GEMSTONES FROM VIETNAM: AN UPDATE

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This article describes the major gem materials of Vietnam, together with their new finds and recent production. The gemological properties and chemical composition of ruby, sapphire, spinel, tourmaline, garnet, and peridot from the most important Vietnamese sources are updated. Other gems such as aquamarine, green orthoclase, topaz, zircon, quartz, and pearls are briefly discussed. Commercially significant deposits of ruby, blue and fancy sapphire, and spinel are located in two northern provinces: Yen Bai (Luc Yen and Yen Binh Districts) and Nghe An (Quy Chau and Quy Hop Districts). Large volumes of blue, green, and yellow sapphire come from the Central Highlands provinces of Dak Lak and Lam Dong, as well as the southern provinces of Dong Nai and Binh Thuan. Of secondary commercial importance are the tourmaline and garnet from Yen Bai and the peridot and zircon from the Central Highlands.

Vietnam, with an area of 335,000 km^2, occupies the eastern side of the Indochinese peninsula. Most of the country's northern and central regions are mountainous, reaching an elevation of 3,142 m in the Fan Si Pan massif, near the Chinese border. The country is endowed with some 70 gem deposits and 160 different occurrences (Nguyen et al., 1995). Present gem production includes ruby, sapphire, spinel, tourmaline, peridot, garnet, aquamarine, topaz, quartz, and green orthoclase (e.g., figure 1). With more than 3,400 km of coastline, the country is also a source of saltwater cultured pearls, and several farms have emerged in recent decades. In addition, Melo pearls are retrieved by fishermen on the southern coast and in Ha Long Bay in the north. Compared with the country's gem wealth, however, the Vietnamese mining industry remains undeveloped. Although it has been nearly 30 years since colored stones were discovered in Vietnam, mining and pearl farming activities are mostly small- and medium-scale operations run by private individuals or small companies.

See end of article for About the Authors and Acknowledgments.
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In March 1988, state-owned Vinagemco (Vietnamese Gems Company) was established to direct the exploration, mining, and trading of gem materials (Kane et al., 1991; Pham et al., 2004b). Two subsidiaries, Yen Bai Gemstone Company and Nghe An Gemstone Company, were set up in those provinces that same year. Ultimately, management problems led to the company's downfall in July 2003. Since then, no state-owned company has been active in the gem sector. Mining, processing, cutting, and trading are all organized by private and joint-stock companies or private individuals.

Scientific investigations of Vietnamese gem materials, including their properties and the genesis of the deposits, have resulted in several publications, with special attention to ruby and sapphire (e.g., Kane et al., 1991; Koivula and Kammerling, 1991; Kammerling et al., 1994; Smith et al., 1995; Pham et al., 2004a,b; Nguyen et al., 2011). This article updates the occurrence, production, and gemological features of Vietnam's major gem materials, and outlines the geology of the deposits.

GEOLOGY OF VIETNAM

Vietnam consists mainly of mountainous fold belts surrounding the Yangtze and Indochina cratons (figure 2). The most important geologic event was the In-

Figure 1. Vietnam is a contemporary source of several gem varieties, including ruby (center, 2.27 ct), spinel (left and bottom stones, 1.97–5.07 ct), aquamarine (second from right, 3.48 ct) and green orthoclase (top, 3.68 ct). Courtesy of Palagems.com and William Larson; photo by Robert Weldon.

dosinian orogeny (Lepvrier et al., 2008) that occurred in the Lower Triassic Period, 245–240 million years ago (Ma). This tectono-metamorphic episode generated northwest-trending dextral shear zones in central Vietnam, giving rise to the north-directed thrusting in northern Vietnam (Lepvrier et al., 2008). Later, several extensional structures formed during the Mesozoic and the Cenozoic (e.g., the Hanoi and Cuu Long graben; see Kušnír, 2000). During the subsequent India-Eurasia collision at around 50 Ma, the lateral displacement of Indochina produced major strike-slip shearing along the Red River and the opening of the East Vietnamese Sea (Tapponnier et al., 1990; Leloup et al., 2001). Left-lateral shearing along the Red River occurred later, after 21 Ma, and was apparently unrelated to the India-Asia collision (Searle, 2006).

Vietnam is formed by various rocks of Precambrian to Quaternary age. Although the old Precambrian basement was generally reworked during the Indosinian Orogeny, isotopic dating has revealed the existence of a protolith of at least Proterozoic age in the Kontum Massif of central Vietnam. The age of the metamorphic rocks related to ruby, sapphire, and garnet along the Chay and Red Rivers is essentially Tertiary, but this metamorphism is superimposed over earlier events (Searle, 2006). Paleozoic formations are widespread, comprising Cambrian series, thick Silurian formations (including schists and sandstones), and Devonian and Permo-Carboniferous limestones that form vast areas of northern Vietnam. Basalts related to Permian mantle plume activity occur along the Da fault. Lower Triassic series are mainly terrigenous, whereas the middle Triassic consists of limestones and volcanic rocks (Tran et al., 2008). In the troughs formed during the Jurassic and Cretaceous, thick continental series and volcanics accumulated. Tertiary and Quaternary formations were deposited in several graben and troughs, the most important of which are located in the Cuu Long and Red River deltas. Plio-pleistocene tholeiitic basalts (traps) form vast plateaus in southern Vietnam (Kušnír, 2000).

The formation of gems such as ruby, sapphire, and garnet along the Red and Chay Rivers was favored by metamorphic conditions that prevailed during the Cenozoic. The tectonic setting, marked by vertical shearing, allowed the circulation of fluids and the formation of ore deposits. In Luc Yen, the Tertiary age of ruby formation clearly matches that of the shearing movements, as shown by Ar/Ar and U/Pb dating on mica and zircon, respectively (Garnier et al., 2005a, 2006). The same Tertiary age of ruby formation is recorded in the Quy Chau area along the northern border of the Bu Khang Massif, where the shearing was manifested as a north-dipping, low-angle shear zone, in an extensional context (Jolivet et al., 1999).

According to Nguyen and Flower (1998), sapphire and zircon from the Central Highlands were emplaced as xenocrysts in Quaternary basalts that formed as a result of mantle plume activity. Two distinct basalt suites are recognized in the area: tholeiitic (without any xenocrysts) and alkaline (containing mantle and lower crustal xenocrysts, including gems). The U/Pb dating of zircon recovered from the basaltic placers suggests two eruptional events, at ~6.5 and ~1 Ma (Garnier et al., 2005b).

MATERIALS AND METHODS

Most of the samples used for this study were purchased or collected by the authors at the mines from 2009 to 2012. Among these were 339 corundum sam-

