copper which dyes the glass has a tendency to sink into the crucible, leaving on top a glass too poorly coloured. The best way to produce emerald-coloured glass (e.g. Figure 1) is to start with the aquamarine-type glass (containing burnt copper) and add *crocus*, so that the ratio of *crocus*:copper is 2:1, and then let the mix season until the glass becomes homogeneous and transparent, reabsorbing any coloured clouds that might form inside.

The list ends with the recommendation of decreasing the fire slowly until the furnace has cooled down enough to safely extract the pots. Finally, when the pots are cool, they are broken and the "fictitious precious stones" ("*confrac-*

[40] "*Cyaneam gemmam colorare. Quam vulgus aquam marinam vocat, speciem sapphiri*" (p. 120).

[41] The first mention of manganese was by Biringuccio (1540, c. 36v). To him it was not a metal, but a *mezzo minerale* (semi-mineral), rust-like in colour, which was imported from Germany for use by glassmakers. He pointed out that the same material could also be found in lower Tuscany and upper Latium, where, indeed, occurrences of oxides and hydroxides of manganese are widespread. Notice that, in Venice, to make glass clear and transparent, people had been adding (probably without knowing it) some imported Mn-bearing mineral powder to the melt since 1290 (Verità, 2014, p. 56). Pliny mentions *magnesium* added for the same purpose, but this name had lost its specificity during the Middle Ages and certainly did not refer to black ore.

taeque (ollulae) ementitos preciosos lapides largientur"; p. 120) can be easily taken out.

Della Porta begins Chapter 6 (p. 121) by saying that he knows other ways of making gem simulants that are even better than the ancient ones found in the ruins of Pozzuoli or, occasionally, in the nearby shore sands. Then, rather suddenly, he goes astray into the mysteries of alchemy (see above). The following chapters describe various enhancements of natural gem materials (in particular quartz), and then move on to enamels, coloured metal sheets for reflection, etc.[42] Della Porta ends Book VI, Chapter 13, with the short but factual statement: "This is all that we experimented on gems so far" ("*Haec sunt quae hoc tempore de gemmis experti sumus*"; p. 126).

Discussion and Conclusion

Comparing the two editions of Della Porta's *Magiae Naturalis* contributes to understanding their audience: The slender 1558 edition, with its few precise recipes accompanied by alchemical suggestions, is intended to stir the interest of cultivated people and induce them to experiment. The large and somewhat confusing 1589 version provides details that enable experiments to be made to the best of the contemporaneous abilities, and it avoids alchemical tracts, or separates them from the bulk of the description of technical recipes. The 1589 version enjoyed fewer editions and translations than the 1558 one did.[43] The local vernacular translations of the 1558 edition continued to be preferred all over Europe, with the exception of Germany.

Implications for English Glassmaking: In England, Della Porta's 1589 *Magiae Naturalis* Latin edition was cursorily quoted by Thomas Nicols in 1652 in the "first independent gemological book written or published by a British author"[44], but only to mention the existence of various enhancement methods to colour quartz, rather than for his description of making glass gem simulants. In fact, Nicols (1652) appears to draw from Della Porta's treatise only once (pp. 25–26), in a concise reference (14 lines), as partially given here:

> …foyls, are made either *ex foliis æris, auri, vel argenti*, then they are wont to prepare these by hanging them in threads in a furnace made for the same purpose; that so they may be tinctured with the vapour of that which being burned in the lower part of the furnace, doth ascend for that purpose.

Unfortunately, the reference is incorrect: nowhere does Della Porta suggest mixing the pigments into the wood fire in the lower part of the furnace, and the method itself applies to enhancing the surface colour of natural gemstones rather than making glass 'gems'. Yet, Nicols' book enjoyed two reissues, in 1653 and 1659, until it was superseded by Robert Boyle's *Essay* (1672).

In 1658, the English translation of Della Porta's 1589 *Magiae Naturalis* was made anonymously. The title plate (Figure 4) shows only the name of the engraver, "R. Gaywood"[45], and nothing of the essential publishing data, which appear instead in the frontispiece that follows, printed in two colours (Figure 5). This book is now exceedingly rare, both in its first printing and in its reissue (1669); the few soiled copies remaining testify that they apparently were used and worn out by practical men operating on a laboratory bench, rather than by scholars preserving them almost untouched on a library shelf. Most probably, the actual readers were high-class people who felt experimenting to be an interesting, albeit unusual activity, or practical men who tried methods first in their laboratories before exposing themselves to a new venture.

The second half of the 17th century in England was characterized by an economic revival with increasing interest for science in general, including those books penned by 'writers of secrets' (i.e. those treatises that described technical undertakings). Della Porta's was among the

[42] Such treatments were studied and carefully described by Nassau (1994).

[43] Balbiani (1999, p. 281) stated that the 1589 enlarged edition had 'only' 35 printings, mostly in the Latin original text. In Germany this became the reference tome, so that it was translated to German only as late as 1680, by Christian Knorr von Rosenroth.

[44] This statement was made by John Sinkankas in his authoritative annotated gemstone bibliography (1993, p. 755b).

[45] Richard Gaywood (active 1650–1680) was a pupil of the British-naturalized Bohemian engraver Wenceslaus Hollar (cf. *Dictionary of National Biography*, Smith, Elder & Co., London, 1885–1900). He worked in London, and the bulk of his work consisted of portraits and frontispieces to books, several of which related to natural science, including Della Porta's *Natural Magick* (1658).

Figure 4: Shown here is the title plate of the first English translation of Natural Magick*, published in London in 1658. Note the profile of Della Porta taken from the 1589 Neapolitan edition surrounded by images engraved by Richard Gaywood of the subjects covered in the volume.*

very first translations printed and used most. This is apparent not only from the faded state of the volumes but also from a comparison with Christopher Merret's translation, issued in 1662, of Antonio Neri's *Arte Vetraria* (Glass Art; 1612), originally published in Florence in Italian but never extensively applied in Tuscany.[46] Notably, both books were translated and published during the Protectorate, when the primary aim was to restore England's national economy after 30 years of disastrous civil wars. This trend continued after the Restoration, which, in particular, took advantage of the newly founded Royal Society (1663) to scout and translate all books written in foreign languages that could stimulate the country's economy.[47]

[46] In his translation of Neri's *Arte Vetraria* (in which Florentine glass knowledge is summarized), Christopher Merret (1614–1695) supplemented the original treatise with 176 pages of comments and new information he had probably deduced from the Venetian glassmaking tradition (cf. Verità, 2014, p. 62).

[47] This project, clearly and repeatedly mentioned by Thomas Sprat and Henry Oldenburg (both secretaries of the Royal Society), was reviewed recently by Henderson (2013).

Indeed, the English glassmaking industry benefited greatly from such translations. In 1674 George Ravenscroft (1632–1684)[48] filed for a glassmaking patent of his own (MacLeod, 1987). He had been in Venice as a youth and had become acquainted with the essentials of Murano glassmaking techniques. When he returned to London, he attempted the production of similar glass with the help of two Murano glassmakers he had convinced to follow him.[49] As primary ore he used the local Thames flint-rich grey sands.[50] The results were not satisfying, but he persisted and, following a suggestion by Robert Plot[51], he moved his kiln upstream to Henley-on-Thames, where the river sands contain white flint similar to that of the Po River delta that the Venetian glassmakers had always exploited. Actually, the success of the enterprise did not depend upon the flint used for silica, but upon the flux. Ravenscroft used a potassic-alkali flux with added lead oxide such as that suggested by Della Porta. The mix produced brilliant, heavy 'crystal' glass easy to mould and, moreover, did not suffer 'crizzling' (i.e. it did not become cloudy with age due to the formation of numerous microscopic internal cracks). Furthermore, his factory used coal from the nearby mines, thus bringing the kiln to higher temperatures at lower cost.

The practice of publishing 'secrets', although unwelcome to many, contributed to the development of both science and the economy. In particular, it is significant that Della Porta's *Magiae Naturalis*, intended for completely different purposes and contributing only poorly to the 'scientific revolution' because of its still rather alchemical bent, eventually helped speed up the English industrial revolution.

[48] During his youth, Ravenscroft travelled throughout Europe and established an import-export network, with bases located in Venice and London.

[49] This was against Venetian law, as it would deprive Venice of essential knowledge and manpower for its (fading) monopoly on high-quality glass.

[50] This is a precise recollection of Della Porta's mention of the river, which can be found only in the 1589 edition (p. 118).

[51] A fellow of the Royal Society (1640–1696), Plot was the first professor of chemistry at Oxford University and the first keeper of the Ashmolean Museum. He knew very well the geology of Oxfordshire and Staffordshire, where flint, coal and lead ores were present together in exploitable quantities, and published a detailed record of this (cf. *Dictionary of National Biography*, Smith, Elder & Co., London, 1885–1900).

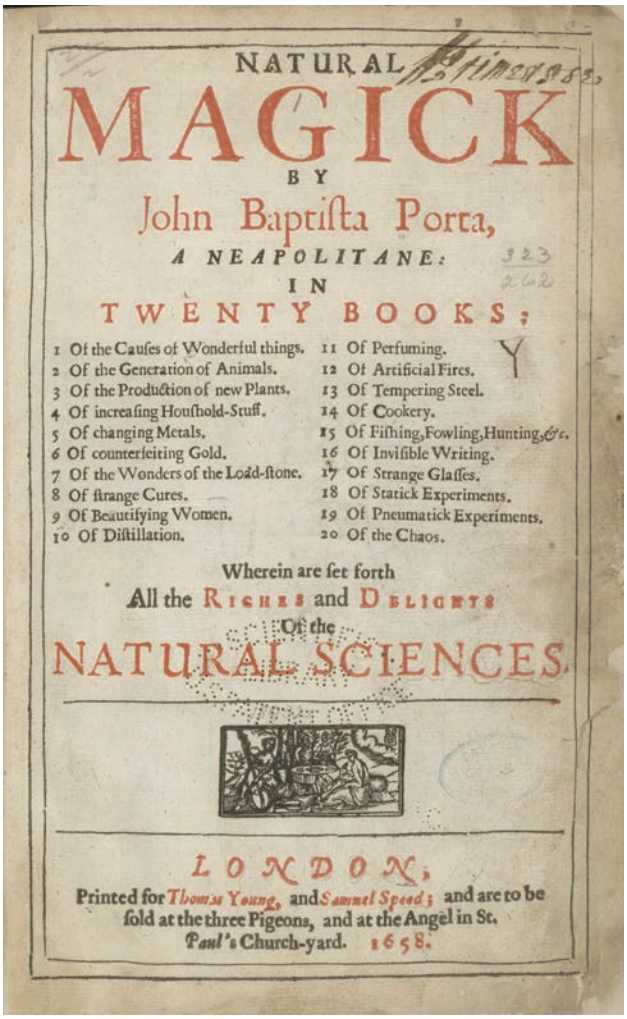

NATURAL
MAGICK
BY
John Baptiſta Porta,
A NEAPOLITANE:
IN
TWENTY BOOKS;
1 Of the Cauſes of Wonderful things.
2 Of the Generation of Animals.
3 Of the Production of new Plants.
4 Of increaſing Houſhold-Stuff.
5 Of changing Metals.
6 Of counterfeiting Gold.
7 Of the Wonders of the Load-ſtone.
8 Of ſtrange Cures.
9 Of Beautifying Women.
10 Of Diſtillation.
11 Of Perfuming.
12 Of Artificial Fires.
13 Of Tempering Steel.
14 Of Cookery.
15 Of Fiſhing, Fowling, Hunting, &c.
16 Of Inviſible Writing.
17 Of Strange Glaſſes.
18 Of Statick Experiments.
19 Of Pneumatick Experiments.
20 Of the Chaos.
Wherein are ſet forth
All the RICHES and DELIGHTS
Of the
NATURAL SCIENCES.
LONDON,
Printed for Thomas Young, and Samuel Speed; and are to be ſold at the three Pigeons, and at the Angel in St. Paul's Church-yard. 1658.

