

# RUBY AND SAPPHIRE FROM THE TAN HUONG–TRUC LAU AREA, YEN BAI PROVINCE, NORTHERN VIETNAM

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Primary and secondary deposits in the Tan Huong–Truc Lau area of northern Vietnam’s Yen Bai Province have supplied rubies (especially star rubies) and some sapphires—mostly of cabochon quality—for more than a decade. The gems are typically translucent to semitransparent and pink to purplish or brownish red, with rare color zoning. The most distinctive features of this corundum after polishing include growth zoning and asterism. The samples contain relatively high amounts of Fe and variable Ti and Cr. The geologic origin and gemological properties of this corundum are distinct from that of the adjacent Khoan Thong–An Phu area.

For more than 20 years, Vietnam’s Yen Bai Province, and the Luc Yen District in particular, have been widely known for producing high-quality rubies and sapphires. Subsequent deposits found elsewhere in Vietnam (Long et al., 2004) include Quy Chau–Quy Hop (Nghe An Province), Di Linh (Lam Dong), Dak Ton (Dak Nong), and Ma Lam and Da Ban (Binh Thuan). Still, Yen Bai remains the country’s most important source of ruby and sapphire. Much of the production consists of cabochon-quality stones from the Tan Huong–Truc Lau area (e.g., figure 1), as described in this article.

Vietnamese geologists first discovered gem-quality corundum and spinel at Luc Yen in 1983 (Vinh, 1991). In early 1987, the Geological Survey of Vietnam found abundant gem material in alluvium in Luc Yen’s Khoan Thong area. Mining activity soon thrived, with many companies operating in the

region (Voi, 1991). Other gem occurrences near Khoan Thong followed, such as Nuoc Ngap, Hin Om, Khau Nghien, Vang Sao, May Thuong, May Ha, An Phu, Phai Chap, Tan Lap, and Lam Dong. These

*Figure 1. These star rubies (6.16–11.66 ct) are from the Tan Huong–Truc Lau area of northern Vietnam. Photo by Nuttapol Kitdee, GIA, Bangkok.*



See end of article for About the Authors and Acknowledgments.

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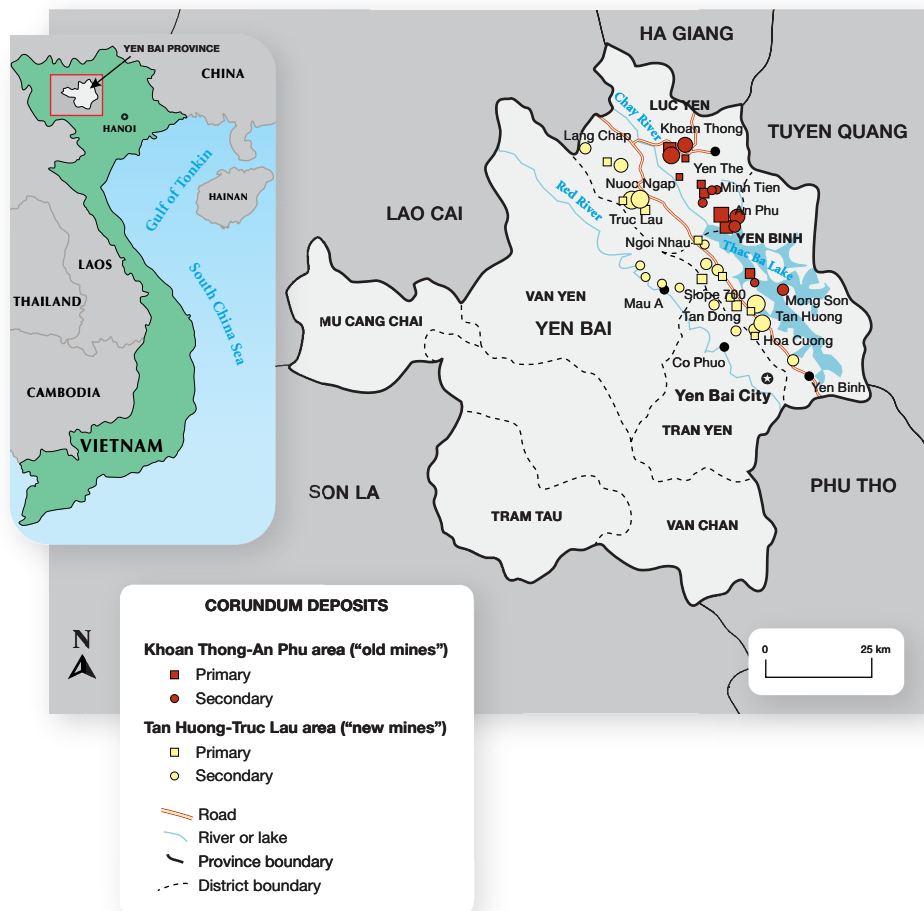


Figure 2. In northern Vietnam's Yen Bai Province, primary and secondary corundum deposits have been mined on both sides of the Chay River: the original Khoan Thong–An Phu mines on the east side and the newer Tan Huang–Truc Lau mines on the west. The size of each symbol is proportional to that mining area. Modified after Xuyen (2000) and Vinh (2005).

are located on the east side of the Chay River and have been referred to by locals as *bãi cũ*, or “old mines” (see figure 2).

In the mid-1990s, several *bãi mới* (“new mines”) were established on the west side of the Chay River. These included Tan Huang, Truc Lau, kilometer 12 of National Road 70, Tan Dong, Hoa Cuong, Cam An, Bao Ai, Ngoi Nhau, and Ngoi Hop (again, see figure 2). Although corundum was discovered in this area in 1986 (Quan et al., 1998), there was no significant mining until local diggers arrived at Tan Huang

in 1994 (Thang, 1998). In 1996 the Vietnam National Gold and Gem Corporation (VIGEGO) conducted systematic assessments of Tan Huang (covering an area of 6 km<sup>2</sup>) and Truc Lau (20 km<sup>2</sup>). Official mining operations by VIGEGO started at Tan Huang the following year, yielding hundreds of kilograms of ruby and star ruby (Thang, 1998). Subsequently, other secondary (placer) and primary occurrences were discovered and mined (e.g., Quan et al., 2000). Currently, the only large-scale mechanized operation (figure 3) belongs to DOJI Gold & Gems Group



Figure 3. DOJI Gold & Gems Group currently conducts the only large-scale mining activities in the Tan Huang–Truc Lau area. These 2010 photos show open-pit mining at Truc Lau (left) and the associated processing plant (right). Photos by N. N. Khoi.