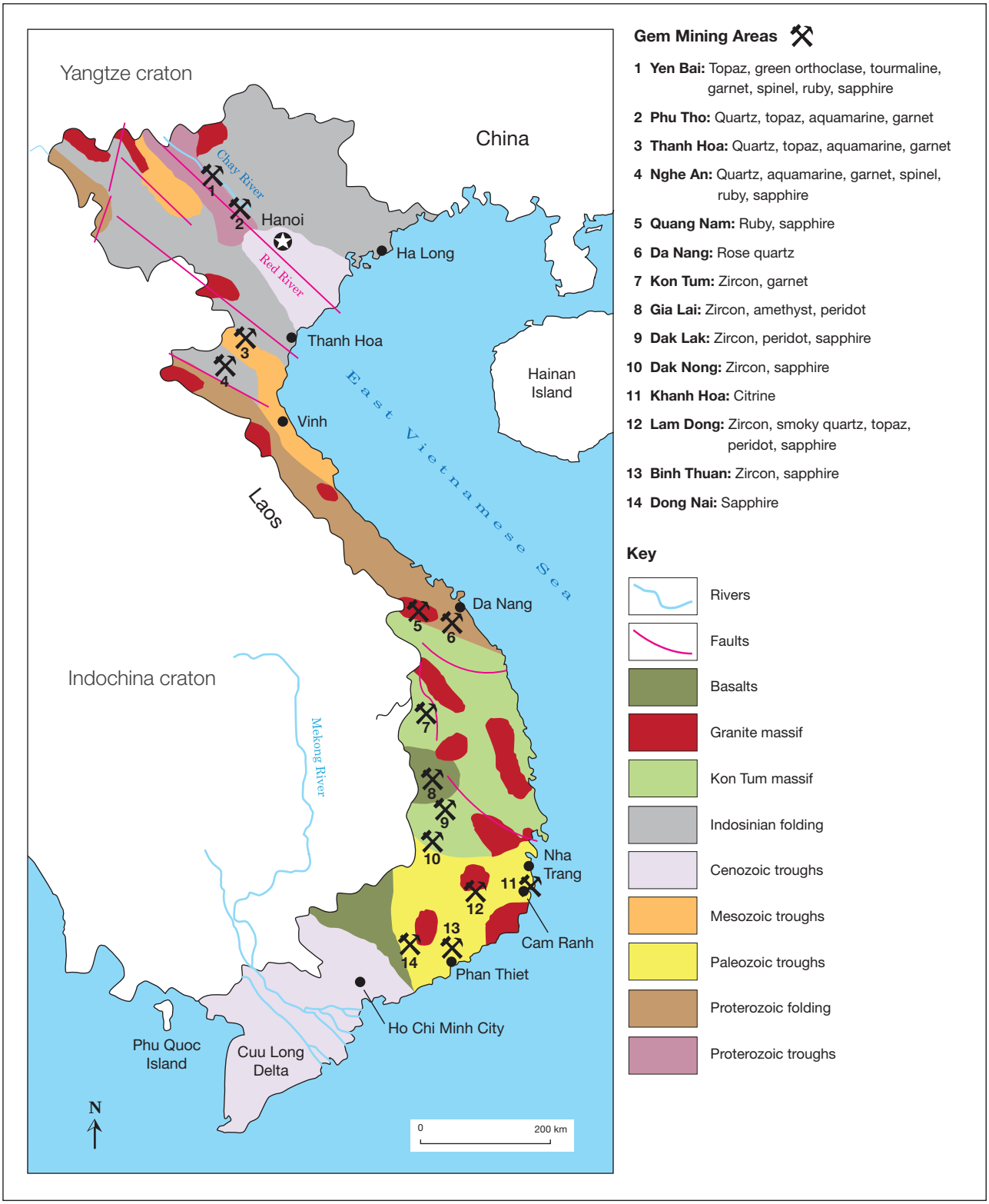


Figure 2. This map shows Vietnam's 14 most important gem provinces and the major geologic environments. Modified after Kušnír (2000) and Lepvrier et al. (2008).

ples, including 143 rough and 196 polished stones (112 faceted and 84 cabochons) ranging from 0.6 to 6.3 ct. We examined 85 faceted spinels and 33 spinel crystals (1.8–4.7 ct) of various colors. The 76 tourmalines (2.4–18.5 ct) consisted of 20 faceted samples, 10 cabochons, and 46 crystals in a variety of colors. We examined 16 faceted garnets (1.5–4.2 ct) and 15 garnet crystals (2.8–6.6 ct), plus 26 faceted and 17 rough peridot (3.2–6.2 ct). The remaining samples consisted of green feldspar: one faceted stone and two cabochons (7.8–8.5 ct), as well as two crystals. Gemological properties of the samples were established using a dichroscope, Schneider refractometer, hydrostatic Shimadzu balance, UV lamp, and Schneider immersion microscope with Zeiss optics.

Electron microprobe analyses of the spinel, tourmaline, peridot, and garnet samples were performed with a JEOL JXA 8900RL instrument equipped with wavelength-dispersive spectrometers, using 20 kV acceleration voltage and 20 nA filament current. The measurements were calibrated with natural minerals and synthetic compound standards. The light elements B and Li were analyzed in the tourmaline samples using an Agilent 7500ce ICP-MS in pulse-counting mode, and ablation was achieved with a New Wave Research UP-213 Nd:YAG laser ablation system, using a pulse repetition rate of 10 Hz, an ablation time of 60 seconds, a dwell time of 10 milliseconds per isotope, a 100 µm crater diameter, and an average of five laser spots for each sample. NIST SRM 612 glass was used as an external calibration standard.

Raman spectra of four feldspar samples were collected with a Jobin Yvon LabRam HR 800 spectrometer coupled with an Olympus BX41 optical microscope and an Si-based CCD (charge-coupled device) detector; samples were excited by a 514 nm green Ar^+ ion laser. Raman microscopy of inclusions in spinel, tourmaline, peridot, and garnet samples was performed in confocal mode, facilitating analysis at the micron scale (2–5 µm).

Powder X-ray diffraction analysis was performed on a portion of one green feldspar sample with a Seifert XRD 3000 TT diffractometer using CuKα radiation (40 kV and 30 mA).

RUBY AND SAPPHIRE

Ruby and several colors of sapphire are found in Yen Bai Province in the north and in Nghe An and Quang Nam Provinces in central Vietnam. Sapphire also occurs in the provinces of Lam Dong, Dak Nong, Dak Lak, Binh Thuan, and Dong Nai in the Central Highlands and southern provinces. While corundum was discovered almost three decades ago in the north, Vietnamese geologists did not find the gems in the central and southern provinces until the early 2000s. Among these localities, Yen Bai remains the most important source of ruby and fancy sapphire, whereas central Vietnam is the main supplier of blue to dark blue sapphire.

The older mines in Yen Bai have been exploited since before the mid-1990s, and many of them have been abandoned. All the old mines (including Nuoc Ngap, Hin Om, Khau Nghien, Vang Sao, May Thuong, May Ha, Phai Chap, Tan Lap, and Lam Dong) are located in Luc Yen District, mainly near Khoan Thong and An Phu along the east side of the Chay River. The newer mines in Yen Bai (opened since the mid-1990s) are situated on the west side of the Chay River. These include the Lang Chap and Truc Lau areas of Luc Yen District and the Tan Dong, Hoa Cuong, and Tan Huong areas of the neighboring Yen Binh District to the southeast (see Nguyen et al., 2011, for a map of the Luc Yen mining area).

Perhaps the most influential company in Vietnam's gem industry today is the DOJI Gold & Gems Group, which now works a ruby and sapphire mine in Truc Lau—the only deposit being exploited on a large scale. Current production from this deposit totals around 10 kg per month, consisting of 20–30% ruby (and some sapphire) and 70–80% spinel. Only 10–15% of the total production is of cabochon quality; the rest is used for carvings or specimens (Nguyen et al., 2011). An 18.8 kg star ruby of good quality, discovered by DOJI in the Tan Huong mine in 2005, is the largest known Vietnamese ruby specimen (see Nguyen et al., 2011).

Ruby and sapphire mining in other areas of the country is sporadic and small scale, and recent overall production is significantly lower than during the peak years of the 1990s. The deposits are situated mostly in remote areas in the mountains and jungles. They require large-scale operation but have only been worked by local people equipped with primitive tools. According to Mr. Duong Anh Tuan, vice general director of the DOJI Group, the country as a whole exported approximately 2 tonnes of gem-quality ruby and sapphire rough in 2010 and 1.5 tonnes in 2011.

