แซปไฟร์ทราปิเชจากบางแหล่งในประเทศไทย ประเทศกัมพูชาและประเทศเวียดนาม

นางสาวสุรีพร พุ่มเพ็ง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา

คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2550

TRAPICHE SAPPHIRE FROM SOME DEPOSITS IN THAILAND, CAMBODIA AND VIETNAM

Miss Sureeporn Pumpang

A Thesis Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Science Program in Geology

Department of Geology

Faculty of Science

Chulalongkorn University

Academic Year 2007

Thesis Title	TRAPICHE SAPPHIRE FROM SOME DEPOSITS IN THAILAND, CAMBODIA AND VIETNAM
By	Miss Sureeporn Pumpang
Field of Study	Geology
Thesis Advisor	Assistant Professor Chakkaphan Sutthirat, Ph.D.
Thesis Co-advisor	Associate Professor Visut Pisutha-Arnond, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

.... Dean of the Faculty of Science

(Professor Supot Hannongbua, Ph.D.)

THESIS COMMITTEE

.... Chairman

(Associate Professor Punya Charusiri, Ph.D.)

.... Thesis Advisor

(Assistant Professor Chakkaphan Sutthirat, Ph.D.)

.... Thesis Co-advisor

(Associate Professor Visut Pisutha-Arnond, Ph.D.)

.... Member

(Assistant Professor Pornsawat Wathanakul, Dr.rer.nat.)

.... Member

(Mr. Bhuwadol Wanthanachaisaeng, Ph.D.)

สุรีพร พุ่มเพ็ง : แซปไฟร์ทราปิเชจากบางแหล่งในประเทศไทย ประเทศกัมพูชา และประเทศเวียดนาม อ. ที่ปรึกษา: ผศ.ดร.จักรพันธ์ สุทธิรัตน์, อ. ที่ปรึกษาร่วม: รศ.ดร. วิสุทธิ์ พิสุทธอานนท์, 156 หน้า.

ตัวอย่างพลอยแซปไฟร์ทราปิเชที่ใช้ในการศึกษาครั้งนี้ได้มาจากแหล่งที่สัมพันธ์กับบะซอลต์ของประเทศไทย ได้แก่ แหล่งจันทบุรีจำนวน 11 ตัวอย่าง แหล่งแพร่จำนวน 2 ตัวอย่าง และ แหล่งกาญจนบุรี จำนวน 1 ตัวอย่าง จากแหล่งไพลิน ประเทศกัมพูชา จำนวน 8 ตัวอย่าง และจากแหล่งดิลิน ประเทศเวียดนาม จำนวน 3 ตัวอย่าง จากการศึกษาพบว่าแซปไฟร์ทราปิเชมีลักษณะปรากฏ ประกอบด้วย 3 ส่วน คือ ส่วนแกน (Core) ส่วนแขน (Arm) และส่วนการพอกผลึก (Growth sector) จากการสังเกตภายใต้กล้องจุลทรรศน์อัญมณี พบลักษณะมลทินที่ประกอบในส่วนของแกนและแขนนั้น ได้แก่ มลทินของไหลซึ่งเป็นลักษณะเด่นที่พบ นอกจากนี้ยังมี มลทินขนาดเล็กคล้ายฝุ่น มลทินเส้นเข็ม และมลทินสีดำขนาดเล็กร่วมอยู่ด้วย ขณะที่ส่วนการพอกผลึกประกอบด้วยมลทินของไหล และมีมลทินขนาดเล็กคล้ายฝุ่น ที่มักวางตัวตามแนวการเติบโตของผลึก สำหรับมลทินแร่ขนาดใหญ่พอที่จะจำแนกได้เป็นแร่ แมกนีไทต์ โคลัมไบต์ ไพโรคลอร์ เฟลสปาร์ โมนาไซต์ เนฟีลีน เซอร์คอน แคลไซต์ พบอยู่ตามส่วนต่างๆ ในบางตัวอย่าง ซึ่งมลทินแมกนีไทต์พบเฉพาะในส่วนของแกนและแขนเป็นสำคัญ ในขณะที่มลทินอื่นพบในบริเวณแขนและส่วนการพอกผลึก จากการศึกษาองค์ประกอบทางเคมี พบว่า โดยปกติที่บริเวณแกนมีปริมาณเหล็กและ ไททาเนียมสูงกว่าบริเวณอื่นแต่ก็มีแตกต่างไปบ้างเป็นบางตัวอย่าง ในส่วนของแขนและส่วนการพอกผลึกพบว่ามีปริมาณธาตุไม่แตกต่างกันมากนัก เช่น บางตัวอย่างมีปริมาณเหล็กและ ไททาเนียมในส่วนแขนมากกว่าส่วนการพอกผลึก ในขณะที่บางตัวอย่างพบที่บริเวณแขนน้อยกว่า ซึ่งองค์ประกอบทางเคมีดังกล่าวคาดว่ามีความสัมพันธ์กับมลทินต่างๆทั้งที่มองเห็นและที่มองไม่เห็นเนื่องจากเป็นมลทินอนุภาคขนาดเล็กมากที่ไม่สามารถตรวจสอบได้ด้วยกล้องจุลทรรศน์อัญมณี ปกติ

จากการพิจารณาถึงขั้นตอนการตกผลึก คาดว่าแซปไฟร์ทราปิเชเริ่มตกผลึกจากส่วนแกนก่อนในสภาวะที่อาจมีหลายเฟสตกผลึกร่วมกันได้ เมื่อสภาวะแวดล้อมเกิดการเปลี่ยนแปลงอย่างกระทันหันจึงเริ่มการตกผลึกใหม่ในส่วนที่เป็นแขนและส่วนการพอกผลึก ซึ่งทั้งสองส่วนหลังนี้คาดว่ามีการตกผลึกพร้อมกัน ส่วนแขนมีการรวมตัวของมลทินของไหลและมลทินต่างๆมากกว่าในส่วนการพอกผลึก เกิดในทิศตั้งฉากกับหน้าผลึกกลุ่ม $\{11\bar{2}0\}$ คาดว่าน่าจะเป็นทิศทางที่เกิดความบกพร่องของผลึกได้ง่าย ในขณะที่ส่วนการพอกผลึกมีการตกผลึกตรงช่องว่างระหว่างแขน ที่พบว่าเป็นส่วนสีฟ้าสะอาดและมีมลทินน้อยกว่า ลักษณะปรากฏของแซปไฟร์ทราปิเชต่างจากทับทิมทราปิเชที่มีกำเนิดสัมพันธ์กับการแปรสภาพสภาวะของแข็ง ส่วนแซปไฟร์ทราปิเชจากแหล่งกำเนิดสัมพันธ์กับบะซอลต์ น่าจะเกิดจากสภาวะที่มีความเป็นไอสูง เช่นจากหินหลอมละลายต้นกำเนิดชนิดเฟลสิกที่มีอลูมินาสูง

ภาควิชา........ธรณีวิทยา............ลายมือชื่อนิสิต...

สาขาวิชา.......ธรณีวิทยา...........ลายมือชื่ออาจารย์ที่ปรึกษา......................................

ปีการศึกษา.....2550.................ลายมือชื่ออาจารย์ที่ปรึกษาร่วม..................................

4772538023 : MAJOR GEOLOGY

KEY WORD: TRAPICHE SAPPHIRE/ BASALTIC / THAILAND/ CAMBODIA / VIETNAM

SUREEPORN PUMPANG: TRAPICHE SAPPHIRE FROM SOME DEPOSITS IN THAILAND, CAMBODIA AND VIETNAM THESIS ADVISOR: ASST. PROF. CHAKKAPHAN SUTTHIRAT, PH.D., THESIS CO-ADVISOR: ASSOC. PROF. VISUT PISUTHA- ARNOND, PH.D., 156 PP.

The number of trapiche sapphire samples from some basaltic gem fields used in this study are eleven from Chanthaburi deposit, two from Phrae deposit and one from Kanchanaburi deposit in Thailand, eight from Pailin deposit in Cambodia, and three from Di Linh deposit in Vietnam). Most samples show three distinguishable parts, namely core, arm and growth sector. Observation under a gem microscope reveals that the core and arm are occupied mainly by thin-film fluid inclusions and usually with the combination of minute particles, short needles and small black inclusions whereas the growth sector generally contains thin-film fluid inclusions and minute particles along hexagonal growth zones. Some large mineral inclusions were observed and identified as magnetite, columbite, pyrochlore, feldspar, monazite, nepheline, zircon and calcite. Magnetite appears to be related particularly to core and arm whereas the others are observed in the arm and growth sector. Trace element analysis and mapping along the different parts of trapiche sapphires significantly indicates that Fe and Ti concentrations at core are commonly higher than those of the other parts, whereas the growth sectors and arms are not clearly different in trace compositions. However in many cases arms may yield slightly higher Fe and Ti concentrations than the growth sectors or vice versa. These variations in geochemical signatures may be related to either visible or invisIble micro- to-nano-sized inclusions.

Regarding to the growth of trapiche sapphire it appears that the core should have been crystallized first from a unique physical and chemical condition that allowed co-precipitation and/or incorporation of many phases before the abrupt change in the growth condition that led to the formation of the arms and growth sectors simultaneously. The arms are the place in the growth sector where thin-film or multi-phase fluid inclusions were likely to form in the direction perpendicular to the $\{11\bar{2}0\}$ faces or along the a-axes direction in which impurities in the crystal lattice could have a tendency to follow. The growth sector mainly developed as clear blue texture with lesser inclusions. These features of trapiche sapphire are quite different from trapiche ruby that usually occurred in the subsolidus metamorphic condition. In conclusion, trapiche sapphires from basaltic deposits may have been crystallized from a high volatile peraluminous felsic melt.

Department............Geology..................Student's signature..........S. P..........

Field of study..........Geology..................Advisor's signature..........C. Sutthirat..........

Academic year.........2007.................... Co-advisor's signature...Visut Pisutha-Arnond...

ACKNOWLEDGEMENTS

The author would like to express my sincere gratitude to Assistant Professor Dr.Chakkaphan Sutthirat and Associate Professor Dr.Visut Pisutha-Arnond for their suggestion and supervision throughout the completion of this thesis.

The author sincerely appreciates the Department of Geology, Faculty of Science, Chulalongkorn University for providing sample preparation facility and Electron Probe Micro-Analyses (EPMA). The Gem and Jewelry Institute of Thailand (Public Organization) (GIT) under Ms. Wilawan Atichat, the director, is greatly acknowledged for facilitating sample collection, gem basic equipments and advanced analytical instruments. Some samples are provided by Assistant Professor Dr. Pornsawat Wathanakul.

Finally, special thanks are given to my parents for their support and encouragement, to laboratory staff members of the GIT and many people, who are not named here for various kinds of help.

CONTENTS

LIST OF TABLES

TABLES PAGE

LIST OF FIGURES

FIGURES PAGE

FIGURES PAGE

FIGURES PAGE

FIGURES PAGE

FIGURES PAGE

CHAPTER I
INTRODUCTION

1.1 General Statement

In the world of gem, corundum better known to most people as ruby and sapphire is an important and valuable gemstone. The appreciation of gem corundum and of course its market price is based upon its color, clarity, size, enhancement, special phenomenon, and surprisingly its geographic origin. The geographic origin of corundum has been an important aspect in the gem trade for decades because some reputable gem localities are traditionally more favourable and being sort after by consumers, for examples, ruby from Myanmar, blue sapphire from Kashmir. Hence a ruby or sapphire from such the localities normally commands a higher price tag. With such the customers' requirement it becomes necessary for a gem laboratory to be able to distinguish ruby and sapphire from different sources. In the early days, gem corundums available in the market were obtained from a hand-full of localities. Hence geographic origin determination was not too difficult in those days. However as more and more gem corundums are available from new sources during the last decade, the aspect of origin determination has been quite a difficult task indeed. This is because corundums from different sources may have overlapping properties such as internal characteristics and chemical fingerprinting. Thus nowadays, in order to distinguish the geographic origin of a gem corundum it requires multi and more sophisticated analytical techniques with strong back-up database as well as a team of highly experienced gemmologist. Hence being able to gather information and carried out further detailed study of a gem corundum deposit, no matter whether it is an old or a new ones, is important not only to help the geographic origin determination but information gain from the study may also help finding a new corundum gem field in the future.

Several researchers studied corundum deposits and divided them into two major modes of origin; magmatic and metamorphic origins. Because the samples used for this study were collected from some deposits in Thailand, Cambodia and Southern Vietnam that are related to basaltic origin (i.e. Coenraads et al. 1995, Gao et al. 1996, Suttherland et al. 1998, Pisutha-Arnond et al. 1999, Intasopa et al. 2000, Sutthirat et al., 2001). The origin of corundum related to basaltic rocks is the main focus in this study.

There are several genetic models proposed for the magmatic origin of corundum, for examples, plutonic crystallization from undersaturated fractionated felsic melts at high pressure (Irving 1986), plutonic crystallization from syenitic melts of crustal to upper mantle origin (Aspen et al. 1990), plutonic crystallization from volatile-rich alkaline melts, produced by low degrees of partial mantle melting (Coenraad et al. 1990; Oakes et al. 1996), mid-crustal crystallization related to hybrid reaction between carbonatitic melts and silicic magmas. Mixing of silica-rich and carbonatitic magmas under relatively low temperatures of about 400°C at depth of 10-20 km (Gao et al., 1996), plutonic crystallization from felsic alkaline melts, produced by melting of metasomatized lithosphere (Sutherland et al, 1996). Information from these studies will support the genetic model of blue sapphire that related to basaltic rock.

1.2 What is the meaning of “trapiche”?

Not only the geographic origin of corundum can influence the price but the special phenomenon also does. The valuable phenomena found in corundum are color-change effect and asterism or star effect. The star effect is caused by the reflection of light from two or more set of needle inclusions that are parallel and plentiful in a cabochon cut stone. In addition, some corundums from many gem deposits may have another diagnostic star-like phenomenon of different nature. They consist of six growth sectors separated by arms of six-ray star (Figure 1.1). However, unlike the star effect, these arms do not move when the stone or light source is moved which makes it different from common star corundum. Such the characteristic is found occasionally in some ruby and sapphire crystals as well as emerald crystals which are later called “Trapiche” (meant spoked wheel for grind sugar cane in Spanish language).

Even through trapiche corundum is not so popular in the gem trade like star corundum, it is however valuable and attractive to gemologists, mineralogists and geologists in term of crystal growth phenomenon and its formation. That is why there are some scientific studies on trapiche corundum in literature.

Figure 1.1 Characteristic of a star ruby (left) compared with a trapiche ruby (right) (right photo from www. crystal-treasure.com).

1.3 How much do we know about the trapiche ruby and sapphire?

There are a lot more of information about the trapiche ruby than that of the sapphire. In general, a trapiche ruby consists of six growth sectors separated by six-ray star (arm). When look closely into some samples, however, the six arms may intersect at one small point, forming six triangular growth sectors, while in the other samples, the arms extend outward from a hexagonal central core, forming six trapezohedral growth sectors (Figure 1.1). Based on the detailed microscopic observation of trapiche samples by a few investigators (Schmetzer et al. 1996 and 1998, Sunagawa et al. 1999), the arms apparently consisted of numerous mineral inclusions and tube-like inclusions filled with calcite, dolomite or 2-phase fluids. Some particular details are reviewed in the next chapter.

1.4 Why is study on trapiche sapphire interesting?

Although, information about the trapiche ruby are available and well documented in details, the studies on trapiche sapphires, on the contrary, are still scare and rather preliminary. Besides, trapiche sapphires from several basaltic deposits were found but detailed study has not been carried out yet. Furthermore, it is likely that the crystallization condition and process of trapiche ruby would not be the same as that of trapiche sapphire. This is because most of the trapiche ruby was formed under a subsolidus metamorphic condition whereas majority of tapiche sapphire was likely to crystallize from a magmatic melt. Hence the growth history of the trapiche ruby will not be directly applicable to that of the trapiche sapphire. Therefore this research project is aimed to work on the trapiche sapphire (mostly blue) from some basaltic terranes including Chanthaburi, Kanchanaburi and Phrae deposits in Thailand, Pailin deposit in Cambodia and Di Linh deposit in Vietnam. The information earned from these stones may be significant to recognize origin and crystallization process of the stone that will lead to understanding the initial sources of stone.

1.5 Objectives

The main objectives of this research is to study the physical properties and internal features of some trapiche sapphires from Chanthaburi, Kanchanaburi and Phrae deposits in Thailand, Pailin deposit in Cambodia and Di Linh deposit in Vietnam. The information obtained from this study will be used to understand the crystallization process and help explain the origin of basaltic sapphire.

1.6 Scope of Work

The scope of this study was limited to a number of samples, the nature of sample and the techniques that were available during the time of this research study. It turns out that majority of the samples are rather turbid, translucent and contain many micro-to-nano-sized inclusions that could not be resolved by modern analytical equipment. As such the methods used for this study are described in details in Chapter III.

CHAPTER II
A REVIEW ON TRAPICHE CORUNDUM AND BASALTIC SAPPHIRE DEPOSITS IN THAILAND, CAMBODIA AND VIETNAM

2.1 Introduction

Corundum is one of the most important colored stones that have been very popular among gem lover, because of its beautiful colors and durability. Chemical compositions of corundum is characterized by a ratio of two aluminium atoms per three oxygen atoms or aluminium oxide (Al_2O_3) that crystallizes in the hexagonal system. Its hardness is 9 as classed in Mohs' scale. Specific gravity of about 4.0 and refractive indices between 1.760-1.764 (extraordinary ray, n_e) and 1.768-1.772 (ordinary ray, n_o) are the common range of corundum. Pure corundum is colorless which is very rare in the nature. Corundum is an allochromatic mineral that colors can be produced by trace elements such as chromium (Cr), titanium (Ti) and iron (Fe). Therefore, color varieties of corundum are usually caused by proportions of these trace elements and perhaps crystal defects. Corundums can be separated, based on color appearance, into two varieties, i.e., ruby and sapphire. Rubies have red hue significantly caused by Cr whereas sapphires are other colors than red, such as blue sapphire caused by Fe and Ti, yellow sapphire caused by Fe or color center.

The crystal habits of sapphire can occur in several shapes that mostly six-sided bipyramids which sometime combines with the flat basal faces giving a barrel shaped. Besides, rhombohedral faces may be developed at the corner (Figure 2.1). The crystals may show horizontal striations at right angles to the c-axis.

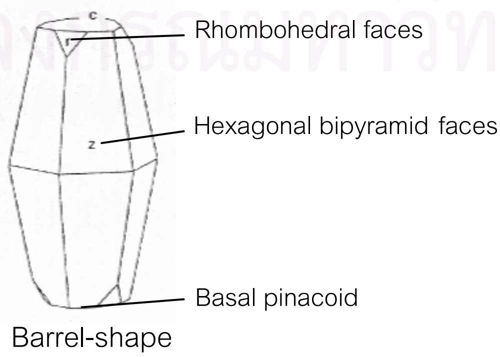


Figure 2.1 A common crystal habit of sapphire

Apart from attractive colors and brilliant, special phenomena of gemstone are additional admiration. Some of these effects in particular stones are demanded by the gem market, for examples, asterism (star) in ruby and sapphire and color-change effect in alexandrite and sapphire. Asterism is described for stone containing cross-cutting arms that are reflection of intersection bands of light. It may be caused by internal reflections from two or more sets of parallel fibrous or channel inclusions (GAGTL 2001). However, the gemstone cut as a cabochon with a smoothly polished dome top can reveal such effect. The star can turn around the stone following movement of lighting source. Asterism can be found in corundum, almandine garnet, spinel, quartz and beryl. Recently, asterism-like effect reported from some emerald, ruby and sapphire. This effect is called *"trapiche"*. It presents six arms similar to star in ruby and sapphire. However, these arms appear clearly in rough stone and they cannot shifted even lighting source is budged. Hence, this effect is likely controlled by the crystal structure and chemical environment during the crystal growth. Although, this effect does not interest the gem market, it is valuable to the academic purpose. That may provide information of crystal growth history and crystallization condition.

2.2 Trapiche Structure

The word *trapiche* (tra-pee-chee) is a Spanish origin, this word used for describing the spoke wheel that was used to grind sugar cane (Figure 2.2), became applied to a specific type of emerald. The earliest record of trapiche emerald was recognition in an emerald from Columbia (Sinkankas, 1981). In 1879, Bertrand found trapiche emerald from Muzo deposit, Columbia when this structure began to be remarked. In 1926, Bernauer described that typical inclusions in trapiche emerald. Cores were rich in inclusions of calcite, dolomite, pyrite, mica, biotite and kaolinite. Finally, he concluded that the sectorial structure was due to repulsion of impurities by slowly growing crystals (Sinkankas, 1981).

Figure 2.2 Trapiche (spoke wheel) was utilized for sugar cane crushing (from www.usuarious.lycos.es).

Nassau and Jackson (1970) reported that trapiche emeralds from Chivor, Columbia, have a clear central region and a sectored outer area. They examined a large number of specimens and found a considerable variation of the internal structure; nevertheless all samples are single crystals which appear to have crystallized in a couple steps of crystallization. During the first step, central hexagonal was slightly tapered and clear emerald prism grew. The second step involved simultaneous growth of emerald and albite from a fluid with saturation of both phases. That led the outer sectored emerald regions separated from each other by emerald intermixed with large amounts of albite. The transition region between the inner prism and the outer sectored region also contains large amounts of albite.

Choudhary and Golecha (2006) observed a suite of four trapiche emeralds that were cut from a single crystal. All the samples exhibit six black rays and central cores are very dark green to black colors. In addition, colorless to milky white zones were formed and followed by the black spokes. The hexagonal cores show a tapered along c-axis. Considering the relative sizes and overall tapering effect of hexagonal cores, most four specimens were arranged in order of decreasing core size from top to bottom. This was consistent with that the stones were cut from a single crystal. Many tiny black inclusions arrange along the horizontal axes forming the black rays. Other inclusions consist of colorless to milky white crystals, tube-like inclusions parallel to the c-axis, and negative crystal jagged by three phase inclusions. Arrangement of inclusions may indicate primary positions during growth that was not interfered after the host emerald had grown.

Subsequently, the trapiche structure has also been observed in other types of gemstone, such as ruby, sapphire, morganite, aquamarine, quartz, and tourmaline. Investigation of trapiche ruby has been published since the last decade. These data can in turn help to understand crystallization process.