Figure 5: Shown here is the frontispiece of the first English translation of Natural Magic*, as printed in London in 1658. Note that there is an error in the title of Chapter 6; inside the book on p. 178 is the correct translation: 'Of Counterfeiting Precious Stones'.*

References

Agricola G., 1546. *Georgii Agricolae De ortu & causis subterraneorum Lib. V. De natura eorum quæ effluunt ex terra Lib. IIII. De natura fossilium Lib. X. De veteribus & novis metallis Lib. II. Bermannus, sive De re metallica Dialogus. Interpretatio Germanica vocum rei metallicæ, addito Indice foecundissimo.* Hieron, Frobenium et Nicolaum Episcopium, Basel (Basileae), Switzerland, 487 pp.

Agricola G., 1556. *Georgii Agricolae De re metallica Libri XII. Quibus officia, instrumenta, machinae, ac omnia denique ad metallica spectantia, non modo loculentissime describuntur, sed et per effigies, suis locis insertas, adjunctis latinis, germanicisque appellationibus ita ob oculos ponuntur, ut clarius tradi non possint. Eiusdem De animantibus subterraneis liber, ab autore recognitus: cum indicibus diversis, quicquid in opere tractatum est, pulchre demonstrantibus.* H. Frobenivm et N. Episcopivm, Basel (Basileae), Switzerland, 502 pp.

Amabile L., 1892. *Il Santo Officio della inquisizione in Napoli: Narrazione con molti documenti inediti,* Vols. 1–2. S. Lapi Tipografo—Editore, Città di Castello, Italy, 599 pp.

Balbiani L., 1999. La ricezione della Magia naturalis di Giovan Battista della Porta nella Cultura e scienza dall'Italia all'Europa. *Bruniana et Campanelliana*, **5**, 277–303.

Baroni S., Brun G. and Travaglio P., 2013. Creation and colouration of stained-glass windows in mediaeval literary sources: New perspectives on technical treatises dated between the 12th and 16th centuries. In H. Roemich and K.v.L. Campagne, Eds., *Recent Advances in Glass, Stained-Glass, and Ceramics Conservation*, ICOM-CC Glass and Ceramics Interim Meeting and Forum of the International Scientific Committee for the Conservation of Stained Glass (Corpus Vitrearum-ICOMOS), 7–10 October, Amsterdam, The Netherlands, 133–140.

Barthélémy P., 2002. *La Sedacina ou l'Oeuvre au crible: L'alchimie de Guillaume Sedacer, carme catalan de la fin du XIVe siècle. Vol. 1, Études et outils. Vol. 2, Sedacina, édition critique et traduction, suivie du Liber alterquinus*. SÉHA-Archè, Paris, France, and Milan, Italy, 388 pp. (Vol. 1) and 484 pp. (Vol. 2).

Beretta M., 2004. *When Glass Matters: Studies in the History of Science and Art from Graeco-Roman Antiquity to Early Modern Era*. Leo S. Olschki, Florence, Italy, 355 pp.

Beretta M., 2009. *The Alchemy of Glass: Counterfeit, Imitation, and Transmutation in Ancient Glass-making*. Science History Publications, Sagamore Beach, Massachusetts, USA, 216 pp.

Biringuccio V., 1540. *De la pirotechnia libri X dove ampiamente si tratta non solo di ogni sorte e diuersita di miniere, ma anchora quanto ricerca intorno à la prattica di quelle cose di quel che si appartiene à l'arte de la fusione ouer gitto de metalli come d'ogni altra cosa simile à questa. Composti per il S. Vanoccio Biringuccio Sennese. Con priuilegio apostolico & de la Cesarea Maesta & del Illustriss. Senato veneto*. Venturino Roffinello, Ad instantia di Curtio Navò et fratelli, al Segno del Lion, Venice (Venetia), Italy, 168 cc.

Boulanger K., 2004. Les traités médiévaux de peinture sur verre. *Bibliothèque de l'École des Chartes*, **162**(1), 9–33.

Boyle R., 1672. *An Essay about the Origine & Virtues of Gems: Wherein are Propos'd and Historically Illustrated some Conjectures about the Consistence of the Matter of Precious Stones, and the Subjects wherein their Chiefest Virtues Reside*. William Godbid, London, 185 pp.

Caffaro A., Ed., 2000. *Teofilo Monaco Le varie arti De diversis artibus. Manuale di tecnica artistica medievale*. Palladio, Salerno, Italy, 445 pp.

Cannella A.-F., 2006. *Gemmes, verre coloré, fausses pierres précieuses au Moyen* Âge*: Le quatrième livre du "Trésorier de philosophie naturelle des pierres précieuses" de Jean d'Outremeuse*. Librairie Droz S.A., Geneva, Switzerland, 495 pp.

Cardano G., 1560. *Hieronymi Cardani Mediolanensis Medici De subtilitate libri XXI : Ab authore plusquam mille locis illustrati, nonnullis etiam cum additionibus : addita insuper Apologia adversus calumniatorem, qua vis horum librorum aperitur.* Officina Petrina, Basel (Basileae), Switzerland, 1,426 pp.

Carutti D., 1883. *Breve storia della Accademia dei Lincei*. Salviucci, Rome, Italy, 259 pp.

Clubb L.G., 1965. *Giambattista Della Porta Dramatist*. Princeton University Press, Princeton, New Jersey, USA, 359 pp.

Corso A., Mugellesi R. and Rosati G., Eds. and Transl., 1988. *Gaio Plinio Secondo: Storia Naturale. V: Mineralogia e Storia dell'Arte*, Libri 33–37. Giulio Einaudi, Turin, Italy, 966 pp.

Della Porta G., 1558. *Magiae Naturalis, sive de miraculis rerum naturalium libri IIII*. Matthiam Cancer, Naples (Neapoli), Italy, 163 pp.

Della Porta G., 1589. *Magiae Naturalis libri XX*. Horatium Saluianum, Naples (Neapoli), Italy, 662 pp.

Della Porta G., 1658. *Natural Magick by John Baptista Porta, a Neapolitane: In Twenty Books (...) Wherein are Set Forth All the Riches and Delights of the Natural Sciences*. Printed for Thomas Young and Samuel Speed, London, 409 pp. (plus index).

Della Porta G., 1669. *Natural Magick by John Baptista Porta, a Neapolitane: In Twenty Books (...) Wherein are Set Forth All the Riches and Delights of the Natural Sciences*. 2nd printing of 1658 English translation, John Wright, London, 424 pp.

Eamon W., 1984. Arcana disclosed: The advent of printing, the books of secrets tradition and the development of experimental science in the sixteenth century. *History of Science*, **22**(2), 111–150, http://dx.doi.org/10.1177/007327538402200201.

Eamon W., 1994. *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture*. Princeton University Press, Princeton, New Jersey, USA, 512 pp.

Fulco G., 1987. Per il 'Museo' dei fratelli Della Porta. In M.C. Cafisse, F. D'Episcopo, V. Dolla, T. Fiorino and L. Miele, Eds., *Rinascimento Meridionale e Altri Studi in onore di Mario Santoro*, Società Editrice Napoletana, Naples, Italy, 105–175.

Garzya Romano C., 1996. Introduzione, testo latino e traduzione, commentario a cura di Chiara Garzya Romano. *Eraclio. I colori e le arti dei Romani e la compilazione pseudo-eracliana*. Il Mulino, Bologna, Italy, 136 pp.

Guardo M., 2008. *Titulus e tumulus. Epitafi di pontefici e cardinali alla corte dei papi del XIII secolo*. Viella Libreria Editrice, Rome, Italy, 192 pp.

Henderson F., 2013. Faithful interpreters? Translation theory and practice at the early Royal Society. *Notes and Records of the Royal Society*, **67**(2), 101–122, http://dx.doi.org/10.1098/rsnr.2013.0017.

MacLeod C., 1987. Accident or design?: George Ravenscroft's patent and the invention of lead

crystal. *Technology and Culture*, **28**(4), 776–803, https://doi.org/10.2307/3105182.
Merret C., 1662. *The art of glass wherein are shown the wayes to make and colour glass, pastes, enamels, lakes, and other curiosities / written in Italian by Antonio Neri ; and translated into English, with some observations on the author ; whereunto is added an account of the glass drops made by the Royal Society, meeting at Gresham College*. A(lice) W(arren) for Octavian Pulleyn, London, 362 pp.
Nassau K., 1994. *Gemstone Enhancement: History, Science and State of the Art*, 2nd edn. Butterworth-Heinemann, Oxford, 252 pp.
Neri A., 1612. *Arte vetraria distinta in libri sette...Ne quali si scoprono, effetti maravigliosi, & insegnano segreti bellissimi del vetro nel fuoco, & altre cose curiose*. Nella stamperia de' Giunti, Florence (Firenze), Italy, 114 pp.
Nicols T., 1652. *Lapidary or, the History of Pretious Stones*. Thomas Buck, Printer to the Universitie of Cambridge, Cambridge, 239 pp.
Orlandi A., 2013. *Le edizioni dell'opera di Giovan Battista Della Porta*. Istituto Nazionale di Studi sul Rinascimento meridionale, Studi, XII, Serra, Pisa-Rome, Italy, 120 pp.
Paolella A., 2002. La presenza di Giovan Battista Della Porta nel Carteggio Linceo. *Bruniana e Campanelliana*, **8**(2), 509–521.
Pereira M., 2006. *Alchimia. I Testi Della Tradizione Occidentale*. Arnoldo Mondadori, Milan, Italy, 1,566 pp.
Perfetti A., 1997. L'alchimia a Napoli tra Cinquecento e Seicento: Leonardo Fioravanti e Giovan Battista Della Porta. *Giornale critico della filosofia italiana*, **17**(2), 171–183.
Piemontese A. (Ruscelli, Girolamo), 1555. *De' secreti del reuerendo donno Alessio Piemontese, prima parte diuisa in sei libri. Opera utilissima et universalmente necessaria e dileteuole a ciascheduno. Ora in questa seconda editione dall'autor medesimo tutta ricorretta et migliorata. Et aggiuntovi nel fine de ogni libro molti bellissimi secreti nuovi*. Sigismondo Bordogna, Venice (Venetia), Italy, 237 pp.
Piemontese A. (Ruscelli, Girolamo), 1567. *Secreti nuoui di marauigliosa virtu del signor Ieronimo Ruscelli i quali continouando a quelli di donno Alessio, cognome finto del detto Ruscelli, contengono cose di rara esperienza, & di gran giouamento*. Marchiò Sessa, Venice (Venetia), Italy, 287 pp.
Plat H., 1594. *The Jewell House of Art and Nature: Containing Divers Rare and Profitable Inventions, Together with Sundry New Experimentes in the Art of Husbandry, Distillation, and Molding*. Peter Short, London, 232 pp.
Price D.J., 1958. Porta and his Natural Magick. In J.B. Porta, Ed., *Natural Magick (The Collector's Series in Science)*, Basic Books, New York, New York, USA, 1–2.
Principe L.M., 2013. *The Secrets of Alchemy*. University of Chicago Press, Chicago, Illinois, USA, 288 pp.
Sarnelli P., 1677. Vita di Gio: Battista Della Porta Napoletano. In G.B. Della Porta, Ed., *Della Chirofisonomia Overo Di quella Parte della Humana Fisonomia, che si appartiene alla Mano Libri Due Del Signor Gio: Battista Della Porta Napolitano Tradotti da un Manoscritto Latino Dal Signor Pompeo Sarnelli Dottor dell'una, e dell'altra Legge*. Antonio Bulifon all'insegna della Sirena, Naples (Napoli), Italy, 8 pp.
Sinkankas J., 1993. *Gemology: An Annotated Bibliography*, Vol. 1. Scarecrow Press, Netuchen, New Jersey, USA, 570 pp.
Tosatti S.B., 2006. *Trattati medievali di tecniche artistiche*. Jaca Book, Milan, Italy, 208 pp.
Valente M., 1999. Della Porta e l'Inquisizione. Nuovi documenti dell'Archivio del Sant'Uffizio. *Bruniana et Campanelliana*, **5**(2), 415–434.
Venturelli P., 1996. *Gioielli e gioiellieri milanesi. Storia, arte, moda (1450-1630)*. Silvana Editoriale, Milan, Italy, 222 pp.
Verità M., 2014. Secrets and innovations of Venetian glass between the 15th and the 17th centuries: Raw materials, glass melting and artefacts. In R. Barovier and C. Tonini, Eds., *Atti Classe di scienze morali, lettere ed arti 172–I: Study Days on Venetian Glass Approximately 1600's,* Istituto Veneto di Scienze, Lettere ed Arti, Venice, Italy, 53–68.
Zwierlein-Diehl E., 2007. *Antike Gemmen und ihr Nachleben*. Walter de Gruyter, Berlin, Germany, 567 pp.