Hauzenberger et al. (2003) noted four types of primary gem corundum deposits in Vietnam:

1. Ruby and sapphire associated with metasomatic-metamorphic processes in high-grade rocks: the Co Man outcrop at Truc Lau Valley,

TABLE 1. Gemological characteristics of ruby and sapphire from Luc Yen, Vietnam.[a]

Property	Khoan Thong–An Phu, Yen Bai (old mines)[b]		Tan Huong–Truc Lau, Yen Bai (new mines)[c]	
	No. samples (this study)	Observations	No. samples (this study)	Observations
Color	118 rough and polished	Colorless, gray, pink, purplish pink, medium to dark red, light to dark blue Moderate to highly saturated purplish red to purplish pink through reddish purple to pinkish purple in medium light to dark stones[b]	73 rough and polished	Colorless, orange, gray (to yellowish gray[c]), pink, medium to dark red, orangy red, light to dark blue Bluish or greenish gray, pink, pinkish to purplish and brownish red[c]
Diaphaneity	118 rough and polished	Opaque to translucent, semitransparent to transparent	73 rough and polished	Poor to moderate clarity, opaque to translucent, semitransparent to transparent
Refractive indices	35 faceted	n_o = 1.760–1.763, n_e = 1.768–1.771 n_o = 1.759–1.762, n_e = 1.768–1.770[b]	20 faceted 10 cabochon	n_o = 1.761–1.763, n_e = 1.769–1.772 n_o = 1.762–1.763, n_e = 1.770–1.771[c] n = 1.76–1.77 (spot method)
Birefringence	35 faceted	0.008–0.009	20 faceted	0.008–0.009
Optical character	35 faceted	Uniaxial negative	20 faceted	Uniaxial negative
Specific gravity	85 polished	3.92–4.04 3.92–4.00[b]	30 polished	3.91–4.02 3.91–4.07[c]
Pleochroism	25 cabochon	Moderate to strong dichroism	30 polished	Moderate to strong dichroism Weak to strong dichroism[c]
UV fluorescence				
Long-wave	25 cabochon	*Pink to red:* Weak to strong red (to orangy red[b]) *Gray and colorless:* Orange *Light to dark blue:* Light blue, orange	30 polished	*Pink to red:* Weak to strong red *Gray and colorless:* Orange (inert[c]) *Light to dark blue:* Light blue, orange *Orange:* Strong orange-red
Short-wave	25 cabochon	*Pink to red:* Weak to strong red *Gray and colorless:* Orange *Light to dark blue:* Light blue, orange	30 polished	*Pink to red:* Weak to strong red *Gray and colorless:* Orange (inert[c]) *Light to dark blue:* Light blue, orange *Orange:* Orange-red
Internal features	50 polished	Apatite, rutile (needles, clouds), ilmenite, zircon, biotite, muscovite, diaspore, boehmite, calcite, amphibole, hematite, tourmaline, chlorite, spinel, kaolinite, pargasite Nordstrandite, pyrrhotite, phlogopite[b] Swirled growth features[b], blue color zones, lamellar twining, fractures Liquid-gas inclusions	30 polished	Rutile (needles, silk, clouds, and stringer formations), ilmenite, zircon, apatite, spinel, diaspore, plagioclase, biotite, muscovite, chlorite, magnetite, hematite Growth zoning, parting, lamellar twinning, fractures Liquid-gas inclusions

[a] *Properties as obtained in this study, unless otherwise noted.*
[b] *Kane et al. (1991).*
[c] *Nguyen et al. (2011).*

the Khe Nhan and Kinh La occurrences in the Tan Huong area, and the Phuoc Hiep mining area in Quang Nam Province.

2. Ruby and fancy sapphire from marble: Yen Bai Province (Khoan Thong, An Phu, Nuoc Ngap, Hin Om, Khau Nghien, Vang Sao, May Thuong, May Ha, Phai Hap, Tan Lap, Lam Dong, Slope 700 outcrop in Bao Ai ward, Tan Huong drill core, and DOJI's Truc Lau mine) and Nghe An Province (Quy Chau–Quy Hop).
3. Sapphire related to basaltic rocks: Dak Lak and Lam Dong in the Central Highland provinces, and Dong Nai and Binh Thuan in the southern provinces.
4. Ruby from pegmatite-like rocks in feldspathic matrix: occurrences near kilometer markers 12, 15, and 23 along National Road 70 in the Luc Yen and Yen Binh areas of Yen Bai Province.

Today, however, ruby and sapphire are primarily mined from secondary deposits.

Figure 3. Ruby and sapphire from Luc Yen are typically of cabochon quality, and some show asterism. The samples on the left are 3.6–5.3 ct; the pair on the right weigh 3.8 and 4.7 ct. Photos by Pham Van Long.

Description of the Material. Several authors (Bank and Henn, 1990; Kane et al., 1991; Koivula and Kammerling, 1991) have concluded that the characteristics of rubies from Luc Yen (the older mines) and Quy Chau are generally comparable with stones from Mogok, Myanmar. The gemological properties of ruby and sapphire from the old and new mines of Luc Yen are summarized in table 1. Rubies from these two Vietnamese sources can be differentiated by their ratios of Cr_2O_3/Fe_2O_3 and Cr_2O_3/TiO_3, both of which are higher in Luc Yen samples (Hauzenberger et al., 2003). A comparative study of the Yen Bai material by one of the authors (Nguyen et al., 2011) indicated lower Cr and higher Fe in ruby from the newer mines. Furthermore, distinctive internal features in ruby and fancy sapphire from the old mines were presented by Kane et al. (1991). Supplies of facet-grade ruby from Luc Yen (as well as Quy Chau) have become rare, and cabochon-quality ruby and fancy sapphire are more common (figure 3).

One interesting feature of ruby and sapphire from the newer mines is that the crystals are very typically surrounded by spinel, which generally follows the morphology of the underlying corundum crystal (see Nguyen et al., 2011). The boundary between the corundum and the spinel is slightly rounded, suggesting disequilibrium between the two (Häger et al., 2010; Hauzenberger et al., 2010). The formation of this spinel is explained by the reaction:

$$Al_2O_3 + CaMg(CO_3)_2 \rightarrow Al_2MgO_4 + CaCO_3 + CO_2$$
$$\textit{Corundum} + \textit{Dolomite} \rightarrow \textit{Spinel} + \textit{Calcite} + \textit{CO}_2$$

The gem properties of gem corundum from Nghe An (Quy Chau–Quy Hop), Quang Nam, and the Central Highlands and southern provinces are summarized in table 2. Most of the sapphires from central and southern Vietnam are associated with basalts, and are notable for their high Fe content. They are generally dark blue, though some have greenish or yellowish hues. Vietnam's finest blue sapphires (e.g., figure 4) come from a metamorphic deposit at Nghe An. Compared to ruby and sapphire from Yen Bai and Nghe An, the material from Quang Nam is of lower quality and transparency. It also typically contains lower concentrations of coloring elements (Cr, Fe, and Ti) than material from elsewhere (Nguyen et al., 2007). According to local dealers, these gems have been traded mostly in the domestic market.

SPINEL

Vietnamese spinel was initially discovered at Luc Yen (Yen Bai Province) and Quy Chau (Nghe An), at the same time as the ruby and sapphire finds. Today, Yen Bai is the only active source. The major deposits are located at An Phu, Khoan Thong, Minh Tien, and Truc Lau in Luc Yen, and at Tan Huong in Yen Binh. The newest deposit, found in February 2010, is Lang Chap, notable for its orange-red padparadscha-like stones (Nguyen et al., 2011). Yet the most productive spinel deposit remains the old Cong Troi mine in An Phu, which yields a wide range of colors (Blauwet, 2010). According to local dealers in Luc Yen, since

Figure 4. The highest-quality Vietnamese sapphires are found in Nghe An Province (Quy Chau–Quy Hop). These examples weigh 4.3–5.2 ct. Photo by Le Thi-Thu Huong.

Figure 5. In Luc Yen, pure white marble typically hosts red spinel (left, largest crystal is 2.5 cm wide), while a more complex marble assemblage hosts spinel of other colors (right, crystal is 4.0 cm wide). Photo by Pham Van Long.

the beginning of 2012 Yen Bai has produced roughly 200 kg of spinel monthly (excluding the production from DOJI's Truc Lau mine).

There are two different geologic origins of gem spinel in Luc Yen. The more intense red spinel typically comes from calcitic to dolomitic marble (e.g., figure 5, left), sometimes associated with clinochlore or phlogopite. In contrast, violet, purple, brown, and blue spinels are found in marble with a more complex mineral assemblage containing clinohumite, pargasite, clinochlore, and forsterite (e.g., figure 5, right). The red spinels from the more pure marbles have a similar formation environment as marble-hosted rubies (i.e., metamorphic), while the spinels from the complex marbles are thought to be metasomatic (Hofmeister, 2001).

In Brief

- Vietnam is a source of ruby, sapphire, spinel, tourmaline, peridot, garnet, aquamarine, green orthoclase, topaz, zircon, quartz, and pearls (cultured saltwater and freshwater, as well as natural Melo).
- Updated gemological data is provided for ruby, sapphire, spinel, tourmaline, peridot, and garnet, and new chemical data is presented for spinel, tourmaline, peridot, and garnet.
- The most important Vietnamese gem localities consist of the marble-hosted ruby, sapphire, and spinel deposits in Yen Bai and Nghe An Provinces.

