

EXPERIMENTAL HEAT TREATING OF TRAPICHE-LIKE BLUE SAPPHIRE OF SOUTHERN VIETNAM

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Received: June 16, 2016; Revised: October 14, 2016; Accepted: October 18, 2016

Abstract

Twenty-seven rough trapiche-like blue sapphire samples from southern Vietnam were heat treated to investigate the effect of heat on their properties and to find the appropriate heat treatment schemes. In the heat treating experiments, the samples were divided into 2 batches. The first batch, consisting of 22 samples, was heated under an oxidizing condition to lighten the dark blue color of the samples, while the 5 samples in the second batch were heated under a reducing condition to intensify the blue color. The results show that heating at 1200°C can lighten the dark blue color and heating at 1400°C can change brown to blue colors. Heating the samples at a temperature higher than 1400°C can intensify the blue color in the samples. However, the trapiche appearance still persisted after the heat treatment. The UV-Vis-NIR absorption spectra of all samples exhibit Fe³⁺ absorption peaks, Fe²⁺/Ti⁴⁺ intervalence charge transfer (IVCT), and Fe²⁺/Fe³⁺ IVCT absorption bands. The more bluish color can be intensified after heating corresponding to the stronger intensity of Fe²⁺/Ti⁴⁺ and Fe²⁺/Fe³⁺ IVCT absorption bands. Chemical compositions reveal iron (Fe) and titanium (Ti) are the most significant minor and trace elements which affect colors in the studied samples. The high iron contents are related to the brown color especially in the dark tone of the brown color.

Keywords: Heat treatment, blue sapphire, trapiche, southern Vietnam, corundum

Introduction

Vietnam has been known as a country with many regions (Khoi *et al.*, 2011). Blue to great potential for deposits of gem-quality bluish green gem-quality sapphires have been corundum in past decades. Several corundum recovered from secondary deposits, mainly deposits have been discovered and mined in alluvials (placers), in basaltic terrains from

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southern Vietnam since the late 1980s (Smith *et al.*, 1995). The geologic setting of these southern Vietnam sapphires is similar to that of alkali basalts elsewhere in Southeast Asia and China (Keller and Keller, 1986; Wang, 1988; Guo *et al.*, 1992; Vichit, 1987). At these localities, the alluvial and eluvial deposits resulted in the crystallization of the corundums by weathering and mechanical processes (Smith *et al.*, 1995).

Trapiche is a Spanish word for sugar cane crushing gear. It was first used to describe a similar feature observed in some Colombian emeralds by McKague (1964) and studied in detail by McKague (1964) and Nassua and Jackson (1970). The trapiche (or fixed star-like appearance) emeralds consisted of a central hexagonal core with trapezohedral-shaped prisms (emerald sections). Colorless or white, fine-grained material (arms) separate the trapezohedral-shaped prisms from each other and from the central hexagonal core (Schmetzer *et al.*, 1996). The similar textures with core, 6 arms, and 6 growth sectors can be seen in ruby, probably originating from the Mong Hsu mining area, Myanmar (Sunagawa *et al.*, 1999). Trapiche textures in sapphire have been described as purple-pink and whitish gray for the blue sapphires from Vietnam, Myanmar, and Cambodia (Koivula *et al.*, 1992; Schmetzer *et al.*, 1996; Khotchanin *et al.*, 2009, 2010).

Blue sapphire is a variety in the corundum species. Corundum, $\alpha\text{-Al}_2\text{O}_3$, has a trigonal crystal symmetry. The crystal structure of corundum is hexagonal close packing of O^{2-} anions, in which two-thirds of the octahedral sites are occupied with the aluminum ions Al^{3+} . The coloration of corundum is mainly caused by 3d-transition metal ions, such as Cr, Ti, Fe, and V, which replace the Al^{3+} ions in the structure during the crystallization (Bgasheva *et al.*, 2012). The quality of rough blue sapphires generally depends on the color and clarity. The color is related to hue, tone, saturation, color distribution, and color zoning. Gem-quality blue sapphires should have a pure hue with high saturation and a uniform color distribution. The blue sapphires which look