2.3 Trapiche Corundum

There have been many researchers working on trapiche rubies such as Schmetzer et al. (1996 and 1998) and Sunagawa et al. (1999). In general, they described trapiche ruby as consisting of six growth sectors separated by six-ray star (arms). In some samples, six arms intersect at one small point forming six triangular growth sectors. On the other hands, some samples have arms extending outward from central hexagonal core and forming six trapezohedral growth sectors. Schmetzer et al. (1996) reported the arms consisting of host mineral and concentrations of inclusions that were characterized by tube-like structures. These tubes are oriented perpendicular to dipyramidal crystal faces. Minerals found in these tubes are calcite and dolomite. Schmetzer et al. (1998) observed chemical zoning that was carried out by element mapping using X-Ray Micro-Fluorescence (XRMF) and Electron Probe Micro-Analysis (EPMA) techniques. Chromium zones within ruby sectors and between a red core and ruby sectors were suggested to be due to growth zoning. The crystallization of calcite, dolomite and K-Al-Fe-Ti silicate inclusions in the yellowish white to yellow arms and in the black core were interpreted as the cause of Al and Cr deficiencies and variable concentrations of Si, Ca, Ti, Fe. The chemical inhomogeneity of sample is caused by iron staining of primary tube-like cavities and secondary irregular fissures due to intense weathering of samples. In summary, element mapping of trapiche rubies reveals a characteristic of primary growth zoning. Sunagawa et al. (1999) studied texture and element partitioning of trapiche rubies. The samples were analyzed also using XRMF and EPMA. The results have indicated the differences of chemistry and mineralogy between arms, core and growth sectors. The arms consist of multiple mineral phases. The element distribution in sample shows Cr zoning parallel to the hexagonal outline; besides, Fe zoning could not be observed in the growth sectors. The arms were formed earlier by dendritic growth and lateral growing of growth sector was subsequently taken place.

Apart from trapiche ruby, only preliminary studies on trapiche sapphires were reported by Wathanakul et al. (2004). They investigated some trapiche sapphires from basaltic origins such as Phrae, Kanchanaburi and Chanthaburi areas in Thailand, and Huay Sai area in Laos PDR. Some of those samples showed anomalously high contents of Be, Sn, Nb, Ta, Th, U, Hf, Ce, and La. Based on such unusual trace element geochemistry together with the mineral chemistry and fluid/melt inclusions characteristically indicated the formation of the Phrae sapphires by magmatic processes (Limtrakun et al., 2001), the authors speculated the crystal growth history and geological origin of trapiche sapphire that it could have formed by a multi-stage crystallization process from a highly evolved, volatile-rich (CO_2,H_2O, Li, Be, B, F), peraluminous (peralkaline?) melt that was also rich in incompatible high field strength elements (e.g. Sn, Nb, Ta, Th, U, Hf, Ce, and La) such as some alkaline granitic pegmatites. The authors postulated further that the core (without any 6 arms) should have crystallized first and later the 6 trapezoidal parts were formed simultaneously like in normal hexagonal growth zoning.

2.4 Basaltic Sapphire Occurrences in Thailand, Cambodia and Vietnam

This research project is focused on trapiche sapphires from specific basaltic deposits in Thailand, Cambodia and Vietnam. Hence, literature reviews on information of these deposits are needed to be carried out. Geographically, Thailand, Cambodia and Vietnam are situated in the center of mainland Southeast Asia (Figure 2.3) in which several gem corundum (both ruby and sapphire) deposits distribute throughout the region. All the deposits in Myanmar such as Mokok and Mong Shu and in northern Vietnam such as Luc Yen are located within high grade metamorphic terranes whereas the rest of deposits in Thailand, Cambodia, Laos, Southern Vietnam and Southern China, are associated with Cenozoic basaltic volcanism of the region. Although, the study areas are situated in the same region and related to Cenozoic basalts, their geologic settings are somehow different in detail. Genetic models of basaltic corundum within this region as well as Australia have been published by many researchers; however, most of recent models are paid attention to exotic sources of corundum beneath the earth surface before basaltic magma passing through and picking up to deposit on the surface (e.g., Gao et al., 1996; Suttherland et al., 1998; Sutthirat et al., 2001). Corundum deposits in the study areas are therefore summarized and reported below.

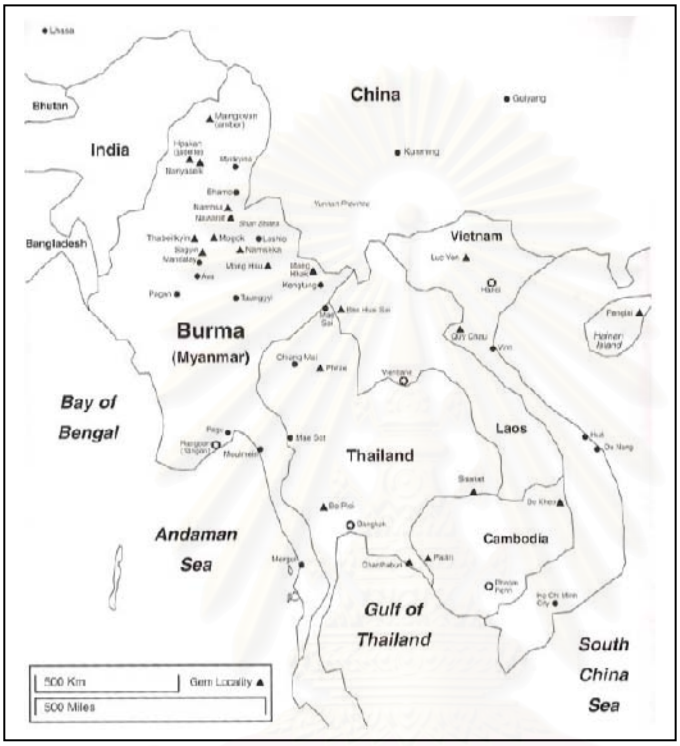


Figure 2.3 Regional map of the mainland Southeast Asia showing locations of Thailand, Cambodia and Vietnam and distribution of corundum deposits in the region (from Hughes, 1997).

2.4.1 Thailand

In general, gem deposits in Thailand are significantly found in a few varieties, particularly corundum and its associated gems such as, zircon, garnet and black spinel. These gem spicies are related to basaltic source. Besides, some lower grades of gems (e.g., chalcedony and rock crystal) have also been discovered but they are not highly demanded by Thai people. On the other hand, corundums (both ruby and sapphire) have been the most favorite gem in this country that leads Thailand becoming the top producer of ruby and sapphire in the world.

All of the significant corundum deposits in Thailand are associated with Cenozoic basalt. These basalts can be subdivided into basanitoids and hawaiite basalts (Barr and Macdonald,1978 and 1981). It expected that corundum typically associated with basanitoid basalts (Jungyusuk and Khositanont, 1992; Vichit 1992; Sutthirat et al., 1994). Corundum deposits in Thailand are found as secondary deposits in which the most important gem deposits are located in Trat, Chanthaburi and Kanchanaburi Provinces (Figure 2.4). In addition, other potential areas of gem corundum have been explored in the vicinities of Phrae, Lampang, Chiang Rai, Ubon Ratchathani and Sri Sa Ket (Sutthirat 1995).

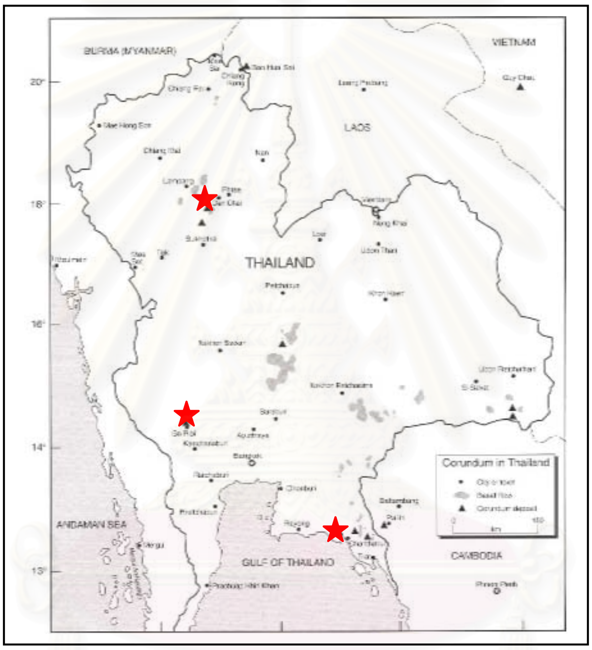


Figure 2.4 Map showing distribution of Cenozoic basalts and locations of ruby and sapphire deposits in Thailand (Hughes, 1997). Red stars are locations of Chanthaburi, Kanchanaburi and Phrae deposits under this study.

Chanthaburi Province is in the eastern region of Thailand. Basaltic corundum occurrences in this area have been discovered in eluvial and alluvial deposits derived from Tertiary to Pleistocene basalts that extruded onto older sedimentary and metamorphic rocks. Age of basaltic volcanism in this area ranges between 0.44$\pm$0.11 Ma (Barr and Macdonald, 1981) and 3.0$\pm$0.19 Ma (Sutthirat et al., 1994). The corundum varieties found in this area are mainly blue, green and yellow sapphires. Accessory minerals include quartz, pyrope, zircon, spinel. Coenraads et al. (1995) found unusual sapphire-zircon-magnetite xenolith from Chanthaburi gem fields. They suggested that origin of sapphires were related to pegmatite-like crystallization in an incompatible-element-enriched, silica-poor magma (partial melt in the deep crust or upper mantle). Intasopa et al. (2000) studied alkaline basalt and corundum from Chanthaburi-Trat Province, Thailand. The mineral inclusions in corundums that were identified are spinel, gahnite, hercynite, pleonaste, biotite, mica, diopside, ferrocolumbite, zircon, monazite, garnet, rutile, boehmite, feldspar, bismuth and thorite. They suggested that corundums possibly crystallized from peraluminous alkaline felsic magma which was formed by partial melting of metasomatized lithospheric rock at the crustal level shallower than 80 km.

Kanchanaburi Province is in the western region of Thailand in which the biggest sapphire deposit of the country have been discovered and big scale mines have been operated for decades. The gem occurrences distribute in the vicinity of Amphoe Bo Phloi. Geologically, sedimentary and metamorphic rocks ranging in age from Precambrian to Recent excluding the Cretaceous and early Tertiary (Bunopas and Bunjitradulya, 1975) were extruded by Cenozoic basaltic volcanism. In fact, basalt at Bo Phloi forms a small, plug-like body in fracture zone in quartzite of Silurian-Devonian age. Age dating data indicate young basaltic volcanism in this area which is about 3.14 ± 0.17 Ma (Barr and Macdonald 1981) and 4.17 ± 0.11 Ma (Sutthirat et al 1994). The volcanism might take sapphire and associated minerals onto the surface before weathering and transportation processes had taken place and led sapphire and its associated gems accumulating along residual, eluvial and alluvial deposits (Sutthirat 2001). However, alluvial deposit has been the main source of Bo Phloi sapphire that was found within a particular gravel bed (1-2 meter thick) lining at depth of about 12-15 meters (Vichit et al., 1978). Choowong (2002) applied C-14 dating for wood and peat above the gem-bearing layers and subsequently reported that the deposit appeared to have formed during the middle to late Pleistocene. In addition, the gem-bearing gravel bed defined a north-south trend along the incised paleo-channel of an ancient braided river system in the middle part of the basin. Pisutha-Arnond et al. (1999) found a *'corsilzirspite'* assemblage which is a fragmental crystalline rock composed of corundum-sillimanite - zircon - spinel from the Bo Phloi gem field, Kanchanaburi Province, Thailand. They eventually suggested a model of contact metamorphic/metasomatic/contaminated gabbroic melt processes for a Kanchanaburi sapphire.

Phrae deposit is a largest area of the corundum-bearing basaltic lavas in the north of Thailand. Gem deposits are found on both banks of Nam Yom River; the most important occurrences are located at Ban Bo Kaeo and Huai Mae Sung in Den Chai District of Phrae Province. Blue and green sapphires have been found associated with black spinel, sanidine, augite, olivine and zircon as alluvium deposits in the streams (Hughes 1997). Age of the basalt is about 5.64$\pm$0.28 Ma (Barr and Macdonald, 1981).

Hughes (1997) reported that mineral inclusions found in Chanthaburi and Phrae sapphires, except yellow sapphire, were plagioclase feldspar, garnet, niobite (columbite), uranopyrochlore whereas mineral inclusions found in Kanchanaburi (Bo Phloi) were identified as plagioclase feldspar, hornblende, pyrrhotite and spinel. In addition, Intasopa et al. (2000) found spinel, gahnite, hercynite, pleonaste, biotite, mica, diopside, ferrocolumbite, zircon, monazite, garnet, rutile, boehmite, feldspar, bismuth and thorite from Chanthaburi-Trat Province, Thailand. Besides, Gao et al. (1996) found Nb-Ta oxides (titaniferous columbite and uranpyrochlore), alkali feldspar, low-Ca plagioclase (albite-oligoclase), zircon, rare inclusions include Fe, Cu sulphide (low in Ni), Cobalt rich spinel and uraninite.

2.4.2 Cambodia

The most famous corundum deposits of Cambodia were discovered at Pailin area, western region close to the border of Thailand. Geologic setting in this area is similar to the eastern part of Chanthaburi-Trat gem deposits in Thailand in which corundum deposits are mostly related to Cenozoic volcanism. Basalt of Pailin area was extruded onto metamorphic rocks of Pre-Cambrian age, and greywacke of Triassic age. They form four separate hills rising above the surrounding plain; these hills, called Phnom O Tang, Phnom Ko Ngoap, Phnom Yat and O Chra, indicate volcanic vents of the whole Pailin area. Characteristics of these basalts are similar to those of Chanthaburi-Trat area in Thailand (Suttherland et al., 1998).

Figure 2.5 Map of Cambodia showing Pailin gem deposit (red star) located closely to the eastern border to Thailand (from www.lib.utexas.edu/maps).

Jobbins and Berrange (1981) reported that the Pailin gem deposits are laying athwart a NW-SE trending fault zone. This fault zone separated a northern region of low relief, underlain by the ancient Precambrian Pailin crystalline complex and some Devonian and Carboniferous rocks, from a mountainous region in the south composing largely of Triassic sandstones and greywackes. They also were able to show the rivers which were draining from the small basaltic bodies carrying gem minerals (e.g., ruby, sapphire, zircon and garnet). Probably the most striking aspect of the corundums from the Pailin area was virtually absent in colorless, yellow and green stones. Hughes (1997) reported mineral inclusions found in corundum from Pailin area are thorite, plagioclase feldspar and uranopyrochlore.

2.4.3 Vietnam

Sapphire deposits of Southern Vietnam are mainly characterized by placers derived from eroded alkali-basalt flows (Smith et al., 1995). Sapphires have been found in basaltic alluvials in four provinces of southern Vietnam region; Binh Thuan, Lam Dong, Dong Nai, and Dac Lac. Basaltic volcanism in the Southern Vietnam appears to have occurred during Tertiary to Quaternary with available age dating data ranging from about 0.4-8 million years (Garnier et al., 2005). Among these basalts, there would have various compositions which may be varying from tholeiite to strong alkali basalts.

Some trapiche sapphire samples taken for this study are from Lam Dong Province, Southern Vietnam in which geologic setting comprises sedimentary rocks, volcanic and intrusive rocks ranging in age from middle Jurassic to Quaternary. Gemstones found in the Lam Dong are categorized as sapphire, topaz, quartz, opal. Christopher et al. (1995) reported geological setting of Southern Vietnam sapphire deposit is similar to those associated with alkali basalts in Southeast Asia and China. Corundums as well as pyroxene, olivine, plagioclase, garnet and zircon occurred as megacrysts in undersaturated lavas (Hoang and Flower, 1998).

Figure 2.6 Map of Vietnam showing locations of Di Linh deposit (red star) in the area of Southern Vietnam (from www.anpa.ualr.edu/digital_library).

CHAPTER III
METHODOLOGY

3.1 Sample

Altogether twenty five samples of trapiche sapphires were collected and used for this study. This includes fourteen rough samples from some deposits in Thailand (eleven from Chanthaburi, two from Phrae and one from Kanchanaburi), eight rough samples from Pailin deposit in Cambodia and three cabochon cut samples from Lam Dong (Di Linh) deposit in Southern Vietnam.

3.2 Method of Study

The methods of this study are summarized in the schematic diagram (Figure 3.1) that contains several steps of investigation as described below.

1. Literature survey is the first step of work to search for relevant information helpful to this study. As has been reviewed above, most of available previous works were focussed on trapiche ruby and trapiche emerald, while trapiche sapphire has rarely been studied by a few researchers. However, knowledge gained from those previous works is useful for research design and discussion in the later parts of this report.

2. Twenty five samples of trapiche sapphires were acquired from some deposits in Thailand, Cambodia and Vietnam as indicated above.

3. Sample preparation was carried out after initial observation. All the samples were then cut perpendicular to the c- axis as slab samples. The slab samples were subsequently polished before further investigation.

4. Physical properties of samples were collected by using the basic gem instruments to confirm that they were the sapphire samples. The basic properties include refractive indices (RI) using a refractometer, the different values of refractive indices are reported as birefringences, specific gravity (SG) using an hydrostatic electronic balance and fluorescence phenomena under long wave ultraviolet light (LWUV, 365 nm) and short wave ultraviolet light (SWUV, 254 nm).

5. Internal features were investigated and photographed under a gem microscope. Some crystal inclusions were able to be identified by a Laser Raman Spectroscope. All equipments are based at the Gem and Jewellery Institute of Thailand (Public Organization) or GIT.

6. The samples were prepared as standard polished blocks for the analysis of their chemical compositions (i.e., Al_2O_3, Fe_2O_3, Cr_2O_3, V_2O_3, Ga_2O_3, SiO_2, TiO_2, Ca_2O, K_2O, MnO and MgO) by a JEOL Electron Probe Micro-Analyzer (EPMA), Model JXA-8100 super probe, based at the Department of Geology, Faculty of Science, Chulalongkorn University. In addition, the element mapping was also carried out to compare the relative element concentration of core, arms and growth sectors on those samples.

7. Interpretation of collected data, discussion, conclusion and thesis writing were carried out in the last part of this research.

3.3 Details of the Advanced Analytical Techniques

3.3.1 Electron Probe Micro-Analyzer (EPMA)

The Electron Probe Micro-Analyzer (EPMA) (Model JXA-8100), based at Department of Geology, Chulalongkorn University (Figure 3.2) was mainly used for the chemical analysis in this study. The EPMA is a non-destructive analytical method; therefore, it has been conventionally used to investigate chemical compositions of minerals and gemstones. The electron beam is focused on the surface of a sample, and produce characteristic X-rays of the sample. The characteristic X-rays are detected at wavelengths, and their intensities are measured to determine concentrations. The EPMA was applied to three different aspects including quantitative trace analyses of trapiche sapphire, quantitative analyses of some mineral inclusions, and qualitatively X-ray mapping of trapiche sapphire samples.

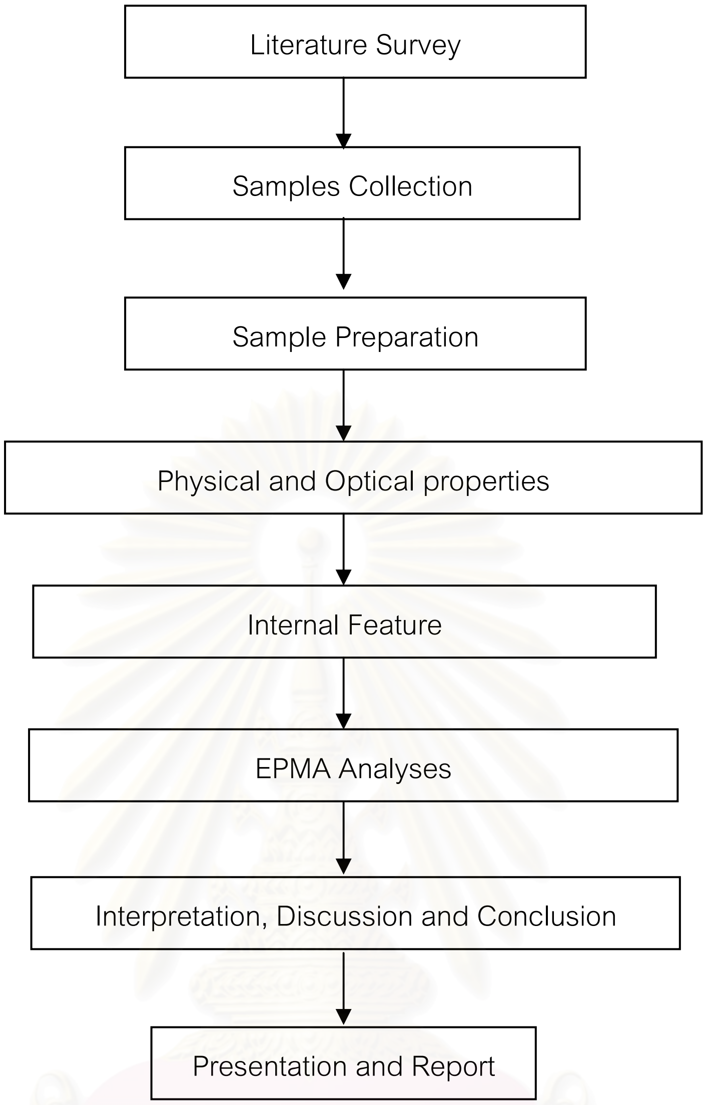


Figure 3.1 Flowchart showing method of study.

For quantitative analyses, most of the standards used for calibration were pure oxide and mineral standards including corundum for Al, wollastonite for Si and Ca, periclase for Mg, fayalite for Fe, pyrophanite for Ti and Mn, K-feldspar for K, jadeite for Na, barite for Ba, eskolaite for Cr, Gd-Ga garnet for Ga and Pb-V-Ge oxide for V. The other elements (i.e., U, Th, Nb, Ta, Ce and Sc) were calibrated using internal standards. Appropriate crystals in all five spectrometers were fully engaged for analyses of these elements.

Trace analyses of trapiche sapphire samples were carried out at acceleration voltage of 20 kV, probe current of about $2.18x10^{-8}$ A and beam diameter of 2 μm. Counting times were set at 100 second peak counts and 50 second background counts. On the other hand, major and minor compositions of mineral inclusion were analyzed using different condition that was operated at 15 kV and about $2.18x10^{-8}$ A with focussed beam (<1 μm diameter). Shorter counting times were set at 30 and 10 seconds for peak counts and background counts, respectively. Both quantitative analytical results were then taken automatic ZAF correction before reporting as percent oxides. For X-ray mapping, all five spectrometers with appropriate crystals were engaged to scan proportionally compositions of Al, Fe, Ti, Cr, Ga, Si, Mg and V along different parts of trapiche sapphire sample. A big beam spot (50 μm diameter) with a long dwell time (500-1000 milli-seconds) were assigned with high acceleration voltage of 20 kV and high probe current of about $5x10^{-8}$ A. Therefore, pixel size was set at 60 μm for all maps. Signals were automatically transfer to color shading for presentation.