Description of the Material. Besides their wide range of colors, including pink to red, orange-red, reddish brown, violet, purple, cobalt blue, and light to dark (figure 6), some Vietnamese spinels exhibit a color change. In these specimens, the violetish blue color seen in fluorescent light changes to violet-purple under incandes-

Figure 6. These faceted Vietnamese spinels from Luc Yen (1.8–3.2 ct) exhibit a wide range of color. Photo by Le Thi-Thu Huong.

TABLE 2. Gemological characteristics of gem corundum from other localities in Vietnam.

Property	Ruby and sapphire from Nghe An (Quy Chau–Quy Hop)[a]		Ruby and sapphire from Quang Nam[b]		Sapphire from Central Highlands and southern provinces[c]	
	No. samples (this study)	Observations	No. samples (this study)	Observations	No. samples (this study)	Observations
Color	37 rough and polished	Pink, purplish pink to red, light to dark blue Moderate to highly saturated purplish red to purplish pink through reddish purple to pinkish purple in medium light to dark stones[b]	35 rough and polished	Colorless, gray, purplish pink to red, grayish blue Violetish pink, brownish red[c]	76 rough and polished	Yellowish light blue, greenish, green yellowish to dark blue Weak to highly saturated colors ranging from blue to bluish green, with tones from light to extremely dark[d]
Diaphaneity	37 rough and polished	Poor to moderate clarity, translucent, semitransparent to transparent	35 rough and polished	Opaque to translucent	76 rough and polished	Opaque, translucent, semitransparent to transparent Most are slightly to moderately included[d]
Refractive indices	14 faceted	n_o = 1.759–1.762, n_e = 1.767–1.771 n_o = 1.759–1.762, n_e = 1.768–1.770[b]	3 faceted	n_o = 1.760–1.761, n_e = 1.768–1.771 n_o = 1.760–1.766, n_e = 1.768–1.774[c]	40 faceted	n_o = 1.761–1.765, n_e = 1.770–1.775 n_o = 1.760–1.764, n_e = 1.769–1.772[d]
Birefringence	14 faceted	0.008–0.009	3 faceted	0.008–0.010	40 faceted	0.008–0.010
Optical character	14 faceted	Uniaxial negative	3 faceted	Uniaxial negative	40 faceted	Uniaxial negative
Specific gravity	18 polished	3.98–4.04 3.92–4.00[b]	11 polished	3.91–4.03 3.90–4.03[c]	52 polished	3.96–4.05 3.99–4.02[d]
Pleochroism	18 polished	Moderate to strong dichroism	11 polished	Moderate (to strong[c]) dichroism	52 polished	Greenish blue, yellowish green dichroism Strong dichroism: blue to violetish blue parallel to the c-axis and mostly green-blue to yellow-green perpendicular to the c-axis[d]
UV fluorescence						
Long-wave	18 polished	*Pink to red:* Weak to strong red (to orangy red[b]) *Light to dark blue:* Light blue, orange	11 polished	*Pink to red:* Inert *Gray and colorless:* Inert *Light to dark blue:* Light blue	20 polished	Inert
Short-wave	18 polished	*Pink to red:* Weak to strong red (to orangy red[b]) *Light to dark blue:* Light blue, orange	11 polished	*Pink to red:* Inert *Gray and colorless:* Inert *Light to dark blue:* Light blue	20 polished	Inert
Internal features	18 polished	Amphibole, boehmite, calcite, diaspore, muscovite, biotite, graphite, kaolinite, rutile, zircon Calcite, apatite, nordstrandite, pyrrhotite, phlogopite[b] Blue color zones[b], color zoning, liquid-gas inclusions	11 polished	Garnet, mica, chlorite Color zoning, twinning	52 polished	Uranpyrochlore[d], plagioclase, boehmite, columbite, zircon, ilmenite, pyrrhotite, spinel, goethite, kaolinite Color zoning, growth structures, laminated twinning, fine-grained clouds, needle-like inclusions, fingerprints, negative crystals

[a] *Properties as obtained in this study, unless otherwise noted.*
[b] *Kane et al. (1991).*
[c] *Nguyen et al. (2007).*
[d] *Smith et al. (1991).*

TABLE 3. Gemological characteristics of spinel from Luc Yen, Vietnam.

Property	No. samples	Observations	Data from the literature
Color	118 rough and faceted	Pink to red, orange-red, reddish brown, violet, purple, light to dark and cobalt blue; some exhibit a color change	Orangy red to purple, orangy pink to purplish pink, violet to blue (Koivula et al., 1993), padparadscha-like (Blauwet, 2011), cobalt-blue (Blauwet, 2011; Smith et al., 2008)
Diaphaneity	114 rough and polished	Semitransparent to transparent	nr[a]
Refractive indices	85 faceted	1.712–1.719	1.714–1.719 (Koivula et al., 1993) 1.712–1.718 (Smith et al., 2008)
Specific gravity	85 faceted	3.58–3.73	3.59–3.63 (Koivula et al., 1993) 3.54–3.71 (Smith et al., 2008)
UV fluorescence			
Long-wave	25 faceted	*Pink to red:* Red *Brown, violet, blue:* Inert	*Pink to red:* Weak to moderate red *Purple to blue:* Weak or inert (Koivula et al., 1993)
Short-wave	25 faceted	*Pink to red:* Red *Brown, violet, blue:* Inert	Similar in color but of lesser intensity (Koivula et al., 1993)
Internal features	85 faceted	Apatite, högbomite, hematite, goethite, rutile, K-feldspar, pyrite Fingerprints, primary liquid-gas inclusions, negative crystals	Muscovite, apatite, zircon, graphite, högbomite, hematite, goethite Rutile silk, decorated intergrowths, ribbon-like stepped growth planes (Koivula et al., 1993; Gübelin and Koivula, 2008)

[a] *Abbreviation: nr = not reported.*

cent light, or the light blue color changes to light lavender (Senoble, 2010; Blauwet, 2011a). See table 3 for the gemological properties of Luc Yen spinel, and figure 7 for some common inclusions.

Chemical analyses of our spinel samples from Luc Yen (see *G&G* Data Depository at gia.edu/gandg) gave various concentrations of chromophores (V, Mn, Ti, Cr, Fe, and Co). Red spinel contained the greatest chromium contents (up to 1.19 wt.% Cr_2O_3). Vanadium was highest in red-orange spinel (0.61 wt.%). Pur-

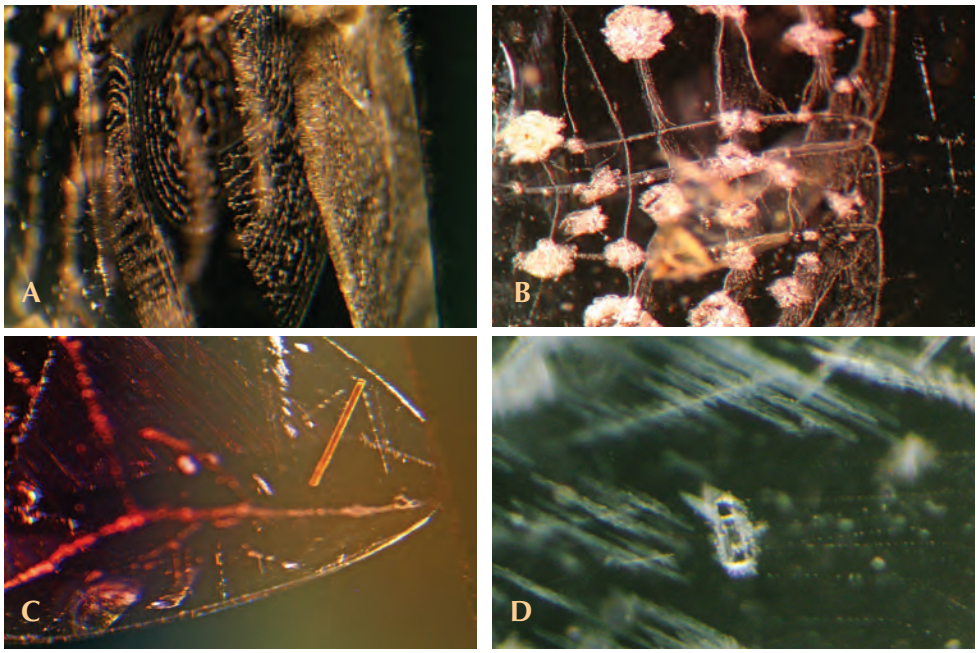


Figure 7. Luc Yen spinel may show parallel layers of "fingerprints" (A), as well as inclusions of K-feldspar (B), rutile (C), and apatite (D). Photomicrographs by Le Thi-Thu Huong; magnified 35×.