The Author

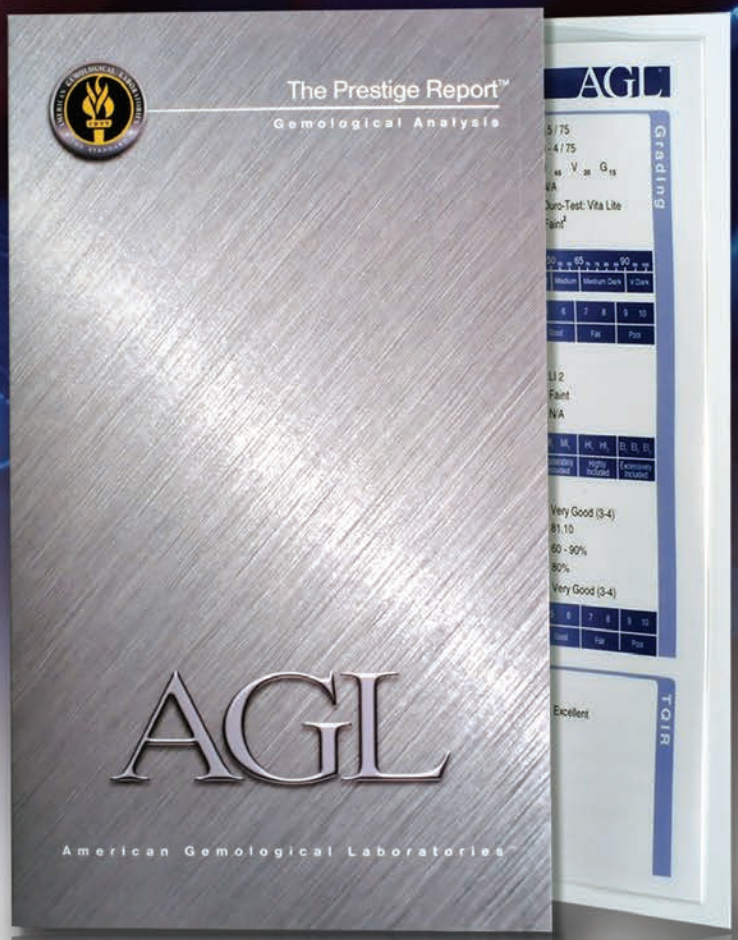
Dr Annibale Mottana
Dipartimento di Scienze, Università Roma Tre,
Largo San Leonardo Murialdo 1,
00146 Rome, Italy
Email: annibalemottana86@gmail.com

Acknowledgements

I dedicate this article to the late Professor Marco Santoro, who suggested assessing Della Porta's *Magiae Naturalis* for information on glass and metals. Dott. Marco Guardo and the library staff of Biblioteca Accademica e Corsiniana of Accademia Nazionale dei Lincei in Rome efficiently supported my research, as did the staff of Biblioteca dell'Area di Scienze e Tecnologia at University Roma Tre. The careful reviews by four unknown referees helped smooth out many aspects of an early version of this manuscript.

An innovator in gemstone reporting

• Identification of colored gemstones • Country of origin determination • Full quality and color grading analysis



AMERICAN GEMOLOGICAL LABORATORIES AGL

580 5th Ave • Suite 706 • New York, NY 10036, USA
www.aglgemlab.com • +1 (212) 704 - 0727

Conferences

3rd Mediterranean Gem and Jewellery Conference

The sunny Mediterranean lured gemmologists, jewellers and appraisers (Figure 1) from 15 countries to the 3rd Mediterranean Gem and Jewellery Conference (MGJC), this year in Syracuse, Italy, with a view of Mount Etna in the distance. The theme of the conference was coloured diamonds, which formed the basis of most of the talks and also workshops before and after the 11–14 May 2017 conference.

A pre-conference morning workshop on the use of the handheld spectroscope for testing gems and coloured diamonds was instructed by Gem-A's **Claire Mitchell**. After her presentation on various techniques for using a spectroscope and the features to look for, the 12 participants practised on sample gems, while Mitchell was at hand to provide viewing tips and answer queries.

In the afternoon, 30 participants filled the room to attend a workshop on identifying synthetic diamonds, both loose and mounted in jewellery. The focus was on small diamonds (including melee), which are a growing concern in the industry. The workshop started with a presentation by conference co-organiser **Branko Deljanin** (CGL-GRS Swiss Canadian Gemlab Inc., Vancouver, British Columbia, Canada), who reviewed synthetic diamond production techniques and characteristics that distinguish them from natural diamonds. Identification techniques included the use of crossed polarisers and observation of luminescence behaviour. The greater part of the workshop was taken with participants examining up to 50 samples of synthetic and natural diamonds with the help of conference co-organizer **George Spyromilios** (Independent Gemological Laboratory, Athens, Greece). He brought new samples that included rings and earrings set with natural and both HPHT-grown and CVD-grown synthetic diamonds. Participants had the opportunity to use a PL Inspector, which provides short- and long-wave UV excitation to examine a sample's fluorescence colour, intensity and, importantly, any phosphorescence, which is a key identifying feature of HPHT synthetic diamonds. The instrument was designed by **this author**, who assisted and demonstrated the use of a smartphone to better view the luminescence reactions. Conference sponsors System Eickhorst and M&A Gemological Instruments brought various lighting devices and instruments (including UV-Vis-NIR, FTIR and PL spectrometers) so participants had access to a mobile gem lab.

The second day of the conference was more formal, with speakers delivering talks on a variety of topics. **Alan Bronstein** (Aurora Gems, and president of Natural Color Diamond Association, New York, New York, USA) related the story of polishing the 'Blue Moon' diamond. He recounted the stone's journey from its origin in South Africa in early 2014 to its transformation into a 12.03 ct Vivid Blue, Internally Flawless diamond that achieved a record $4 million/carat at auction three years later. Grading fancy-coloured

Figure 1: Conference attendees gather at this year's MGJC for a group photo. Photo by J. G. Chapman.

diamonds has been a mystery to some, even those in the trade, so it was instructive to hear from **Thomas Gelb** (Natural Color Diamond Association), who once worked in GIA's diamond colour-grading department, outline the methods and terminology of fancy-colour grading, including viewing geometry, colour space and the concept of 'characteristic colour'. **Dr Katrien De Corte** (HRD Antwerp, Belgium) delivered a more technical discussion on natural and synthetic type II diamonds. She outlined some of the spectroscopic testing HRD does to detect synthetics when stones are submitted for grading. **This author** followed by describing how technology can be applied to grading coloured diamonds and fluorescence intensity using digital cameras and image-processing techniques. While body colour is one of the prime factors in determining the value of a diamond, provenance is also playing an increasing role, particularly with regard to pink diamonds. **Branko Deljanin** described a new service being offered by CGL-GRS of grading colour to finer resolution (11 rather than five grades) and also identifying whether a pink or blue diamond is from the Argyle mine in Australia. Pink diamonds from Argyle were the main topic of a talk by **Kym Hughes** (Symmetry Jewellery Valuation Specialists, Nerang, Queensland, Australia), who covered pricing factors for coloured diamonds and pitfalls in valuations for jewellery in which mountings can complicate the determination of a diamond's true colour appearance.

A buffet lunch break overlooking the Mediterranean Sea allowed delegates to discuss some of the morning's issues with one another before returning to hear more presentations. The importance of sponsors cannot be underestimated for the viability of conferences and, in exchange, sponsors can promote their businesses. Russia's mining giant—Alrosa—was a major sponsor, and **Alexey Useinov** (Technological Institute for Superhard and Novel Carbon Materials, Moscow, Russia, on behalf of Alrosa) introduced the Alrosa Diamond Inspector for screening both loose and mounted synthetic diamonds. **Marco Pocaterra**, from sponsor Diamond Love Bond (Milan, Italy), also took the podium to highlight the investment market for diamonds in Italy.

Although diamonds dominated the conference theme, other gems also were covered. **Ilaria Adamo** (Italian Gemmological Institute, Milan) introduced conference participants to the world of demantoid, covering their sources and geological origins—serpentinite- and skarn-related—for which distinctive inclusions are associated. Then **Victor Tuzlukov** (Russian Faceters Guild, Moscow, Russia) and **Alicia de Vildósola** (Tasarjoyas, Madrid, Spain) together discussed unconventional cuts and how they should be judged and valued. With jewellery as another topic of the conference, the audience

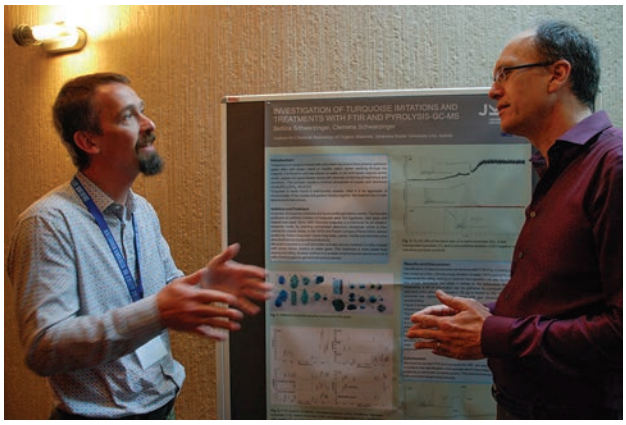


Figure 2: Clemens Schwarzinger discusses his MGJC poster presentation on turquoise imitations and treatments with Branko Deljanin. Photo by J. G. Chapman.

was entranced by examples of the exquisite work of Italian jewellery designer Gainmaria Buccellati, as told by **Larry French** (Gianmaria Buccellati Foundation, Milan), who also described Buccellati's techniques that involved mostly their 'Tulle' and 'Honeycomb' styles. **Manfred Eickhorst** (System Eickhorst, Hamburg, Germany) gave a short presentation on the importance of lighting in examining and grading diamonds and coloured stones, and offered some practical solutions.

A round-table session ended the day with a panel comprising **Thomas Gelb**, **Katrien de Corte**, **Alan Bronstein**, **Branko Deljanin** and **Kym Hughes**, moderated by **this author**, which covered coloured-diamond grading methods and reports. Members of the panel and the audience voiced their opinions on such matters as the reliability of reports for trading and valuation. A second part of the round table addressed fluorescence in diamonds, particularly its impact on appearance and whether discounts applied to strongly fluorescing diamonds are justified. In light of historical accounts of price premiums for fluorescence and its desirability to consumers, it was generally considered that the time is right for revisiting the impact of fluorescence on diamond grade and the appropriate discount (or premium) to be applied.