pale or black with patches or bands of differing colors are classified as non-gem (Hughes, 1997; Suwa, 1999; Newman, 2000). Most natural blue sapphires from several localities are of non-gem quality which is not commercially desirable for jewelry purpose. They are commonly heat-treated to improve their color, clarity, and value (Themelis, 1992). Heat treatment of sapphires was known to the commercial world when gem dealers learned that not only could they enhance the existing color of some sapphires, but they could also transform near-colorless sapphires with inherent latent qualities into fine fancy-colored stones. Heating could also result in cracked or shattered stones, or in the dulling of color, or other damage. The color of sapphire depends on the presence of trace amounts of certain elements, such as iron and titanium. The heating process will do nothing to improve the color if these elements are absent from the original material. Generally, the specific objectives of heat treatment are varied according to the quality of the sapphire being heated and the country of its origin. Sapphires from different localities may require different heating processes to enhance their quality (Abraham, 1982). Although heat treatment processes of blue sapphires have been reported in several publications (Nassau, 1981, 1994; Tombs, 1982; Coldham, 1985; Themelis, 1992; Emmett and Douthit, 1993; Häger, 2001; Maxwell, 2002; Emmett *et al.*, 2003), the processes for the trapiche blue sapphire have been rarely reported. The main purpose of this research is to study the appropriate heat treatment configuration for the trapiche-like blue sapphires from southern Vietnam, and to determine the physical and optical properties including the chemical compositions of the studied sapphires.

Materials and Methods

Sample Preparation

Twenty-seven rough crystals of trapiche-like blue sapphire with a dark tone from southern Vietnam were selected for this study. The crystals were large ranging from 7 to 15

mm in diameter and from 8 to 18 mm in length. Most of them exhibited a barrel shape, and broken fragments of bipyramid and prismatic shapes. All samples were cleaned by soaking in hydrochloric acid for 24 h to dissolve any sulphides, phosphates, and carbonates that might be present on the samples' surfaces. The samples were next washed with distilled water. After that, they were embedded in epoxy resin and cut into slabs 1 to 2 mm thick in the direction perpendicular to the *c*-axis of the crystal. The slabs were then polished on both sides to reveal the color, distinct structural appearance, and internal features. All samples were photographed and kept as references before the heat treatment process.

Standard Gemological Techniques

The standard gemological techniques used in this study include specific gravity determination with a hydrostatic balance, refractive index and birefringence determination with a Duplex II refractometer with a sodium equivalent light source, ultraviolet luminescence observation with an ultraviolet lamp (using both long-wave (365.4 nm) and short-wave (253.7 nm) radiation), and the use of a gemological microscope with additional fiber optic illumination to examine the internal features and surfaces of the samples. These standard gemological techniques were carried out at the Gemological Section, Department of Geological Sciences, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand.

Advanced Techniques in Gem Analysis

The absorption spectra were obtained with a U-4001 UV-Vis-NIR spectrophotometer (Hitachi Ltd., Tokyo, Japan) with a beam condenser and polarizing filter for the polarized spectroscopy in the ultraviolet-visible through near-infrared range. The light sources used were deuterium (D_2) and tungsten (W) lamps which produce continuous radiation of the UV and Vis-NIR regions, respectively. A photomultiplier (for the UV-Vis region) and a cooled-type PbS cell (for the NIR region) detectors incorporated with an automatic wavelength calibration function were used to obtain the spectra with wavelength accuracies

of ± 0.2 nm in the UV-Vis region and ± 1.0 nm in the NIR region. The absorption spectra were recorded over a range of 250 to 1200 nm at a scan speed of 300 nm/min and a slit width of 2 millimeters. The intensity of light passing through a crystal at a given wavelength was measured in the absorbance unit. The data were compiled with the Hitachi spectrophotometer UV solution program.