Figure 8. The principal colors of Luc Yen tourmaline are pink, green, brown, and yellow. The crystals range up to 2.7 cm long, and the cut samples weigh up to 5.1 ct. Photos by Nguyen Duc Trung Kien.

ple and dark blue samples had the greatest iron contents, with up to 1.84 wt.% FeO, though the purple spinel had higher Cr and Ti. Dark cobalt-blue material had only a small amount of cobalt (0.09 wt.% CoO), but also contained 0.71 wt.% FeO, 0.23 wt.% NiO, and 0.14 wt.% Cr_2O_3. Therefore, each particular color in spinel is attributable not to any one element but rather a combination of elements. Further study is required to explain the exact causes of color in these spinels.

TOURMALINE

To date, Luc Yen is Vietnam's only known source of gem tourmaline. Along with spinel, tourmaline was first discovered in alluvial gravels, mainly at Khoan Thong, An Phu, and Minh Tien. Pegmatite-hosted, non-gem-quality tourmaline was probably found in the Luc Yen area during the early 2000s. Yet gem-quality stones have only been mined since 2004 at Minh Tien and since 2009 at Khai Trung (Blauwet, 2007; Wilson, 2007; Nguy et al., 2010). The Luc Yen area produces approximately 200 kg of tourmaline annually, which is lower than its output of ruby, sapphire, and spinel. Nevertheless, the quality and variety of colors make tourmaline one of the most important gems from the area.

Description of the Material. The crystals consist of typical striated prisms with rounded triangular cross sections and various terminations. The principal colors of tourmaline, whether from primary or secondary deposits, are pink, green, brown, and yellow (figure 8). Multicolored crystals usually display alternating pink/green and brown/yellow colors. Color zoning is often observed from the center to the periphery of the crystals, with a combination of pink/dark green (Pham et al., 2004a) or yellowish green/red (Laurs et al., 2002). See table 4 for gemological properties, and figure 9 for examples of some inclusions in Luc Yen tourmaline.

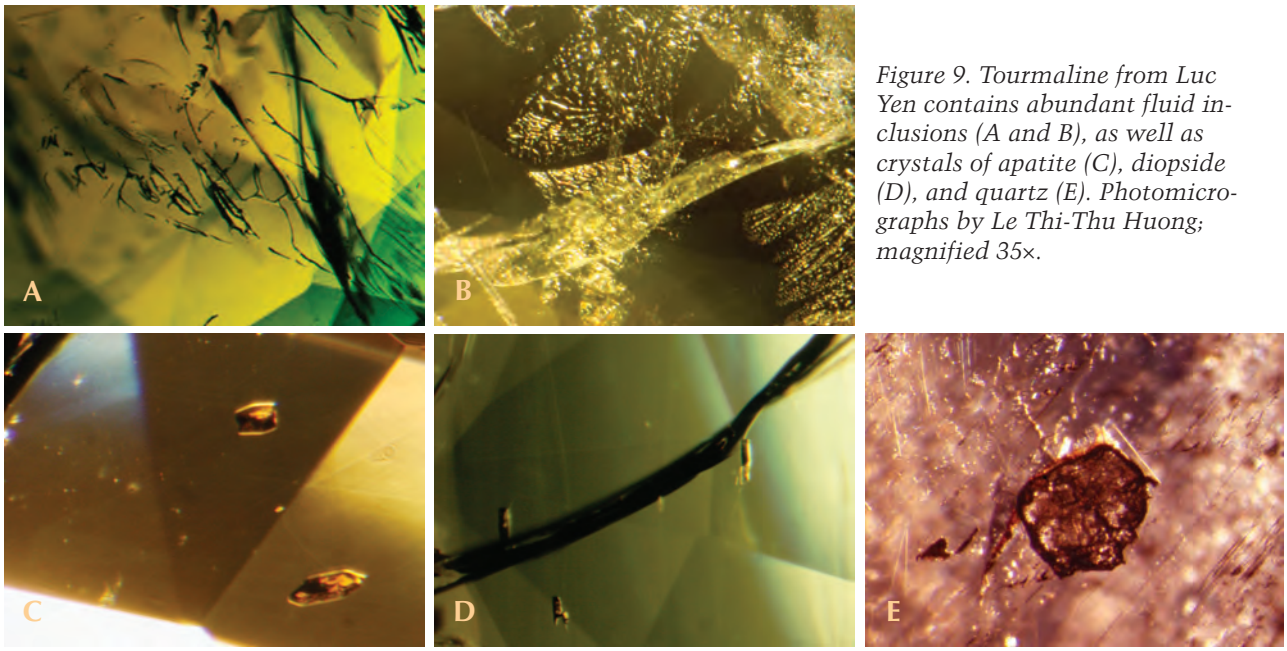


Figure 9. Tourmaline from Luc Yen contains abundant fluid inclusions (A and B), as well as crystals of apatite (C), diopside (D), and quartz (E). Photomicrographs by Le Thi-Thu Huong; magnified 35×.

Chemical analyses of our samples showed that they all were elbaite (table 5). Studies by Laurs et al. (2002) and Wilson (2007) also identified rossmanite and liddicoatite from Luc Yen.

PERIDOT

Peridot was discovered in Vietnam in the early 1990s (Koivula et al., 1993). Gem-quality peridot has been obtained from three provinces in the Central Highlands: Gia Lai, Dak Lak, and Lam Dong. Of these, Gia Lai is the most important source. Two deposits there, Ham Rong and Bien Ho, yield about 100 kg monthly, with 15–20% being gem quality. Including the output from the two other provinces, Vietnam could produce up to several hundred kilograms of gem peridot annually.

Vietnamese peridot occurs in lherzolite xenoliths within basalt flows. The gem has been extracted mostly from alluvial gravels. In some places, miners must dig pits 5 m deep to reach the peridot-bearing layers.

Description of the Material. Most Vietnamese peridot occurs as pebbles averaging 0.6 to 1.5 cm in diameter. Pieces as large as 4 cm in diameter are occasionally found. Faceted stones show an attractive yellowish green color (figure 10). See table 6 for the gemological properties of Vietnamese peridot, and figure 11 for some common inclusions. No systematic differences were noted in the gemological characteristics or chemical composition (table 7) of Vietnamese peridot from the three provinces. The samples all consisted of 91% forsterite and 9% fayalite, with trace amounts of Ni, Cr, Mn, and Ca.

GARNET

Gem-quality garnet (almandine and pyrope) occurs in the Luc Yen area and in smaller amounts elsewhere in northern Vietnam, including Thach Khoan (Phu Tho Province), Thuong Xuan (Thanh Hoa), and Ky Son (Nghe An). Pyrope-almandine also occurs with olivine, phlogopite, and perovskite in some kimberlite dikes in Kon Tum Province in the Central Highlands. In Luc Yen, where garnet production could reach 50–60 kg annually, almandine-pyrope is found as an accessory gem mineral with other stones such as ruby, sapphire, and spinel in placer deposits. The output from Kon Tum and other localities is unknown.

Figure 10. These Vietnamese peridot gemstones range from 5.7 to 6.2 ct. Photo by Nguyen Duc Trung Kien.

Description of the Material. Vietnamese garnets have a brownish red color and yield cut stones ranging from 1.5 to 4.5 ct (e.g., figure 12). See table 8 for their gemological properties, and figure 13 for some typical inclusions.