The day finished with a conference dinner, taking advantage of the al fresco conditions of Sicily, with some delegates passing the time beforehand browsing the posters. The poster presentations included one by **Dr Brad Cann** (De Beers, Maidenhead, Berkshire) on a thermometer for the HPHT treatment of CVD synthetic diamond. **Dr Clemens and Bettina Schwarzinger** (Johannes Kepler University, Linz, Austria) presented a poster on how to identify turquoise imitations and treatments using FTIR spectroscopy and pyrolysis mass spectroscopy (Figure 2). Asterism in gems was the subject of a poster by **Martin Stein-**

bach (Steinbach – Gems with a Star, Idar-Oberstein, Germany), and **Nick del Re** (independent gemmologist, New York) provided an insight into a smartphone accessory for recording digital spectra.

The third day of the conference returned to the workshop format, and was attended by 40 participants eager to learn how to distinguish natural from synthetic or treated coloured diamonds using the techniques mentioned above for the pre-conference workshop, as well as more advanced instrumentation such as UV-Vis-NIR, FTIR and PL spectrometers supplied by M&A Gemological Instruments. A second part of the day's workshop had participants learning how GIA grades colour in fancy-colour diamonds and what other labs such as GRS and CGL-GRS are offering as alternatives. A wide range of coloured diamonds were available for examination in a new Eickhorst grading cabinet, using Munsell colour chips for grading. Lectures were offered by **Branko Deljanin** and **Thomas Gelb** and assisted by **George Spyromilios**, **Elena Deljanin** and **this author**.

The following day provided an excursion to the historical part of Syracuse, where delegates could marvel at ancient ruins, enjoy the atmosphere of a food market and explore the narrow streets.

Every fourth year, the MGJC will 'travel' to a large country or market, and the 2018 conference will be held in Russia this summer with the theme 'Diamonds in 21st Century'. In addition, the 2019 MGJC is being planned for Israel. Further details on the conferences can be found at www.gemconference.com.

John G. Chapman (john@gemetrix.com.au)
Gemetrix Pty. Ltd., Perth, Australia

75th Anniversary Congress of the Swiss Gemmological Society/ European Gemmological Symposium

From 29 June to 2 July 2017, the Swiss Gemmological Society (SGS) celebrated its 75th anniversary in conjunction with the European Gemmological Symposium. The congress and jubilee events took place at the Grand Hotel Zermatterhof in the alpine resort village of Zermatt, Switzerland, and were attended by approximately 120 SGS members and guests (Figure 3). Former Swiss prime minister, **Adolf Ogi**, and president of SGS, **Hans Pfister**, gave commemorative speeches at the anniversary gala dinner. **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) and **Dr Michael Krzemnicki** (Swiss Gemmological Institute SSEF, Basel, Switzerland) received SGS Excellence Awards for their contributions to the field of gemmology (Figure 4). The conference concluded on Sunday with a field excursion to the Gornergrat,

Figure 3: Conference participants recently gathered at the Swiss Gemmological Society Congress and European Gemmological Symposium in Zermatt, Switzerland. In the centre of the first row is honorary guest Adolph Ogi, who is the former Swiss prime minister. Photo by M. Hügi.

Figure 4: The SGS Excellence Award is presented to Dr Thomas Hainschwang (left) and to Dr Michael Krzemnicki (centre-left) by SGS president Hans Pfister (right) and SGS director Michael Hügi (centre-right). Photo by D. Bellandi.

where **Prof. Dr Kurt Bucher** (University of Freiburg im Breisgau, Germany) gave an overview of the geology of the Zermatt region. **Dr Walter Balmer** (SGS scientific committee) and **the authors of this report** chaired the conference, which covered a broad variety of topics.

Martin Rapaport (Rapaport Diamond Corp., New York, New York, USA) focused his keynote lecture on the importance of gemmology to the diamond market. To maintain consumer confidence in the jewellery industry, there is a strong need now and in the future for well-trained people who are able to assess the different certifications and declarations of a gem's quality, especially in view of the emerging Internet trade. **Dr Thomas Hainschwang** provided an overview of the development of diamond treatments from the early simple methods of irradiation and annealing to the modern complex combinations of HPHT processing with irradiation and annealing, which allow a broad variety of diamond colours to be produced. To increase the knowledge of current diamond treatments, GGTL Laboratories have launched a study on the effects of different treatments on lattice defects in diamond. **Dr Wuyi Wang** (Gemological Institute of America, New York) presented the principles and current status of diamond synthesis. Although it is possible for laboratories to easily distinguish natural from synthetic diamonds, retailers and jewellers often reach the limits of their capabilities. For such cases, GIA is developing an easy-to-handle device to indicate samples that require further testing for separating between natural or synthetic origin. **Dr Andrey Katrusha** (New Diamond Technology Ltd., St Petersburg, Russia) presented his achievements in the production of large type IIa synthetic diamonds. In the near future, he predicted that it will be possible to produce ultra-large (>100 ct) synthetic diamond crystals exhibiting excellent structural perfection. High-quality colourless crystals in the range 10–20 ct could enter the market in large quantities within the next few years. **Alan Hart** (Gem-A, London) illustrated the history and meticulous reconstruction of the original cut of the Koh-i-Noor diamond through the analysis of a rediscovered plaster model and subsequent modelling of a CZ replica. His findings enhance our knowledge of the cutting of other so-called Mogul-cut diamonds such as the Orlov and Taj-e-Mah. **Guillaume Chautru** (Piaget, Paris, France) presented the point of view of the watch industry concerning melee-sized synthetic diamonds. The integration of a reliable testing routine within short production cycles is a difficult but crucial quest.

Author MSK highlighted how the combination of mineral inclusion studies and sophisticated scientific instrumentation is advancing gem treatment and origin research. This work has focused on inclusions such as zircon and amphibole, which can be found in various gem materials of different origins. Understanding the formation and properties of these inclusions offers great clues toward how and where a gem formed. **Dr Daniel Nyfeler** (Gübelin Gem Lab, Lucerne, Switzerland) focused on his lab's development of a new system for the traceability of gemstones from the mine to the consumer. This system is based on nanoparticles containing DNA, which are introduced into the rough gem material at the mine and cannot be removed even by cleaning and cutting processes. With this technology, trade organisations, jewellers and customers can determine the provenance of a cut stone at any time. **Helen Molesworth** (Gübelin Academy, Lucerne) gave an overview of the historical perspective of the gem market. When comparing historical prices of rubies corrected with the purchasing power of currency at the time, a 1 ct stone had a value that corresponded to a soldier's salary for a period of several years. Against this background, the current record prices for rubies and sapphires at auction can be explained by strong driving forces such as scarcity and the emotional value of certain gems.

Willy Bieri (GRS Gemresearch Swisslab AG, Meggen, Switzerland) gave an overview of the recently discovered sapphire deposits near Bemainty in the Ambatondrazaka region of Madagascar. This mining area has produced important and very beautiful sapphires, including 'royal' to 'cornflower' blue colours. Kashmir-like sapphires from this area can be distinguished from those of Kashmir by studying specific inclusions. **Vincent Pardieu** (VP Consulting, Manama,

Bahrain) reported on the gem deposits of East Africa. Beginning with the discovery of major sapphire deposits in Madagascar in the 1990s—especially those of the Ilakaka area—there have been many new mining areas found on this island. The most recent sapphire discoveries near Bemainty lay within a protected forest area, and mining of these deposits might trigger serious criticism from NGOs, which in turn might affect the jewellery industry in the future. **Dr Hanco Zwaan** (Netherlands Gemmological Laboratory, Naturalis, Leiden, The Netherlands) described the complex metamorphic processes that led to the formation of sapphire crystals in a primary deposit at Wellawaya, Sri Lanka. The gem sapphire growth is metasomatic, promoted by ultra-high-temperature metamorphism, in proximity to a tectonic contact and fluid/melt transfer associated with a pegmatite. **Franck Notari** (GGTL Laboratories, Geneva, Switzerland; lecture given by Dr T. Hainschwang) showed that the linear structures along the intersections of twin lamellae in corundum are not boehmite, as frequently described in the gemmological literature. Rather than mineral inclusions, they seem to consist of linear void structures that result from the crystallography of corundum.

Author LC shared insights on the history of emeralds, the meanings and uses of these stones, and their various geographic origins. Developments in emerald treatments and the discovery of new deposits in recent decades (most recently, Ethiopia) have provided challenges for gem laboratories. This has fuelled the need for extensive gemmological research on treatment detection and origin determination. **Klemens Link** (Gübelin Gem Lab, Lucerne) discussed the age determination of gem-quality emeralds by Rb-Sr geochronological analysis. The recently acquired triple-quadrupole LA-ICP-MS instrumentation at his laboratory allows the chemical separation of Rb and Sr isotopes and the subsequent mass-spectrometric measurement in one step. This technology will enable better origin determination of emerald as well as aquamarine. **Dr Raquel Alonso-Perez** (Mineralogical & Geological Museum, Harvard University, Cambridge, Massachusetts, USA) showed that the emerald deposit at Irondro, eastern Madagascar, formed from a combination of different geological processes and tectonic conditions. Her study contributes to the refining of the genetic classification of emerald deposits and might help enhance the economic assessment of such deposits in the future.

The history of tsavorite from the first discoveries to the present time was the theme of a presentation by **Bruce Bridges** (Bridges Tsavorite, Tucson, Arizona, USA). His father, Campbell Bridges, discovered the new green garnet variety in 1967, and subsequently developed the famous Scorpion mine. Today, the Bridges company activities cover the full production cycle from mining of the rough material to the marketing and sale of cut stones. **Alan Hodgkinson** (Whinhurst, West Kilbride) gave an overview of the occurrences and treatments of zircon, focusing on the effects of metamictization on optical properties. He showed that visual optics alone can provide important information. By the observation and measurement of dispersion and birefringence, it is possible to distinguish between a high and low zircon. The discovery of 'Sannan-Skarn', a new ornamental stone resembling maw-sit-sit, was the topic of a lecture by **Prof. Dr Henry Hänni** (GemExpert GmbH, Basel, Switzerland). This new material, mined in western Pakistan, is a dense, green granular rock consisting of up to 10 minerals including hydrogrossular, diopside, aegirine and pectolite.

Dr Ulrich Henn (German Gemmological Association, Idar-Oberstein, Germany) gave an overview of the gem deposits in western Namibia. Numerous pegmatites in the areas surrounding granitic plutons of the Erongo massif, the Spitzkoppe and Brandberg have provided high-quality gems, mostly blue-to-green, red and pink elbaite tourmaline. **Author MFH** provided an overview of Swiss gem deposits. Due to the complex geological structure of the Alps, there is a broad variety of gem minerals, mostly consisting of ornamental and collector stones. Only large transparent quartz crystals from alpine fissures deposits have enjoyed significant economic importance in history, as they were used as raw material for the lapidary industry in Italy and in Prague, which produced outstanding works of art in the past.

Dr Joseph Taylor (PT Cenada Indopearls, Denpasar, Bali, Indonesia) discussed the effects of technology transfer on marine pearl farming. The introduction of modern selective breeding practices based on genetic knowledge can lessen the reliance on wild pearl oysters. The application of these techniques has enhanced cultured pearl production and created new opportunities for the communities in islands where they are farmed.

Bernhard Berger (Cartier Tradition, Geneva, Switzerland) described Cartier's historic collection. Founded by Eric Nussbaum in 1973, the Cartier Collection manages a systematic search for the masterpieces of the company in order to establish a Cartier Museum showing the great eras and influence on jewellery design that members of the famous jeweller family have had.