A scanning electron microscope model (JEOL Ltd., Tokyo, Japan) with energy dispersive X-ray fluorescent spectrometry (SEM-EDS), equipped with INCA software (Oxford Instruments plc, Abingdon, UK), was used to analyze and identify the mineral inclusions present in the samples.

The chemical composition of some sapphire samples was analyzed using SX50 and SX100 electron microprobes (CAMECA SAS, Gennevilliers, France) with wavelength dispersive X-ray fluorescent spectrometry. The analyses were operated with the Sun Ray program for data management (Oracle Corp., Redwood City, CA, USA). Operating parameters were 20 kV accelerating voltage, 60 nA current, 5-micron spot size, and counting times of 10 and 60 sec for major and trace elements, respectively. The standards used were a combination of natural minerals and synthetics. Detection limits of Al_2O_3 , $FeO_{(total)}$, TiO_2 , Ga_2O_3 , SiO_2 , MgO , V_2O_5 , and Cr_2O_3 were 0.015, 0.012, 0.010, 0.013, 0.009, 0.008, 0.016, and 0.013 wt%, respectively.

Heating Experiments

The trapiche-like blue sapphire samples were heated in an electric furnace at the Department of Geological Sciences, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand. The heating experiments were conducted under 2 atmospheric conditions: oxidizing and reducing conditions, to observe the change of the blue color of the studied samples. Since most of the studied samples were very dark blue to nearly black, 22 samples were heated under the oxidizing condition to lighten the very dark blue color. Five samples were heated under the reducing condition to intensify the blue color. The heating atmosphere of the oxidizing condition

was carried out in the chamber with an approximately 35% oxygen gas level. The reducing condition was created through continuous purging of Ar gas into the heating chamber to reduce the oxygen gas level in the heating chamber, by which the oxygen content in the chamber was lowered to 0.5-1%. For both conditions, the samples were placed in alumina crucibles. The maximum temperatures were set at 1200, 1300, 1400, 1500, 1600, 1700 and 1800°C for the oxidizing condition, and at 1200, 1400, and 1600°C for the reducing condition with the heat rate of 3-7°C/min and 5 h soaking time. When the programmed temperatures and soaking times were reached, the furnace was switched off.

Results and Discussion

Visual Appearance

Since the rough crystals of the trapiche-like blue sapphire with a very dark tone from southern Vietnam are large, they appeared opaque before being cut into slabs. However, the samples appeared more translucent to semi-translucent after they were cut into slabs. All the slabs of the blue sapphire samples showed the fixed star-like appearance which is considered to be a trapiche pattern following the definition described previously. The trapiche-like blue sapphire samples consisted

of 3 main parts; a hexagonal core, 6 arms in the form of a fixed 6-rayed star, and 6 blue sectors separated by the 6 arms, as shown in Figure 1. The core area of the samples was usually brown to yellowish brown and formed the center of the star-like formation. The arms were similar in color to the core area ranging from brown to yellowish brown and oriented perpendicular to the hexagonal faces. The blue sectors had a blue body color in different tones and saturation. Some samples showed a strong hexagonal color zoning.

Gemological Properties

The specific gravity of all the blue sapphire samples ranged from 3.96 to 4.02. Refractive indices varied from 1.762 to 1.764 for n_e and from 1.770 to 1.773 for n_o with a birefringence of 0.008 to 0.009. The samples were uniaxially negative and appeared inert when exposed to ultraviolet radiation, both long wave and short wave. The blue area of the samples showed moderate to strong dichroism (blue to violetish blue). Apart from the trapiche pattern, the determined values were similar to blue sapphires found in southern Vietnam (Smith *et al.*, 1995; Van Long *et al.*, 2004; Khotchanin *et al.*, 2010) and from all other locations world-wide. Microscopic examination revealed clouds of very tiny brown to nearly black inclusions in the core and arms, especially in the zones close to the core, the