Figure 4. Local miners dig for spinel and corundum at the Lang Chap occurrence in June 2010. Photo by N. N. Khoi.

in the Truc Lau valley. Also some small-scale mining using primitive methods occurs sporadically, particularly during the dry season. Most recently, in February 2010, hundreds of local miners began operating illegally at Lang Chap, mostly for spinel (figure 4).

The mines on the west side of the Chay River typically yield cabochon-quality ruby and pink sapphire. However, some very large rubies weighing tens of kilograms have been found. Some of these contain transparent, gem-quality portions that can be faceted. A semitransparent to nearly transparent 290 ct fragment, detached from a 2.58 kg rough ruby discovered at Tan Huong in 1997, sold for US\$290,000 at the Rangoon Gem Emporium (Myanmar) later that year (Nguyen Xuan An, pers. comm., 1998). Large star rubies and pink sapphires are also known. Two pieces (1.96 and 2.58 kg) now belong to the State Treasury's collection, while DOJI Gold & Gems Group has preserved an 18.8 kg specimen (figure 5).

For the sake of clarity, we will refer to the original deposits on the east side of the Chay River as *Khoan Thong–An Phu* and to the newer localities on the west side as *Tan Huong–Truc Lau* (the latter names are the main mining areas). The older deposits also have been referred to in the literature as simply *Luc Yen* (Kane et al., 1991; Long et al., 2004; Garnier et al., 2008), while the newer ones have been called *Yen Bai* (Long et al., 2004). This terminology is potentially confusing because Khoan Thong, An Phu, and Truc Lau administratively belong to the Luc Yen District, while Tan Huong is part of the Yen Binh District (again, see figure 2). Nevertheless, all of these

occurrences occupy the northeastern part of Yen Bai Province, ~250 km northwest of Hanoi. From the city of Yen Bai, it is easy to reach the new mining area by driving northwest along National Road 70, along which most of the occurrences are located.

This article describes the geology and gemological characteristics of gem corundum from Tan Huong–Truc Lau and compares it to the material from the well-known Luc Yen deposits.

## GEOLOGY AND OCCURRENCE

The Khoan Thong–An Phu and Tan Huong–Truc Lau mining regions lie about 15 km from one another, but their geologic settings are clearly different. Most primary and secondary corundum occurrences in the Tan Huong–Truc Lau area are located within the Dãy Núi Con Voi mountain range, which stretches from

Figure 5. The 18.8 kg Great Star Ruby, one of many large gems mined at Tan Huong–Truc Lau, belongs to DOJI Gold & Gems Group. The stone measures approximately 32 × 24 × 17 cm and has been partly tumbled and polished to reveal its asterism. Photo by N. N. Khoi.



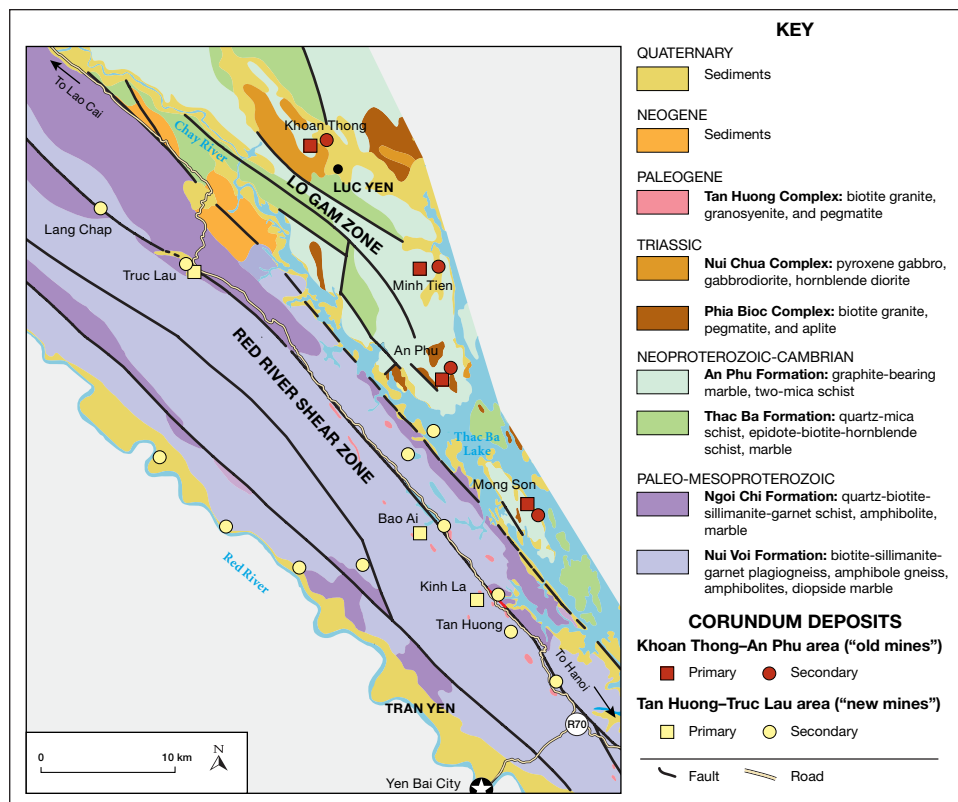


Figure 6. This simplified geologic map shows the locations and rock formations of the corundum occurrences at Khoan Thong–An Phu and Tan Huong–Truc Lau. Modified after Vinh (2005) and Xuyen (2000). Smaller deposits are not shown here.

Lao Cai Province southeast to Yen Bai Province. The mountains are bounded by lateral strike-slip faults (figure 6) forming a major Cenozoic geologic discontinuity in Southeast Asia known as the Ailao

### NEED TO KNOW

- Northern Vietnam's Yen Bai Province has produced ruby and sapphire from adjacent geologically distinct areas referred to as "Luc Yen" and "Yen Bai."
- The latter area pertains to deposits (both primary and secondary) located on the west side of the Chay River in the Tan Huong–Truc Lau area.
- Since the mid-1990s, these deposits have produced mainly cabochon-quality rubies (especially star rubies) and some sapphires.
- Although large pieces are known, the corundum is typically semitransparent to translucent, and most ranges from pink to purplish or brownish red.

Shan–Red River Shear Zone (Trinh et al., 1998, 1999; Leloup et al., 2001).