Figure 3.2 Electron Probe Micro-Analyzer (EPMA) based at the Department of Geology, Chulalongkorn University.

3.3.2 Laser Raman Spectroscopy

The Laser Raman spectroscope (Model inVia Raman Microscope) based at the GIT (Figure 3.3) was mainly used for this study. Raman spectroscopy is a result of vibrational phenomena of molecular structure activated by light energy. The principal of vibrational spectroscopy is interaction between electrical field associated with photon and changes induced by vibrational movements in electronic charges distribution within the substance. Traditional Raman spectroscopy has been introduced as an analytical tool for minerals. However, the equipment cannot distinguish clearly some mineral inclusions that set deep into sapphire samples. The best result is obtained from mineral inclusions that are exposed or very close to the samples' surfaces.

Instrumentation for Laser Raman spectroscopy is composed of monochromatic light sources; laser is the best light source because it can give high intensity of monochromatic light. Most Raman spectroscopic studies use laser within the visible range of spectrum. The most famous excitation source is Argon ion gas laser which can generate high power laser with extreme stability. The wavelength of this laser is in blue-green region usually between 488 and 514.5 nm and generally provides the power of about 1-2 W output for 4-5 W laser. Spectrometer, in general, is a grating monochromater which dispersion takes place by selective reflection of the grating surface due to constructive and destructive interferences caused by the regularly ruled surface. It is considered to be the most suitable spectrometer for Raman spectroscope. Detectors of Raman spectrometer contain commonly charge couple device (CCD) as a detector because of its obviously higher sensitivity.

Before using the Raman spectroscope for the identification of mineral inclusions, the machine was calibrated with silicon plate at its center about 520 nm. The laser source that used for this study is 514.5 nm. Raman data scan range was set at 150-2000 cm^{-1} and data acquisition times of 10 seconds with accumulations for three times.

Figure 3.3 Laser Raman spectroscope (Model inVia Raman Microscope) based at the GIT.

CHAPTER IV
PHYSICAL PROPERTIES AND INTERNAL FEATURES

4.1 Introduction

Trapiche sapphires used this study were collected from some particular sapphire deposits related to basalts in Thailand, Cambodia and Vietnam. Altogether twenty five samples were selected for investigations under this research project. They comprise fourteen samples from Thailand, eight samples from Cambodia and three samples from Vietnam. All of the samples were received directly from local miners in these countries. The physical properties and internal features of samples from each deposit obtained from this study are reported in detail herein this chapter starting from those of Thailand to Cambodia and Vietnam, respectively.

Regarding to trapiche ruby, growth sector has been denoted for trapezohedral or trapezoidal portions whereas arms has been defined for dendritic structures intercepting between growth sectors; these different regions are suspected to have been formed after the poor to moderate formation of core, then dendritic arms are likely to be faster developed (Sunagawa et al.,1999). On the contrary, trapiche sapphires in this study appear to have white band of impurity extending from the poorly to well developed hexagonal faces of core toward directions of basal (a) axes which is later defined as arm. However, the arm areas are likely perpendicular to $\{11\bar{2}0\}$ faces forming rectangular instead of trapezoidal. Consequently, clear blue areas between the arms are described as growth sector (Figure 4.1.1). These definitions will be applied throughout the report.

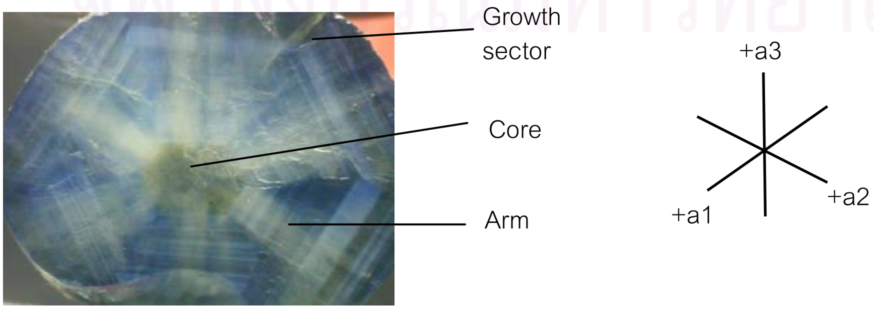


Figure 4.1.1 A sample of trapiche sapphire showing defined parts of core, arm and growth sector.

4.2 Trapiche Sapphires from Thailand

The fourteen samples of trapiche sapphire collected from Thailand include eleven samples from Chanthaburi deposit in the eastern region, one sample from Kanchanaburi (Bo Phloi) deposit in the western region and two samples from Phrae, in the northern region.

4.2.1 Physical Properties

All the trapiche sapphire samples from Thailand are rough stones (Figure 4.2.1). Their physical properties are summarized in Table 4.2.1. Their majority are tabular hexagonal-shaped single crystals with distinct short prism faces and large basal pinacoid faces. They have sizes ranging from 0.4 to 1.1 centimeters in diameter and weights of 0.4-2.4 carats. Colors of all samples are mainly blue, and in some samples, with the combination of yellowish shade. Other physical properties of all the samples fall within common range of corundum. The refractive indices (RI) are 1.770-1.772 for n_o and 1.760-1.764 for n_e and birefringences range between 0.006 and 0.010. Specific gravity (SG) values are about 3.96-3.99. All the samples are inert under ultraviolet (UV) lamps both long wave (LW) and short wave (SW).

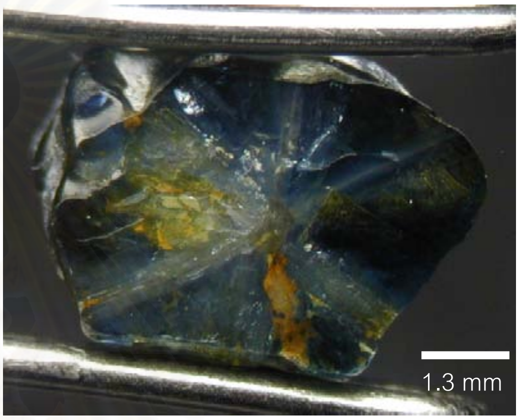
4.2.2 Internal Features

Internal features of trapiche sapphires from Thailand observed under a gemological microscope are summarized in Table 4.2.2.

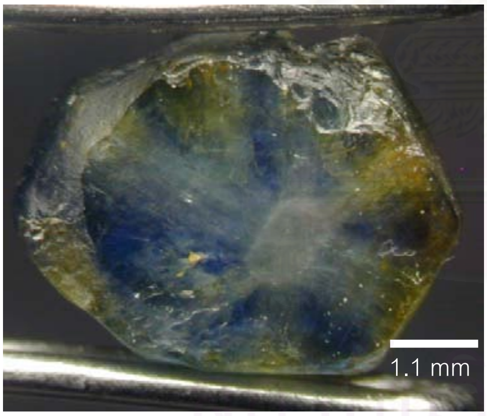
Chan1

Chan2

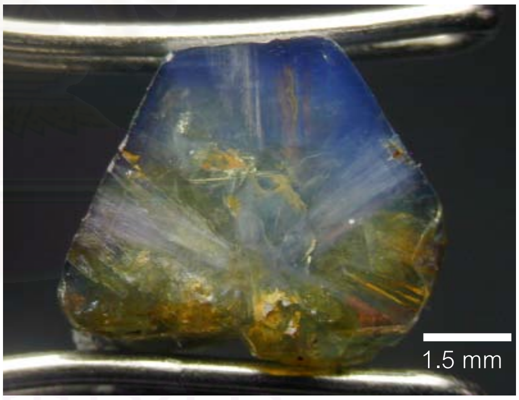
Chan3



Chan4



Chan5



Chan6

Figure 4.2.1 Trapiche sapphire samples from Thailand including 11 samples from Chanthaburi (Chan1 to Chan11), 1 sample from Kanchanaburi (Kan) and 2 samples from Phrae (Phrae1 and Phrae2).

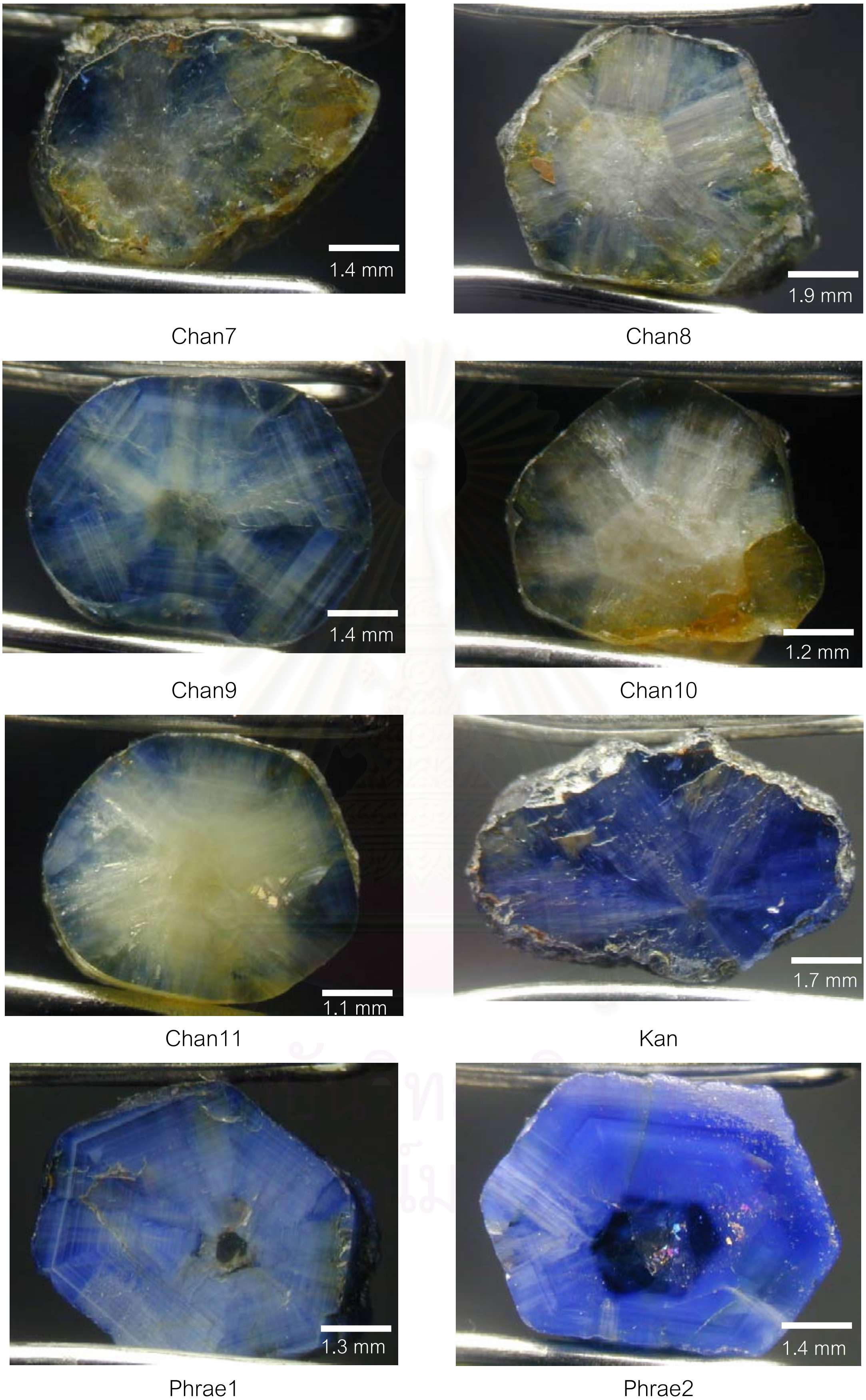


Figure 4.2.1 (cont.).

Table 4.2.1 Summary of physical properties of trapiche sapphire samples from Thailand.

Sample no.	Weight (ct)	Crystal Habit & Size (mm)	Color	RI (Birefringence)	SG	Fluorescence	
						LW	SW
Chan1	1.34	roughly tabular hexagonal crystal, 9.1 x 7.0 x 1.6	blue	1.770-1.763 (0.007)	3.994	inert	inert
Chan2	2.37	irregular tabular crystal, 11.2 x 8.2 x 2.3 , basal parting filled with iron oxides	blue	1.770-1.762 (0.008)	3.965	inert	inert
Chan3	2.34	rounded tabular hexagonal crystal, 9.0 x 5.8 x 3.7	blue, yellowish	1.770-1.760 (0.010)	3.987	inert	inert
Chan4	0.85	irregular tabular crystal, 6.0 x 4.4 x 2.7	blue, yellowish	1.770-1.762 (0.008)	3.972	inert	inert
Chan5	1.04	tabular hexagonal crystal, 5.9 x 5.0 x 2.7 , basal parting filled with iron oxides	blue, yellowish	1.770-1.763 (0.007)	3.981	inert	inert
Chan6	1.32	tabular hexagonal crystal, 7.0 x 6.0 x 2.5 , rhombohedral parting filled with iron oxides	blue, yellowish	1.770-1.762 (0.008)	3.980	inert	inert

Table 4.2.1 (cont.).

Sample no.	Weight (ct)	Crystal Habit & Size (mm)	Color	RI (Birefringence)	SG	Fluorescence	
						LW	SW
Chan7	0.82	irregular tabular crystal, 6.5 x 5.1 x 2.0	blue, yellowish	1.770-1.763 (0.007)	3.987	inert	inert
Chan8	2.40	tabular hexagonal crystal, 8.7 x 6.8 x 3.3	blue, yellowish	1.772-1.764 (0.008)	3.984	inert	inert
Chan9	0.83	rounded tabular hexagonal crystal, 6.2 x 4.8 x 2.0	blue	1.770-1.760 (0.010)	3.990	inert	inert
Chan10	0.69	tabular hexagonal crystal, 4.6 x 4.3 x 2.6	blue, yellowish	1.771-1.763 (0.008)	3.990	inert	inert
Chan11	0.80	rounded tabular hexagonal crystal, 4.9 x 4.3 x 2.4	blue, yellowish	1.770-1.762 (0.008)	3.980	inert	inert
Kan	1.02	irregular tabular crystal, 8.4 x 5.7 x 1.7	blue	1.770-1.763 (0.007)	3.962	inert	inert
Phrae1	0.48	tabular hexagonal crystal, 5.9 x 4.9 x 1.2	blue	1.770-1.764 (0.006)	3.982	inert	inert
Phrae2	1.36	tabular hexagonal crystal, 6.9 x 5.4 x 2.8	blue	1.770-1.763 (0.007)	3.977	inert	inert

Table 4.2.2 Summary of internal features observed in trapiche sapphire samples from Thailand.

Sample No.	Core	Arm	Growth sector
Chan1	Moderately well developed hexagonal core, mainly thin-film fluid inclusions with some iron oxides, white minute particles	Poorly defined white arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, some whitish minute particles along thin-film	Mainly contain thin-film fluid inclusions, white minute particles along hexagonal growth zone, nepheline and calcite inclusions
Chan2	Poorly defined hexagonal core, mainly very short needles, thin-film fluid inclusions, small black inclusions	Moderately well defined white arm, mainly thin-film fluid inclusions, very short needles and small black inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces	Clear with some thin-film fluid inclusions, white minute particles along hexagonal growth zone, long hexagonal hollow tubes filed with iron oxides and oriented in all directions
Chan3	Moderately developed brown hexagonal core, mainly very short needle inclusions, many small black inclusions along the core, fluid inclusions	Well defined grey arm, mainly thin- film fluid inclusions and very short needle perpendicular to $\{11\bar{2}0\}$ faces, some thin-film filled with iron oxides, many small black inclusions along the arm, plane of 2-phase inclusions near the arm	Clear, thin-film fluid inclusions with iron oxides, some white minute particles along hexagonal growth zone, partly small black inclusions
Chan4	Moderately developed brown hexagonal core, mainly thin-film fluid inclusions, brown minute particles and some small black inclusions	Moderately well defined white arm, mainly thin-film fluid inclusions and some white minute particles oriented perpendicular to $\{11\bar{2}0\}$ faces, some small black inclusions	Clear with some thin-film fluid inclusions, some white minute particles along hexagonal growth zone, thin-film partly filled with iron oxides,

Table 4.2.2 (cont.).

Sample No.	Core	Arm	Growth sector
Chan5	Well defined greyish hexagonal core, mainly thin-film fluid inclusions, white minute particles	Well defined grey arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, some filled with iron oxides	Mainly thin-film fluid inclusions partly filled with iron oxides, some whitish blue minute particles along hexagonal growth zone
Chan6	Poorly defined yellowish hexagonal core , mainly thin-film fluid inclusions, some white minute particles	Poorly defined white arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, some whitish minute particles, some small black inclusions along the arm, some defined as magnetite	Clear with some thin-film fluid inclusions partly filled with iron oxides, some white minute particles along hexagonal growth zone, some tube parallel with arm and filled with iron oxides, nepheline inclusion
Chan7	Moderately developed grey hexagonal core, mainly thin-film fluid inclusions, many small black inclusions and some very short needles, magnetite inclusion	Poorly defined white arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces and mostly filled with iron oxides, very short needles, some small black inclusions, some defined as magnetite, pyrochlore and zircon	Mainly contain thin-film fluid inclusions, some filled with iron oxides, some minute particles along hexagonal growth zone, feldspar inclusion
Chan8	Well defined yellowish grey hexagonal core, some thin-film fluid inclusions, some very small mineral inclusions	Well developed grey arm, mainly thin-film fluid inclusions and very short needles perpendicular to $\{11\bar{2}0\}$ faces, some small black inclusions, some defined as columbite	Mainly thin-film fluid inclusions, some minute particles along hexagonal growth zone, some hexagonal hollow tube and negative crystal filled with iron oxides

Table 4.2.2 (cont.).

Sample No.	Core	Arm	Growth sector
Chan9	Well developed greenish hexagonal core, thin-film fluid inclusions, some minute particles and small black inclusions, some defined as magnetite	Well developed white arm, mainly thin-film fluid inclusions, some white minute particles perpendicular to {11 $\bar{2}$ 0} faces	Clear with some thin-film fluid inclusions, many white minute particles band along hexagonal growth zone, nepheline inclusion
Chan10	Moderately developed yellowish hexagonal core, mainly fluid inclusions, some small black inclusions	Moderately well developed yellowish arm, mainly thin-film fluid inclusions perpendicular to {11 $\bar{2}$ 0} faces, monazite and zircon inclusions	Mainly contain thin-film fluid inclusions, some minute particles along hexagonal growth zone
Chan11	Poorly defined yellowish hexagonal core, mainly fluid inclusions, some small black inclusions	Moderately well defined yellowish arm, mainly thin-film fluid inclusions perpendicular to {11 $\bar{2}$ 0} faces	Mainly contain thin-film fluid inclusions, some minute particles along hexagonal growth zone
Kan	Moderately developed yellowish brown hexagonal core, mainly thin-film fluid inclusions, minute particles, some small black inclusions	Moderately well developed grey arm, mainly thin-film fluid inclusions perpendicular to {11 $\bar{2}$ 0} faces, some minute particles along thin-film fluid inclusions	Mainly contain thin-film fluid inclusions, some minute particles along hexagonal growth zone, zircon inclusion
Phrae1	Well developed dark hexagonal core, thin-film fluid inclusions, grey minute particles	Moderately developed whitish arm, mainly thin-film fluid inclusions and very short needles perpendicular to {11 $\bar{2}$ 0} faces	Mainly thin-film fluid inclusions, very short needles along hexagonal growth zone
Phrae2	Well developed dark blue hexagonal core initiated by central trigonal, thin-film fluid inclusions, some white minute particles, multi phase inclusions	Poorly defined white arm (present only 2-3 arms), mainly whitish minute particles oriented perpendicular to {11 $\bar{2}$ 0} faces, magnetite inclusion	Mainly fluid inclusions, distinct whitish blue cloud along hexagonal growth zone, multi phase inclusions

Regarding to core area, Thai Trapiche sapphires are generally characterized by poorly defined to well developed hexagonal cores that have various shades of color such as brown, grey, yellowish grey, greenish and dark blue. The core areas of all samples significantly contain thin-film fluid inclusions; in addition, minute particles, short needles and small black inclusions may also be observed around the core area in some samples. For black inclusions, it is defined generally for small minerals observed under microscope; they may be identified further using Raman or EPMA. These important internal features are rather variable; however, they can be divided, based on combination of the internal feature mentioned earlier, into 5 groups of core characteristics that are assigned as C1 to C5. Details of each group are described below.

C1 (thin-film + minute + black inclusion): Core characteristics of this group are mainly composed of thin-film fluid inclusions in combination with minute particles and black inclusions. Therefore, samples Chan4, Chan9 and Kan are described within this group. For example, the core of Chan 9 show well developed greenish hexagonal core mainly occupied by thin-film fluid inclusion with some minute particle and many black inclusion (Figure 4.2.2).

C2 (thin-film + minute): Internal features in core area of group C2 are combination between thin-film fluid inclusions and minute particles. This composite feature is found in samples Chan1, Chan5, Chan6 and Phrae1. For example, Phrae1 show well developed dark hexagonal core which only thin-film fluid inclusion and minute particle can be observed inside (Figure 4.2.3). It should be noted that Phare2 also have similar internal features as found in this group but some specific core formation is recognized. Hence, it is separated into particular group (C5).

C3 (thin-film + black inclusion): Thin-film fluid inclusions and black inclusions are found in the core area that becomes characteristics of this sample group. Consequently, Chan8, Chan10 and Chan11 are recognized as C3 group. For example, the core of Chan8 shows well defined yellowish grey hexagonal core that contains thin-film fluid and black inclusion (Figure 4.2.4).

C4 (thin-film + short needle + black inclusion): Apart from minute particle, the other inclusions, i.e., thin-film fluid inclusions, short needles and black inclusions are significantly distinguished in core area of this group. In fact, short needles are particularly present in this type of core that contains samples Chan2, Chan3 and Chan7. However, short needles observed in Chan7 are not dense as those in Chan2 and Chan3. As shown in Figures 4.2.5 and 4.2.6, the core of Chan3 shows moderately developed brown hexagonal core containing a lot of short needle (Figure 4.2.5) whereas the core of Chan7 reveals moderately developed grey hexagonal core with some short needles present (Figure 4.2.6).