Chemical analyses revealed that the Luc Yen and Kon Tum garnets are composed mainly of almandine-pyrope solid solutions. The composition of Luc Yen garnet consists of approximately 83% almandine, 13% pyrope, 3% grossular, and 1% spessartine. Kon Tum garnet contains 63% pyrope, 33% almandine, 3% grossular, and 1% spessartine (table 9).

OTHER GEMS

Aquamarine and Irradiated Beryl. Aquamarine is known from northern Vietnam at Thuong Xuan (Thanh Hoa Province), Que Phong (Nghe An), and Thach Khoan (Phu Tho), and has been described in several references (Pham et al., 2004a; Laurs, 2010;

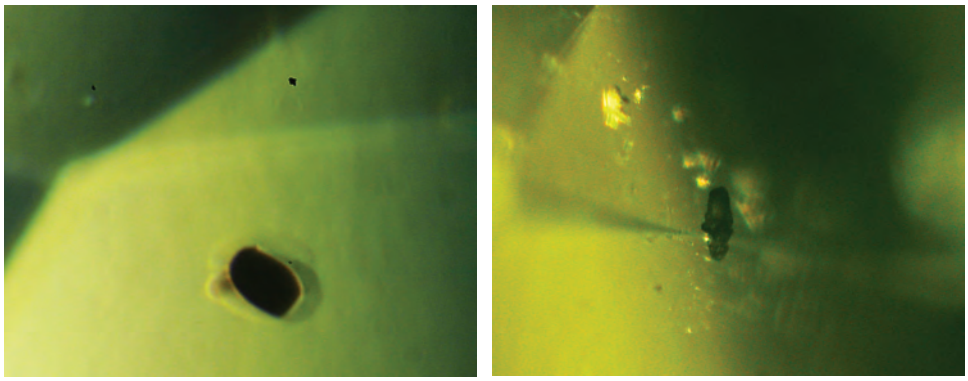


Figure 11. Vietnamese peridot may contain inclusions of spinel (left, with an associated discoid fracture) or sphalerite (right). Photomicrographs by Le Thi-Thu Huong; magnified 35×.

TABLE 4. Gemological characteristics of tourmaline from Luc Yen, Vietnam.

Property	No. samples	Observations		Data from the literature	
Color	76 rough and polished	Pink, yellow, green, reddish brown		Pink, "raspberry" red to yellow-green and yellow-orange (Wilson, 2007; Laurs et al., 2002)	
Diaphaneity	76 rough and polished	Semitransparent to transparent			
Refractive indices	20 faceted	*Pink:*	n_o = 1.638–1.639 n_e = 1.619–1.621	*Pink:*	n_o = 1.641, n_e = 1.623
		Yellow:	n_o = 1.642–1.646 n_e = 1.625–1.628	*Yellowish green:*	n_o = 1.640, n_e = 1.620
		Green:	n_o = 1.635–1640 n_e = 1.621–1.625	*Red:*	n_o = 1.647, n_e = 1.625
		Reddish brown:	n_o = 1.638–1.644 n_e = 1.624–1.626	(Obtained from a color-zoned sample; Laurs et al., 2002)	
Birefringence	20 faceted	*Pink:*	0.018–0.019	*Pink:*	0.018
		Yellow:	0.017–0.018	*Yellowish green:*	0.020
		Green:	0.017–0.019	*Red:*	0.022
		Reddish brown:	0.016–0.020	(Obtained from a color-zoned sample; Laurs et al., 2002)	
Optical character	20 faceted	Uniaxial negative		nr[a]	
Specific gravity	28 polished	*Pink:*	3.05–3.08	nr	
		Yellow:	3.17–3.19		
		Green:	3.17–3.20		
		Reddish brown:	3.06–3.08		
Pleochroism	28 polished	*Pink:*	Light pink to pink	nr	
		Yellow:	Yellowish to yellow		
		Green:	Yellowish green to green		
		Reddish brown:	Greenish yellow to brownish green		
UV fluorescence					
Long-wave	28 polished	Inert (in all colors)		*Pink to red:* Inert *Yellowish green:* Weak yellow-green	
Short-wave	28 polished	Inert (in all colors)		*Pink to red:* Inert *Yellowish green:* Inert (Laurs et al., 2002)	
Internal features	28 polished	Apatite, quartz and diopside Growth tubes, color zoning Liquid-gas inclusions Planar fluid inclusions		Healed fractures, color zoning, unknown solid inclusions (Laurs et al., 2002)	

[a] *Abbreviation: nr = not reported.*

Shigley et al., 2010; Blauwet, 2011b; Le et al., 2011). The Thuong Xuan mining area, located 170 km southeast of Hanoi, is the most productive. According to local dealers, production from this area alone was 300–400 kg in 2010 and about 500 kg in 2011.

Vietnamese aquamarines are generally light to

Figure 12. These faceted garnets from Luc Yen (left) and Kon Tum (right) range from 1.5 to 2.2 ct. Photos by Nguyen Duc Trung Kien.

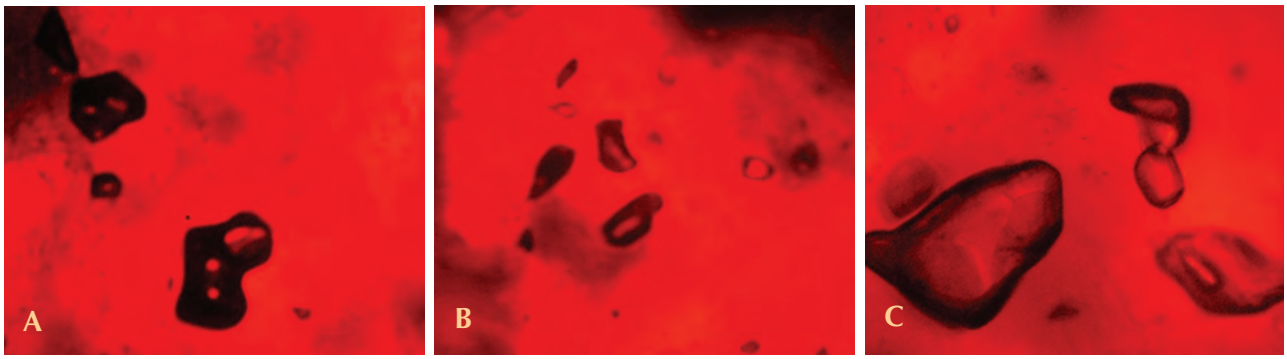
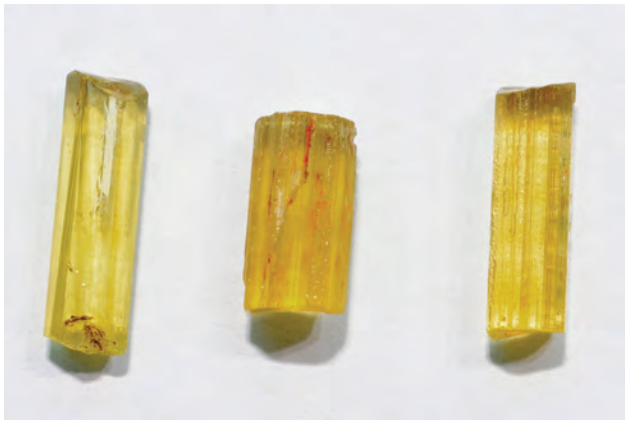


Figure 13. Vietnamese garnets may contain mineral inclusions of zircon (A), quartz (B), and monazite (C). Photomicrographs by Le Thi-Thu Huong; magnified 35×.

Figure 14. These irradiated beryl crystals (up to 5 cm long) were being sold in the Vietnamese market as untreated heliodor. Photo by Nguyen Duc Trung Kien.



medium blue with moderate saturation. While no internal features are considered locality specific, chemical data of samples from Thuong Xuan have identified low amounts of K and Na and high amounts of Fe and Cs compared to other sources (Le et al., 2011). Although emerald and more recently heliodor finds have been reported in nearby Chinese and Cambodian localities (Laurs, 2010), they have not yet been uncovered in Vietnam. Aquamarine is the only gem variety of beryl produced there so far. According to some Vietnamese dealers, a large volume of pale aquamarine from Vietnam has been irradiated in Laos and then sold back on the domestic market as natural heliodor (figure 14).