Rocks in the Tan Huong–Truc Lau area mainly consist of plagiogneiss and other gneisses intercalat-

ed with lenses of amphibolite and marble; they are grouped as the Nui Voi Formation (Long et al., 2004; Nam, 2007; Garnier et al., 2008; again, see figure 6). These rocks underlie the Ngoi Chi Formation, which comprises schist, amphibolite, and marble. Both formations appear to have been intruded by granite, syenite, and pegmatite of the Tan Huong magmatic complex, which is 22–25 million years old (Nam and Huyen, 2010).

Primary corundum deposits in the Tan Huong–Truc Lau area can be classified into three main types:

1. Gray, grayish white to bluish gray, and yellowish gray corundum embedded in gneisses, such as the Co Man outcrop in Truc Lau valley, and the Khe Nhan and Kinh La occurrences in the Tan Huong area (Nam, 2007; Thuyet, 2008). The corundum usually consists of large (1–3 cm, with some over 10 cm) well-formed crystals of very low or non-gem quality (Nam, 2007; Thuyet, 2008; figure 7, left).
2. Dark red to pinkish red rubies of low-to-medium gem quality. These are usually also large and come from weathered pegmatoid feldspathic rocks (e.g., the occurrences at kilometers 12,



Figure 7. The left sample of corundum-bearing gneiss, from Co Man, contains mainly feldspar, biotite, sillimanite, and sapphire crystals up to 3 cm long. The feldspathic rock from the Slope 700 outcrop (right) typically consists of K-feldspar, biotite, and ruby. Photos by N. V. Nam.

15, and 23 along National Road 70, and also Slope 700).

3. Rubies in large marble lenses intercalated with in gneiss, mica schist, and amphibolites (e.g., the Tan Huong drill core, and DOJ's Truc Lau mine). This type of ruby appears to have higher gem quality, but its distribution is limited.

These occurrences, mostly related to gneisses and schists of metasedimentary origin, are much different from the corundum deposits of Khoan Thong–An Phu, which are mainly hosted by marble formations.

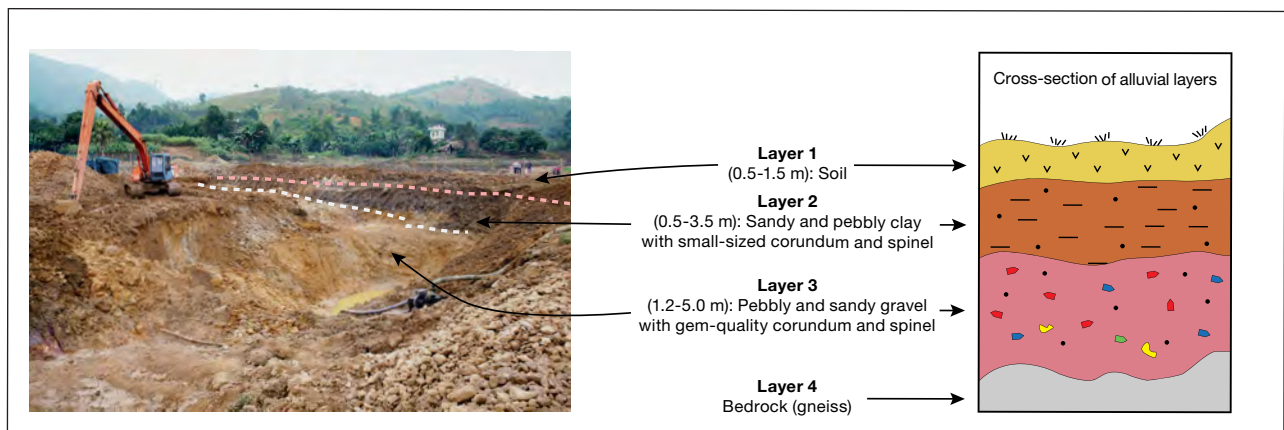
The corundum-bearing host rocks in the Tan Huong–Truc Lau area appear to have originated from the metamorphism of fine-grained sediments of variable composition (Katz, 1972; Simandl and Paradis, 1999). For example, gneisses from the Co Man and Kinh La outcrops have a wide compositional range, from 50–90% feldspar, up to 40% biotite, and up to 20% sillimanite. In addition, ruby-bearing feldspathic rocks (e.g., the Slope 700 outcrop) typically consist of K-feldspar and biotite (or vermiculite; figure 7, right).

The primary host rocks are usually deeply weathered, forming numerous eluvial deposits.

The secondary (eluvial and alluvial) corundum deposits usually contain dark red ruby, pink sapphire, and red and brown spinel, as well as some garnet, trapiche-like bluish gray sapphire, sillimanite, and quartz. Of these mining areas, Truc Lau and Tan Huong are the most important. Truc Lau occupies a large valley, about 5 km long, that contains eluvial and alluvial sediments. The eluvium consists of three layers: topsoil (averaging 1 m thick); a gem-bearing layer (0.8–1 m thick) containing corundum and spinel that is composed of pebbles, gravel, and sand; and a deeply weathered gneiss layer (3 m thick) that typically contains ruby and sapphire. Compared to the eluvium, the alluvial deposits at Truc Lau are thicker (~10 m). Ruby, sapphire, and spinel are found within a gravel paleoplacer (1.2–5.0 m thick) that lies on bedrock, and is buried below 0.5–3.5 m of Quaternary sediments and 0.5–1.5 m of topsoil (figure 8). In 2002, 1–2 kg per month of pink sapphire and star ruby were produced from this paleoplacer.

At Tan Huong, the main gem occurrences are

Figure 8. Alluvial layers in the Tan Huong–Truc Lau area consist of soil, sandy and pebbly clays, and gravels containing gem corundum.



arranged in a northwesterly direction, bounded by two small lakes. The alluvial deposits consist of a topsoil layer (~0.5 m thick); a sand horizon with areas of humus (~0.5–1 m thick); and a ruby-, sapphire-, and spinel-bearing layer above the bedrock that contains mixed sand, pebbles, and boulders (~1.2–2.5 m thick). All of the alluvial deposits in the Tan Huong–Truc Lau area are quite similar to those shown in figure 8.