C5 (thin-film + minute): Phrae2 contains a clear dark blue hexagonal core that is mainly occupied by thin-film fluid inclusions. However, its hexagonal core is clearly separated into an inner trigonal and three outer trigonals. The outer trigonals appear to have developed from individual $\{10\bar{1}0\}$ faces of the inner trigonal and assembled these face as their bases. Consequently, two remaining faces of each outer trigonal have formed as $\{11\bar{2}0\}$ faces of the core region. In general, this core is occupied significantly by thin-film fluid inclusion; besides, the inner trigonal also contains cloudy minute particles (Figure 4.2.7).

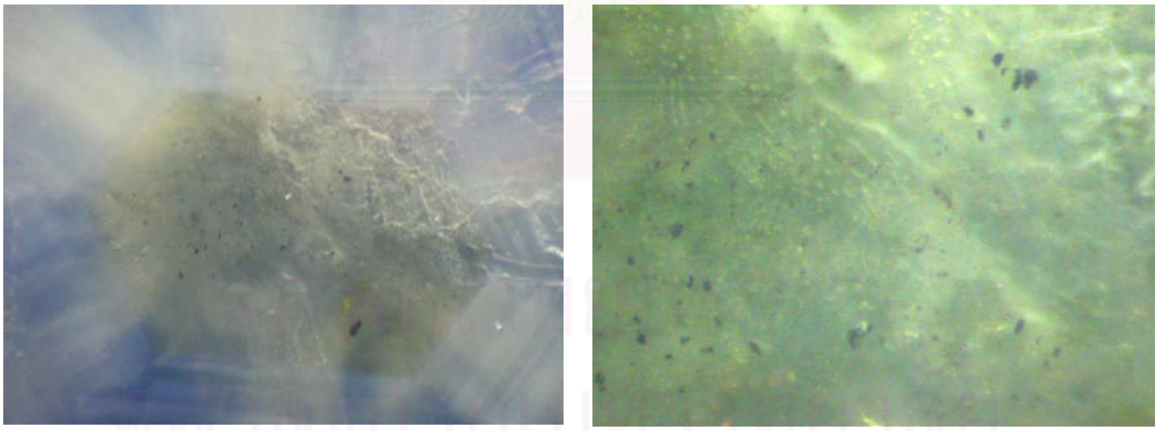


Figure 4.2.2 Internal features observed around the core of sample Chan9 (C1 group) showing well developed greenish hexagonal core (50x) (left); mainly occupied by thin-film fluid inclusions with some minute particles and many small black inclusions (100x) presenting in the core area (right).

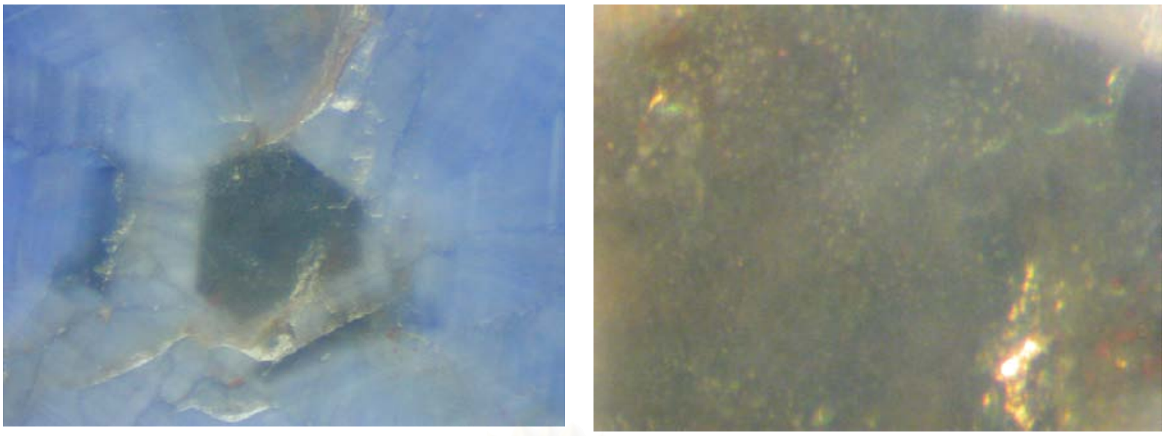


Figure 4.2.3 Internal features observed around the core of sample Phrae1 (C2 group) showing well developed dark hexagonal core (70x) (left); mainly occupied by thin-film fluid inclusions and minute particles (140x) (right).

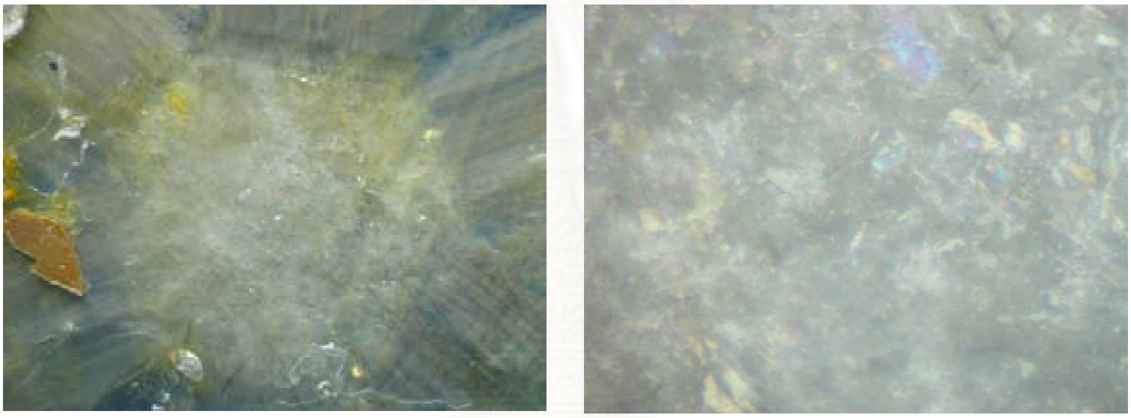


Figure 4.2.4 Internal features observed around the core of sample Chan 8 (C3 group) showing well defined yellowish grey hexagonal core (25x) (left); mainly occupied by thin-film fluid inclusions (70x) (right).

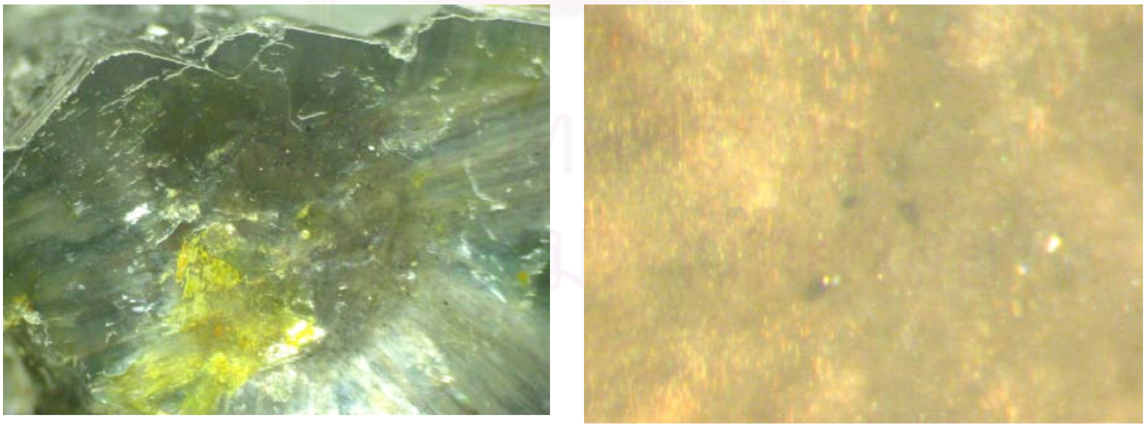


Figure 4.2.5 Internal features observed in around the core of sample Chan3 (G4 group) showing moderately developed brown hexagonal core (30x) (left); in which thin-film fluid inclusions and very short needle inclusions are significantly observed associated with many small black inclusions (100x) (right).

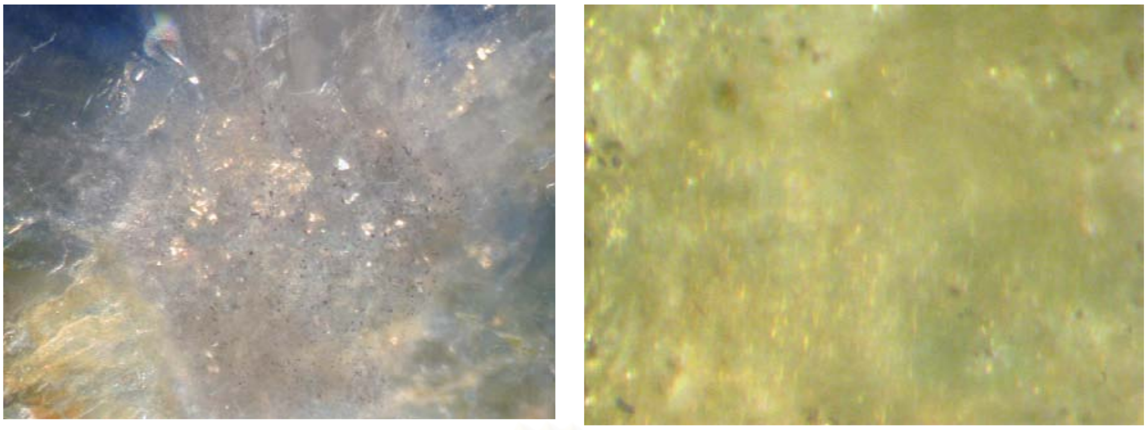


Figure 4.2.6 Internal features observed around the core of sample Chan7 (G4 group) showing moderately developed grey hexagonal core (50x) (left); in which thin film fluid inclusions and many small black inclusions are found associated with some very short needle inclusions (140x) (right).

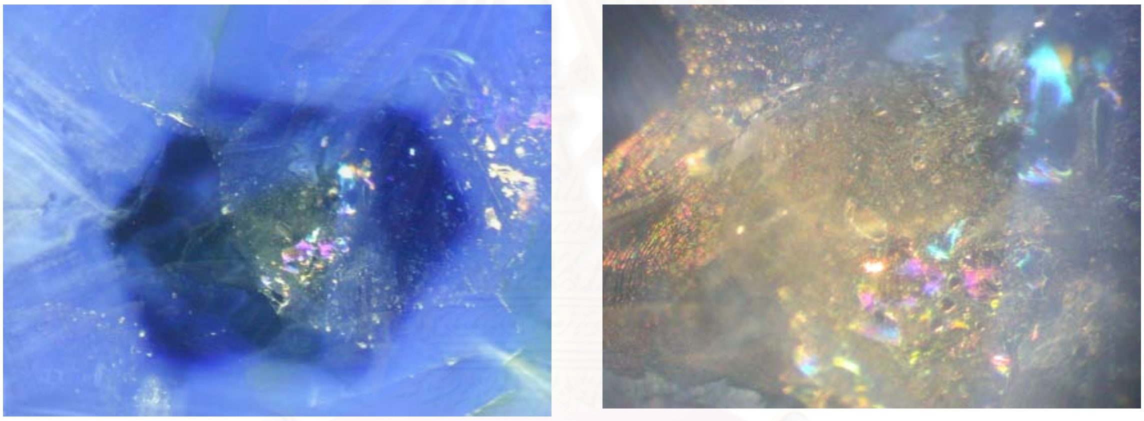


Figure 4.2.7 Internal features observed around the core area of sample Phrae2 only specific sample of G5 group showing well developed dark blue hexagonal core, a combination between inner trigonal and three outer trigonals developed from the $\{10\bar{1}0\}$ faces of the inner trigonal (30x) (left); cloudy minute particles and thin-film fluid inclusions can be observed within the inner trigonal area (90x) (right) whereas the outer area is only occupied by thin-film fluid inclusion.

In general, six arms extending outward from the hexagonal core can be observed in most of the samples from Thailand. These arms have various shades of color such as white, grey and yellowish. The major internal features that make these arms appear as such distinct characteristic are the abundant thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces. Other internal features in the arms are minute particles, short needles and some small black inclusions. Furthermore, some samples contain columbite, pyrochlore, magnetite, monazite and zircon in the arm area. The amount of mineral inclusions found at the arm area is similar to that found at the core area. However, all of the trapiche sapphire samples from Thailand are characterized by 4 different combinations of internal features within arm area. They are assigned as groups A1-A4 that are described below.

A1 (thin-film + minute + black inclusion): The arm areas of this group contain internal features that are characterized by thin-film fluid inclusions, minute particles and black inclusions. Two samples (Chan4 and Chan6) present such characteristics. For example, Chan6 shows poorly defined white arms containing thin-film fluid inclusions, minute particles and small black inclusions (Figure 4.2.8).

A2 (thin-film + minute): Only thin-film fluid inclusions and minute particles are found within the arm area of this group that is composed of Chan1, Chan9, Kan and Phrae2. For example, Chan1 shows poorly defined white arm that contains thin-film fluid inclusions and minute particles (Figure 4.2.9).

A3 (thin-film): Only thin-film fluid inclusions are found within the arm areas of samples Chan5, Chan10 and Chan11 that are consequently grouped as A3. For example, the arm of Chan10 shows moderately well developed yellowish arm partly occupied by thin-film fluid inclusions (Figure 4.2.10).

A4 (thin-film + short needle + black inclusion): This arm group contains a hybrid of internal features containing thin-film fluid inclusions, short needles and black inclusions. This feature is found along arms of samples Chan2, Chan3, Chan7, Chan8 and Phrae1. For example, Chan2 shows moderately well defined white arms that contain such mixed inclusions (Figure 4.2.11).

Figure 4.2.8 Internal features observed around arm of Chan6 (a sample of A1 group) showing poorly defined white arm (70x) containing thin-film fluid, minute and black inclusions.

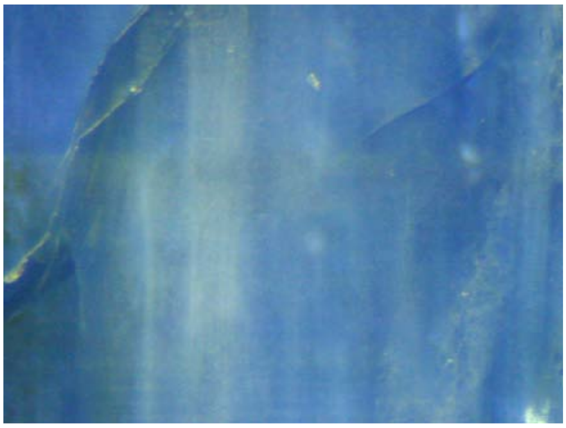


Figure 4.2.9 Internal features observed around arm of Chan1 (a sample of A2 group) showing poorly defined white arm (70x) containing thin-film fluid and minute inclusions.

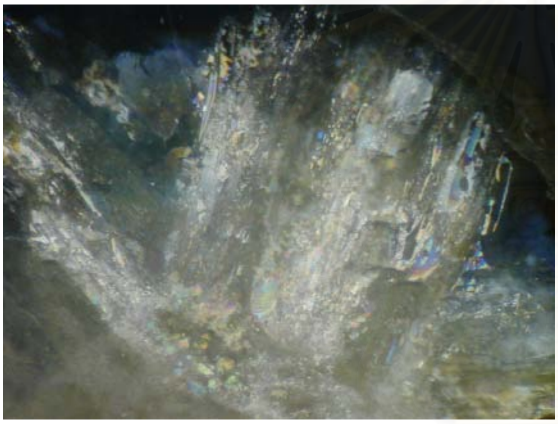


Figure 4.2.10 Internal features observed around arm of Chan10 (a sample of A3) showing moderately well developed yellowish arm (40x) containing only thin-film fluid inclusion.

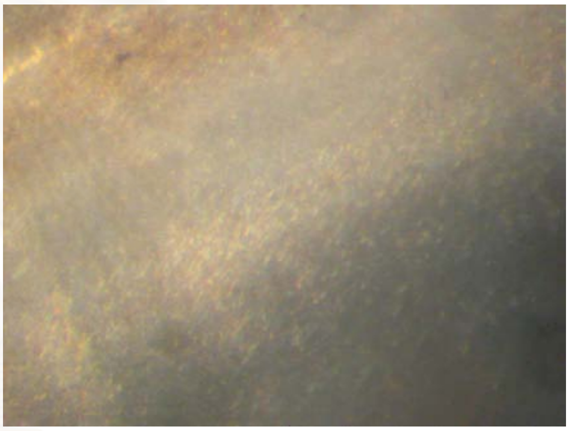


Figure 4.2.11 Internal features observed around arm of Chan2 (a sample of A4 group) showing moderately well defined white arm (140x) presenting short needles with some thin-film fluid and black inclusions.

For growth sectors, they are usually characterized by blue, clear to cloudy areas between arms. These areas often contain thin-film fluid inclusions, hexagonal white cloudy or blue zones that appear clearly to have developed outward the core region and these zones cover both areas of arm and growth sectors (Figure 4.2.12). Occasionally some colorless mineral inclusions (e.g., nepheline, calcite, feldspar, zircon) are also identified in these areas.

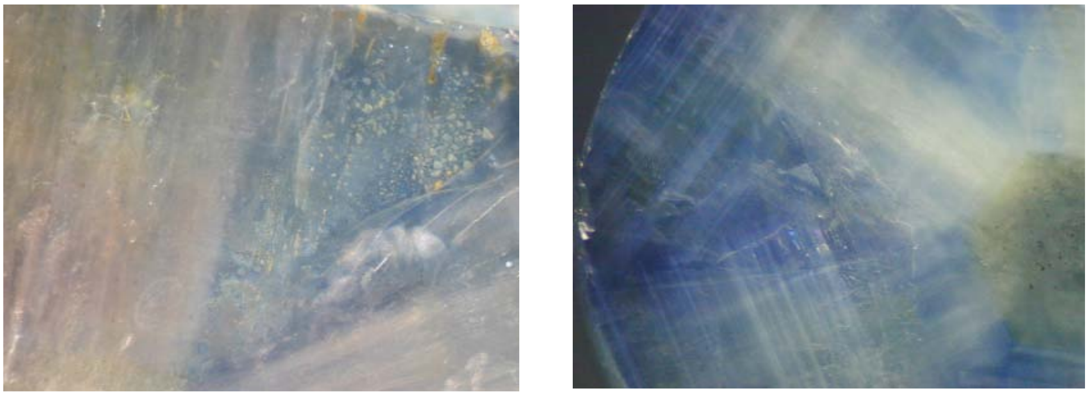


Figure 4.2.12 Internal features observed around growth sectors of trapiche sapphire from Thailand; they contain thin-film fluid inclusions and minute particles forming hexagonal growth zones in Chan8 (40x) (left) and Chan9 (40x) (right).

Although, trapiche sapphire samples contain mainly thin-film fluid inclusions in both arm and growth sector areas, thin-film fluid inclusions along the growth sector areas are not dense as those found in the arm areas. However, fluid inclusions found in all parts of these trapiche samples are similarly characterized by 2- or 3-phase inclusions and sometime by multi-phase inclusions (Figures 4.2.13 to 4.2.15).

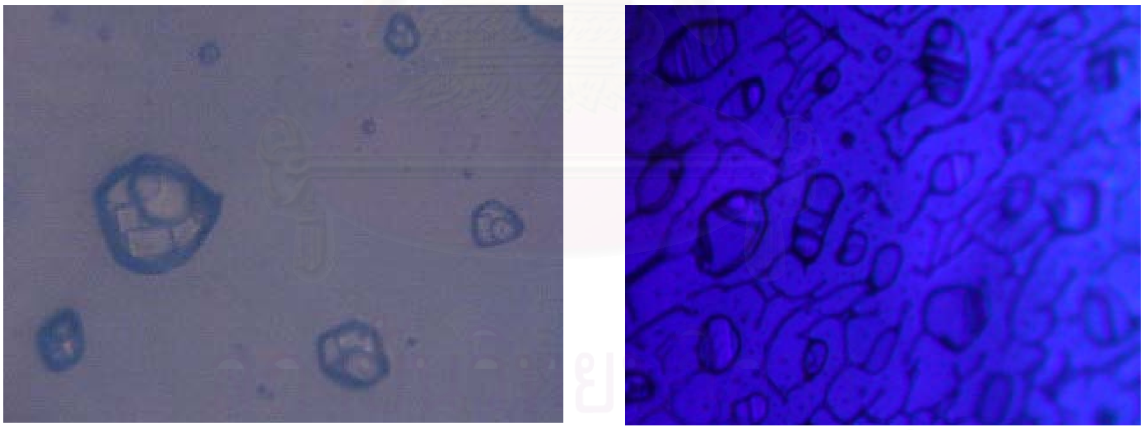


Figure 4.2.13 Multi phase inclusions (100x) in growth sector (left) compared with multi phase inclusions (100x) in the core of the same sample Phrae2 (right).

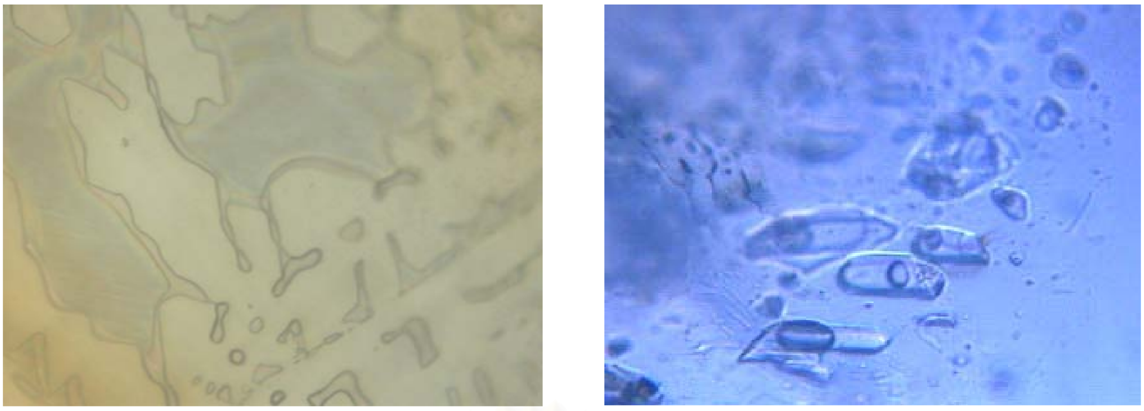


Figure 4.2.14 Thin-film fluid inclusions (100x) in growth sector of sample Chan9 (left) and multi phase inclusions (100x) in growth sector of sample Kan (right).