Figure 1. Hexagonal cross-section of the trapiche-like blue sapphire from southern Vietnam with color zoning showing a brown core, 6 brown arms, and 6 blue sectors between the arms

arm areas (Figure 2). The surface of both areas showed a pearly luster when viewed under reflected light. Healed fractures were commonly observed in the studied samples. Eight samples were selected for examination of the mineral inclusions exposed to the sample surfaces using SEM-EDS. The SEM-EDS analysis revealed the presence of mangan-ilmenite [(Fe,Mn)TiO₃], ulvospinel (Fe₂TiO₄), and mangan-hercynite [(Fe,Mn)Al₂O₄]. According to Smith *et al.* (1995), opaque and black crystal inclusions found in sapphire samples from southern Vietnam are most frequently identified as columbite, magnetite-hercynite spinel, and ilmenite.

Chemical Compositions

Twenty-seven slabs of trapiche-like blue sapphire samples were analyzed for Al₂O₃, FeO_(total), TiO₂, Ga₂O₃, SiO₂, MgO, V₂O₅, and Cr₂O₃ using electron probe microanalysis. Two to 3 analysis points were measured on each sample, and a total of 162 analysis points were measured. The analysis points on each sample were measured on the core, arm, and blue sector areas. The data shown in this section summarized all results of the trace elements in wt% oxide concentration for the 3 areas (Table 1). The information provided consists of the number of samples and analysis points for each group of samples, the maximum,

minimum, arithmetic mean, and the number of analysis points with a value above the detection limit for each trace element. The electron probe microanalysis revealed the presence of various major, minor, and trace elements. Al₂O₃ was the sole major element. Iron (Fe) and titanium (Ti) were the most significant minor and trace elements which caused coloration in the studied samples. They were the dominant color-causing elements in yellow (due to Fe³⁺) and blue (due to Fe²⁺/Ti⁴⁺ and Fe²⁺/Fe³⁺ IVCT). Gallium (Ga) and silicon (Si) were also detected as trace elements present in the studied sapphires. Magnesium (Mg) and vanadium (V) were present in negligible amounts. Chromium (Cr) was only present in the blue sector area and was only detected in 3 samples.

The maximum mean value of the FeO_(total) content was 1.348 wt% found in the core area while the minimum mean value was 1.122 wt% found in the arm area. The maximum mean value of the TiO₂ content was 0.055 wt% also found in the core area, whereas the minimum mean value was 0.021 wt% found in the arm area. Overall, the core area of the trapiche-like blue sapphire samples showed higher iron oxide and titanium oxide contents than the other measured areas. The mean values of the iron oxide and titanium oxide contents in the arm and blue sector areas were

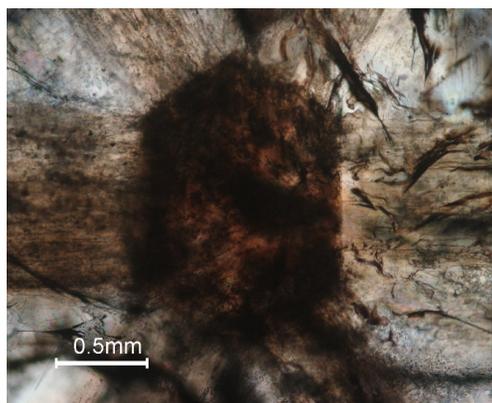


Figure 2. A number of very small dark brown inclusions in the core area and in the arm areas next to the core of the trapiche-like blue sapphire sample under transmitted light

not significantly different. Chromium oxide, the main cause of the red color in ruby, was found in the blue sector area causing a violet tint in the blue hue of the samples and the hue showed a violetish blue. The results of the chemical analysis in this study indicate that high iron contents are related with the brown color, especially in the dark tone of the brown color. Both iron and titanium are probably the exsolved phase of the mineral inclusions, as described in the gemological properties section.