## PRODUCTION AND DISTRIBUTION

Current production of gem material from Tan Huong–Truc Lau is about 10 kg per month. This includes approximately 20–30% ruby and some sapphire, and 70–80% spinel. Only 10–15% of the stones are of gem quality; the rest are suitable for carving material or as specimens. Most of the gems are cut and sold locally. DOJI Gold & Gems Group is the major exporter of faceted Vietnamese gemstones to the world market, either directly or through the international gem fairs in Bangkok, Hong Kong, Tokyo, and Kobe. The main markets for high-quality corundum are Japan, North America, and Hong Kong. Large, medium-quality stones are sold in the Middle East, Taiwan, and Southeast Asia, while low-quality commercial products go to India and China.

Heat treatments, including lead-glass filling, have been applied to these materials, but most appear to be unsuccessful. After heat treatment, white stripes often appear along fractures.

## MATERIALS AND METHODS

A total of 57 gem samples from Tan Huong–Truc Lau, including 15 rough and 42 cut stones (12 faceted and 30 cabochons), were collected by the authors over a period of many years, and examined as summarized in table 1. Among these, 29 cut samples (nine faceted and 20 cabochons) and 10 pieces of rough were from secondary deposits (e.g., figure 9). The remaining 13 cut samples (three faceted and 10 cabochons) and five pieces of rough were from primary host rocks (e.g., figure 10) along National Road 70, at kilometers 12, 15, and 23, and at Slope 700. All of these were gem quality, although those from primary occurrences typically were of much lower quality.

We used standard gemological equipment to record optic character, refractive indices and birefringence, pleochroism, absorption spectra, and UV fluorescence (to long- and short-wave radiation). Specific

gravity was measured by the hydrostatic method using an electronic balance. Various gemological microscopes (vertical and horizontal, incorporating different lighting techniques) were used to observe internal features.

Raman microspectroscopy was performed on nine observable mineral inclusions embedded in transparent hosts. The spectra were collected using a Jobin Yvon LabRam HR 800 spectrometer coupled with an Olympus BX41 optical microscope and an Si-based CCD (charge-coupled device) detector at the Institute of Geosciences, Johannes Gutenberg University (Mainz, Germany). The samples were excited by a 514 nm Ar-ion laser. The confocal mode was used to enable analysis at the micron scale (~0.2–0.5  $\mu\text{m}$ ).

Absorption spectra of three Tan Huong–Truc Lau rubies were collected using a Shimadzu UV-2450 UV-Vis spectrophotometer at the Center for Material Sciences, Hanoi University of Science.

Polished thin sections of 23 samples selected from primary and secondary deposits at Truc Lau and Tan Huong were prepared for quantitative chemical analysis by electron microprobe. The analyses were performed using three different instruments, as indicated in table 2. Also analyzed were 29 mineral inclusions exposed on the polished surfaces.

## GEMOLOGICAL CHARACTERISTICS

**Crystal Morphology.** Two main crystal forms characterized the morphology of the corundum from primary deposits:

1. Prismatic crystal habits composed of the hexagonal prism  $a$  {11 $\bar{2}$ 0} and basal pinacoid  $c$  {0001}
2. A modification of this habit, with the addition of the positive rhombohedron  $r$  {10 $\bar{1}$ 1}

The crystals had short prismatic and sometimes tabular hexagonal shapes, with a height-to-width ratio ranging from 1 to 3.

**Visual Appearance.** In general, rubies and sapphires from Tan Huong–Truc Lau are only of cabochon quality. Transparent to semitransparent pieces with more marketable red to pink colors occur in secondary deposits, while those extracted from primary deposits are usually opaque to translucent and have dull to dark colors unsuitable for cutting. Corundum from the primary deposits ranges from colorless to gray, pale blue, and yellowish to dark red and violetish pink; only the latter is typically of gem quality (again, see figure 10). Corundum from

**TABLE 1.** Gemological characteristics of rubies and sapphires from Tan Huong–Truc Lau, Vietnam.

Property	Primary deposits		Secondary deposits	
	No. of samples	Observations	No. of samples	Observations
Color	13 polished	Colorless, gray to yellowish gray, bluish or greenish gray Dark red, red to pink, purplish pink	29 polished	Pink, pinkish to purplish and brownish red, dark red
Pleochroism	13 polished	Weak to moderate <i>Dark red to red, pink:</i> Violet to violetish red, orange to orangy red <i>Bluish gray:</i> Greenish gray to bluish gray	29 polished	Moderate to strong <i>Dark red to red, pink:</i> Violet to violetish red, orange to orangy red
Diaphaneity	5 rough, 13 polished	Poor to moderate clarity and opaque to translucent; rarely semitransparent to transparent	10 rough, 29 polished	Poor to moderate clarity, opaque to translucent and semitransparent; some parts may be transparent
Refractive Indices	3 faceted  10 cabochon	$n_o = 1.762\text{--}1.763$ $n_e = 1.770\text{--}1.771$ $n = 1.76\text{--}1.77$ (spot method)	9 faceted  20 cabochon	$n_o = 1.762\text{--}1.763$ $n_e = 1.770\text{--}1.771$ $n = 1.76\text{--}1.77$ (spot method)
Birefringence	3 faceted	0.008–0.009	9 faceted	0.008–0.009
Optic character	3 faceted	Uniaxial negative	9 faceted	Uniaxial negative
Specific gravity	5 rough, 13 polished	3.91–3.99	10 rough, 29 polished	3.92–4.07
UV fluorescence <sup>a</sup>	5 rough, 13 polished	<i>Gray to white, bluish gray:</i> Inert to both LW and SW <i>Red to pink:</i> • LW: Moderate to weak red • SW: Weak red	10 rough, 29 polished	<i>Red to pink:</i> • LW: Moderate to strong red • SW: Weak to moderate red
Spectroscope spectrum	5 rough, 13 polished	<i>Red to pink:</i> Chromium spectra <i>Bluish and greenish gray:</i> 450 nm (faint line)	10 rough, 29 polished	<i>Red to pink:</i> Chromium spectra
Internal features	5 rough, 13 polished	<ul style="list-style-type: none"> <li>• Ilmenite, plagioclase, biotite, muscovite, apatite, zircon, rutile needles, magnetite, chlorite</li> <li>• Primary and secondary liquid-gas inclusions</li> <li>• Growth zoning, parting, fractures, lamellar twinning</li> </ul>	10 rough, 29 polished	<ul style="list-style-type: none"> <li>• Rutile (needles, silk, clouds, and stringer formations), ilmenite, zircon, apatite, spinel, diaspore, plagioclase, biotite, muscovite, chlorite, allanite(?), magnetite</li> <li>• Primary and secondary liquid-gas inclusions</li> <li>• Growth zoning, parting, fractures, lamellar twinning</li> </ul>

<sup>a</sup> Abbreviations: LW = long-wave, SW = short-wave.