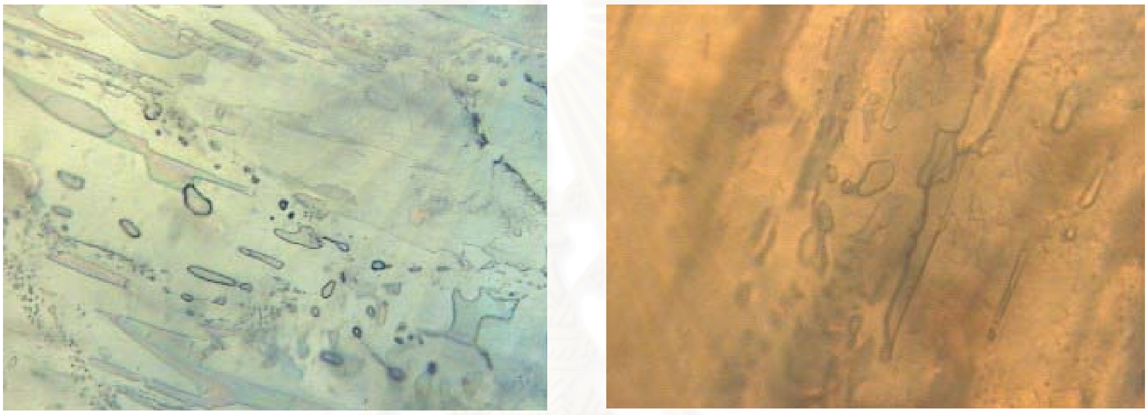


Figure 4.2.15 Thin-film fluid inclusions (100x) at an arm of sample Chan5 (left) and thin-film fluid inclusions (100x) at an arm of sample Chan2 (right).

4.2.3 Inclusion Identification

Large discrete mineral inclusions were observed in many trapiche sapphire samples from Thailand. They were found in the core, arm and growth sectors. In the core area, the abundant black inclusions were identified by the Raman technique as magnetite (Figure 4.2.16). In the arm area, the following mineral inclusions were also identified by this technique; magnetite (Figure 4.2.17) in Chan6 Chan7 and Phrae2, columbite (Figure 4.2.18) in Chan8, pyrochlore (Figure 4.2.19) in Chan7, zircon (Figure 4.2.20) in Chan7 and Chan10 and monazite (Figure 4.2.21) in Chan10. In the growth sector, they were identified as nepheline (Figure 4.2.22) in Chan1, Chan6 and Chan 9, feldspar (Figure 4.2.23) in Chan7, calcite (Figure 4.2.24) in Chan1 and zircon (Figure 4.2.25) in Kan sample. Besides these mineral inclusions, CO_2 was also detected in some fluid inclusions (Figure 4.2.26). Summary of mineral inclusions found in each part of trapiche sapphire samples from Thailand and identified using Raman technique is present in Table 4.2.3.

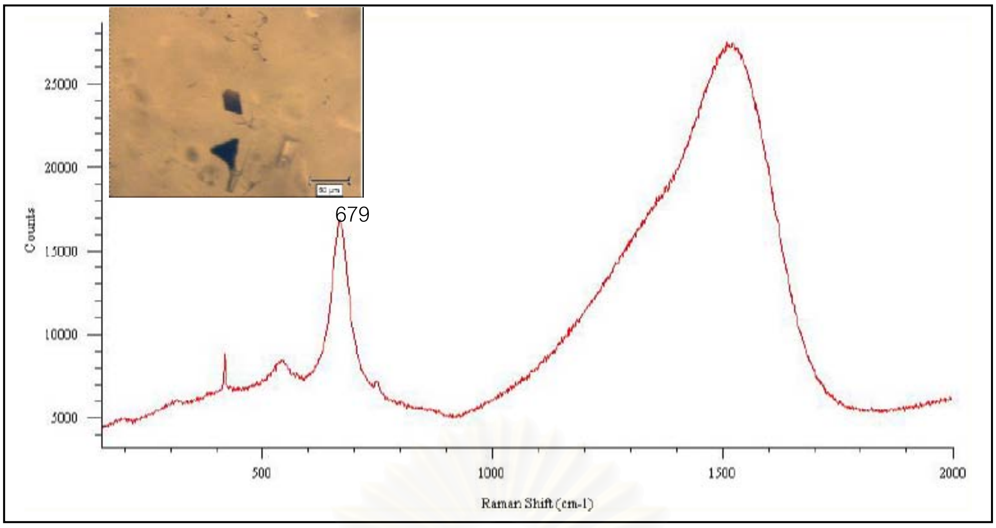


Figure 4.2.16 Raman spectrum of magnetite inclusion found at core of Chan 7 sample from Chanthaburi deposit, Eastern Thailand.

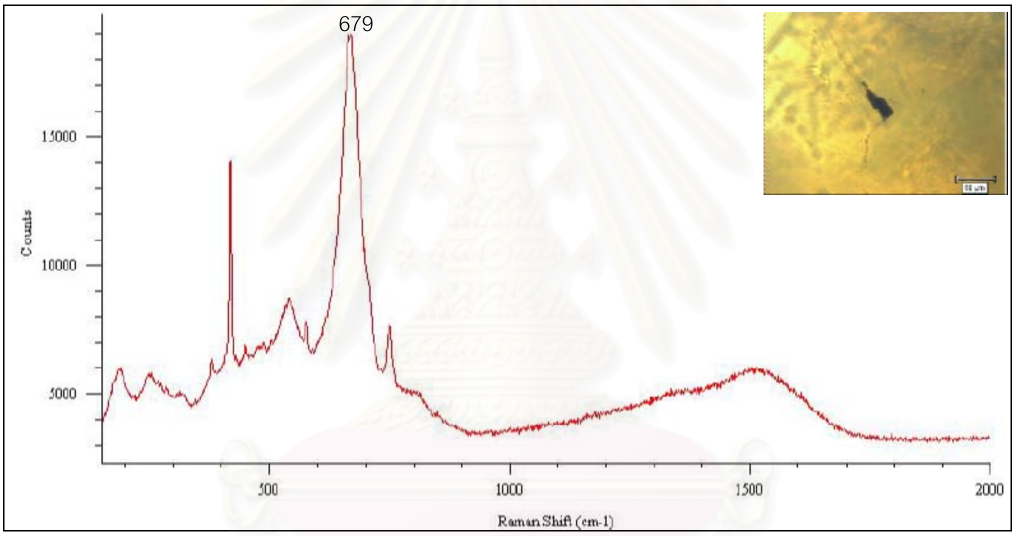


Figure 4.2.17 Raman spectrum of magnetite inclusion found at arm area of Chan 7 sample from Chanthaburi deposit, Eastern Thailand.

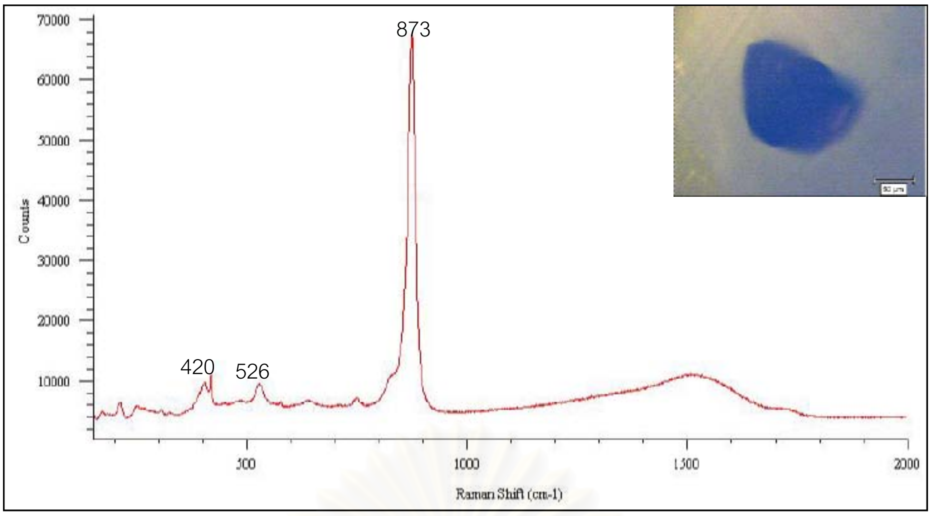


Figure 4.2.18 Raman spectrum of columbite inclusion found at arm area of Chan 8 sample from Chanthaburi deposit, Eastern Thailand.

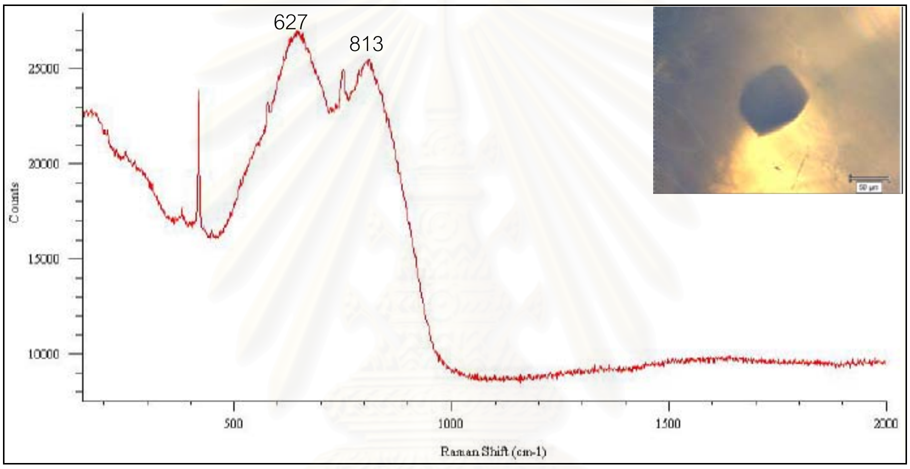


Figure 4.2.19 Raman spectrum of pyrochlore inclusion found at arm area of Chan 7 sample from Chanthaburi deposit, Eastern Thailand.

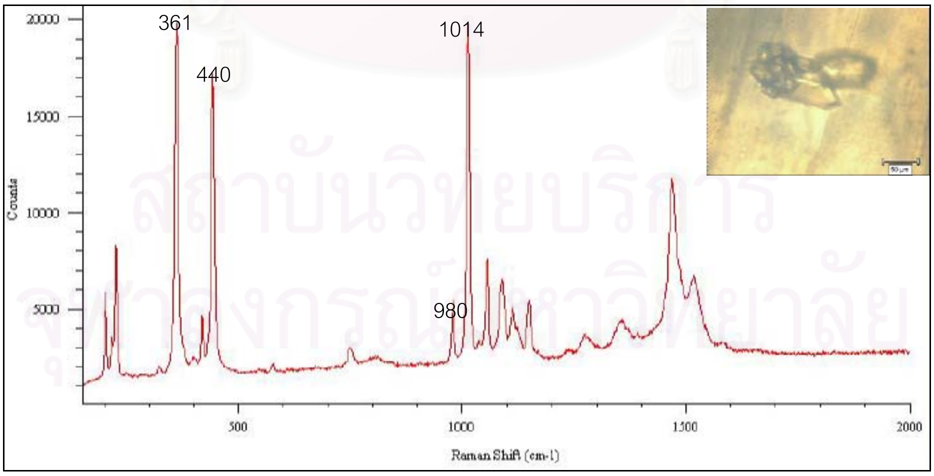


Figure 4.2.20 Raman spectrum of zircon inclusion found at arm area of Chan 7 sample from Chanthaburi deposit, Eastern Thailand.

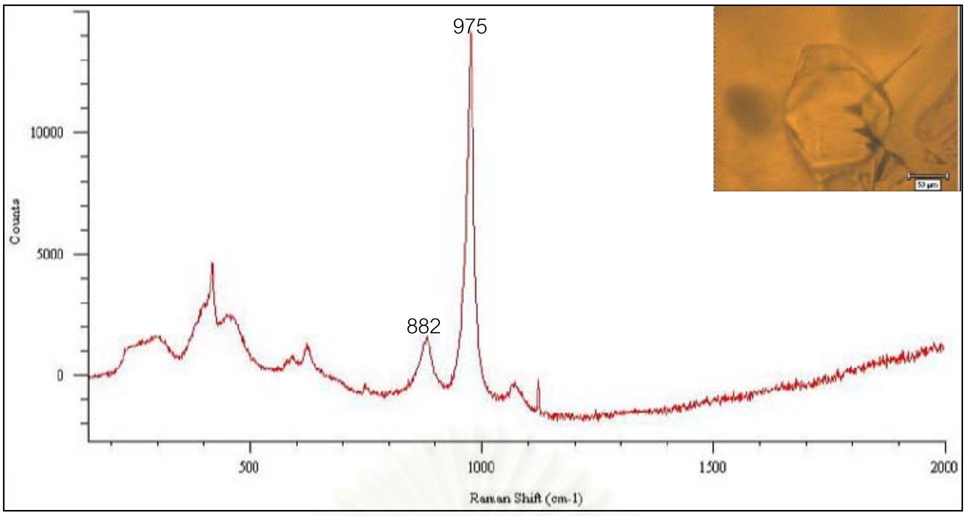


Figure 4.2.21 Raman spectrum of monazite inclusion found at arm area of Chan 10 sample from Chanthaburi deposit, Eastern Thailand.

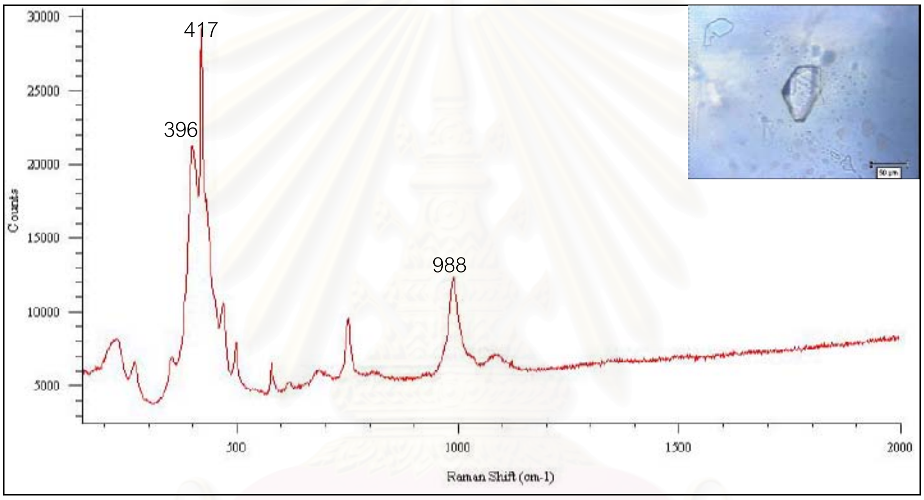


Figure 4.2.22 Raman spectrum of nepheline inclusion found at growth sector area of Chan 1 sample from Chanthaburi deposit, Eastern Thailand.

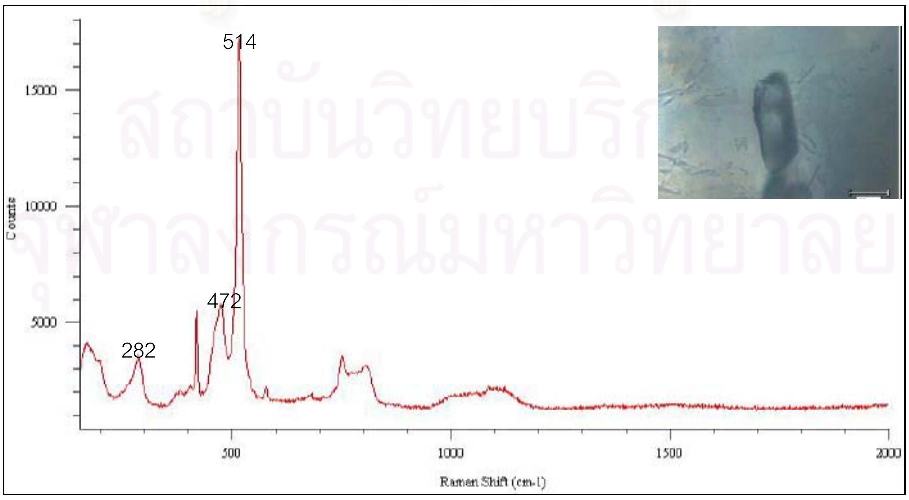


Figure 4.2.23 Raman spectrum of feldspar inclusion found at growth sector area of Chan 7 sample from Chanthaburi deposit, Eastern Thailand.

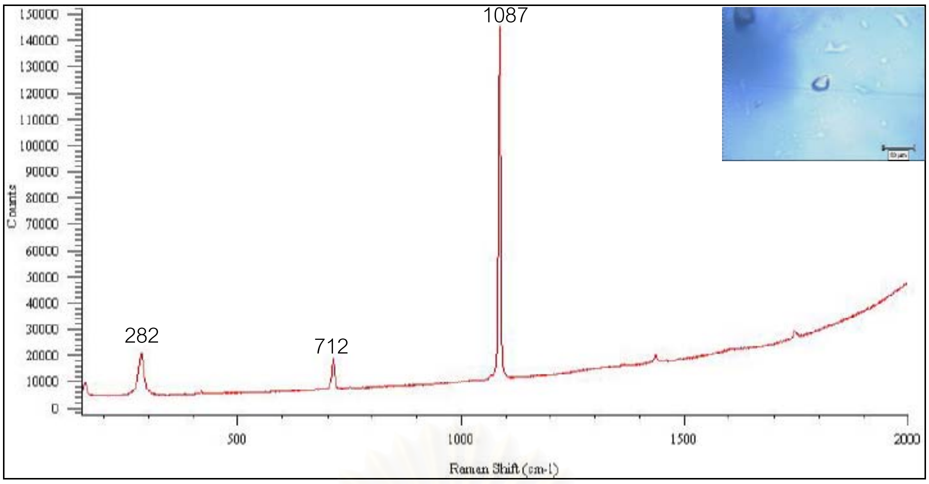


Figure 4.2.24 Raman spectrum of calcite inclusion found at growth sector area of Chan 1 sample from Chanthaburi deposit, Eastern Thailand.

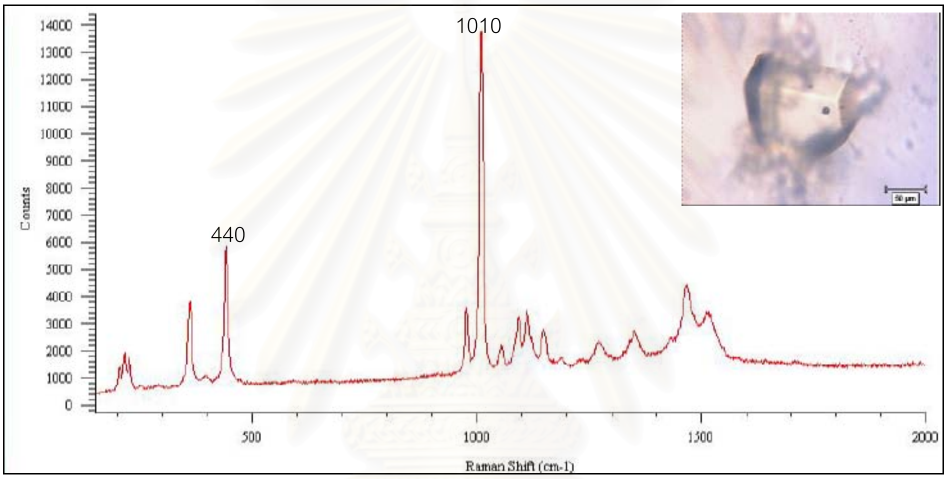


Figure 4.2.25 Raman spectrum of zircon inclusion found at growth sector area of Kan sample from Kanchanaburi deposit, Western Thailand.

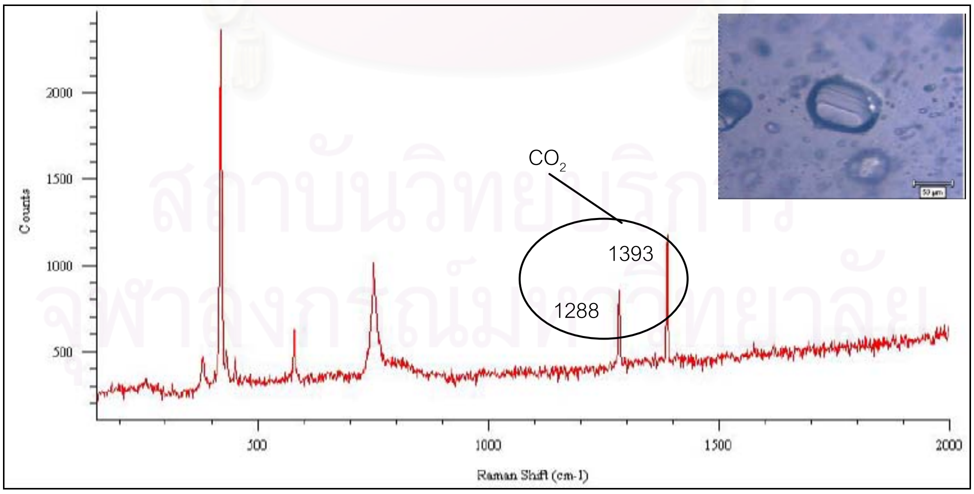


Figure 4.2.26 Raman spectrum of CO_2 found in Phrae2 sample from Phrae deposit, Northern Thailand.

Table 4.2.3 Summary of mineral inclusions identified using Raman technique from each part of trapiche sapphire samples from Thailand.

Sample No.	Core	Arm	Growth Sector
Chan1	_	_	nepheline, calcite
Chan6	_	magnetite	nepheline
Chan7	magnetite	magnetite, pyrochlore, zircon	feldspar
Chan8	_	columbite	_
Chan9	magnetite	_	nepheline
Chan10	_	zircon, monazite	_
Kan	_	_	zircon
Phrae2	_	magnetite	_

4.3 Trapiche Sapphires from Cambodia

The Cambodian trapiche sapphires used under this study are eight samples collected from Pailin deposit in the western region of Cambodia (Figure 4.3.1). Examination of general physical properties and specific features of these samples were carried out and reported herein this section.