Spectroscopic Features and Effect of Heat Treatment on the Trapiche-like Blue Sapphire from Southern Vietnam

Absorption spectra were determined for all trapiche-like blue sapphire samples. The spectra were recorded for the core, arms, and blue areas, separately. The samples which had

been heat treated were observed in the same area twice in order to compare the spectra before and after the heat treatment of the same samples. Generally, the absorption spectra of the samples were recorded depending on whether the light propagating in the crystal had its polarization parallel or perpendicular to the *c*-axis of the crystal. Thus, each sample was also run twice, once for the extraordinary (e) spectrum (parallel to the *c*-axis) and the other time for the ordinary (o) spectrum (perpendicular to the *c*-axis). The determined spectra are shown in the vertical absorbance scale and horizontal wavelength scale in nanometers. The recorded spectra vary in the relative intensities of the absorption bands associated with color-causing mechanisms. The overall patterns of the absorption spectra are similar for the 3 recorded areas; core, arm, and blue sector, with variations in the intensity

Table 1. Chemical compositions of the elements in wt% oxide with minimum and maximum values along with the arithmetic mean values (M) in parenthesis obtained from the analyses of the trapiche-like blue sapphire samples by the EPMA-WDS

Compound (wt%)	Area of analyses		
	Core (N = 47)	Arm (N = 44)	Blue sector (N = 71)
Al ₂ O ₃	94.990 – 99.610 (M = 98.060) n = 47	96.280 – 101.31 (M = 98.827) n = 44	96.690 – 101.079 (M = 98.850) n = 71
FeO (total)	0.810 – 2.340 (M = 1.348) n = 47	0.810 – 1.690 (M = 1.122) n = 44	0.494 – 1.610 (M = 1.146) n = 71
TiO ₂	0.010 – 0.510 (M = 0.055) n = 44	0.010 – 0.130 (M = 0.021) n = 38	0.010 – 0.080 (M = 0.024) n = 57
Ga ₂ O ₃	0.017 – 0.043 (M = 0.029) n = 47	0.015 – 0.042 (M = 0.025) n = 41	0.015 – 0.050 (M = 0.027) n = 69
SiO ₂	0.009 – 0.180 (M = 0.025) n = 35	0.009 – 0.040 (M = 0.022) n = 36	0.009 – 0.060 (M = 0.023) n = 54
MgO	0.008 – 0.010 (M = 0.009) n = 2	0.010 – 0.010 (M = 0.010) n = 3	0.010 – 0.010 (M = 0.010) n = 9
V ₂ O ₃	0.024 n = 1	bdl n = 0	0.017 – 0.018 (M = 0.018) n = 2
Cr ₂ O ₃	bdl n = 0	bdl n = 0	0.013 – 0.017 (M = 0.015) n = 5

N = number of all point analyses, n = number of point analyses with the values above the detection limit, and bdl = below

of the absorption (Figure 3). The absorption spectra of sapphires are generally related to the substituted transition metals which, in blue sapphire, are iron (Fe) and titanium (Ti). The blue coloration in sapphire is essentially caused by the intervalence charge-transfer processes (IVCT) of the ion pairs $\text{Fe}^{2+}/\text{Ti}^{4+}$ and probably $\text{Fe}^{2+}/\text{Fe}^{3+}$ (Fritsch and Rossman, 1987, 1988). The studied sapphire samples commonly show a peak at 450 nm assigned to the Fe^{3+} pair on the nearest-neighbor lattice sites, a broad band between 500 and 650 nm with a maximum approximately at 580 nm due to the $\text{Fe}^{2+}/\text{Ti}^{4+}$ IVCT, and an absorption band between 700 and 980 nm with a maximum approximately at 875 nm due to the $\text{Fe}^{2+}/\text{Fe}^{3+}$ IVCT (Ferguson and Fielding, 1971, 1972; Emmett and Douthit, 1993; Emmett *et al.*, 2003), as shown in Figure 3. The peaks at 377 nm due to the Fe^{3+} pair and 388 nm due to the Fe^{3+} can be seen in some samples. The position at around 880 nm of the absorption spectra in this study is caused by the change of the detector between the ultraviolet-visible and near infrared regions. The UV-Vis-NIR absorption spectra obtained from the studied samples are typical of sapphires in general and, more specifically, of basaltic sapphires, particularly in relation to the absorption bands toward the near-infrared region resulting from the $\text{Fe}^{2+}/\text{Fe}^{3+}$ IVCT. This particular color-causing mechanism is absent in sapphires of

metamorphic origin (such as those from Sri Lanka, Myanmar, or Kashmir), although it can be produced to a minor degree in metamorphic sapphires through heat treatment (Smith *et al.*, 1995).

