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Characteristics of Natural-Color Blue Diamonds

Black Diamonds from Zimbabwe

Characterization of Yogo Sapphires

Synthetic Diamonds Chart

system allowed inclusions beneath the surface to be analyzed. The black core was identified as an FeS_2 (iron sulfide) mineral, likely pyrite. The brownish tiny inclusions in arms could not be identified but were likely goethite (E.J. Gübelin and J.I. Koivula, *Photoatlas of Inclusions in Gemstones*, Vol. 2, Opinio Verlag, Basel, Switzerland, p. 558) based on appearance and occurrence in quartz matrix.

The texture of trapiche-like amethysts is often caused only by the distribution of color-inducing elements (K. Schmetzer and B. Williams, "Gem-quality amethyst from Rwanda: Optical and microscopic properties," *Journal of Gemmology*, Vol. 36, No. 1, 2018, pp. 26–36). The fact that the texture was caused by two sets of distinctly colored inclusions makes these four gemstones unique.

Ziyin Sun, Jonathan Muyal, and Dylan Hand

Twelve-rayed star sapphire from Thailand. The Thai city of Chanthaburi is a well-known international trading hub for colored gemstones but was once an important corundum mining center. In recent decades, mining activity in the area has decreased, but there are still several smaller-scale operations active. The 3.6 ct 12-rayed black star sapphire shown in figure 9 was mined in 2017 in Bang Kha Cha (or Bang Kaja), a mining locality near Chanthaburi.

Figure 9. A 12-rayed black star sapphire, weighing 3.6 ct, with one set of golden rays and another set of silver rays producing two different-colored stars. Photo by Simon Bruce-Lockhart.

Thailand's gemstone deposits typically produce blue, green, and yellow sapphires (and combinations of these colors). The deposits in eastern Thailand also produce a peculiar sapphire variety: black star sapphire. This variety is found in other basalt-related deposits like Australia, but they rarely match the size, quality, and abundance that the Thai stones are famous for.

The black color is due to a very high concentration of Fe-rich particles, identified as hematite and ilmenite. This high density of particles completely masks the bodycolor of the stone. When strongly illuminated from the back, glimpses of the bluish green bodycolor in this gem can be seen. If the platy, Fe-rich particles are oriented in the correct way, they result in a six-rayed star pattern. This star is often yellowish golden in color.

Another common inclusion in corundum is rutile needles. When they are abundant and correctly oriented in the crystal, this might also result in a six-rayed pattern, often with a whitish silvery color. In some cases, both of these patterns overlap, creating a 12-rayed star with one set of golden-yellow rays and one set of silver-white rays. The stone in figure 9 is an excellent example of this phenomenon, displaying well-centered, sharp asterism with two different-colored stars.

Wim Vertriest
GIA, Bangkok

Simon Bruce-Lockhart
Chanthaburi, Thailand

Update on trace-element chemical characteristics of golden sheen sapphire. GIA's Tokyo laboratory recently examined 23 sapphires displaying a "golden sheen" effect, reportedly from Kenya (e.g., T.N. Bui et al., "From exsolution to 'gold sheen': A new variety of corundum," *Journal of Gemmology*, Vol. 34, No. 8, 2015, pp. 678–691). Bui et al. (2015) were the first to describe gemological characteristics of golden sheen sapphires from Kenya; updated characteristics of inclusions, UV-Vis-NIR spectra, and chemistry of golden sheen material was published the following year (N. Narudeesombat et al., "Golden sheen and non-sheen sapphires from Kenya," The Gem and Jewelry Institute of Thailand, July-August 2016, pp. 282–288; Winter 2016 Lab Notes, pp. 413–414). Here we update the gemological and chemical characteristics of the recently examined material, and compare the information with various sapphire sources including other golden sheen sapphire data previously documented.

We examined 15 cabochons, three faceted, and five rough stones (figure 10). The samples were semi-transparent to opaque, with a blue and yellow bodycolor and weight range of 1.75 to 34.00 ct. The cabochons displayed a "golden sheen" effect and/or golden six-ray asterism. For the polished samples, standard gemological testing revealed RI values of 1.760 to 1.770 and hydrostatic SG values of 3.98–4.01, except for one densely included stone with an SG of 4.04 (see Lab Notes this issue, pp. 212–213). These SG values suggested that they were all corundum. The rough stones showed SG values of 3.82–4.01 and the Raman signatures of corundum.