4.3.1 Physical Properties

All eight trapiche sapphire samples from Pailin deposit of Cambodia are rough stones having tabular-hexagonal-shaped single crystals with distinct short prism faces and large basal pinacoid faces (Figure 4.3.1). Their sizes vary from 0.5-1.3 centimeter and weights range from 1.0-6.3 carats. Their physical properties are summarized in Table 4.3.1. The colors of the samples are mainly blue with white to yellowish brown core and arms. General physical properties of all samples fall within a normal range of corundum. The refractive indices (RI) are 1.770-1.771 for n_o and 1.761-1.762 for n_e and birefringences range between 0.009 and 0.010. Specific gravity (SG) values are about 3.92-4.00. In addition, their fluorescence are inert under ultraviolet (UV) lamps both long wave (LW) and short wave (SW).

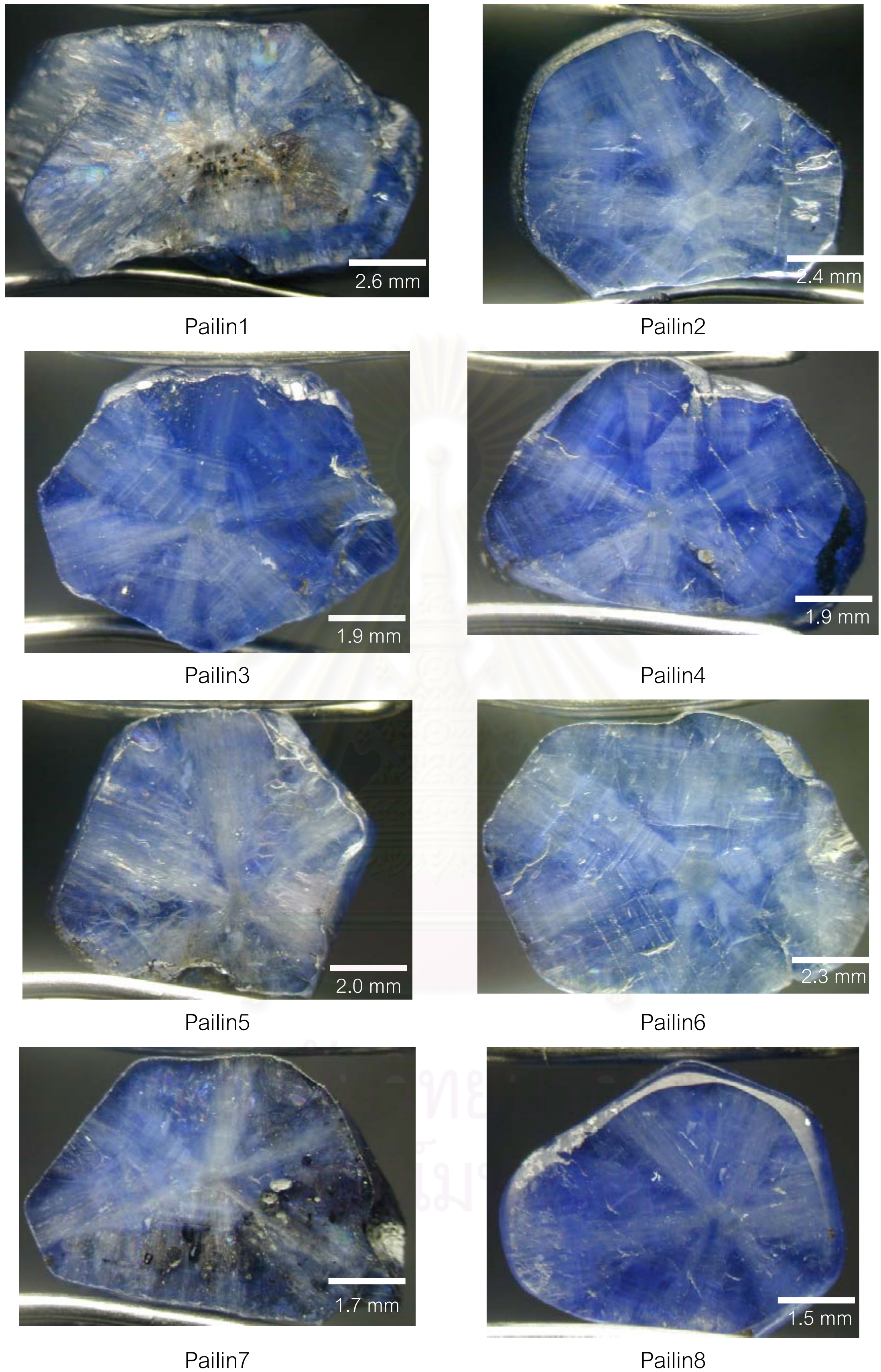


Figure 4.3.1 Trapiche sapphire samples from Cambodia (Pailin1 to Pailin8).

4.3.2 Internal Features

The internal features of all trapiche sapphire samples from Cambodia are summarized in Table 4.3.2.

Table 4.3.1 Summary of physical properties of trapiche sapphire samples from Cambodia.

Sample no.	Weight (ct)	Crystal Habit & Size (mm)	Color	RI (Birefringence)	SG	Fluorescence LW	Fluorescence SW
Pailin1	6.38	tabular hexagonal crystal, 13.2 x 8.7 x 4.67	blue	1.770-1.761 (0.009)	3.928	inert	inert
Pailin2	5.63	rounded tabular hexagonal crystal, 11.0 x 9.1 x 4.4	blue	1.770-1.761 (0.009)	3.966	inert	inert
Pailin3	2.90	tabular hexagonal crystal, 8.6 x 7.8 x 3.5	blue	1.770-1.761 (0.009)	3.994	inert	inert
Pailin4	2.50	tabular hexagonal crystal, 9.7 x 6.9 x 2.8	blue	1.771-1.762 (0.009)	3.938	inert	inert
Pailin5	3.15	tabular hexagonal crystal, 8.1 x 7.2 x 4.1	blue	1.771-1.761 (0.010)	3.935	inert	inert
Pailin6	3.74	tabular hexagonal crystal, 11.4 x 9.0 x 2.6	blue	1.770-1.761 (0.009)	3.964	inert	inert
Pailin7	1.78	tabular hexagonal crystal, 8.5 x 6.0 x 2.5	blue	1.770-1.761 (0.009)	3.997	inert	inert
Pailin8	1.01	rounded tabular hexagonal crystal, 6.5 x 5.6 x 2.1	blue	1.771-1.762 (0.009)	3.952	inert	inert

Table 4.3.2 Summary of internal features of all trapiche sapphire samples under this study from Cambodia.

Sample No.	Core	Arm	Growth sector
Pailin1	Poorly defined grey hexagonal core, mainly thin-film fluid inclusions, some minute particles, small black inclusions	Poorly defined white arm, mainly thin-film fluid inclusions oriented perpendicular to {11$\bar{2}$0} faces, many columbite and pyrochlore presenting outside the core parallel to hexagonal faces, some small black inclusions	Mainly thin-film fluid inclusions, minute particles along hexagonal growth zones, many columbite and pyrochlore presenting outside the core parallel to hexagonal faces,
Pailin2	Well developed greyish white hexagonal core, mainly thin-film fluid inclusions, some white minute particles	Moderately well developed whitish arm, mainly thin-film fluid inclusions oriented perpendicular to {11$\bar{2}$0} faces, columbite, plane of orange crystals (mostly pyrochlore) parallel to hexagonal faces	Mainly thin-film fluid inclusions, whitish minute particles along hexagonal growth zones, plane of orange crystals (mostly pyrochlore parallel to hexagonal faces, some negative crystals
Pailin3	Well developed greyish hexagonal core, mainly thin-film fluid inclusions, some white minute particles, some black inclusions	Moderately well developed whitish arm, mainly thin-film fluid inclusions oriented perpendicular to {11$\bar{2}$0} faces, some black inclusions	Clear of thin-film fluid inclusions, whitish minute particles along hexagonal growth zones
Pailin4	Moderately well developed greyish hexagonal core, mainly thin-film fluid inclusions, some minute particles, small black inclusions	Moderately well developed whitish arm, mainly thin-film fluid inclusions oriented perpendicular to {11$\bar{2}$0} faces, small black inclusions	Mainly thin-film fluid inclusions, whitish minute particles along hexagonal growth zones
Pailin5	Moderately developed grey hexagonal core, mainly thin-film fluid inclusions, some white minute particles, small black inclusions	Poorly developed grayish arm, mainly thin-film fluid inclusions, small black inclusions oriented perpendicular to {11$\bar{2}$0} faces, some hollow tube parallel to the direction of arm	Mainly thin-film fluid inclusions, whitish minute particles along hexagonal growth zones

Table 4.3.2 (cont.).

Sample No.	Core	Arm	Growth sector
Pailin6	Well developed greyish hexagonal core, mainly thin-film fluid inclusions, some minute particles, some small black inclusions	Moderately developed whitish arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, some small black inclusions	Mainly thin-film fluid inclusions, whitish minute particles along hexagonal growth zones
Pailin7	Poorly defined greyish hexagonal core, mainly thin-film fluid inclusions, some minute particles	Poorly defined whitish arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, columbite and pyrochlore inclusions	Mainly thin-film fluid inclusions, whitish minute particles along hexagonal growth zones, columbite and pyrochlore inclusions
Pailin8	Moderately developed whitish grey hexagonal core, mainly thin-film fluid inclusions, some minute particles	Moderately developed whitish arm, mainly thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, black inclusions	Mainly thin-film fluid inclusions, whitish minute particles along hexagonal growth zones

In general, all samples of the Cambodian trapiche sapphires contain poorly to well developed hexagonal cores that have various shades of color such as greyish, grey, whitish grey and greyish white. The internal features observed in the core areas consist of thin-film fluid inclusions, some minute particles and in some samples, a few small black inclusions can be found additionally. These internal features can be used to divide cores of these trapiche sapphires into 2 groups which are assigned as C1 and C2. Their descriptions are reported below.

C1 (thin-film + minute + black inclusion): This group of core is significantly composed of thin-film fluid inclusions, minute particles and black inclusions. This core group can be recognized in samples Pailin1, Pailin3, Pailin4, Pailin5, Pailin6 and Pailin8. For example, Pailin6 shows well developed greyish hexagonal core (Figure 4.3.2); however, all inclusion types mentioned above are quite small to present in the photo.

C2 (thin-film + minute): Only thin-film fluid inclusions and minute particles are recognized in this core group. The samples presenting this core group is composed of Pailin2 and Pailin7. For example, Pailin2 shows well developed greyish white hexagonal core (Figure 4.3.3) but its inclusions are quite tiny to be observed in the photo.

Regarding to arm area, six whitish and greyish arms of all samples extend outward from the core perpendicular to $\{11\bar{2}0\}$ faces. They are occupied similarly by abundant thin-film fluid inclusions and some small black inclusions (Figure 4.3.4). In addition, columbite and pyrochlore inclusions can be analyzed in some samples. Growth sectors are mostly blue and contain mainly fluid inclusions and hexagonal cloudy zones. The hexagonal zones are clearly developed outward from the core region covering both arm and growth sector (Figure 4.3.5). In some samples, columbite and pyrochlore inclusions can also be found similar to the arm areas.

In conclusion, these trapiche samples contain mainly thin-film fluid inclusions in most parts, i.e., core, arm and growth sector areas (Figures 4.3.6 to 4.3.8); however, thin-film fluid inclusions at the growth sector areas are not dense as those in the arm and core areas, respectively. In addition, two- and three-phase inclusions also occur in association with these thin-film fluid inclusions, particularly in arm and growth sector (Figures 4.3.7 and 4.3.8).

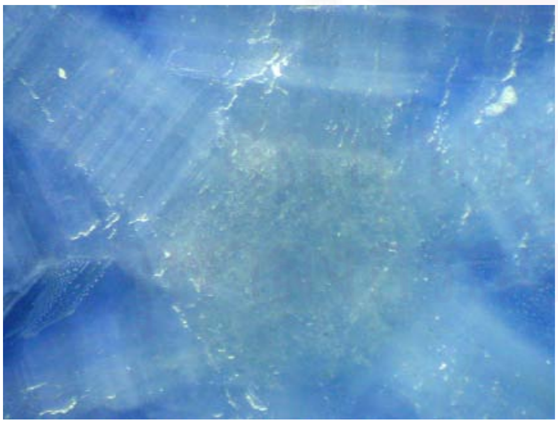


Figure 4.3.2 Internal features observed in Pailin6 (C1) showing well developed greyish white hexagonal core (50x) containing very tiny inclusions of thin-film fluid, minute particles and black inclusions.

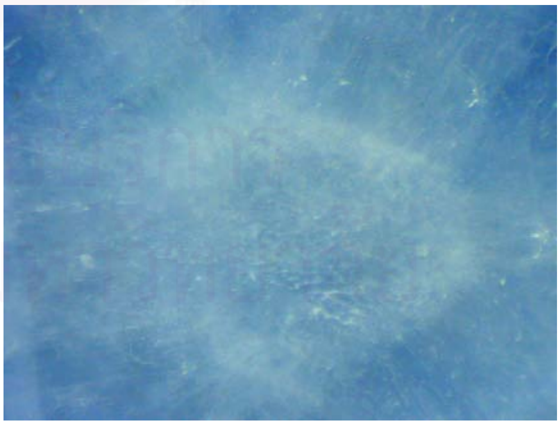


Figure 4.3.3 Internal features observed in Pailin2 (C2) showing well developed hexagonal core (70x) containing very tiny inclusions of thin-film fluid and minute particles

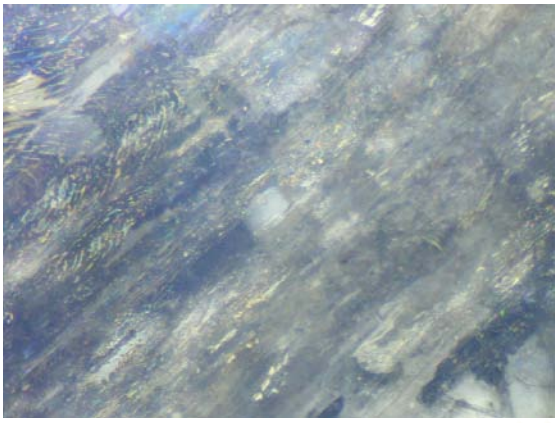
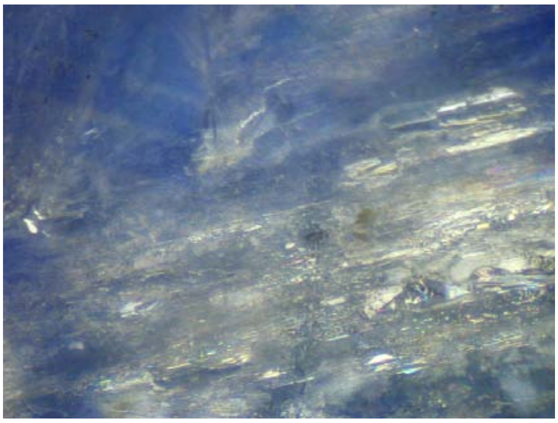



Figure 4.3.4 Arm areas of all trapiche sapphires contain mainly thin-film fluid inclusions, some small black inclusions as present here from an arm of Pailin1 (50x) (left) and an arm of Pailin5 (50x) (right).

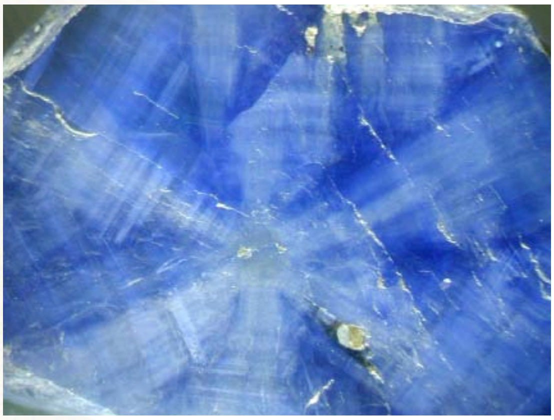



Figure 4.3.5 Hexagonal zones containing cloudy minute particles developed outward from the core region covering both arm and growth sector in Pailin2 (20x under transmitted light) (left) and Pailin4 (20x under reflected light) (right).

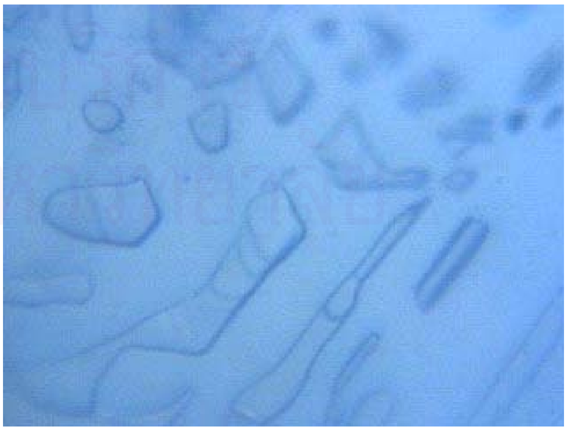



Figure 4.3.6 Fluid inclusions found along hexagonal core (20x) (left) and multi phase along the arm (100x) (right) of Pailin2 from Cambodia.

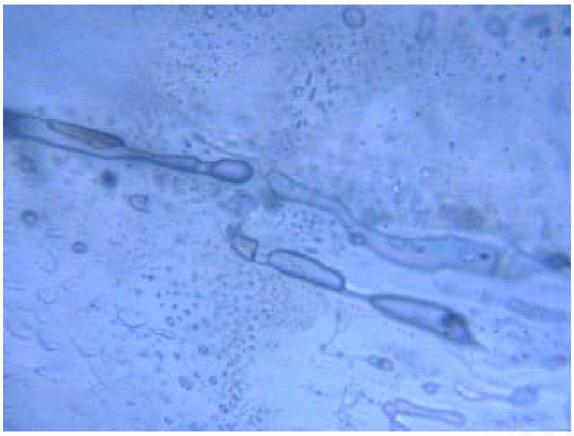
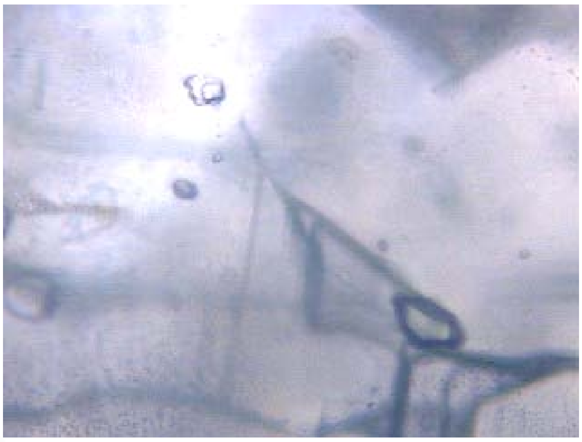



Figure 4.3.7 Fluid inclusions with multi phase inclusions along the arm (100x) of Pailin5 (left) and fluid inclusions with multi phase inclusions along the arm (100x) of Pailin8 (right) from Cambodian trapiche sapphires.

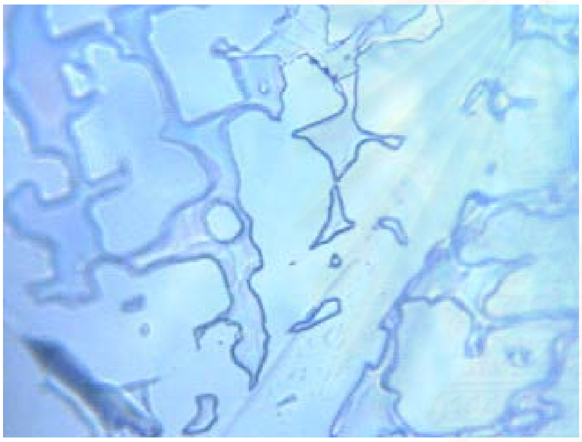



Figure 4.3.8 Thin-film fluid inclusions in growth sector (100x) of Pailin7 (left) and thin-film fluid inclusions with multi phase inclusion in growth sector (100x) of Pailin1 (right).

4.3.3 Inclusion Identification

Mineral inclusions found in each part of trapiche sapphire samples from Pailin deposit, Cambodia were partly identified as available using Raman technique. Consequently, columbite and pyrochlore inclusion are recognized in the arms and growth sectors (Figures 4.3.9 to 4.3.12). In addition, presence of CO_2 in fluid inclusions is also confirmed by the same technique (Figure 4.3.13).

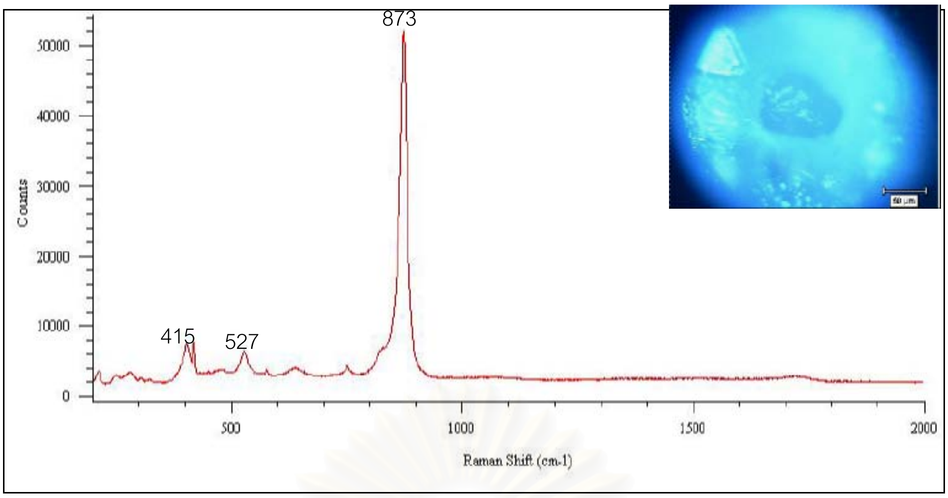


Figure 4.3.9 Raman spectrum of columbite inclusion found at an arm of Pailin1 sample from Pailin deposit, Cambodia.