A total of 27 slab samples of the trapiche-like blue sapphire were heated in an electric furnace. Twenty-two samples were heated in the oxidizing condition to lighten the dark blue color. Five samples were heated under the reducing condition to deepen the blue color. The maximum temperatures were set at 1200, 1300, 1400, 1500, 1600, 1700, and 1800°C under the oxidizing condition, and at 1200, 1400 and 1600°C for the reducing condition, as mentioned in the heating experiments section. Under the oxidizing condition, after heating at 1200 and 1300°C, the blue color intensity in the blue sector area was reduced and some slab samples which contained some large fractures came apart along those fractures, or along the arms of the trapiche structure. In addition, most of the slab samples broke up further at higher temperatures. The brown core and brown arm of the trapiche-like blue sapphire samples were unchanged. After heating at 1400 and 1500°C, the blue color intensity in the blue sector area started to develop. The brown core and brown arm of the trapiche structure changed to blue. However, the structure of the core and arm sectors could still be seen. According to Li (2006), a star-like

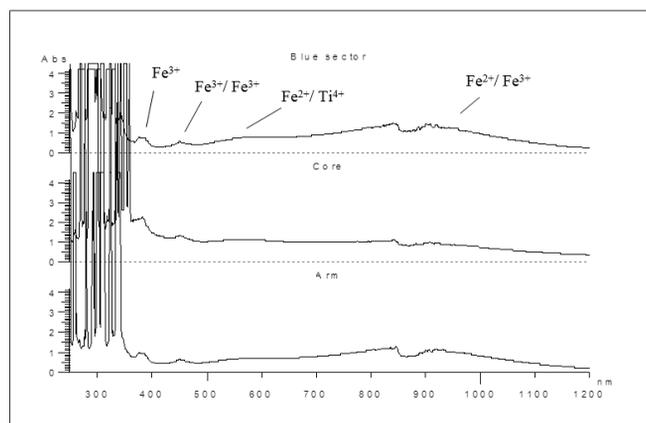


Figure 3. UV-Vis-NIR absorption spectra of the blue sector (top), the core (middle), and the arm (bottom)

pattern in Shandong sapphire from China is often formed by parting. Parting is the breaking of crystal along planes of structural weakness. The parting that appears in Shandong sapphire often develops along (0001), (1011), and occasionally along (1120) of the sapphire crystal. Micro-inclusions are also found associated with these planes of parting. According to Emmett and Douthit (1993), heating to a high temperature will not generally improve the clarity of a stone that has multiple fractures. Therefore, fracture filling with some additives such as borax is often part of the heat-treatment process. However, in this study, the heat treating of trapiche-like blue sapphires from southern Vietnam was carried out without any additives. After heating at 1600°C, more blue color was developed in the samples. After heating at 1700 and 1800°C, the blue color intensity was slightly developed. Under the reducing condition, the samples heated at 1200, 1400, and 1600°C showed similar results with the other heating experiment at the same temperatures under the oxidizing condition. Figures 4 and 5 show the progressive change in the representative samples after heat treatments at different maximum temperatures under the oxidizing and reducing conditions,