Figure 9. These rough and cut rubies are from secondary deposits at Truc Lau. The cabochons on the right range from 8.24 to 19.53 ct. Note the asterism in the stone on the lower right. Photos by N. N. Khoi.

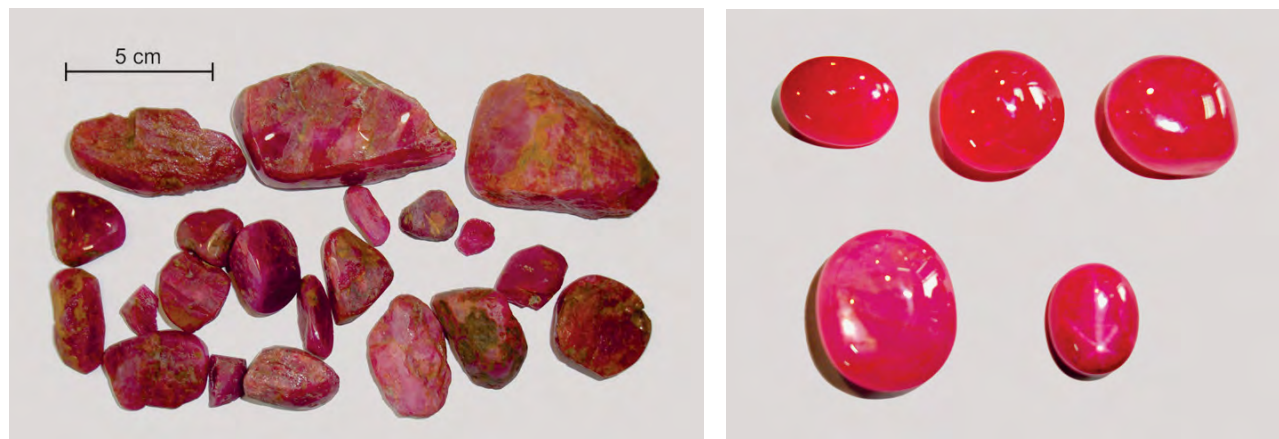




Figure 10. This ruby crystal (2.45 g) formed in feldspathic host rock (see figure 7, right). Photo by N. V. Nam.

the secondary deposits, however, has more desirable colors that commonly range from dark red, brownish red, and violetish to pinkish red (figures 1 and 11). The secondary deposits also yield sapphires that are usually colorless, yellowish gray, bluish gray, or multicolored. Blue, green, and yellow hues are very rare. Diaphaneity ranges from opaque to nearly transparent.

The corundum's dimensions vary considerably, from several millimeters to several centimeters. The most significant visual features are growth zoning (straight and angular) and asterism (figure 12); about 30% of the gem-quality stones show a star phenomenon, according to the miners. Color irregularities such as spots, streaks, and patches are uncommon in these rubies and sapphires.

Another distinct characteristic of corundum (especially ruby) from both primary and secondary deposits in Tan Huong-Truc Lau is an overgrowth of iron-stained spinel. These coated stones have an unsightly yellowish gray appearance until the spinel crust is cut away to reveal a red core of ruby (figure 13). Local gem dealers call the spinel-encrusted material *hàng mó bát* (gamble merchandise), indicating the uncertainty of dealing with these goods.

**Optical Characteristics and Specific Gravity.** The refractive indices, birefringence, and specific gravity values of ruby and sapphire from Tan Huong-Truc Lau fell within typical values for corundum, and there was little difference in these properties

TABLE 2. Summary of electron microprobe analyses of corundum from Tan Huong-Truc Lau, Vietnam.<sup>a</sup>

Oxide (wt.%)	Primary corundum		Secondary corundum		
	Bluish gray to pale blue, from Truc Lau <sup>b</sup> (10)	Pale pink, from Truc Lau <sup>c</sup> (3)	Pink to red, from Truc Lau <sup>c</sup> (4)	Dark red, from Tan Huong <sup>d</sup> (1)	Violetish red to violetish pink, from Tan Huong <sup>d</sup> (5)
Al <sub>2</sub> O <sub>3</sub>	97.12–98.95	99.00–99.30	98.90–99.30	99.76	98.90–99.98
SiO <sub>2</sub>	nd–0.10	nd–0.10	–	–	–
TiO <sub>2</sub>	nd–0.05	nd–0.22	nd–0.05	–	0.014–0.11
Cr <sub>2</sub> O <sub>3</sub>	nd–0.04	0.11–0.44	0.07–0.69	0.18	0.69–0.27
FeO	0.94–1.38	0.15–0.48	0.03–0.37	–	0.005–0.15
MnO	nd–0.02	–	–	–	–
MgO	nd–0.02	–	–	–	–
NiO	nd–0.04	–	–	–	–
CaO	nd–0.04	–	–	–	–
Na <sub>2</sub> O	nd–0.02	–	–	–	–
K <sub>2</sub> O	nd–0.03	–	–	–	–
V <sub>2</sub> O <sub>5</sub>	–	–	–	–	nd–0.12
ZnO	nd–0.23	–	–	–	–
Ga <sub>2</sub> O <sub>3</sub>	–	–	–	–	nd–0.04
Total	99.51	99.84	99.67	99.94	100.16

<sup>a</sup> Number of samples shown in parentheses; average of 4–5 analyses per sample. Total iron is reported as FeO. Abbreviation: nd = not detected.

<sup>b</sup> Analyzed at Vietnam Institute of Geosciences and Mineral Resources, using a JEOL JXA 8800R/8900 microprobe with an accelerating voltage of 15 kV, a beam current of 1.2 nA, and a collection time of 20 seconds (major elements) or 15 kV, 50 nA, and 80 seconds (trace elements).

<sup>c</sup> Analyzed at the Institute of Geology, Russian Academy of Science, using a Camebax-KeveX microprobe with an accelerating voltage of 15 kV, beam current of 20 nA, and collection time of 20 seconds.

<sup>d</sup> Analyzed at the Earth Sciences Institute, Academia Sinica, Taiwan, using a JEOL JXA 8900-R microprobe with an accelerating voltage of 15 kV, a beam current of 20 nA, and a collection time of 20 seconds.