The inclusions were similar to those in other golden sheen sapphires described by Bui et al. (2015) and Narudeesombat et al. (2016). Characteristics included dense clouds composed of brownish needles and platelets displaying a golden sheen effect. Raman analysis identified the needles as ilmenite and hematite, although their Raman signals

Figure 10. Eighteen of the 23 golden sheen sapphires examined for their trace-element chemical characteristics. The largest stone weighs 34 ct. Photo by Shunsuke Nagai.

were weak because of their thinness. Some showed six-ray asterism caused by reflection from dense clouds of oriented needles. Inclusion-free zones like the center stone and rough stones in figure 1 contained mineral crystals and healed fissures with negative crystals (see Lab Notes, pp. 212–213). Various euhedral to subhedral mineral inclusions (figure 11) were confirmed as hematite, diaspore, and zircon. Hematite was found as needles and euhedral crystals; these euhedral hematite crystals coexisted with goethite (figure 11B). Some carbonate minerals such as siderite ($FeCO_3$) and dawsonite [$NaAlCO_3(OH)_2$] were found as irregular inclusions with a vein-like appearance, although their primary or secondary origin was unknown (figure 11C, D). Additionally, magnetite and mica (paragonite and muscovite series) were identified.

Quantitative LA-ICP-MS analysis of trace elements on the 23 samples—90 spots in total—is summarized in table 1 and figure 12. Six of the samples had both blue and yellow bodycolors, and only one had a single yellow bodycolor (again, see figure 10). The other 16 contained numerous inclusions and fractures, and were not clear in color distribution. Chemical analyses were conducted on three spots for each blue, yellow, and included zone. The blue zones had high Fe content ranging 2630 to 3486 ppma and low to medium V content of 0.13 to 0.37 ppma. Their Ti concentration was higher than their Mg content. Ga/Mg ratios for the blue zones varied from 3.50 to 25.35. The yellow zones showed similar Fe, V, and Ga contents as the blue zones, with high Fe (2923 to 3846 ppma), low to medium V (0.13 to 0.40 ppma), and Ga/Mg ratios of 7.78 to 10.06. Included zones also showed similar concentrations of all elements as the blue and yellow zones, although some spots tended to be slightly high in Fe, Ti, Al, and Ga. Enrichment in these elements probably indicates compositions of dense inclusion phases, because most of the inclusion phases were Fe-Ti oxides such as hematite and ilmenite, as documented by Bui et al. (2015) and Narudeesombat et al. (2016). *G&G* previously published that other trace elements, such as Zr, Nb, Ta, W, Th, and U, were enriched in the included zones of some golden sheen sapphires (again, see Winter 2016 Lab Notes, pp. 413-414). Only Ta and U were detected in our samples. Elements such as Na and K that can be considered to be related to inclusions were also detected in some spots on included zones.

TABLE 1. Average and range of trace-element concentration of gold sheen sapphires (in ppma).

Sample	Mg	Ti	V	Cr	Fe	Ga	Ga/Mg ratio
Blue zone (6 samples, 18 spots)	5.88 (1.70–9.29)	13.13 (11.00–19.51)	0.24 (0.13–0.37)	bdl	3258 (2841–3486)	37.67 (31.88–45.04)	10.06 (3.50–25.35)
Yellow zone (7 samples, 21 spots)	8.00 (1.95–15.99)	19.38 (9.26–40.22)	0.26 (0.13–0.40)	bdl	3404 (2923–3846)	39.83 (34.32–46.31)	9.08 (2.65–22.90)
Included zone (17 samples, 51 spots)	8.49 (1.95–23.24)	21.56 (3.63–52.5)	0.10 (bdl–0.56)	bdl	3477 (2630–4552)	39.92 (31.78–53.23)	7.78 (2.29–24.89)

Detection limits: 0.049 for Mg, 0.335 for Ti, 0.035 for V, 0.409 for Cr, 5.28 for Fe, and 0.010 for Ga. bdl: below detection limit.