Green Orthoclase. Recently, gem-quality green feldspar has been sold in gem markets in Luc Yen and Hanoi as amazonite, the term for bluish green microcline. The material has been recovered with tourmaline from pegmatite bodies reportedly located near Minh Tien. The feldspar is pale to moderate green, and is mostly translucent to semitransparent (figure 15). Although green transparent material has been reported in the area since the beginning of the 2000s

Figure 15. This green orthoclase crystal (left, ~10 cm wide) was purchased in Luc Yen and contains some transparent areas that could be faceted. Most green orthoclase from Luc Yen is of cabochon quality (center, 7.8 and 8.5 ct). Faceted samples are very rare in the market (right, 1.5 cm long). Left photo by Le Thi-Thu Huong; center and right photos by Nguyen Duc Trung Kien.

TABLE 5. Chemical composition of tourmaline (elbaite) from Luc Yen, Vietnam.[a]

Oxides (wt.%)	Pink	Green	Reddish brown	Yellow	Data from Wilson (2007)[b]
SiO_2	36.28	36.97	36.40	36.51	36.35–36.65
TiO_2	bdl	0.25	0.38	0.20	bdl–0.26
B_2O_3	11.01	10.84	10.93	11.03	10.75–11.04
Al_2O_3	40.08	41.63	37.88	42.27	38.07–42.70
Cr_2O_3	bdl	0.26	bdl	bdl	nr
V_2O_3	bdl	0.12	bdl	0.05	bdl–0.01
Bi_2O_3	bdl	bdl	bdl	bdl	bdl–0.01
FeO	0.02	0.03	3.20	0.11	bdl–4.88
MnO	0.09	0.01	0.37	bdl	0.02–6.08
CuO	0.01	bdl	bdl	0.04	nr
PbO	0.20	bdl	0.20	0.02	nr
MgO	0.02	0.02	bdl	0.03	bdl–0.04
CaO	2.25	0.47	0.95	0.48	0.33–1.93
Li_2O	2.18	1.92	2.03	2.12	1.46–1.98
Na_2O	1.29	2.57	2.17	2.58	0.65–2.45
K_2O	0.01	bdl	0.02	bdl	0.01–0.04
F	0.90	0.14	0.93	0.05	0.85–1.22
−O=F	0.38	0.06	0.39	0.02	0.36–0.55
Total	93.98	95.16	95.06	95.47	95.45–97.17
Ions on the basis of 31 (O,OH,F)					
Si	5.905	6.016	5.924	5.942	nr
Ti	bdl	0.039	0.059	0.031	nr
B	3.095	3.047	3.071	3.100	nr
Al	7.688	7.986	7.266	8.108	nr
Cr	bdl	0.033	bdl	bdl	nr
V	bdl	0.014	bdl	0.005	nr
Bi	bdl	bdl	bdl	bdl	nr
Fe	0.003	0.004	0.435	0.015	nr
Mn	0.012	0.002	0.051	0.000	nr
Cu	0.002	bdl	bdl	0.005	nr
Pb	0.009	bdl	0.009	0.001	nr
Mg	0.004	0.005	bdl	0.007	nr
Ca	0.392	0.081	0.166	0.084	nr
Li	1.429	1.261	1.329	1.388	nr
Na	0.460	0.915	0.773	0.919	nr
K	0.001	bdl	0.004	bdl	nr
F	0.463	0.072	0.476	0.024	nr

[a] *Values from this study represent the average of four points per sample. All iron is reported as FeO. Abbreviations: bdl = below detection limit, nr = not reported.*
[b] *Colors included pink, yellow, green, "olive," and gray.*

(Ponahlo et al., 2001), the lead author continues to see rare facet-grade stones in the market (figure 15, right).

X-ray powder diffraction analysis of a crystal sample identified it as orthoclase. A comparison of the band shapes in the specimen's Raman spectra allowed a further distinction between microcline and orthoclase. Due to the partially disordered arrangement of Al-Si in tetrahedral sites, orthoclase has wider Raman peaks (Freeman et al., 2008). A well-resolved triplet in the 515–450 cm^{-1} range and a doublet at 290–250 cm^{-1} widen to the less-resolved features in the orthoclase spectrum (figure 16). Raman spectra of four samples (the crystal, in addition to faceted and cabochon samples) showed a closer resemblance to orthoclase than to microcline. Our findings are consistent with the infrared spectroscopy results reported by Laurs et al. (2005).

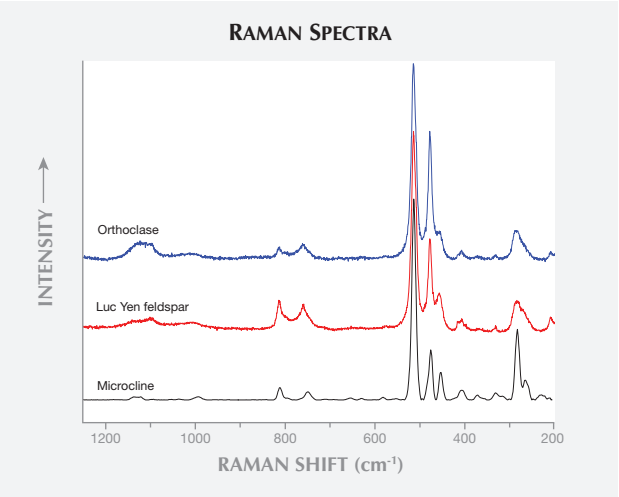


Figure 16. This representative Raman spectra of Luc Yen green feldspar shows a closer resemblance to orthoclase than microcline.

Topaz. Topaz is recovered along with aquamarine in mining areas such as Thuong Xuan and Thach Khoan. Other sources include Bao Loc (Lam Dong Province) and Tu Le (Yen Bai). Among these, the pegmatite-hosted topaz at Thuong Xuan has the most potential, and this area is estimated to contain ~40 tonnes of colorless topaz (Nguyen et al., 1995). At the other mining areas, topaz is extracted from placers that yield high-quality gem material suitable for faceting. The crystals, which tend to be broken during alluvial transport, are typically colorless (rarely blue) with high clarity. Colorless and irradiated blue topaz from Vietnam are shown in figure 17.

Quartz. Rock crystal and smoky quartz are found in pegmatites in several districts: Thuong Xuan, Ky Son (Nghe An Province), and Thach Khoan. Amethyst is mined at Chu Boc (Gia Lai Province). Rose quartz has been found near Da Nang, and smoky quartz near

TABLE 6. Gemological characteristics of peridot from the Central Highlands of Vietnam.

Property	No. samples	Observations	Data from Kammerling and Koivula (1995)
Color	43 rough and faceted	Yellowish green to "olive" green or brownish green	Medium light to medium dark yellowish green to brownish green of low to moderate saturation
Diaphaneity	43 rough and faceted	Semitransparent to transparent	Transparent
Refractive indices	26 faceted	n_x = 1.650–1.652 n_y = 1.665–1.669 n_z = 1.686–1.690	n_x = 1.650 n_y = 1.665–1.667 n_z = 1.687–1.688
Birefringence	26 faceted	0.036–0.038	0.037–0.038
Optical character	26 faceted	Biaxial negative	nr[a]
Specific gravity	26 faceted	3.32–3.37	3.34 ± 0.01
Pleochroism	26 faceted	Weak, brownish to yellowish green	Weak, very slightly brownish green and yellowish green
UV fluorescence			
Long-wave	26 faceted	Inert	nr
Short-wave	26 faceted	Inert	nr
Internal features	26 faceted	Spinel, sphalerite, "lily pad" inclusions	Chromian spinel(?), biotite mica(?), "lily pad" inclusions surrounding negative crystals, smoke-like veiling, optically active intergrowth

[a] *Abbreviation: nr = not reported.*

Lam Dong. Large citrine gemstones (figure 18) have been cut from rough material mined near Cam Ranh (Khanh Hoa Province).