Figure 11. These red to pinkish red rubies (4.26–14.58 ct) are from alluvial deposits in the Tan Huong–Truc Lau area. Note the asterism in some of the stones. Photo by N. N. Khoi.

between primary and secondary corundum (table 1). Although high-SG mineral inclusions were common in corundum from the primary deposits, some samples from the secondary deposits actually had higher SG values (up to 4.07, versus 3.99). This may be caused by a higher content of heavy inclusions such as ilmenite.

Figure 12. Growth zoning and asterism are often observed in corundum from secondary deposits in the Tan Huong–Truc Lau area. These samples range from 13.77 to 24.54 ct. Photo by N. N. Khoi.



**Internal Features.** The majority of the gem-quality samples were from secondary deposits, which we aimed to separate from the Khoan Thong–An Phu gem materials. Nevertheless, some samples from the primary deposits were investigated for comparison. These contained various mineral inclusions, such as ilmenite, plagioclase, biotite, muscovite, apatite, zircon, rutile, magnetite, and chlorite. Among these, ilmenite, biotite, and magnetite were the most common. Primary and secondary gas-liquid inclusions were also encountered frequently.

The most common mineral inclusions in samples from secondary deposits were rutile, ilmenite, zircon, apatite, spinel, and diaspore; some plagioclase and mica (biotite and muscovite) were also observed. The rutile usually occurred as short needles, but also seen were tiny rutile inclusions with a silk-like appearance that formed antenna-like patterns (figure 14).

In general, the range of mineral inclusions was similar between the primary and secondary samples. Ilmenite was typical, and easily recognized by its stubby crystal shape, black color (figure 15, left), and submetallic luster when exposed to the surface. Apatite (figure 15, right) and zircon were also frequently encountered in our samples, forming near-colorless euhedral crystals. In addition, we observed a wide range of fluid inclusions that often showed various stages of healing, forming negative crystals (figure 16), “fingerprints,” feathers, folded patterns, and irregular fluid droplets. Iron stains were also apparent.

Figure 13. Rubies from secondary deposits at Tan Huong–Truc Lau are often coated by an iron-stained spinel aggregate. Here the spinel overgrowth has partially broken away from a ruby crystal (~2 cm across) after the specimen was sawn open. Photo by N. V. Nam.



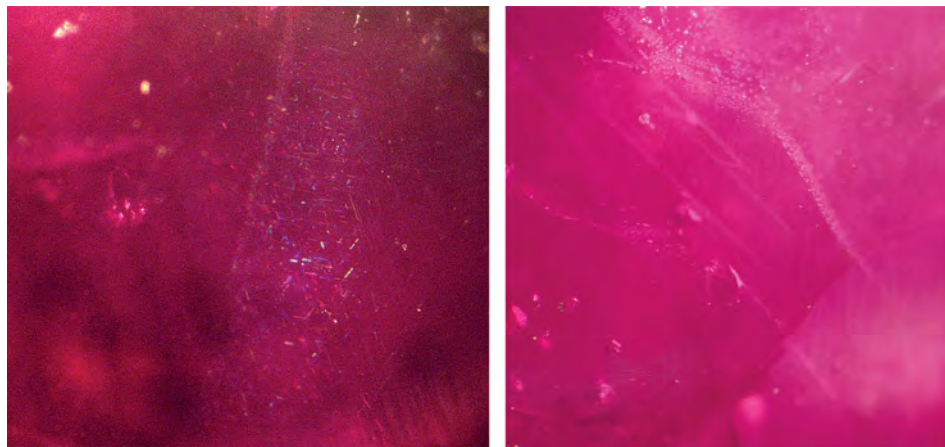


Figure 14. Rutile inclusions, usually as short needles oriented in three directions (left), may contribute to the asterism in some of the corundum. Rutile inclusions may also show a silky appearance (left) or antenna-like patterns (right). Photomicrographs by N. N. Khoi; magnified 45 $\times$ .

Optical phenomena such as asterism, chatoyancy, and sheen were caused by oriented micro-inclusions, rutile needles in particular. The star effect in many of the rubies was quite sharp and attractive. Straight and angular growth zones, typically sharp and well defined, were conspicuous in most stones. Asterism and growth structures were observed together in some instances (figure 17, left). Three systems of polysynthetic lamellar twinning parallel to the positive rhombohedron  $r$  {10 $\bar{1}$ 1} were quite common (figure 17, right). Fracturing along these twin planes yielded parallelogram-shaped rough material.

**Absorption Spectra.** Preliminary observation of the ruby samples with the desk-model spectroscope showed essentially the same features as the diagnostic absorption spectra described by Liddicoat (1993) for natural and synthetic rubies and purple sapphire. The strong lines at 692 and 694 nm often appeared as a single bright emission line at 693 nm. UV-Vis absorption spectroscopy (figure 18) showed peaks at ~378, 389, and 456 nm related to iron ( $\text{Fe}^{3+}$  and  $\text{Fe}^{2+}$ ).

A broad band centered around 570 nm, related to  $\text{Fe}^{2+}/\text{Ti}^{4+}$ , also appeared in these spectra.  $\text{Cr}^{3+}$  features were evidently superimposed by the iron absorptions.

**Chemical Analysis.** Microprobe analyses of sapphires from primary deposits (table 2) showed relatively high contents of iron, especially in bluish gray stones (0.15–1.38 wt.% FeO). Chromium contents ranged from low (<0.04 wt.%  $\text{Cr}_2\text{O}_3$ ) in bluish gray sapphires to moderate (0.11–0.44%  $\text{Cr}_2\text{O}_3$ ) in the pink sapphires. Titanium contents ranged up to 0.22 wt.%  $\text{TiO}_2$ . In addition, some samples showed very small amounts of Si, Ca, K, Na, Ni, and Zn, probably due to tiny mineral inclusions.

The trace-element compositions of stones from placer deposits were similar to those from primary deposits. Their varying proportions clearly corresponded to differences in color. Greater contents of Cr were recorded for pink sapphires and rubies. In general, both rubies and sapphires from Tan Huong–Truc Lau had high Fe contents.