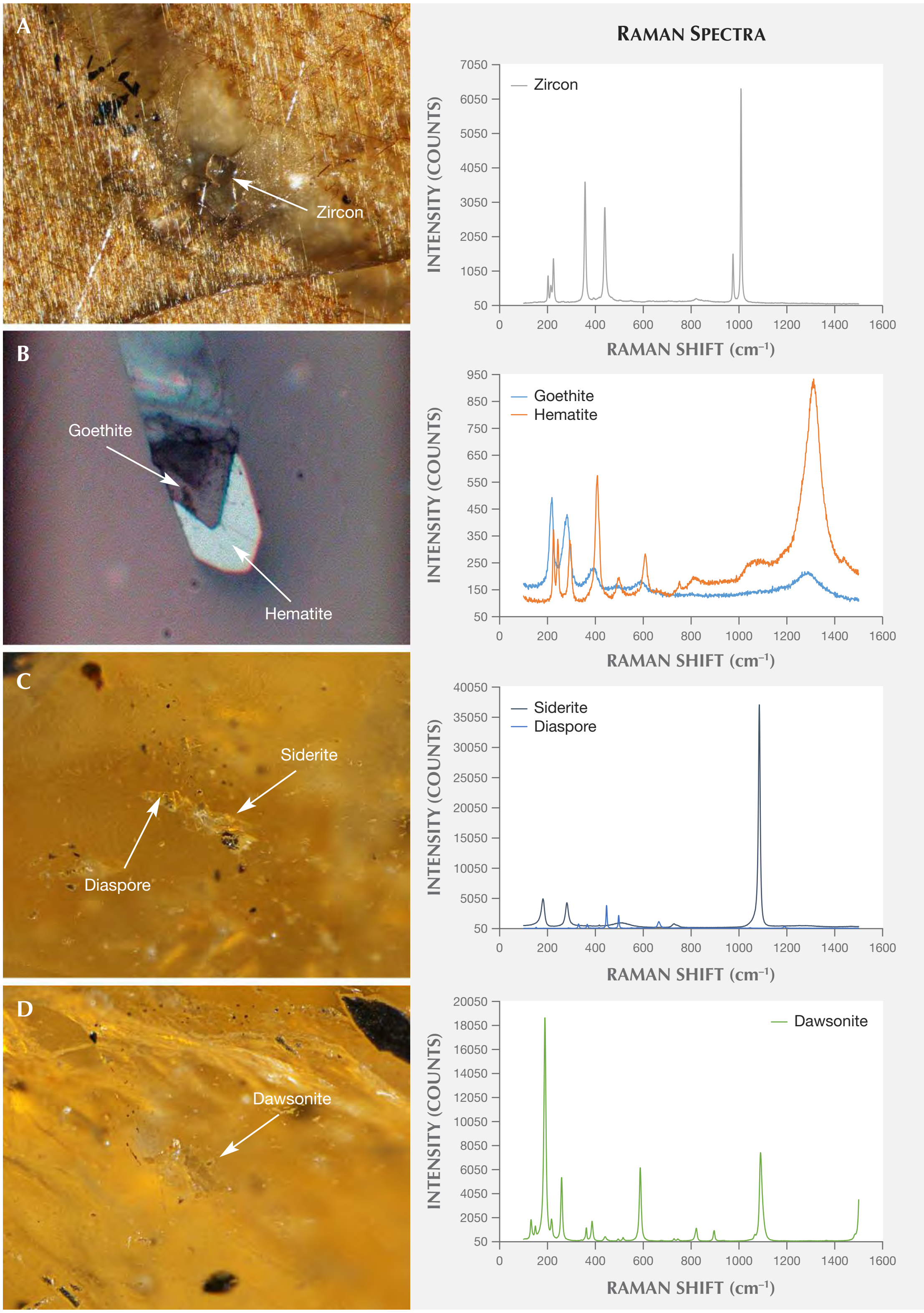

Figure 11. Photomicrographs (left) and Raman spectra (right) of micro-inclusions in golden sheen sapphires: zircon inclusion with intersecting needles (A), hematite and goethite inclusion (B), diaspore and siderite inclusion (C), and dawsonite inclusion (D). Darkfield illumination (A, C, and D) and reflected light (B). Photomicrographs by Makoto Miura; fields of view 1 mm (A), 0.06 mm (B), and 0.8 mm (C and D).