Jeff Scovil (Scovil Photography, Phoenix, Arizona, USA) conveyed the techniques of aesthetic scientific photography. It takes a lot of experience and patience

to depict crystals and gemstones according to the different types and intensities of reflections, as well as to establish a fitting background. Even with the aid of digital image processing such as image stacking and combining different illuminations, the making of an aesthetic gem or mineral photograph remains an artistic endeavour.

Michael F. Hügi FGA
Swiss Gemmological Society SGS
Bern, Switzerland

Drs Michael S. Krzemnicki FGA
and Laurent Cartier FGA
Swiss Gemmological Institute SSEF
Basel, Switzerland

Gem-A Notices

GIFTS TO THE ASSOCIATION

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

Roy (Basil) Duran, Chicago, Illinois, USA, for various gem materials, including two faceted citrines, a broken faceted round brilliant diamond, baguette melee diamonds, a blue melee diamond, cultured pearls, small faceted rubies, a soudé emerald and a synthetic star sapphire.

Charles Evans FGA DGA, Gem-A, London, for two large rough salt crystals from Devil's Golf Course, Death Valley, California, USA.

Marcus McCallum FGA, Hatton Garden, London, for a twinned alexandrite crystal slice from near Masvingo, Zimbabwe.

'Keke' Saint-Clair Fonseca Junior, BC Gemas do Brasil, Governador Valadares, Brazil, for several sawn fragments and preforms of yellow tourmaline from Mavuco, Mozambique.

Susan Stocklmayer FGA, Perth, Western Australia, Australia, for a copy of her book *Gemstones of Western Australia* 2nd edn. and an olivine lamproite tuff from Ellendale Diamond Pipe #9, Western Australia.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Gemmological Association of Great Britain was held on 27 July 2017 at the Goldsmiths' Centre, Britton Street, London. The meeting was chaired by Justine Carmody.

Kerry Gregory FGA DGA retired in rotation and was re-elected to serve on the Council. Two new members had been nominated for election, Joanna Hardy FGA DGA and Philip Sadler FGA DGA, both of whom were elected. Alan Hodgkinson FGA DGA and Richard Slater FGA DGA retired in rotation and did not seek re-election.

Hazlems Fenton were re-appointed auditors for the year.


THE GEM-A CONFERENCE 2017: BRINGING TOGETHER THE GREATEST MINDS IN GEMMOLOGY

4 - 7 November 2017

Gemmologists from around the world will gather in London to attend the annual Gem-A Conference. The Conference boasts an incredible line-up of speakers including expert gemmologists from every area of the field. It is a must-attend Conference for anyone interested in gemmology.



"This conference was one of the best of all that I attended in the last two decades. Great speakers, good pace and a good choice of topics."

Gem-A Conference attendee 2016

Book now on Eventbrite: https://gemaconference.eventbrite.com

Learning Opportunities

CONFERENCES AND SEMINARS

ASA International Appraisers Conference
7–10 October 2017
Houston, Texas, USA
www.appraisers.org/education/conferences/asa-joint-conferences

200th Anniversary Meeting of the Russian Mineralogical Society
10–13 October 2017
Saint Petersburg, Russia
www.minsoc.ru/2017
Session of interest: Natural Stone in History of Civilization (Including Gemology)

35th International Gemmological Conference
11–15 October 2017
Windhoek, Namibia
www.igc-gemmology.org (requires log-in to access information)

Chicago Responsible Jewellery Conference
13–14 October 2017
Chicago, Illinois, USA
www.chiresponsiblejewelryconference.com

Friends of Mineralogy Pacific Northwest Chapter 43rd Annual Symposium: Minerals of the Pacific Northwest
13–15 October 2017
Kelso, Washington, USA
www.pnwfm.org/symposium

Canadian Gemmological Association Conference
20–22 October 2017
Toronto, Ontario, Canada
www.canadiangemmological.com/index.php/com-virtuemart-menu-configuration/conferences-and-special-events

ICA Congress
21–24 October 2017
Jaipur, India
www.gemstone.org/events/2017-congress

Geological Society of America Annual Meeting
22–25 October 2017
Seattle, Washington, USA
http://community.geosociety.org/gsa2017/home
Session of interest: Gemological Research in the 21st Century: Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals

Compiled by Sarah Salmon and Brendan Laurs

9th International Congress on the Application of Raman Spectroscopy in Art and Archaeology
24–28 October 2017
Évora, Portugal
www.raa2017.uevora.pt

The Munich Show
27–29 October 2017
Munich, Germany
www.munichshow.com/en
Note: Includes a seminar programme.

Inaugural Conference on Applied Earth Sciences in Myanmar and Neighboring Regions
2–3 November 2017
Yangon, Myanmar
www.maesa.org/info.html
Session of interest: Applied Mineralogy and Gem Deposits

World Ruby Forum 2017
4 November 2017
Bangkok, Thailand
www.worldrubyforum.com

Gem-A Conference
4–5 November 2017
London
https://gem-a.com/event/conference

MJSA ConFab
5 November 2017
New York, New York, USA
www.mjsa.org/eventsprograms/mjsa_confab

CIBJO Congress 2017
5–7 November 2017
Bangkok, Thailand
www.cibjo.org/congress2017

Jewellery Matters. Context and Material Research
15–17 November 2017
Amsterdam, The Netherlands
www.rijksmuseum.nl/en/jewellery-matters

15th Swiss Geoscience Meeting
17–18 November 2017
Davos, Switzerland
https://geoscience-meeting.ch/sgm2017
Session of interest: Gemmology

Kenya Mining Forum
4–5 December 2017
Nairobi, Kenya
www.kenyaminingforum.com
Session of interest: Gemstone Industry: A Sector Sure to Shine in Time

AGTA Gemfair
30 January–4 February 2018
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Includes a seminar programme.

AGA Tucson Conference
31 January 2018
Tucson, Arizona, USA
www.accreditedgemologists.org/currevent.php

2018 Tucson Gem and Mineral Show: Crystals and Crystal Forms
8–11 February 2018
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme.

Amberif International Fair of Amber, Jewellery and Gemstones
21–24 March 2018
Gdańsk, Poland
www.amberif.amberexpo.pl/title,PROGRAMME,pid,3275.html
Note: Includes a seminar programme.

45th Rochester Mineralogical Symposium
19–22 April 2018
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
23–26 April 2018
Nashville, Tennessee, USA
www.americangemsociety.org/page/conclave2018

The 32nd Annual Santa Fe Symposium
20–23 May 2018
Albuquerque, New Mexico, USA
www.santafesymposium.org

Society of North American Goldsmiths' 47th Annual Conference
23–26 May 2018
Portland, Oregon, USA
www.snagmetalsmith.org/conferences/made

JCK Las Vegas
1–4 June 2018
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/en/Events/Education
Note: Includes a seminar programme.

22nd Meeting of the International Mineralogical Association
13–17 August 2018
Melbourne, Victoria, Australia
www.ima2018.com
Sessions of interest:
- Recent Advances in our Understanding of Gem Minerals
- Sciences Behind Gemstone Treatments
- Mantle Xenoliths, Kimberlites and Related Magmas: The Diamond Trilogy

EXHIBITIONS

Europe

A Ring is a Ring is a Ring
Until 6 October 2017
London Design Festival, London
www.londondesignfestival.com/events/ring-ring-ring

Showstoppers Silver Centrepieces
Until 15 October 2017
Temple Newsam House, Leeds, West Yorkshire
www.leeds.gov.uk/museumsandgalleries/Pages/templenewsamhouse/Silver-Centrepieces.aspx

Jewellery—Materials Craft Art
Until 22 October 2017
Swiss National Museum, Landesmuseum Zürich, Switzerland
www.nationalmuseum.ch/e/microsites/2017/Zuerich/Schmuck.php

Wiener Werkstätte 1903–1932: The Luxury of Beauty
26 October 2017–29 January 2018
Neue Galerie, New York, New York, USA
www.neuegalerie.org/content/wiener-werkst%C3%A4tte-1903-1932-luxury-beauty

Pretty on Pink—Éminences Grises in Jewellery
27 October 2017–25 February 2018
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Liv Blåvarp: Jewellery
Until 29 October 2017
Lillehammer Kunstmuseum, Lillehammer, Norway
http://lillehammerartmuseum.com/exhibitions/?lang=en

Vanity: Stories of Jewelry in the Cyclades
Until 31 October 2017
Archaeological Museum of Mykonos, Greece
http://www.mymykonosapp.com/articles/the-exhibition-to-see-in-mykonos-vanity-stories-of-jewelry-in-the-cyclades

Jewellery: Designs in Print and Drawing
Until 26 November 2017
Rijksmuseum, Amsterdam, The Netherlands
www.rijksmuseum.nl/en/jewellery-designs-in-print-and-drawing

North America

Linda MacNeil: Jewels of Glass
Until 1 October 2017
Museum of Glass, Tacoma, Washington, USA
https://museumofglass.org/mog/exhibition/linda-macneil-jewels-of-glass

Colors of the Universe: Chinese Hardstone Carvings
Until 9 October 2017
The Met Fifth Avenue, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2016/colors-of-the-universe

Spectacular Gems and Jewelry from the Merriweather Post Collection
Until 7 January 2018
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/Spectacular-Gems-and-Jewelry

Past is Present: Revival Jewelry
Until 19 August 2018
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/news/past-is-present-revival-jewelry

Gemstone Carvings: The Masterworks of Harold Van Pelt
Ongoing
Bowers Museum, Santa Ana, California, USA
www.bowers.org/index.php/exhibitions/upcoming-exhibitions/484-gemstone-carvings-masterworks-by-harold-van-pelt

Australasia

The House of Dior: Seventy Years of Haute Couture
Until 7 November 2017
The National Gallery of Victoria, Melbourne, Australia
www.ngv.vic.gov.au/exhibition/the-house-of-dior

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses

Sri Lanka Trip with Gem-A and The National Association of Jewellers
16–30 October 2017
Visit mines, markets and cutting centres in Sri Lanka
http://tinyurl.com/kujwh72
Note: Open to members of Gem-A and NAJ.

DUG Advanced Gemology Program (in English)
6 November–8 December 2017
Nantes, France
www.gemnantes.fr/en

Gemstone Safari to Tanzania
8–25 January 2018
Visit Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara in Tanzania
www.free-form.ch/tanzania/gemstonesafari.html
Note: Includes options for a lapidary class and/or a private trip to visit ruby mines near Morogoro and Mpwapwa (including Winza).

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Birmingham
Email Georgina@fellows.co.uk

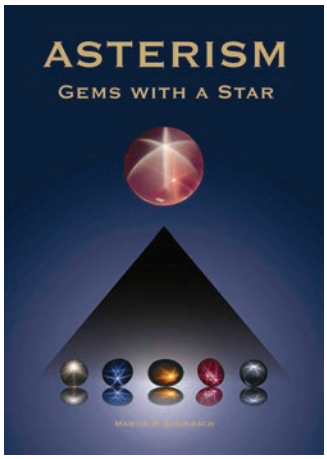
- 29 September 2017
  Geoff Whitefield—Valuation Practice
- 27 October 2017
  Stephen Alabaster—The History of Alabaster & Wilson

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

- 3 October 2017
  Raymond Sancroft-Baker—Hidden Gems – Jewellery Stories from the Salesroom
- 24 October 2017
  Lynne Bartlett—The Rise and Fall of the Chatelaine
- 28 November 2017
  Judy Rudoe—Cartier Gold Boxes: A Visionary Patron and a Bet with Ian Fleming

New Media

Asterism: Gems with a Star



By Martin Steinbach, 2016. MPS Publishing and Media, Idar-Oberstein, Germany, 896 pages, illus., ISBN 978-3000504945. US$199.00 hardcover or $399.00 VIP edn.