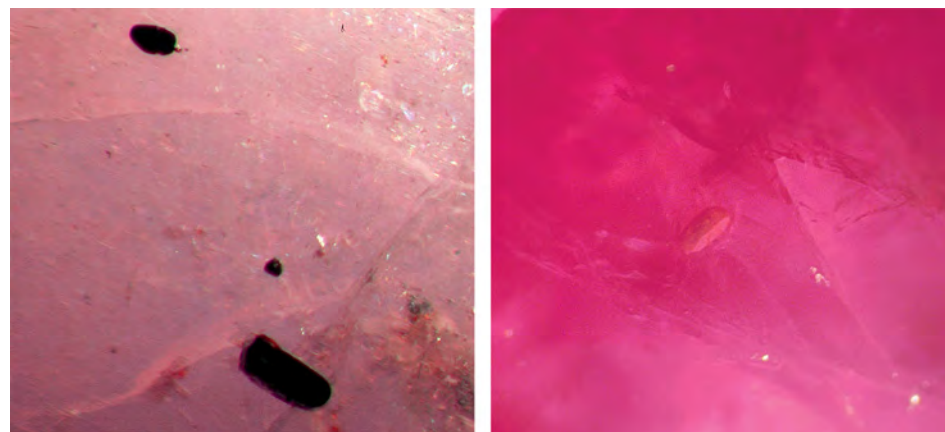


Figure 15. Ilmenite is a typical inclusion in ruby and sapphire from Tan Huong–Truc Lau, and usually shows a stubby shape and black color (left). Apatite typically occurs as colorless to light-colored euhedral crystals, as shown on the right. Photomicrographs by N. N. Khoi; magnified 45 $\times$ .

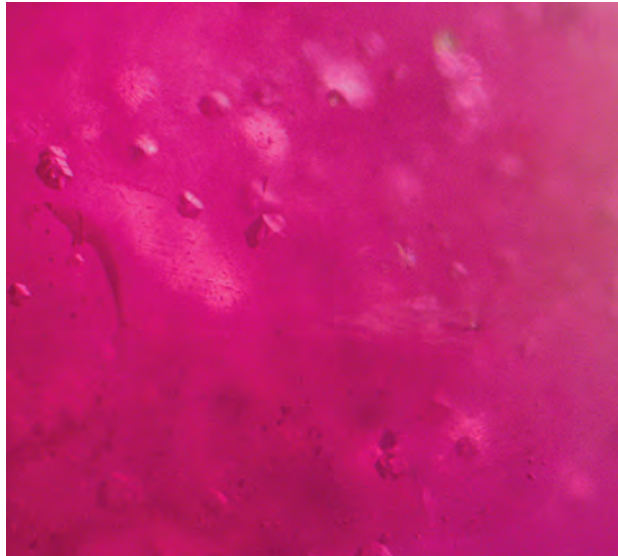


Figure 16. Negative crystals are quite common in ruby and sapphire from Tan Huong-Truc Lau, usually distributed along fractures and fissure planes. Two phases (gas and liquid) were occasionally observed in these inclusions. Photomicrograph by N. N. Khoi; magnified 45x.

## DISCUSSION

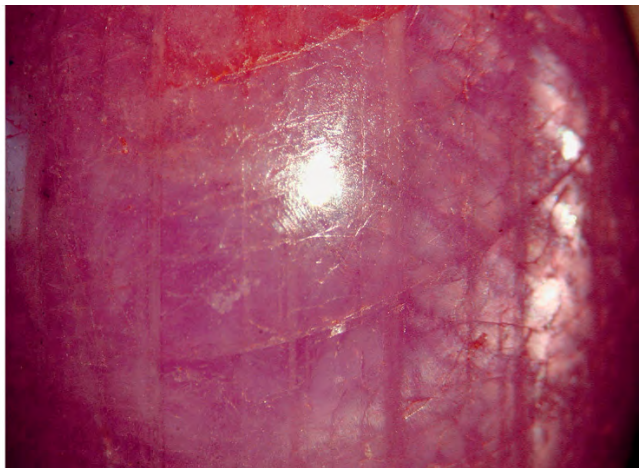
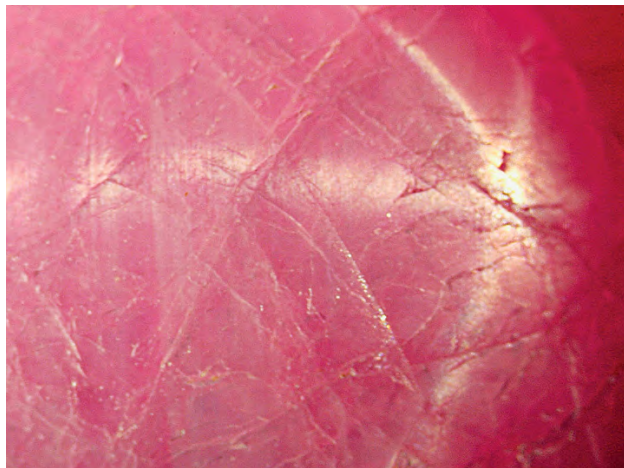
Although gem corundum from Tan Huong-Truc Lau, especially star ruby, has been sold in the world market for more than 10 years, these Vietnamese deposits remain largely unknown. Many in the trade assume the stones are from Luc Yen (i.e., Khoan Thong-An Phu), but those belong to different geologic settings and consequently have distinctive gem-

logical properties (Khoi, 2004; Khoi et al., 2010a,b), as discussed below.

**Morphology and Appearance.** In contrast to the short prismatic and sometimes tabular morphologies of corundum from Tan Huong-Truc Lau, crystals from Khoan Thong-An Phu typically have a barrel or spindle shape with  $n$ ,  $z$ , and  $\omega$  hexagonal dipyrramids,  $r$  rhombohedra, and  $c$  pinacoidal faces with length-to-width ratios from 5 to 6 (Long, 2003; Nam, 2007; Thuyet, 2008). The most distinctive feature of the Tan Huong-Truc Lau corundum is its coating of granular spinel (Häger et al., 2010; Hauzenberger et al., 2010). Also, pieces of rough from Tan Huong-Truc Lau are generally much larger than those from Khoan Thong-An Phu.

The majority of cut stones from Khoan Thong-An Phu range from “pure” red or pink to purplish red or pink; other hues such as blue, orangy red, violet, or multicolored are also found with varying tones and saturations. Both rough and polished stones commonly have strong color zoning visible to the unaided eye. Diaphaneity usually ranges from transparent to translucent (Kane et al., 1991; Long, 2003; Khoi et al., 2010a). In contrast, corundum from Tan Huong-Truc Lau shows less color variation, mostly consisting of pink to purplish or brownish red hues. Color zoning is uncommon. Diaphaneity is commonly semitransparent to translucent or opaque because of fracturing and the abundance of inclusions. Interestingly, some features typical of this

Figure 17. Asterism and growth structures are seen in this 14.45 ct pink sapphire from Truc Lau (left). Polysynthetic twinning, parallel to the positive rhombohedron  $r \{10\bar{1}1\}$ , is a common feature of ruby and sapphire from Tan Huong-Truc Lau (right). Photomicrographs by N. N. Khoi; magnified 12x.