respectively. The development of the blue color after heating at higher temperatures is due to the change of the oxidation state of iron and dissolved titanium. The change of the oxidation state from Fe^{2+} to Fe^{3+} still occurs but titanium in the presence of titanium-containing inclusions in the samples can be activated. Iron and titanium may be present in the form of micro-inclusions before the heat treatment. When the samples were heated at high temperatures, these micro-inclusions dissolved and diffused to areas where Fe^{2+} is available, and $\text{Fe}^{2+}/\text{Ti}^{4+}$ and $\text{Fe}^{2+}/\text{Fe}^{3+}$ IVCT were activated. Thus, the blue color in the samples can be intensified after heating at higher temperatures, even though they are heated under the oxidizing condition. Moreover, the higher intensity of the $\text{Fe}^{2+}/\text{Fe}^{3+}$ absorption band after heating probably contributes to the darker tone in the blue color.

Absorption spectra of the heated samples were observed again after each temperature of the heat treatment and compared with the spectra before the heat treatment. The samples showed changes in their absorption patterns or intensities of peaks or bands corresponding with the changes in color. A broad band between 500 and 650 nm and a peak at 450 nm

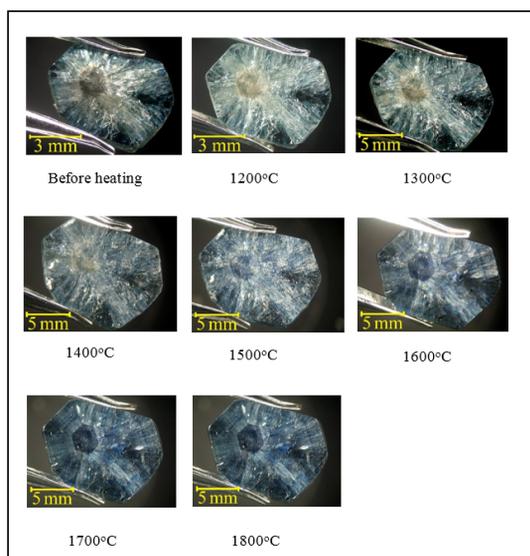


Figure 4. Progressive changes in trapiche-like blue sapphire sample before and after heat treatment at different maximum temperatures under an oxidizing condition

were persistent throughout the heat treatment process. A band between 700 and 980 nm was more developed after heating (Figures 6 and 7). The broad band between 500 to 650 nm gradually decreased in intensity when the blue color faded after heating and this band increased in intensity again when the blue color developed after heating at higher temperatures. The peaks at 377 nm and 388 nm were difficult to recognize in some samples because the transparency of the samples appeared to be lower after heating. The peak or band intensity varied depending on the developed color and change of transparency. After the heating experiments, the inclusions in the samples were re-examined with the gemological microscope to verify whether they had changed. Most samples showed darker colors after the heating making the inclusions much more difficult to observe. However, some very small brown inclusions in the core and arm areas were likely to disappear. Color zoning in some samples was clearly seen. Some healed fractures grew larger. After the heat treatment, there was no significant variation of the specific gravity and refractive indices of all samples. The samples were still inert under short-wave and long-wave ultraviolet radiation.

Conclusions

Heat treating experiments of trapiche-like blue sapphires from southern Vietnam in this study indicated that heating slab samples under both oxidizing and reducing conditions yields similar results. Heating at 1200°C can lighten the blue color and heating at 1400°C can change brown to blue colors. Heating over 1400°C can intensify the blue color in the samples. However, the trapiche appearance still persists after heat treatment although the brown color in the core and arm areas can change to a blue color. Inclusions found in the samples are mainly healed fractures and some mineral inclusions which are iron- and/or titanium-containing minerals and often occur as micro-inclusions are scattered in the samples. These mineral inclusions can affect the blue color of the samples after heating because some of them are likely to disappear after heating at the highest temperature in this study. The absorption spectra of all samples exhibit Fe^{3+} absorption peaks and $\text{Fe}^{2+}/\text{Ti}^{4+}$ IVCT and $\text{Fe}^{2+}/\text{Fe}^{3+}$ IVCT absorption bands. The more intense blue color after heating corresponds to the stronger intensity of the $\text{Fe}^{2+}/\text{Ti}^{4+}$ IVCT absorption band. The $\text{Fe}^{2+}/\text{Fe}^{3+}$