Martin Steinbach has masterfully compiled the most comprehensive treatise on gems displaying asterism. His passion for star gems is evident in each chapter, in which he covers topics such as history, famous stars, scientific aspects, treatments, synthetics, imitations, all known star varieties, types of stars and stars in art. To whet the reader's palate for what follows, the first few pages of this compendium feature the largest-known and most famous star rubies and sapphires. Steinbach has devoted 20 years to creating this book, which features over a thousand photos depicting more than 60 varieties of gems with stars.

The first chapter, on asterism throughout history, begins with a focus on Greco-Roman references to stars (*asterius-asteria*) from ancient history, then continues into the Middle Ages, and culminates with early modern times to the present. Steinbach also includes translations from Latin, French and German references that are particularly enjoyable because so many famous European mineralogists and gemmologists were studying and writing about gem materials during the European Renaissance. One interesting reference from Anselmus Boëtius de Boodt's book, *Gemmarum et Lapidum Historia* (1609), mentions that Germans commonly referred to star stones as Siegstein (victory stone).

The second chapter focuses almost exclusively on notable star rubies and sapphires. While most of the star stones mentioned in this chapter are deserving of their place, some that lack accompanying photos or exact weights could have been left out and replaced by notable stars of other gem species. This chapter provides an invaluable reference to the sizes, qualities and origins of many of the most important corundum stars that are known, and includes where many of them currently reside.

The third chapter, on the scientific aspects of asterism, explains how the orientation of the inclusions combined with the cutting of the gem material into a cabochon is responsible for the optical phenomenon of asterism. This reviewer found the addition of diagrams by Fischer and the charts by Eppler particularly informative and useful. The various inclusions that commonly cause asterism are described and characterized according to when they formed in relation to the host gem. Steinbach provides concise descriptions of the basic optical properties of gems, as well as a section that defines and compares various colour phenomena in gems with asterism. This reviewer also found the section on crystallography and symmetry easy to understand, beautifully illustrated and appropriately focused on its relation to asterism. However, the basic gemmology and geology described in the rest of this chapter could have been left out, perhaps to focus more on the optical mechanisms producing asterism.

The chapter on treatments of star gems covers all the major processes, including heating, irradiation, diffusion, fracture filling etc. Iron and titanium diffusion treatment is of highest concern in relation to star stones because this process can simultaneously alter the colour and create a star. Fracture filling is another treatment that is commonly applied and often missed by unsuspecting buyers. Lead-glass filling, frequently employed to treat corundum, also is being used to enhance star rubies and sapphires. One of the more interesting photos is of an irradiated greenish yellow 8-rayed star quartz from Brazil.

Synthetic star gems, manufactured by companies such as Djeva and Linde, were immensely popular from the mid-1940s to the mid-1970s. Chapter 5 focuses on these virtually perfect stars and their creators. Examples of synthetic star alexandrite, opal, spinel and even zincite also are included.

Imitations, including assembled and artificial products, are covered in Chapter 6. Scratching the surface of a cabochon is one of the most common ways to create a fake star, and an unscrupulous seller can employ this treatment method with minimal effort and skill. Doublets and triplets, as well as coatings and foil-backs, are shown in numerous colours and gem varieties.

The reverence that Steinbach gives to every gem displaying asterism is evident in the largest chapter, devoted to all known star varieties from andalusite to zircon. The fact that it starts with a photo of a cat's-eye andalusite reflects the equal importance Steinbach places on chatoyant gems as compared to star stones. (In this reviewer's opinion, he could have placed equal focus on both chatoyancy and asterism throughout the entire book.) For each gem, he includes a detailed

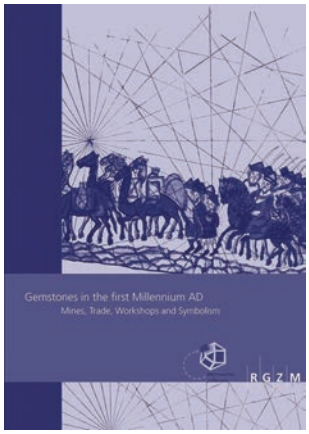
chart of its chemical, physical and optical properties, and occurrences. Some of the rarities featured are a 6-rayed star apatite, 4- and 6-rayed star emeralds, a 4-rayed star rhodochrosite, an 8-rayed star moonstone, a 12-rayed star rose quartz, and a unique 6-rayed star tourmaline. Along with numerous photos, Steinbach includes full-page charts of the countries and regions producing star rubies and star sapphires, followed by a brief description of each source. Charts of record auction results for many famous stars also are included in this section.

Steinbach concludes the book with an interesting finale of 'dream stars' (such as 14- and 24-rayed stars and trapiche gems), 'stars-n-art' featuring artful photos, and several interesting annexes. A list of famous 'fantasy stars' is useful from an historical standpoint for anyone studying or writing about the more well-known star gems. An annex featuring a star grading scale provides photos of Steinbach's black star sapphire master stones, and his star rating system could be useful to educators and appraisers for comparing star quality. Finally, a comprehensive list of scientific institutions provides an excellent resource for those seeking information, further education or laboratory services.

At 896 pages, the physically heavy and large size of the book limits its portability and ease of use. However, Martin Steinbach's obsessive passion and attention to detail has resulted in the most complete work on star gems that will likely be published for many decades to come. Any collector or hopeful connoisseur of star gems should definitely add this passionate ode to stars to their gemmological library.

Edward Boehm FGA
RareSource, Chattanooga, Tennessee, USA

Gemstones in the First Millennium AD—Mines, Trade, Workshops and Symbolism



Ed. by Alexandra Hilgner, Susanne Greiff and Dieter Quast, 2017. Römisch-Germanisches Zentralmuseum, Mainz, Germany, RGZM-Conferences, Vol. 30, 332 pages, illus., ISBN 978-3884672716. €44.00 softcover.

Enthusiasts of ancient gems and jewellery will be pleased to know that the German Federal Ministry of Education and Research has sponsored a project called 'Weltweites Zellwerk/International Framework', which examines changes in the cultural significance of early medieval gemstone jewellery against the background of economic history and the transfer of ideas and technologies. The project led to an international conference titled *Gemstones of the First Millennium* AD, held in Mainz, Germany, in October 2015. An impressive group of international researchers participated, with backgrounds in archaeology, history and natural sciences, and their findings were published in the proceedings volume being reviewed here. The researchers focused on trade activities, production methods and interpreting cross-cultural dynamics through gem materials—garnet in particular—during the first millennium AD.

This substantial volume demonstrates the intricate modern research methods used in the interpretation of ancient gems. The chapters, by various authors, are presented in three main sections: (1) Mines and Trade, (2) Gemstone Working and (3) The Value and the Symbolic Meaning(s) of Gemstones, as well as an additional Poster Session section.

The Mines and Trade section consists of six chapters presenting studies on the intensive trade of raw and finished products, including gems, between Ancient Rome and the South Sea China region through seafarers, as well as overland to the Indian sub-continent via the Punjab area, the Hindu Kush mountains and the Arabian Peninsula. The researchers discuss the possibilities of cultural exchange along these routes and the various types of exotic goods such as garnet, amber and beaver fur. Considering the popularity of cloisonné work of the era, garnet was a desirable gem material, and the Europeans might have reached out to deposits in the East as well as local sources. It is compelling to see how the authors studied particular gem and mineral products to understand the trade dynamics and cultural exchange of the first millennium AD.

The Gemstone Working section consists of five chapters and presents studies of the era's gem-cutting workshops, mining regions, trade routes of raw materials and manufacturing techniques. These subjects are presented through garnet and rock crystal research in different regions including Sweden, East Africa (Kenya to Madagascar), Egypt and Germany.

The section titled The Value and the Symbolic Meaning(s) of Gemstones contains six chapters. Following the more evidential and practical study of trade routes, exotic goods and manufacture of gemstones, the authors discuss the value and meaning of gemstones (incorporating religious and magical symbolism) in the context of the first millennium AD. Traditionally, researchers interpret ancient writings and

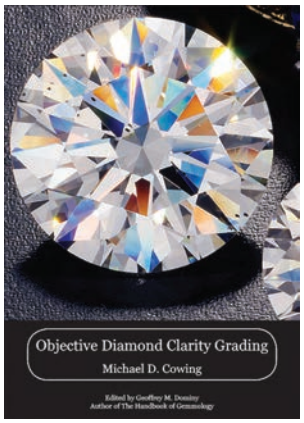
therefore rely on textual evidence to explain the aforementioned concepts. These texts include religious and mythical scripture as well as translations from different eras. Hence the interpretations of the meaning and value of the ancient objects might not be clear to the modern world. However, today's technology allows scientists to use more solid evidence for establishing gemstone identity and determining origin beyond speculation. This section also addresses the issue of gem identification and terminology, as most archaeologists rely on information in the translated ancient texts rather than taking advantage of modern identification and classification techniques. The symbolism of gemstones in different religions such as Hinduism, Christianity and Islam of the first millennium AD is also discussed with specific examples in different chapters of this section.

The section covering the Poster Session includes six studies, mainly focusing on garnet jewellery of the era, and provides informative images.

The International Framework project, and this accompanying publication, provide a rare and inspirational example of multidisciplinary work pertaining to gemmology. Reading this volume makes the modern gemmologist realize that the nomenclature issues we face on a daily basis are also engrained in the historical studies, and it will take time for some scientists to embrace modern gemmological terminology. The volume should appeal not only to gem historians but also to archaeologists, art historians, gemmologists and archaeometry researchers. It is refreshing to see the growing interest in multidisciplinary sciences incorporating gemmology.

Dr Çiğdem Lüle FGA DGA GG
Kybele LLC, Buffalo Grove, Illinois, USA

Objective Diamond Clarity Grading



By Michael D. Cowing, 2017. Amazonas Gem Publications, Mallorca, Spain, 138 pages, illus., ISBN 978-0998483702. US$19.95 ebook.

The author of this book, Michael D. Cowing, has been studying diamond design, light performance analysis and grading for a long time. This book expands on his article published in *The Journal* (Cowing, 2014), and explains an objective methodology for diamond clarity grading using more than 100 examples accompanied by magnified images and clarity diagrams. As an ebook, it is available in various formats for computer, smartphone or tablet, and allows the user to highlight text or insert memos, as well as zoom in on photos and bookmark pages.

Cowing's objective diamond clarity grading system is based on concepts proposed by Roy Huddlestone and Kazumi Okuda, and includes aspects of GIA clarity grading gathered through interviews with authorities who were involved with GIA's laboratory. According to Cowing, the system yields results that have a high degree of consistency with clarity grades determined by GIA or AGS. In this book, the author demonstrates that anyone, regardless of their degree of expertise, can use this system to obtain a diamond clarity grade that is very close to that determined by these laboratories.

Chapter 1 describes how grade-maker inclusions (e.g. a single large inclusion or a small number of similar major inclusions) often determine a diamond's clarity grade. Such inclusions are evaluated by assessing five factors: size, number, contrast (colour and relief), position and nature. Among these, size is the main factor that determines the visibility of a given inclusion; therefore, the size of a grade-maker inclusion plays a key role in determining the initial grading call in this system.

Chapter 2 examines the clarity characteristics that experienced graders use to arrive at a clarity grade. Each decrease in clarity grade corresponds to a large (2×) multiplicative increase in inclusion size and visibility. Also discussed is the influence of a larger inclusion of consistent size on the clarity grade of different-sized diamonds.