Zircon. Together with basaltic sapphires, zircon is recovered from placers in the provinces of Kon Tum, Dak Lak, Dak Nong, Gia Lai, Lam Dong, and Binh Thuan. The zircon ranges from colorless to orange, brownish orange, and reddish brown. The crystals, typically combinations of the bipyramid and the tetragonal prism, are usually etched and waterworn and between 0.5 and 2.2 cm in dimension (figure 19). The reddish brown zircon is typically heated to turn it blue, orange, or colorless.

Pearl. Vietnam has many natural advantages for saltwater pearl farming: a long coastline with numerous bays, large islands, and an ideal water temperature. The marine area suitable for pearl culture amounts to about 568,424 hectares (Nguyen, 2008). Nguyen (a biologist and owner of a pearl farm in Ha Long Bay) has found that the waters surrounding many large islands, including Phu Quoc, Con Dao, Phu Quy, Ly Son, Con Co, Bach Long Vi, and Co To, are suitable for the culture of *Pinctada maxima* and *P. margaritifera*. Several bays in the north, namely Van Don, Bai Tu Long, Ha Long, and Lan Ha, are favorable for akoya (*P. martensii*, *P. fucata*). The production of

Figure 17. The topaz crystal on the left (~4 cm tall) is representative of material from Thanh Hoa Province. The Vietnamese irradiated blue topaz shown on the right ranges from 16.7 to 29.8 ct. Photos by Le Thi-Thu Huong.

TABLE 7. Chemical composition of peridot from the Central Highlands of Vietnam.[a]

Oxides (wt.%)	Gia Lai	Dak Lak	Lam Dong
SiO_2	41.95	41.78	41.74
Al_2O_3	0.01	bdl	bdl
Cr_2O_3	0.03	0.04	0.04
FeO	8.47	8.49	8.48
MnO	0.11	0.15	0.12
MgO	50.07	49.95	49.99
CaO	0.05	0.04	0.05
NiO	0.37	0.36	0.37
Total	101.06	100.80	100.80
Cations per 4 oxygens			
Si	1.007	1.008	1.008
Al	0.000	bdl	bdl
Cr	0.001	0.001	0.001
Fe	0.171	0.170	0.171
Mn	0.002	0.002	0.003
Mg	1.798	1.795	1.797
Ca	0.001	0.001	0.001
Ni	0.007	0.007	0.007

[a] *Values represent the average of five points per sample, and one sample from each locality was analyzed. Abbreviation: bdl = below detection limit. Ti and V were analyzed but not detected.*

freshwater cultured pearls from *Hyriopsis cumingii*, *Cristaria bialata*, and *Sinanodonta elliptica* has occurred on a smaller scale in lakes throughout the country, especially Thac Ba, Cam Son, Hoa Binh, Ke Go, and Tri An.

During the past 20 years, Vietnamese pearl farms have developed under the training and supervision of Japanese experts. Today, the farms are operated by Vietnamese technicians. The akoyas typically range from 5 to 8 mm in diameter, with natural "golden" or gray colors (figure 20). Their nacre layer can reach 1–1.5 mm in 12 months. Black cultured pearls are mainly farmed around southern islands such as Phu Quoc. They vary from 4 to 8 mm. Freshwater cultured pearls are typically pink, "cream," brown, and gray, and range from 6 to 12 mm. Vietnam's pearl farms are still small scale and mostly private. The annual production of one akoya farm in Ha Long Bay, for example, averages between 12 and 15 kg.

Figure 18. Citrine from Khanh Hoa Province is known for its large size. The square cushion cut measures 4.2 × 4.2 cm. Photo by Le Thi-Thu Huong.

TABLE 8. Gemological characteristics of garnet from Luc Yen and Kon Tum, Vietnam.

Property	Luc Yen		Kon Tum	
	No. samples (this study)	Observations	No. samples (this study)	Observations
Color	19 rough and faceted	Brownish red	12 rough and faceted	Brownish red
Diaphaneity	19 rough and faceted	Semitransparent to transparent	12 rough and faceted	Semitransparent to transparent
Refractive indices	10 faceted	1.800–1.805	6 faceted	1.790–1.795
Specific gravity	10 faceted	4.08–4.15	6 faceted	3.92–3.96
UV fluorescence				
Long-wave	10 faceted	Inert	6 faceted	Inert
Short-wave	10 faceted	Inert	6 faceted	Inert
Internal features	10 faceted	Monazite, quartz, apatite, and zircon Hollow tubes filled with fluid	6 faceted	Monazite, quartz, apatite, and zircon Hollow tubes filled with fluid

TABLE 9. Chemical composition of garnet from Luc Yen and Kon Tum, Vietnam.

Oxides (wt.%)	Luc Yen 1	Luc Yen 2	Luc Yen 3	Kon Tum 1	Kon Tum 2	Kon Tum 3
SiO_2	36.52	36.23	36.43	39.97	40.63	40.75
TiO_2	0.01	bdl	0.03	0.01	0.01	bdl
Al_2O_3	21.78	21.84	21.90	24.09	23.98	23.88
Cr_2O_3	bdl	0.04	0.03	0.06	0.01	0.10
V_2O_3	bdl	0.01	bdl	bdl	0.02	bdl
FeO	36.91	37.12	37.08	16.47	16.50	16.15
MnO	0.39	0.38	0.47	0.57	0.58	0.56
MgO	3.32	3.27	3.30	17.33	17.15	17.16
CaO	1.06	1.04	1.15	1.30	1.30	1.27
Na_2O	0.07	0.04	0.04	0.00	0.00	0.04
Total	100.06	99.96	100.44	99.79	100.18	99.91
Cations per 12 oxygens						
Si	2.941	2.929	2.934	2.924	2.950	2.970
Ti	0.001	bdl	0.000	0.000	0.001	bdl
Al	2.067	2.081	2.081	2.077	2.053	2.051
Cr	bdl	0.002	0.002	0.003	0.001	0.005
V	bdl	0.000	bdl	bdl	0.000	bdl
Fe	2.486	2.511	2.498	1.008	1.002	0.985
Mn	0.027	0.026	0.032	0.035	0.036	0.035
Mg	0.399	0.394	0.396	1.891	1.857	1.865
Ca	0.091	0.090	0.099	0.102	0.101	0.099
Na	0.012	0.006	0.006	0.000	0.000	0.006

[a] *Values represent the average of five points per sample, and three samples from each locality were analyzed. Abbreviation: bdl = below detection limit.*

Melo pearls are natural non-nacreous concretions produced by the marine gastropod *Melo melo*. This large snail lives mainly in the waters of the South China Sea. Melo pearls are recovered off the coast of Vietnam, Thailand, Myanmar, and Malaysia (Pardieu, 2009). Vietnam is the leading source of these pearls (e.g., figure 21). They are found in Ha Long Bay and along the southern coast from Nha Trang to Phan Thiet. Melo pearls have apparently not been successfully produced by culturing, and they remain extremely rare and expensive.

Figure 19. These pieces of zircon from Lam Dong range from 0.5 to 2.2 cm. Photo by Pham Van Long.

Figure 20. Akoya cultured pearls from Ha Long Bay typically display "golden" and gray colors. Photo by Pham Van Long.

Figure 21. This fine 161 ct Melo pearl is from Phan Thiet, on the south coast of Vietnam. Photo by Pham Van Long.

CONCLUSIONS

Due to its geologic position along the margins of two cratons, Vietnam is endowed with a diversity of gem minerals. These include ruby, sapphire, spinel, tourmaline, garnet, peridot, aquamarine, topaz, zircon, green orthoclase, and several quartz varieties. The two important geologic events affecting gem formation in Vietnam were (1) the Himalayan orogeny (50–21 Ma), which resulted in ruby, sapphire, and spinel in the northern provinces of Yen Bai and Nghe An; and (2) basaltic volcanism (~6.5 and ~1 Ma), which accounts for blue, green, and yellow sapphire as well as peridot and zircon in the Central Highlands. Of greatest commercial potential are the marble-hosted ruby, sapphire, and spinel deposits in Yen Bai and Nghe An.

Compared to its gem wealth, Vietnam's mining and pearl farming sectors are still relatively small and undeveloped, leaving many potential resources unexploited. This situation is likely to change in the near future with greater emphasis by the government on developing the country's gem industry and promoting its resources on an international level.

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