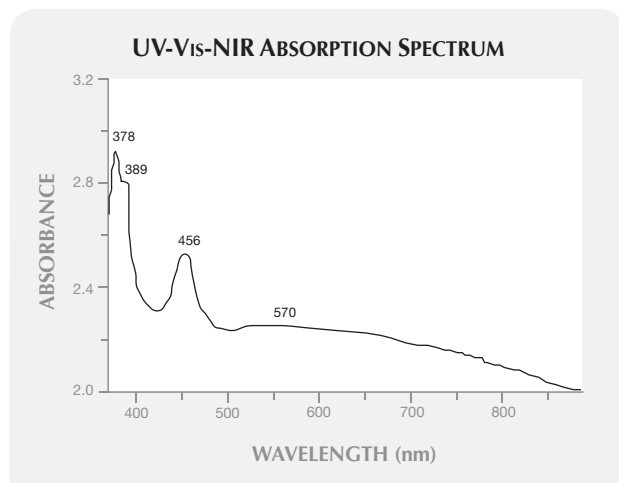


Figure 18. This UV-Vis-NIR spectrum of a ruby from a primary deposit at Truc Lau is dominated by Fe-related absorptions.

corundum (large size, asterism, and angular growth structures) are also seen in ruby crystals from Karnataka, India (Panjikar et al., 2009).

**Internal Features.** A summary of mineral inclusions in corundum reported from both mining areas is presented in table 3. The most common mineral inclusions in Khoan Thong–An Phu corundum are calcite, rutile, apatite, spinel, zircon, corundum, pyrrhotite, graphite, boehmite, hematite, phlogopite, muscovite, hercynite, tourmaline, and iron oxide or hydroxide (Kane et al., 1991; Long, 1999; Long et al., 2004; Khoi et al., 2010a,b). Straight, angular color zones and colored patches and spots are usually seen in the blue sapphires, and swirl growth marks are observed occasionally (see Kane et al., 1991; Long et al., 2004).

Gem corundum from Tan Huong–Truc Lau contains a diversity of mineral inclusions, most commonly ilmenite, rutile, apatite, zircon, diaspore, boehmite, magnetite, plagioclase, biotite, muscovite, and chlorite. Although straight and angular growth structures are quite common, color irregularities are rare. Trapiche rubies and pink sapphires are also known from this region (Schmetzer et al., 1996), but were not examined for this report.

The common polysynthetic twinning in corundum from the Tan Huong–Truc Lau area may be related to deformation from the Red River Shear Zone (Khoi et al., 2010b).

## CONCLUSIONS

For more than two decades, Vietnam has been an important source of gem ruby and sapphire. Most of

**TABLE 3.** Comparison of internal features in corundum from Tan Huong–Truc Lau and Khoan Thong–An Phu, Vietnam.<sup>a</sup>

Internal feature	Tan Huong–Truc Lau <sup>b</sup>	Khoan Thong–An Phu <sup>c</sup>
<b>Solid Inclusions</b>		
Anatase		+
Anhydrite		+
Apatite	++	++
Biotite	+	
Boehmite	+	+
Calcite		+++
Chlorite	+	
Corundum		+
Diaspore	+	+
Dolomite		+
Graphite		+
Halite		+
Hematite		+
Hercynite	+	+
Ilmenite	++	
Iron oxide or hydroxide	+++	+++
Magnetite	++	
Margarite		+
Monazite		+
Muscovite	+	+
Nepheline		+
Nordstrandite		+
Phlogopite	+	+
Plagioclase	+	
Pyrite		+
Pyrrhotite		+
Rutile (primary)	+	+
Rutile needles (silk, cloud)	++	++
Sphene		+
Spinel	+	+
Tourmaline		+
Zircon	++	+
<b>Liquid Inclusions</b>		
“Fingerprints”	++	++
Negative crystals	+	+
Salts (Na, Ca, K chlorides)		+
<b>Other Features</b>		
Color zoning	+	++
Growth structures	++	++
Twinning	+	+
Swirl growth marks		+
Wedge-shaped growth features		+

<sup>a</sup> Symbols: +++ = common, ++ = frequently encountered, + = encountered.

<sup>b</sup> From this study.

<sup>c</sup> References: Kane et al. (1991), Long (1999), Vinh et al. (1999), Dao and Delaigue (2001), Giuliani et al. (2003), and Long (2003).

the production has come from Yen Bai Province; the original deposits in the Khoan Thong–An Phu area and the newer ones in Tan Huong–Truc Lau are con-

sidered to have the most potential (see figure 19). Despite their proximity, the two areas belong to different geologic settings (marble- and gneiss-hosted, respectively). The Tan Huong-Truc Lau deposits are mostly restricted to the Dãy Núi Con Voi mountain range, which is associated with the Red River Shear Zone. Recent mining activities mostly consist of sporadic diggings by local people, though a few mechanized pits are active.

Gem corundum from Tan Huong-Truc Lau usually shows a tabular crystal form with deformed polysynthetic twinning along rhombohedral faces and sharp growth zones. Their typical colors range from pink to pinkish red. Color irregularities such as zoning and spots or patches are rare. Many stones, particularly the sapphires, have low transparency due to abundant fracturing and inclusions. The density of mineral inclusions appears crucial to differentiating these stones from those from the Khoan Thong-An Phu deposits. The most common mineral inclusions in the Tan Huong-Truc Lau stones are clusters of tiny short rutile needles, black stubby ilmenite, euhedral apatite, and assemblages of various minerals (e.g., ilmenite, rutile, and zircon), often in the same stone.

Although the vast majority of gem corundum from Tan Huong-Truc Lau is suitable for cutting cabochons (including star rubies) rather than faceted stones, some exceptionally large pieces of rough containing gem-quality areas are known. The deposits



Figure 19. This ring is set with a 17.50 ct star ruby from Truc Lau. The star is sharp and complete throughout the stone. Jewelry courtesy of DOJI Gold & Gems Group; photo © DOJI Gold & Gems Group and N. N. Binh.

show strong potential for producing commercial quantities of gem corundum for many years. The main markets for gem material from the Tan Huong-Truc Lau area are Japan, the Middle East, and India.

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