Chapter 3 explains an orderly sequence of steps that are followed to reach the initial clarity call based on inclusion size, using graphs and diagrams. The influence of the various factors mentioned above is considered, as evaluated at GIA's laboratories. The system also includes adjustments for the reflection or appearance of an inclusion (or multiple inclusions) from the sides or pavilion of a stone, as well as the visibility of an inclusion under overhead lighting, consistent with the viewing environment used at GIA for determining a final clarity grade.

Starting with Chapter 4, the book then illustrates examples of each clarity grade using photos and clarity diagrams of a large number of diamonds graded by GIA or AGS. In these chapters, the reader can take advantage of the ability of the digital format to zoom in on the photos and diagrams while referring to the text. This is particularly useful to confirm VVS_1-class inclusions, and provides a higher level of understanding of all the clarity grades.

I believe that readers will want to use Cowing's system because it provides a standardized method to give more consistent clarity grading results. The system shows how the relationship of increasing inclusion size (by a factor of two in dimension and a factor

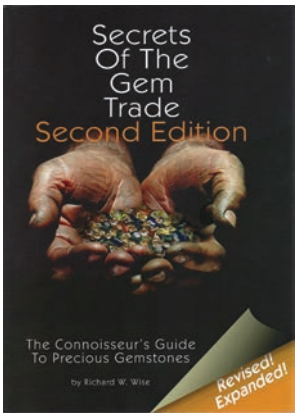
of four in area) varies almost consistently from grade to grade across the entire scale. Furthermore, adjustments for the number, contrast and position of inclusions that influence a clarity grade can be quantified. These features suggest that diamond clarity grading could be automated in the future.

Reference

Cowing M.D. 2014. Objective diamond clarity grading. *Journal of Gemmology*, **34**(4), 316–333, http://dx.doi.org/10.15506/jog.2014.34.4.316.

Yoichi Horikawa FGA
Central Gem Laboratory, Tokyo, Japan

Secrets of the Gem Trade, 2nd edn.



By Richard W. Wise, 2016. Brunswick House Press, Lenox, Massachusetts, USA, 404 pages, illus., ISBN 978-0972822329. US$99.95 hardcover.

Why publish a second edition of the successful *Secrets of the Gem Trade*? Wise perhaps explains it best in his preface: "This second edition has been enlarged and largely rewritten. Five new introductory essays and 10 new chapters have been added together with numerous photographs." The new volume has 64 chapters and covers 45 gems that Wise believes "should be included in any contemporary list of precious gemstones". He has added 11 more gems in this second edition. He also notes "that the essays in this edition assume that the reader has studied and understands" the principles in his first edition.

The table of contents covers four pages, and is followed by a five-page preface titled 'Lifting the Veil', which personalizes Wise's experience learning the secrets of the trade, followed by an introduction written by Vincent Pardieu and a foreword penned by Benjamin Zucker, both well-known authors who praise this second edition.

The book is then divided into Parts 1 and 2. Each chapter starts off with a relevant quotation, often by historic gem authors—a nice touch. In Part 1, the first seven chapters (90 pages) cover gemmology, history, connoisseurship, enhancement and new sources. Wise redefines the 'Four Cs' (colour, cut, clarity and carat weight) by adding a fifth C: 'crystal'. He often uses this term 'crystal' instead of referring to a gemstone as being transparent or diaphanous in his descriptions of the individual gem materials. This reviewer thinks this term belongs together with the concept of clarity—perhaps as a top clarity.

Part 2 is titled 'A New List of Precious Gemstones'. It starts with Chapter 8, on page 91, with alexandrite and continues to page 361, Chapter 54, on cobalt-blue spinel. Throughout these chapters are numerous images of historic subjects, gem mining areas, gemstones and fine jewellery pieces. Notable photographers are given credits throughout.

The book ends with a good glossary, a five-page bibliography and an extensive 16-page index to make finding information easy.

Both editions of *Secrets of the Gem Trade* showcase Wise's passion for the gemstone world. This reviewer recommends this book to amateurs and professionals alike.

William F. Larson FGA
Palagems.com, Fallbrook, California, USA

OTHER BOOK TITLES*

Coloured Stones

Collector's Guide to Silicates: Orthosilicates (Silicate Mineralogy)
By Robert Lauf, 2017. Schiffer Publishing Ltd, Atglen, Pennsylvania, USA, 240 pages, ISBN 978-0764352867. US$45.00 hardcover.

Jade: From Emperors to Art Deco
By Marie-Catherine Rey and Huei-chung Tsao, 2017. Somogy Editions d'Art, Paris, France, 288 pages, ISBN 978-2757211779. €38.00 hardcover.

Diamond

Buying Sierra Leone Rough Diamonds with "Small Small Money"
By Greg Lyell, 2017. Self-published, 66 pages, ASIN B07387HH2H. US$5.00 Kindle edition.

Genesis of Diamonds and Associated Phases
By Yuriy A. Litvin, 2017. Springer, Cham, Switzerland,

* Compiled by Sarah Salmon and Brendan Laurs

137 pages, ISBN 978-3319545424. €90.47 hardcover and €71.39 eBook.

Koh-i-Noor: The History of the World's Most Infamous Diamond
By William Dalrymple and Anita Anand, 2017. Bloomsbury Publishing, London, 160 pages, ISBN 978-1408888841. £14.99 hardcover.

Stateless Commerce—The Diamond Network and the Persistence of Relational Exchange
By Barak D. Richman, 2017. Harvard University Press, Cambridge, Massachusetts, USA, 192 pages, ISBN 978-0674972179. US$35.00 hardcover.

General Reference

Care and Documentation of Mineral Collections
By Jean F. DeMouthe, 2017. Mineralogical Society of America, Chantilly, Virginia, USA, 94 pages, ISBN 978-0939950997. US$30 softcover.

***Gems of the World,* 2nd edn.**
By Cally Oldershaw, 2017. Firefly Books, Richmond Hill, Ontario, Canada, 256 pages, ISBN 978-0228100072. US$24.95 softcover.

Mineral Collections in California
By Don and Gloria Olson and Wendell Wilson, 2017. Mineralogical Record Inc., Tucson, Arizona, USA, 296 pages. US$70.00 hardcover.

Minerals and Gemstones: 300 of the Earth's Natural Treasures
By David C. Cook and Wendy L. Kirk, 2017. Amber Books Ltd., London, 320 pages, ISBN 978-1782742593. £9.99 flexibound.

Jewellery and *Objets d'Art*

Bulgari, the Joy of Gems: Magnificent High Jewelry Creations (Legends)
By Vivienne Becker, 2017. Assouline Publishing, New York, New York, USA, 240 pages, ISBN 978-1614286158. US$250.00 hardcover.

Christie's: The Jewellery Archives Revealed
By Vincent Meylan, 2016. ACC Art Books, Woodbridge, Suffolk, 244 pages, ISBN 978-1851498475. £55.00 hardcover.

Clasps—4,000 Years of Fasteners in Jewellery
By Anna Tabakhova, 2017. Éditions Terracol, Paris, France, 288 pages, ISBN 978-2953521856. €55 hardcover.

Cravat & Tie Pins
By James G. Gosling, 2017. Self-published, Wolverhampton, West Midlands, 100 pages, ISBN 978-1526206800. £35.00 hardcover.

Embossing, Punching and Guilloché Engraving: Contemporary Artisanal Jewellery Production
Ed. by Andreas Gut and Frida Dorfer, 2017. Arnoldsche Art Publishers, Stuttgart, Germany, 156 pages, ISBN 978-3897905108. €28.00 softcover.

Enduring Splendor: Jewelry of India's Thar Desert
By Thomas K. Seligman and Usha R. Balakrishnan, 2017. Fowler Museum, University of California, Los Angeles, California, USA, 136 pages, ISBN 978-0990762645. US$25.00 paperback.

In Quest of the Indescribable: The Artistry and Life of a Gem Carver
By Glenn Lehrer, 2016. Gemporia, Lewes, Delaware, USA, 288 pages, ISBN 978-0995683907. US$29.99 softcover.

The Jewellery Box – Danish Jewellery Art of the 20th Century
By Jens Ingvordsen, 2017. Strandberg Publishing, Copenhagen, Denmark, 323 pages, ISBN 978-8792949882. DKK350 hardcover.

Jewellery Matters
By Marjan Unger and Suzanne van Leeuwen, 2017. NAI010 publishers and the Rijksmuseum, Amsterdam, The Netherlands, 640 pages, ISBN 978-9462083752. €39.95 hardcover.

Jewelry: From Pearls to Platinum to Plastic
By Ulysses Grant Dietz and Newark Museum, 2017. Newark Museum, New Jersey, USA, 66 pages. ISBN 978-0932828453. US$29.95 softcover.

Nubian Gold: Ancient Jewelry from Sudan and Egypt
By Peter Lacovara and Yvonne J. Markowitz, 2017. The American University in Cairo Press, Cairo, Egypt, 224 pages, ISBN 978-9774167829. £39.95 hardcover.

Oscar Heyman: The Jewelers' Jeweler
By Yvonne J. Markowitz and Elizabeth Hamilton, 2017. MFA Publications, Museum of Fine Arts, Boston, Massachusetts, USA, 160 pages, ISBN 978-0878468362. US$45.00 hardcover.

Spectacular: Gems and Jewelry from the Merriweather Post Collection
By Liana Paredes, 2017. D Giles Ltd., London, 200 pages, ISBN 978-1907804922. £29.95 hardcover.

Women Jewellery Designers
By Juliet de la Rochefoucauld, 2017. Antique Collectors Club, Woodbridge, Suffolk, 360 pages, ISBN 978-1851497416. £60.00 hardcover.

Organic Materials

Nautilus: Beautiful Survivor: 500 Million Years of Evolutionary History
By Wolfgang Grulke, 2016. At One Communications, 224 pages, ISBN 978-0992974022. £38 hardcover or £120 collectors' boxed edn.

Literature of Interest

Coloured Stones

Age and origin of the tsavorite and tanzanite mineralizing fluids in the Neoproterozoic Mozambique metamorphic belt. J. Feneyrol, G. Giuliani, D. Demaiffe, D. Ohnenstetter, A.E. Fallick, J. Dubessy, J.-E. Martelat, A.F.M. Rakotondrazafy, E. Omito, D. Ichang'i, C. Nyamai and A.W. Wamunyu, *Canadian Mineralogist*, **55**(4), 2017, 763–786, http://dx.doi.org/10.3749/canmin.1600085.

Astérisme pivotant et changeant de couleur dans des saphirs noirs étoilés thaïlandais [Color-changing asterism in black Thai star sapphires]. T.N. Bui, A. Solyga, K. Deliousi and J.-P. Gauthier, *Revue de Gemmologie A.F.G.*, No. 199, 2017, 4–6 (in French with English abstract).

Cotterite [quartz with pearly metallic lustre]: Historical review; extant specimens; etymology of 'Cotterite' and the genealogy of 'Miss Cotter'; new observations on the Cotterite texture. P.D. Roycroft, *Irish Journal of Earth Sciences*, **34**, 2016, 45–78, http://dx.doi.org/10.3318/ijes.2016.34.45.

Gemmological and spectral characteristic of zultanite: Colour-change diaspore. M. Ye, A.H. Shen and P. Wei, *Journal of Gems & Gemmology*, **18**(5), 2016, 34–39 (in Chinese with English abstract).

The Hamlin [tourmaline] Necklace. R. Alonso-Perez and T. Smith, *GemGuide*, **36**(4), 2017, 8–10.

How to facet gem-quality chrysoberyl: Clues from the relationship between color and pleochroism, with spectroscopic analysis and colorimetric parameters. Z. Sun, A.C. Palke, J. Muyal and R. McMurtry, *American Mineralogist*, **102**(8), 2017, 1747–1758, http://dx.doi.org/10.2138/am-2017-6011.