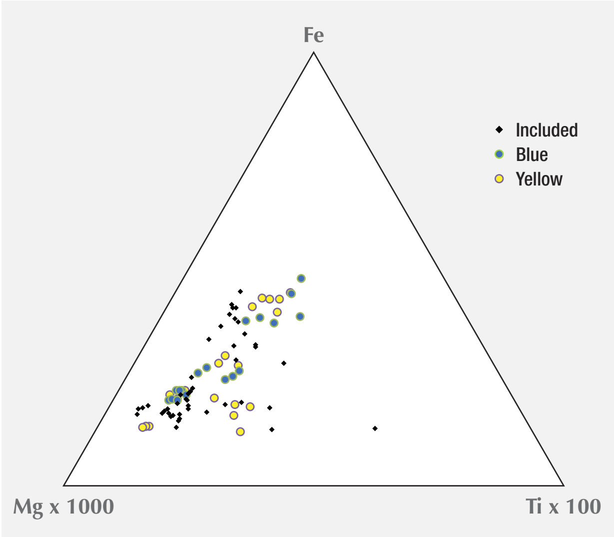

Figure 12. This ternary diagram shows the relationships between Fe, Mg, and Ti in golden sheen sapphires. Note that most of samples have similar Fe, Mg, and Ti content. Some of the yellow and included zones are rich in Mg and Ti.

While golden sheen sapphires are reportedly mined in northeastern Kenya, there is no other published chemical data available from this region. We compared our chemical characteristics with those of other samples documented in the Winter 2016 Lab Notes entry; metamorphic sapphires from Sri Lanka, Myanmar, and Madagascar; and basalt-related sapphires from Thailand, Australia, Nigeria, Kenya, and Cambodia (figure 13). Compositional data for metamorphic and basalt-related sapphires are from previously published articles (J.J. Peucat et al., "Ga/Mg ratio as a new geochemical tool to differentiate magmatic from metamorphic blue sapphires," *Lithos*, Vol. 98, 2007, pp. 262–274; V. Pardieu et al., "Sapphires from the gem rush Bemainty area, Ambatondrazaka (Madagascar)," *GIA News from Research*, Feb. 24, 2017; W. Soonthorntantikul et al., "An in-depth gemological study of blue sapphires from the Baw Mar mine (Mogok, Myanmar)," *GIA News from Research*, Feb. 24, 2017; Fall 2017 GNI, pp. 380–382). As shown in figure 13, the samples in this study were similar to other golden sheen sapphires in Fe, Ga, and V contents. The Fe concentration and high Ga/Mg ratio (table 1) were far from those of metamorphic sapphires but close to those of some basalt-related sapphires. Kenya, where golden sheen sapphires may occur, has two known types of sapphire deposits; one is associated with alkali basalts from the Gregory Rift, an eastern branch of the African Rift Valley, and the other is associated with syenite (Peucat et al., 2007). Both types of sapphire showed a high Fe concentration and Ga/Mg ratio, which are similar to the chemical data in this study.

The similarities in inclusions and trace-element composition between our samples and other golden sheen sapphires indicate that they possibly come from the same origin. A wide variety of inclusions observed in golden sheen sapphires suggests the specific condition during the formation processes. The presence of hematite inclusions especially implied formation in a highly oxidized environment. Further gemological studies are required to construct the database for origin determination.

Makoto Miura, Yusuke Katsurada, and Kazuko Saruwatari
GIA, Tokyo

DIAMONDS

D-color natural IIa diamond with walstromite inclusion. Nondestructive testing methods such as Raman, photoluminescence (PL), and infrared spectroscopy have been

Figure 13. Log plots of chemical variations of Fe vs. Ga contents (expressed in ppma) in golden sheen sapphires. Only blue sapphire data was plotted.