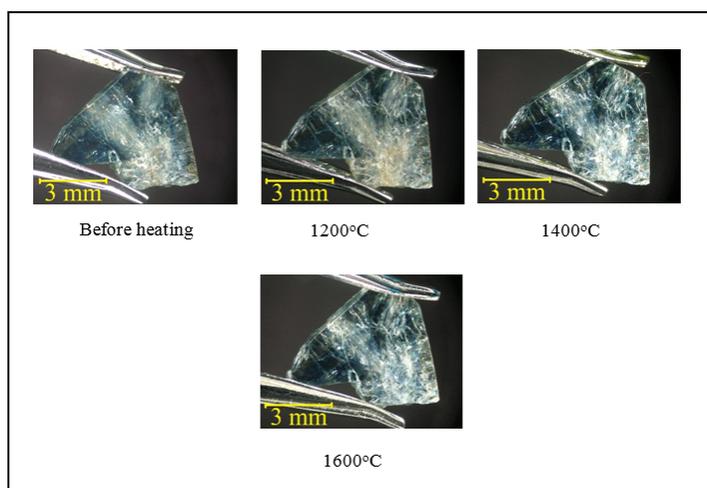


Figure 5. Progressive changes in trapiche-like blue sapphire sample before and after heat treatment at different maximum temperatures under a reducing condition

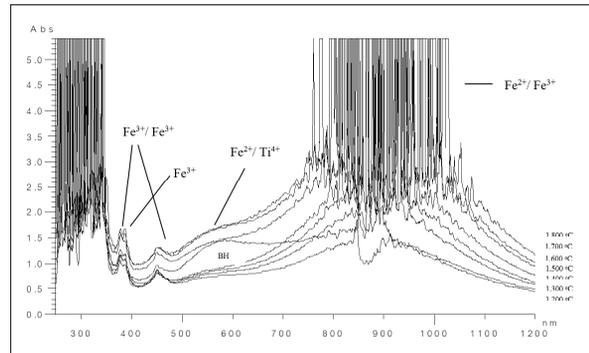


Figure 6. UV-Vis-NIR absorption spectra in trapiche-like blue sapphire sample before and after heating under an oxidizing condition and at different temperatures (BH = before heat treatment)

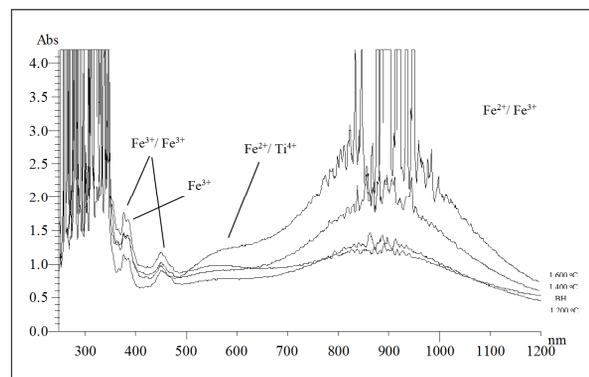


Figure 7. UV-Vis-NIR absorption spectra in trapiche-like blue sapphire sample before and after heating under a reducing condition and at different temperatures (BH = before heat treatment)

IVCT absorption band probably contributes to the darker tone in the samples. Chemical compositions reveal that iron and titanium are the most significant minor and trace elements because both of them are necessary for the color-causing mechanism in blue sapphire. The gemological properties of all samples are in the same ranges as those from other deposits world-wide. There is no significant variation of these properties before and after heat treatment.

Acknowledgements

The authors would like to thank the Department of Geological Sciences, Faculty of Science, Chiang Mai University for providing the laboratory facilities. Special thanks are extended to Thaitawan Corp., Mr. Worachat Angkahiran, and Mr. Phatsapong Chin-Udompong for donating samples for this study.

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