Identification characteristic of natural nephrite pebble from West Kunlun, Xinjiang, China. Y. Zhang, T. Lu, P. Deng, H. Chen, J. Ke, L. Bi, X. Feng and S. Yang, *Journal of Gems & Gemmology*, **18**(5), 2016, 7–14 (in Chinese with English abstract).

Inclusions in natural, synthetic, and treated sapphire [chart]. N.D. Renfro, J.I. Koivula, J. Muyal, S.F. McClure, K. Schumacher and J.E. Shigley, *Gems & Gemology*, **53**(2), 2017, 213–214, http://dx.doi.org/10.5741/GEMS.53.2.213.*

The origin of needle-like rutile inclusions in natural gem corundum: A combined EPMA, LA-ICP-MS, and nanoSIMS investigation. A.C. Palke and C.M. Breeding, *American Mineralogist*, **102**(7), 2017, 1451–1461, http://dx.doi.org/10.2138/am-2017-5965.

Pink and red spinels in marble: Trace elements, oxygen isotopes, and sources. G. Giuliani, A.E. Fallick, A.J. Boyce, V. Pardieu and V.L. Pham, *Canadian Mineralogist*, **55**(4), 2017, 743–761, http://dx.doi.org/10.3749/canmin.1700009.

Research on the gemological characteristics of blue kyanite and its color contributing factors. J. Luo, X. Yan and L. Chen, *Superhard Material Engineering*, **28**(5), 2016, 57–61 (in Chinese with English abstract).

Why are some crystals gem quality? Crystal growth considerations on the "gem factor". E. Fritsch, B. Rondeau, B. Devouard, L. Pinsault and C. Latouche, *Canadian Mineralogist*, **55**(4), 2017, 521–533, http://dx.doi.org/10.3749/canmin.1700013.

Cultural Heritage

Ancient sapphires and adventures in Ceylon. H. Molesworth, *Gems&Jewellery*, **26**(3), 2017, 28–31.

Laboratory analysis of an extraordinary artefact: A sapphire tiara found during the excavations in Colonna (Rome). E. Butini and F. Butini, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 1, 2017, 37–43, www.rivistaitalianadigemmologia.com/en_GB/category/magazine.*

Le talisman de Charlemagne: nouvelles decouvertes historiques et gemmologiques [The talisman of Charlemagne: New historical and gemmological discoveries]. G. Panczer, G. Riondet, L. Forest, M.S. Krzemnicki and F. Faure, *Revue de Gemmologie A.F.G.*, No. 199, 2017, 18–25 (in French).

Diamonds

Carbonado diamond: A review of properties and origin. S.E. Haggerty, *Gems & Gemology*, **53**(2), 2017, 168–179, http://dx.doi.org/10.5741/GEMS.53.2.168.*

Geology and development of the Lomonosov diamond deposit, northwestern Russia. K.V. Smit and R. Shor, *Gems & Gemology*, **53**(2), 2017, 144–167, http://dx.doi.org/10.5741/GEMS.53.2.144.*

Think pink: Exploring the pink in diamond. A. Casdagli, *Gems&Jewellery*, **26**(3), 2017, 32–35.

Gem Localities

Big sky country sapphire: Visiting Montana's alluvial deposits. T. Hsu, A. Lucas, R.E. Kane, S.F. McClure and N.D. Renfro, *Gems & Gemology*, **53**(2), 2017, 215–227, http://dx.doi.org/10.5741/GEMS.53.2.215.*

* Article freely available online, as of press time

Découverte de spinelle vert en Afghanistan [Discovery of green spinel in Afghanistan]. M.B. Vyas, *Revue de Gemmologie A.F.G.*, No. 199, 2017, 8–10 (in French).

The forbidden road to Chila [Ethiopian sapphires]. S. Bruce-Lockhart, *Gems&Jewellery*, **26**(3), 2017, 10–12.

The lifecycle of a sapphire rush [Bemainty, Madagascar]. R. Perkins, *Gems&Jewellery*, **26**(3), 2017, 14–15.

Reflectance spectroscopy and hyperspectral imaging of sapphire-bearing marble from the Beluga occurrence, Baffin Island, Nunavut. D. Turner, L.A. Groat, B. Rivard and P.M. Belley, *Canadian Mineralogist*, **55**(4), 2017, 787–797, http://dx.doi.org/10.3749/canmin.1700023.

Smaragde aus Äthiopien [Emeralds from Ethiopia]. C. C. Milisenda, S. Koch and S. Müller, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **66**(1/2), 2017, 59–62 (in German with English abstract).

An update on tourmaline from Luc Yen, Vietnam. N.T. Nhung, L.T.T. Huong, N.T.M. Thuyet, T. Häger, N.T.L. Quyen and T.T. Duyen, *Gems & Gemology*, **53**(2), 2017, 190–203, http://dx.doi.org/10.5741/GEMS.53.2.190.*

Instrumentation

Characterization of Mg and Fe contents in nephrite using Raman spectroscopy. X. Feng, Y. Zhang, T. Lu and H. Zhang, *Gems & Gemology*, **53**(2), 2017, 204–212, http://dx.doi.org/10.5741/GEMS.53.2.204.*

Gemological applications of UV-Vis-NIR spectroscopy. A. Scarani and M. Åström, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 1, 2017, 32–35, www.rivistaitalianadigemmologia.com/en_GB/category/magazine.*

Handheld spectroscopy. C. Mitchell, *GemGuide*, **36**(4), 2017, 11–13.

Miscellaneous

Navigating coloured gemstone laboratories. C. Williams, *Gems&Jewellery*, **26**(3), 2017, 16–19.

What is a gem? M. Macrì, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 1, 2017, 21–23, www.rivistaitalianadigemmologia.com/en_GB/category/magazine.*

News Press

Beads made from meteorite reveal prehistoric culture's reach. T. Watson, *Nature.com*, 15 May 2017, www.nature.com/news/beads-made-from-meteorite-reveal-prehistoric-culture-s-reach-1.21990.*

Bird caught in amber 100 million years ago is best ever found. M. Le Page, *New Scientist*, 7 June 2017, www.newscientist.com/article/2133981-bird-caught-in-amber-100-million-years-ago-is-best-ever-found.*

Organic Gems

A connection to coral. M. Campbell Pedersen, *Gems&Jewellery*, **26**(3), 2017, 24–26.

Gas bubble characteristic of translucent to opaque amber and its relationship to quality assessment. Y. Wang, Q. Wang and S. Nie, *Journal of Gems & Gemmology*, **18**(5), 2016, 20–27 (in Chinese with English abstract).

Simulants

Diaspor mit Farbwechsel und eine Glas-Imitation [Diaspore with colour-change and a glass imitation]. H.A. Hänni, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **66**(1/2), 2017, 31–38 (in German with English abstract).

Identification of turquoise imitation. H. Zhu, Y. Cheng and G. Shan, *Superhard Material Engineering*, **28**(6), 2016, 58–60 (in Chinese with English abstract).

Structure ordonnée d'une imitation d'oeil-de-chat en fibres de verre arrangement en carré [Orderly structure of a cat-eye imitation in glass fibres arranged in a square]. J.-P. Gauthier, J. Fereire and F. Mazzero, *Revue de Gemmologie A.F.G.*, No. 199, 2017, 12–16 (in French with English abstract).

Synthetics

Fluid CH_4 and H_2 trapped around metallic inclusions in HPHT synthetic diamond. E.M. Smith and W. Wang, *Diamond and Related Materials*, **68**, 2016, 10–12, http://dx.doi.org/10.1016/j.diamond.2016.05.010.

Gemmological characteristic of hydrothermal synthetic Paraíba-colour beryl. Q. Zhong, Z. Liao, Z. Zhou and H. Wang, *Journal of Gems & Gemmology*, **18**(6), 2016, 1–7 (in Chinese with English abstract).

An overview of the properties and detection methods of synthetic diamonds currently in the market. T. Hainschwang, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 1, 2017, 25–31, www.rivistaitalianadigemmologia.com/en_GB/category/magazine.*

Photoluminescence mapping of optical defects in HPHT synthetic diamond. L.C. Loudin, *Gems & Gemology*, **53**(2), 2017, 180–188, http://dx.doi.org/10.5741/GemS.53.2.180.*

A sapphire's secret. E. Billie Hughes, *GemGuide*, **36**(4), 2017, 18–20.

The strange revival of diffused sapphires. But this time they are synthetic. A. Scarani and P.

Minieri, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 1, 2017, 11–13, www.rivistaitalianadigemmologia.com/en_GB/category/magazine.*

Zur Unterscheidung von natürlichen und synthetischen Quarzen – eine aktuelle Betrachtung [On the distinction between natural and synthetic quartz – A current observation]. U. Henn, T. Stephan and F. Schmitz, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **66**(1/2), 2017, 7–30 (in German with English abstract).

Compilations

***G&G* Micro-World.** Iridescence in aquamarine • Chlorapatite crystals in quartz • 'Christmas tree' feature in diamond • Cosalite inclusions in quartz • Kyanite in diamond • Red oil treatment of Burmese ruby • Concentric 'eyes' in sapphire • Molybdenite phantoms in quartz. *Gems & Gemology*, **53**(2), 2017, 240–246, http://tinyurl.com/ycq53u5u.*

Gem News International. Sapphire from northern Ethiopia • Mexican common opal • Red garnet with black core • 'Sango' akoya cultured pearl • Tektite with large fluid inclusion • Dyed freshwater cultured pearls imitating South Sea cultured pearls • 'Starburst Stone' chatoyant glass • Titanium nitride coating of chalcedony bead necklace • Tri-color-change synthetic cubic zirconia. *Gems & Gemology*, **53**(2), 2017, 247–260, http://tinyurl.com/y9yc5ouu.*

Gemmologie aktuell [Gemmology update]. Goyazite from Fichtelgebirge, Germany • 'Billitonite' tektite from Indonesia • Lemurian quartz with natural limonite overgrowth. *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **66**(1/2), 2017, 3–6 (in German and English).

Lab Notes. Concentric inclusions in diamond • Unusual fluorescence distribution in diamond • Cat's-eye kornerupine • Conch 'rosebud' pearls • Partially hollow *Tridacna* blister pearls • Atypical bead-cultured pearls with unusual nacre growth • Punsiri heat treatment of basaltic blue sapphire • CVD synthetic submitted for verification of a previously graded natural diamond • Melee parcel composed of one-third CVD synthetic diamonds • CVD synthetic overgrowth on natural diamond • HPHT synthetic diamond melee in jewellery. *Gems & Gemology*, **53**(2), 2017, 228–239, http://tinyurl.com/ybj5xtpm.*

World Ruby Forum 2017

Bangkok, Thailand

"How Red is Your Love"

In association with CIBJO Congress

November 4th, 2017

At Grand Ballroom, Shangri-La Hotel, Bangkok

Big Day Event

- The World Ruby Forum Opening Ceremony
- Panel Discussion With Leaders of The Gem & Jewelry Industry
- The World's Ruby Gala Night

* Seminar Fee 50 USD, Gala Fee 100 USD

Online Registration at www.worldrubyforum.com

DITP Department of International Trade Promotion Ministry of Commerce, Royal Thai Government

GIT

JTC Jewelry Trade Center Bangkok

AIGS Asian Institute of Gemological Sciences

A. F. G.

Pala International

Palagems.com / Palaminerals.com

+1 800 854 1598 / +1 760 728 9121

Padparadscha Sapphire from Malawi • 5.65 ct • 12.08 x 9.80 x 6.34 mm

Bloom from Pala International Grounds • Photo: Mia Dixon