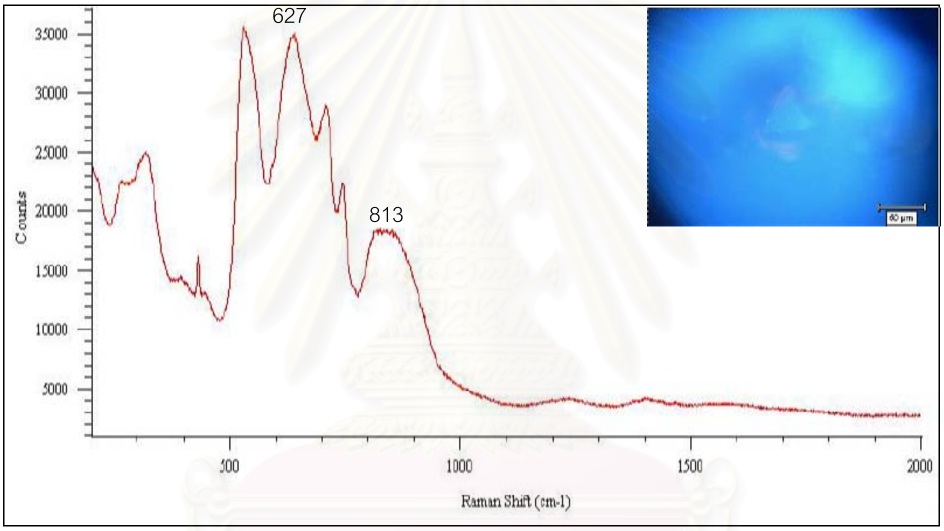


Figure 4.3.10 Raman spectrum of pyrochlore inclusion found at an arm of Pailin1 sample from Pailin deposit, Cambodia.

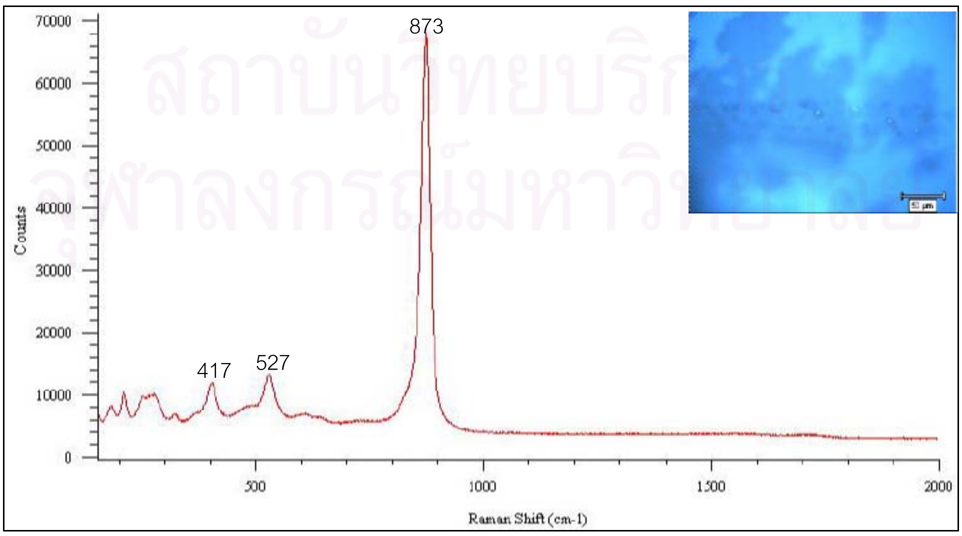


Figure 4.3.11 Raman spectrum of columbite inclusion found at a growth sector of Pailin7 sample from Pailin deposit, Cambodia.

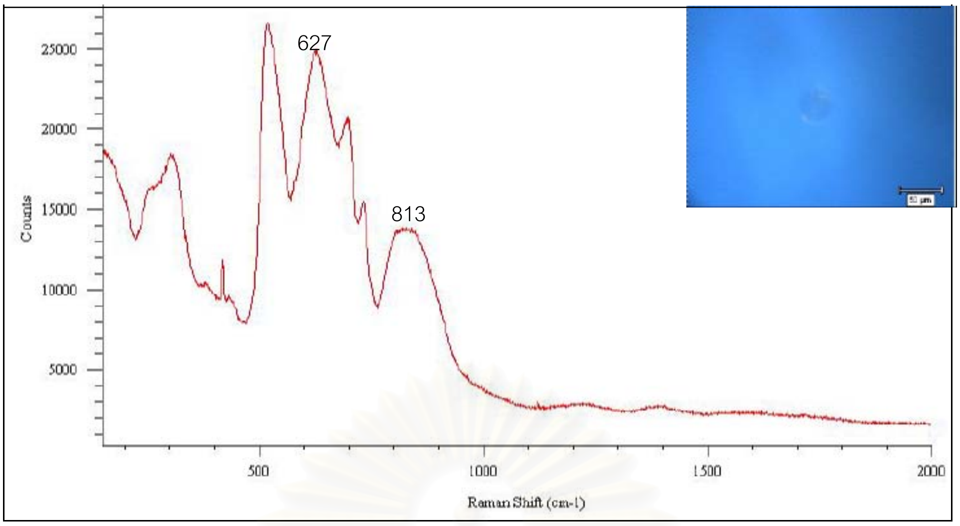


Figure 4.3.12 Raman spectrum of a pyrochlore inclusion found at a growth sector of Pailin2 sample from Pailin deposit, Cambodia.

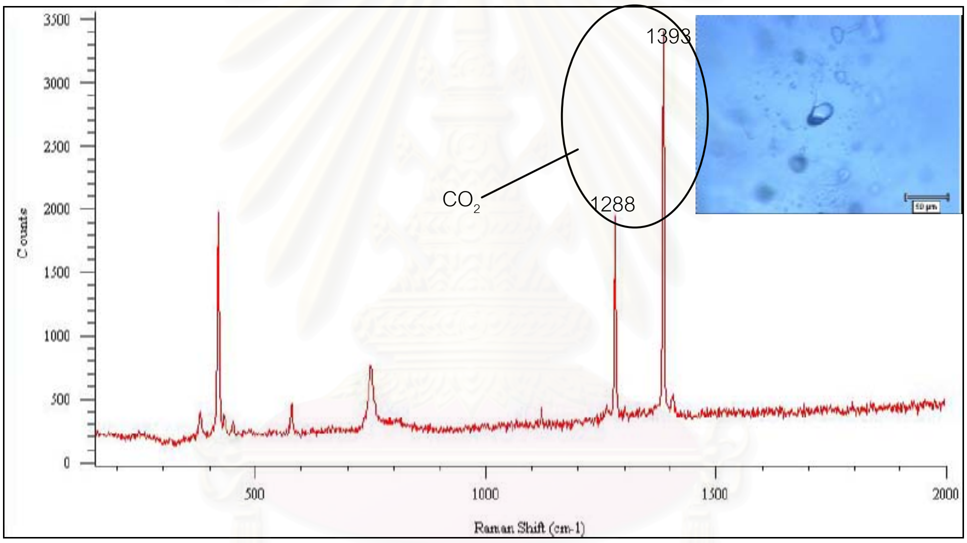


Figure 4.3.13 Raman spectrum of CO_2 in a fluid inclusion of Pailin2 sample from Pailin deposit, Cambodia.

In addition, some mineral inclusions exposed onto the polished surfaces were also analyzed quantitatively by the EPMA technique. However, only two kinds of mineral inclusions, i.e., pyrochlore and columbite, were available to analyzed using this technique (Figure 4.3.14). Their chemical compositions are present in Tables 4.3.3 and 4.3.4, respectively.

The formula of pyrochlore group is $A_1\text{-}_2B_2O_6(O,OH,F).nH_2O$ where A site can be occupied by Ca, K, Ba, Y, Ce, Pb, U, Sr, Cs, Na, Sb^{3+}, Bi, and/or Th whereas B site can be occupied by Nb, Ta, Ti, Sn, Fe, W. Pyrochlore inclusions from Pailin yielded analyses of all cations allocated in A site ranging between 1.384 and 1.954, and in B site between 1.618 and 1.798. Although, they are slightly ranging in composition, their approximate composition of $(Na_{0.75}Ca_{0.50}U_{0.46}Th_{0.01})$ $(Nb_{1.30}Ta_{0.12}Ti_{0.25}\ Fe_{0.04})$ O_6 (O,OH, F) indicating a Nb-U-rich pyrochlore composition. However, some vacancies in both A and B site and low total analyses may be caused by some elements those were unable to be analyzed.

Concerning columbite group, it is formulated as AB_2O_6 where A site is allocated for Fe, Mn and Mg whereas B site is for Nb and Ta. Columbite inclusions in Pailin samples mostly yielded similar composition that contains total cations approximatly 0.950 atom in A site and 1.773 atoms in B site. These inclusions have and approximate composition of $(Fe_{0.5}Mn_{0.3}Mg_{0.02})(Nb_{1.7}Ta_{0.04})O_6$ closely indicating ferrocolumbite. However, some vacancies in the cation sites may appropriate to rare earth elements (REE) that were not analyzed in this study.

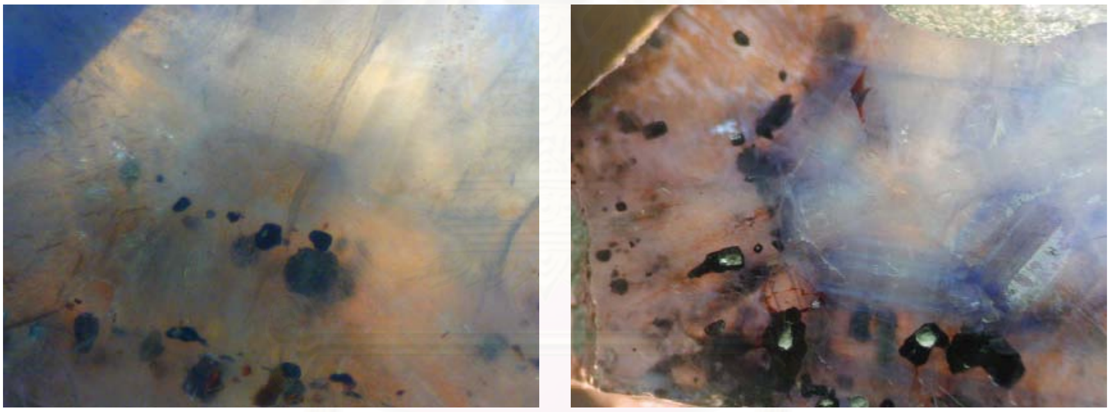


Figure 4.3.14 Mineral inclusions analyzed by the EPMA technique; black columbite and reddish brown pyrochlore (50x) in arm and growth sector area of Pailin1 (left); black columbite (20x) in arm and growth sector of Pailn7 (right).

Table 4.3.3 EPMA analyses of pyrochlore inclusions in Pailin deposit, Cambodia.

Point	1	2	3	4	5	6	7
TiO_2	4.95	6.09	5.00	3.34	5.03	3.97	4.60
UO_2	29.93	27.80	29.72	30.38	29.06	28.47	29.63
ThO_2	1.19	0.71	1.04	0.40	0.87	0.78	0.83
Al_2O_3	0.55	1.06	0.67	0.56	0.77	1.22	1.21
Ce_2O_3	0.26	0.09	0.14	0.40	0.22	0.14	0.20
FeO_{total}	0.57	1.35	0.73	0.24	0.81	0.85	0.79
MnO	0.19	0.19	0.14	0.06	0.17	0.06	0.10
CaO	6.49	5.95	5.76	6.99	6.05	7.33	7.48
K2O	0.07	0.07	0.06	0.23	0.06	0.07	0.07
Na_2O	3.77	3.54	7.62	2.25	7.45	6.96	6.87
Nb_2O_5	41.13	41.11	39.91	38.28	38.94	40.25	39.75
Ta_2O_5	5.51	5.21	5.21	10.47	6.25	5.67	5.41
Total	94.61	93.18	96.00	93.61	95.69	95.77	96.94
Formula 6(O)							
Ti	0.265	0.322	0.263	0.187	0.265	0.208	0.238
U	0.474	0.434	0.463	0.504	0.454	0.440	0.454
Th	0.019	0.011	0.017	0.007	0.014	0.012	0.013
Al	0.046	0.088	0.055	0.049	0.064	0.100	0.098
Ce	0.007	0.002	0.004	0.011	0.006	0.003	0.005
Fe^{2+}	0.031	0.071	0.039	0.014	0.043	0.045	0.041
Mn	0.012	0.011	0.008	0.004	0.010	0.004	0.006
Ca	0.495	0.448	0.432	0.558	0.455	0.546	0.552
K	0.007	0.006	0.006	0.022	0.006	0.006	0.006
Na	0.519	0.482	1.033	0.325	1.013	0.937	0.917
Nb	1.323	1.305	1.263	1.290	1.235	1.265	1.238
Ta	0.107	0.100	0.099	0.212	0.119	0.107	0.101
Total*	3.303	3.281	3.681	3.183	3.684	3.674	3.670
A site	1.521	1.384	1.954	1.427	1.947	1.946	1.948
B site	1.725	1.798	1.664	1.703	1.663	1.624	1.618

Note:

Pyrochlore Group: $A_{1-2}B_2O_6(O,OH,F).nH_2O$

A= Ca, K, Ba, Y, Ce, Pb, U, Sr, Cs, Na, Sb^{3+}, Bi, and/or Th

B= Nb, Ta, Ti, Sn, Fe, W

Table 4.3.4 EPMA analyses of columbite inclusions in Pailin Deposit, Cambodia.

Point	1	2	3	4	5*	6*	7*	8	9	10	11	12	13	14	15	16	17
TiO_2	1.32	1.18	1.23	0.99	0.99	1.01	0.82	1.31	1.08	0.96	1.21	1.18	1.39	0.97	1.12	1.18	1.14
Al_2O_3	2.99	2.45	2.12	1.29	1.14	1.10	0.77	2.66	1.92	1.00	0.92	2.39	3.27	1.08	0.47	0.88	2.95
Cr_2O_3	0.04	0.00	0.00	0.00	0.03	0.00	0.00	0.03	0.02	0.00	0.02	0.02	0.01	0.00	0.00	0.00	0.01
Ce_2O_3	0.12	0.09	0.00	0.06	0.07	0.12	0.17	0.08	0.00	0.02	0.01	0.01	0.00	0.00	0.03	0.17	0.07
Sc_2O_3	0.67	0.12	0.27	0.40	0.43	0.45	0.23	0.46	0.66	0.30	0.17	0.25	0.65	0.18	0.26	0.12	0.19
FeO_{total}	13.22	16.04	17.29	12.44	12.16	11.87	11.06	13.46	12.58	12.92	13.71	13.69	15.86	13.65	14.32	13.66	12.86
MnO	6.21	5.15	5.24	7.44	7.09	7.16	7.82	6.21	6.79	7.26	6.77	6.60	4.83	7.11	6.55	6.57	6.39
MgO	0.28	1.63	0.69	0.17	0.52	0.44	0.56	0.22	0.28	0.20	0.15	0.14	0.83	0.10	0.14	0.11	0.19
BaO	0.07	0.07	0.01	0.15	0.05	0.02	0.05	0.00	0.06	0.00	0.01	0.09	0.09	0.00	0.00	0.00	0.11
CaO	0.03	0.06	0.04	0.02	0.04	0.08	0.07	0.00	0.02	0.04	0.12	0.12	0.02	0.07	0.15	0.07	0.04
Nb_2O_5	64.22	61.09	61.66	68.05	67.94	67.19	67.77	64.92	66.19	67.20	66.47	66.21	63.01	66.38	68.07	67.17	66.29
Ta_2O_5	2.99	2.37	2.39	2.47	2.82	2.90	2.36	3.09	3.11	2.66	2.55	2.44	3.19	2.39	1.80	1.99	2.31
Total	92.27	90.28	90.96	93.49	93.29	92.37	91.68	92.50	92.81	92.59	92.11	93.18	93.15	92.04	92.91	92.03	92.67
Formula 6(O)																	
Ti	0.057	0.052	0.054	0.043	0.043	0.045	0.036	0.057	0.047	0.042	0.053	0.051	0.059	0.043	0.049	0.052	0.049
Al	0.203	0.170	0.146	0.088	0.078	0.076	0.053	0.181	0.132	0.069	0.064	0.161	0.219	0.075	0.032	0.061	0.200
Cr	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
Ce	0.002	0.002	0.000	0.001	0.001	0.003	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.004	0.001
Sc	0.034	0.006	0.014	0.020	0.022	0.023	0.012	0.023	0.033	0.015	0.009	0.012	0.032	0.009	0.013	0.006	0.009
Fe	0.574	0.709	0.762	0.542	0.530	0.524	0.492	0.585	0.550	0.568	0.606	0.590	0.678	0.604	0.626	0.602	0.557
Mn	0.304	0.256	0.260	0.365	0.348	0.356	0.391	0.304	0.334	0.359	0.337	0.320	0.233	0.354	0.322	0.326	0.312
Mg	0.024	0.142	0.061	0.015	0.045	0.038	0.049	0.019	0.024	0.017	0.013	0.012	0.070	0.008	0.012	0.009	0.016
Ba	0.002	0.002	0.000	0.003	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.002	0.002	0.000	0.000	0.000	0.002
Ca	0.002	0.004	0.003	0.001	0.003	0.005	0.004	0.000	0.001	0.003	0.008	0.007	0.001	0.004	0.009	0.004	0.003
Nb	1.677	1.622	1.633	1.780	1.781	1.782	1.810	1.696	1.737	1.776	1.764	1.714	1.619	1.764	1.787	1.779	1.726
Ta	0.047	0.038	0.038	0.039	0.045	0.046	0.038	0.049	0.049	0.042	0.041	0.038	0.049	0.038	0.028	0.032	0.036
Total*	2.928	3.003	2.970	2.898	2.898	2.898	2.891	2.916	2.909	2.893	2.895	2.909	2.963	2.899	2.880	2.875	2.914
A site	0.902	1.108	1.083	0.922	0.923	0.918	0.932	0.908	0.908	0.945	0.955	0.922	0.981	0.966	0.961	0.938	0.886
B site	1.723	1.660	1.671	1.819	1.825	1.828	1.848	1.744	1.786	1.818	1.805	1.752	1.668	1.802	1.815	1.810	1.762

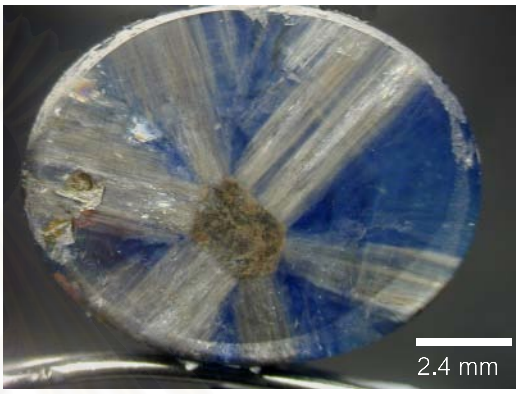
Note: Columbite Group AB_2O_6: A = Fe, Mn, Mg; B= Nb, Ta

* Point No. 5, 6 and 7: these composition analyzed from the same crystal

4.4 Trapiche Sapphires from Vietnam

Only three samples of trapiche sapphires (Figure 4.4.1) from Di Linh deposit, Southern Vietnam are available for this study. They were investigated for basic physical properties as well as specific features which results are reported herein this section.

Di Linh_O1



Di Linh_O2

Di Linh_H

Figure 4.4.1 Trapiche sapphire samples from Di Linh deposit, Southern Vietnam.

4.4.1 Physical Properties

Trapiche sapphire samples from Di Linh deposit, Southern Vietnam are two oval-shaped and one heart-shaped cut stones (Figure 4.4.1). Their sizes vary from 0.8-2.2 centimeter and weights range from 3.1-17.5 carats. Physical properties of these samples are summarized in Table 4.4.1. Colors of stones are mainly blue with yellowish brown core and arms. Other physical properties of all samples fall within a common range of corundum. The refractive indices (RI) range between 1.770-1.771 for n_o and 1.760-1.767 for n_e with birefringences range between 0.004 and 0.010. Specific gravity

(SG) values are about 3.98–3.99. In addition, they are inert under ultraviolet (UV) lamps both long wave (LW) and short wave (SW).

Table 4.4.1 Summary of physical properties of trapiche sapphires from Di Linh deposit, Southern Vietnam.

Sample No.	Weight (ct)	Shape & Size (mm)	Color	RI (Birefringence)	SG	Fluorescence	
						LW	SW
Di Linh_O1	15.0	oval, 21.7 x 18.5 x 2.7	blue, yellowish brown	1.771-1.767 (0.004)	3.997	inert	inert
Di Linh_O2	3.10	oval, 11.2 x 8.9 x 2.1	blue, yellowish brown	1.770-1.765 (0.005)	3.983	inert	inert
Di Linh_H	17.5	heart, 22.5 x 20.1 x 3.1	blue, yellowish brown	1.770-1.760 (0.010)	3.994	inert	inert

4.4.2 Internal Features

Internal features of trapiche sapphires from Di Linh deposit, Southern Vietnam are summarized in Table 4.4.2. Trapiche sapphire samples from Di Linh deposit, Southern Vietnam are mostly characterized by well developed brown hexagonal cores (Di Linh_O1 and Di Linh_O2) and well developed brown trigonal core (Di Linh_H). In general, internal features in the core region are characterized by brown short needles intersecting at 60/120° angle making brown appearance, irregular patches of black inclusions and oriented thin-film fluid inclusions (Figure 4.4.2), some two- or three-phase inclusions.

Table 4.4.2 Summary of internal features of trapiche sapphires from Di Linh deposit, Southern Vietnam.

Sample No.	Core	Arm	Growth sector
Di Linh_O1	Well developed brown hexagonal core, mainly brown short needles intersecting at 60/120° angle, many irregular patches of black inclusions, thin-film fluid inclusions	Well developed yellowish brown arm, intersected brown short needles, black inclusions, thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, magnetite is analyzed	clouds of fine minute particles along growth zones, thin-film fluid inclusions
Di Linh_O2	Well developed brown hexagonal core, mainly brown short needles intersecting at 60/120° angle, many irregular patches of black inclusions, thin-film fluid inclusions	Well developed yellowish brown arm, intersected brown short needles, black inclusions, thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, magnetite, pyrochlore and feldspar are analyzed	Clear thin-film fluid inclusions, some minute particles along hexagonal growth zones
Di Linh_H	Well developed brown triangular core, mainly brown short needles intersecting at 60/120° angle, many irregular patches of black inclusions, thin-film fluid inclusions	Moderately developed yellowish brown arm, intersected brown short needles, black inclusions, thin-film fluid inclusions oriented perpendicular to $\{11\bar{2}0\}$ faces, magnetite is analyzed	Mainly thin-film fluid inclusions, some minute particles along growth zones

For arm areas, six yellowish brown arms extending outward from hexagonal core similarly contain intersecting brown short needles, black inclusions and thin-film fluid inclusions with some two- or three-phase inclusions. However, these inclusions found in arm area have different proportion compared to those occur in the core (Figure 4.4.4). Although the boundary between the core and each arm looks rather sharp boundary, the brown zones or patches of intersected short needles appear to continue from the core into the arm areas with somewhat lesser concentration of the needles but increase in concentration of thin-film fluid inclusions oriented perpendicular to the $\{11\bar{2}0\}$ faces (Figure 4.4.4). In contrast to the core and arm regions, the growth sectors are mostly blue and consist of clouds of fine minute particles following internal growth plane and appearing as straight and angular whitish bands and oriented thin-film fluid inclusions (Figure 4.4.5), some two- or three-phase inclusions (Figure 4.4.6). However, two- and three-phase inclusions found in growth sectors have some differences (e.g., size and shape) compared to those observed in arm area. In addition, the boundary between the arms and growth sectors is rather diffused.

In conclusion, all the trapiche sapphires under this study have similar internal features in each part of the crystal. As for the sample Di Linh_H, it comprises similar internal features as those of the samples Di Linh_O1 and Di Linh_O2 except that instead of hexagonal core it comprises triangular core (Figure 4.4.3).

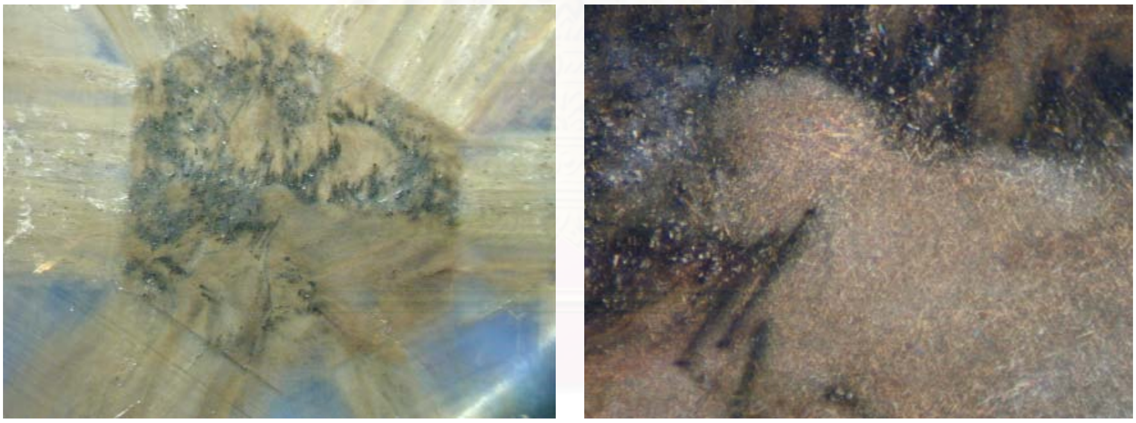


Figure 4.4.2 Internal features observed around core of trapiche sapphire (Di Linh_O1) from Southern Vietnam showing well developed brown hexagonal core (20x) (left) and short needles intersecting at 60/120° angle with many irregular patches of black inclusions (70x) (right).

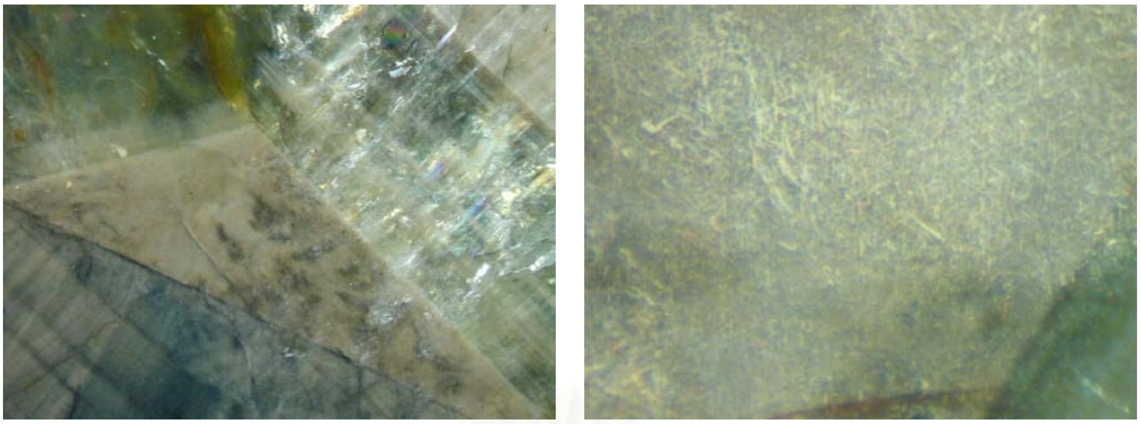


Figure 4.4.3 Internal features observed around core of trapiche sapphire (Di Linh_H) from southern Vietnam showing well developed brown trigonal core (20x) (left) and short needles intersecting at 60/120° angle with black inclusions (70x).

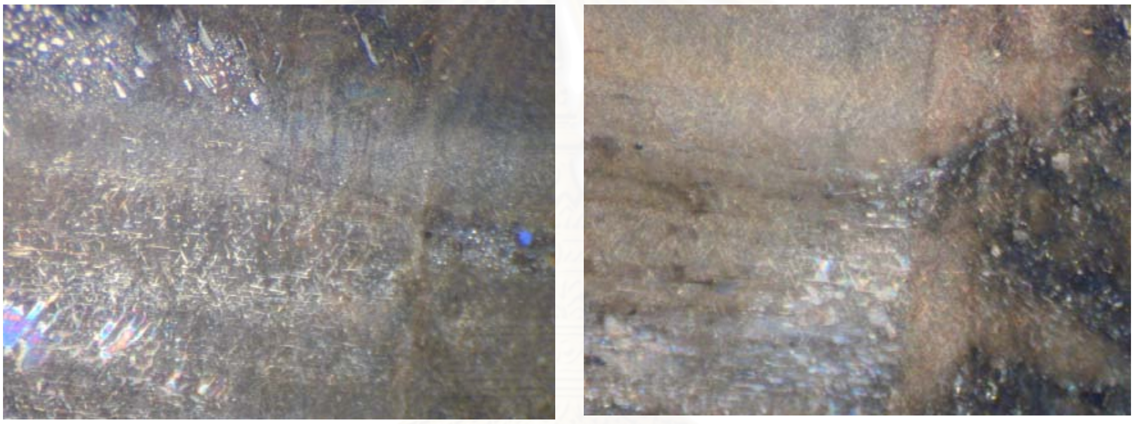


Figure 4.4.4 Internal features observed in trapiche sapphire (Di Linh_O1) from southern Vietnam showing short needles intersecting at 60/120° angle, thin-film fluid inclusions and black inclusions in an arm (70x) in left photo whereas right photo comparing between those inclusions found between dark brown core (right bottom) and arm region (70x) (detail described in text).

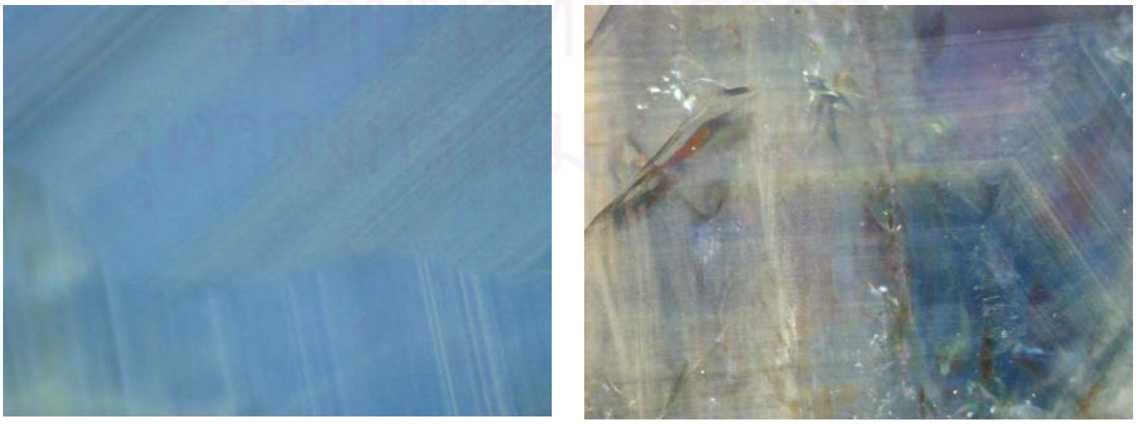


Figure 4.4.5 Internal features observed around growth sectors of trapiche sapphires from Vietnam showing clouds of fine minute particles along growth zones (70x) of Di Linh_O1 (left) and blue growth sector with mainly thin-film fluid inclusions and minute particles along growth zones (20x) in Di Linh_H.

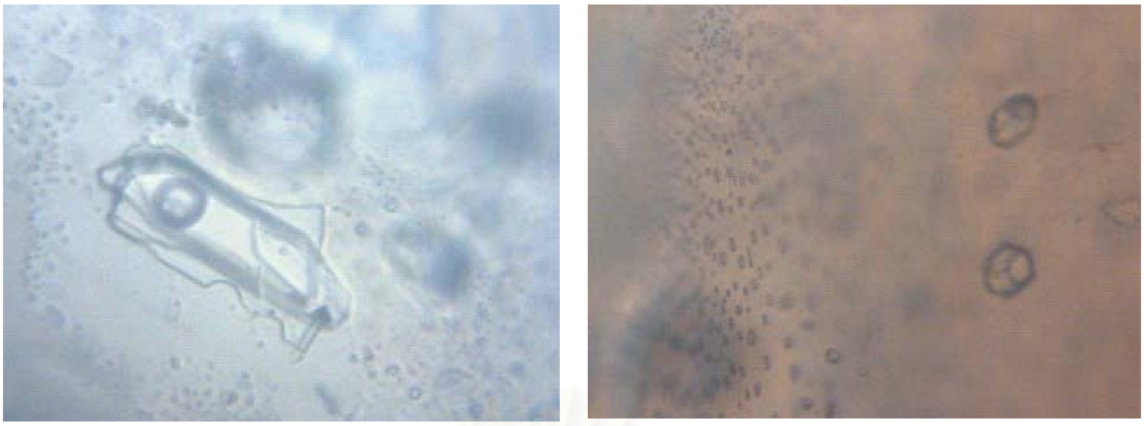


Figure 4.4.6 Thin-film fluidinclusions with three-phase inclusions (100x) in growth sector (left) and thin- film fluid inclusions with three-phase inclusions (100x) in the arm (right) of Di Linh_O2 trapiche sapphire from Southern Vietnam.

4.4.3 Inclusion Identification

Black mineral inclusions observed in the trapiche sapphire samples from Vietnam were identified using Raman technique. As the result, these inclusions are mainly magnetite in both core and arm (Figures 4.4.7 and 4.4.8). Other inclusions found in the arm are pyrochlore (Figure 4.4.9) and feldspar (Figure 4.4.10).

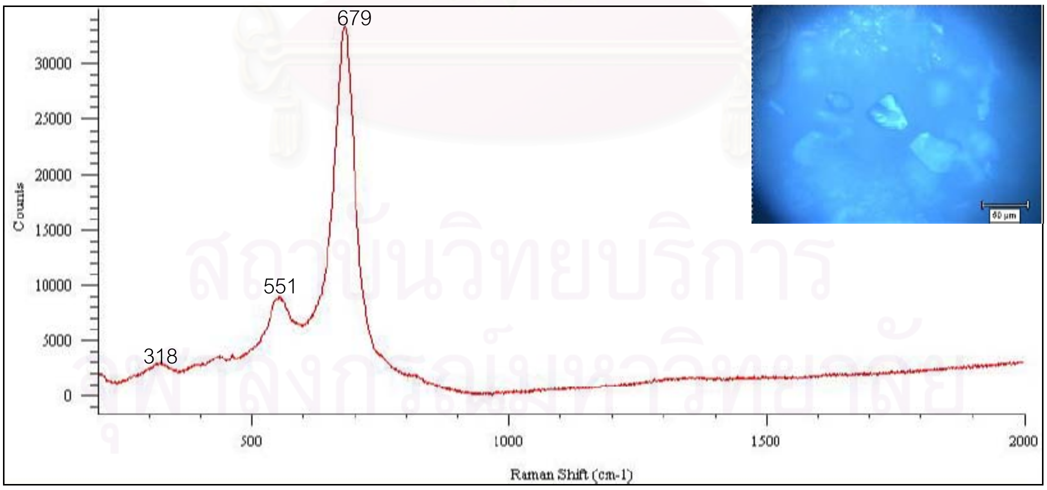


Figure 4.4.7 Raman spectrum of magnetite inclusion found at core of Di Linh_O1 sample from Di Linh deposit, Southern Vietnam.

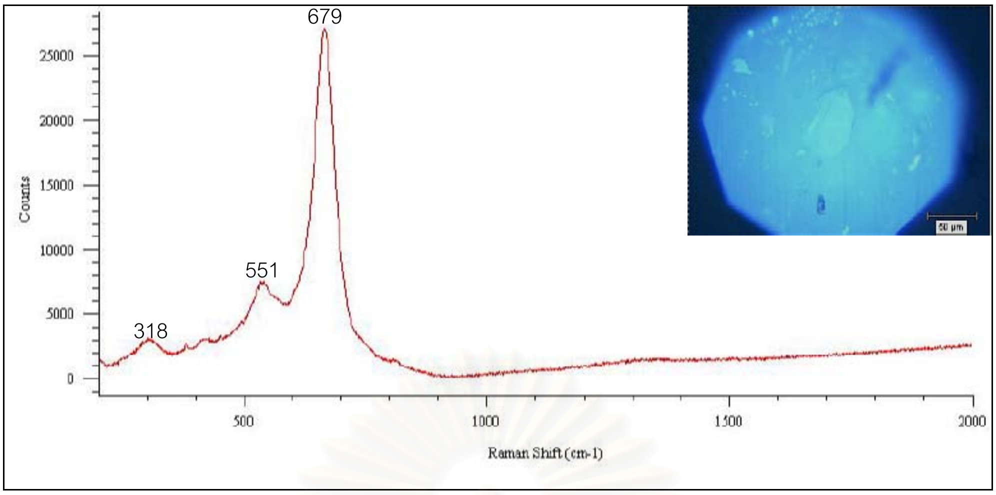


Figure 4.4.8 Raman spectrum of magnetite inclusion found at core of Di Linh_O2 sample from Di Linh deposit, Southern Vietnam.

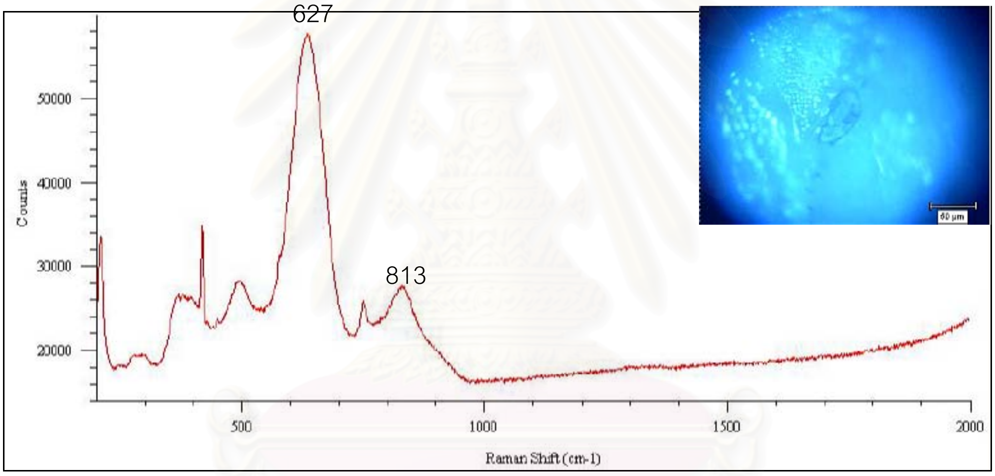


Figure 4.4.9 Raman spectrum of pyrochlore inclusion found at an arm of Di Linh_O2 sample from Di Linh deposit, Southern Vietnam.

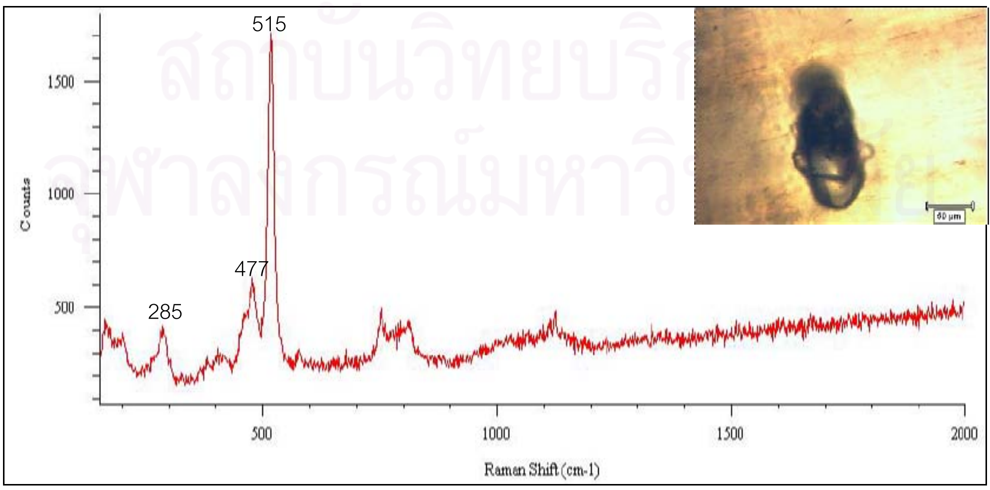


Figure 4.4.10 Raman spectrum of feldspar inclusion found at an arm of Di Linh_O2 sample from Di Linh deposit, Southern Vietnam.

CHAPTER V
TRACE ELEMENT GEOCHEMISTRY

5.1 Comparison of Trace Element Analyses

The chemical compositions of trapiche sapphire, mostly analyzed by using EPMA technique, are described and interpreted in specific aspects within this chapter. Initially, quantitative trace elements of three sapphire samples, i.e., Pailin4, Di Linh_O1 and Di Linh_H, were analyzed by using Laser Abrasion-Inductively Coupled Plasma-Mass Spectrometer (LA-ICP-MS) at Center of Gemstone Research, Institute of Geosciences, University of Mainz, Germany. Subsequently, analytical results obtained from the LA-ICP-MS technique were used to compare with those of the EPMA analysis. Tables 5.1-5.3 show atomic proportions of main Al component and other trace elements, based on 3 oxygen atoms, of three samples; these data were recalculated from different original format of LA-ICP-MS and EPMA analyses for comparison on the same basis.

Among the trace elements in corundum, iron and titanium appear to be the main focus because their concentrations are higher than those of the rest (see Table 5.1-5.3 and Appendix I). Therefore, comparison between results of LA-ICP-MS and EPMA are displayed graphically for these elements. As such, the average atomic proportions (based on 3 oxygen atoms) and standard deviation of iron and titanium analyzed along core, arm and growth sector are plotted in Figure 5.1. As shown in the figure and tables, EPMA results are quite similar to those of LA-ICP-MS; hence, EPMA techniques applied for trace analyses of corundum are conclusively sufficient to determine geochemical fingerprint in these stones. Consequently, EPMA technique had been utilized throughout this study.

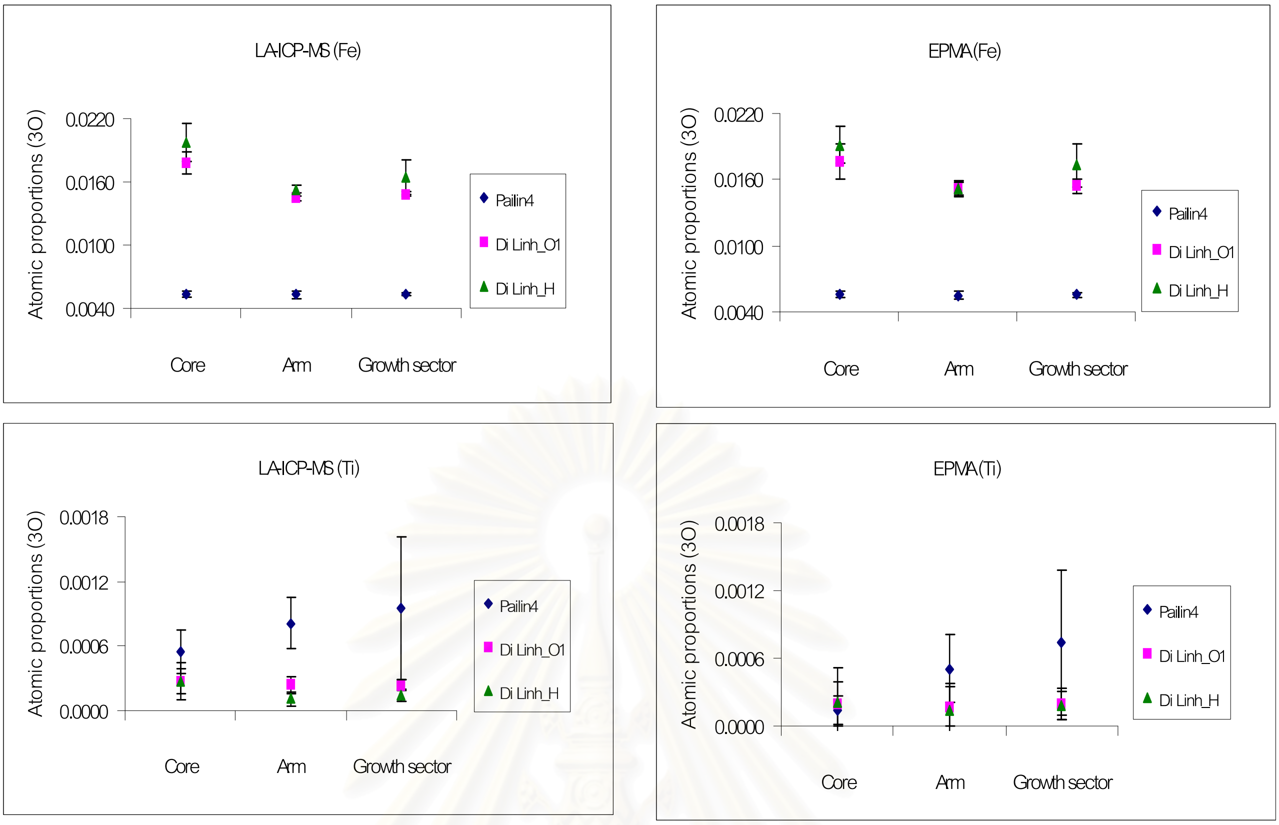


Figure 5.1 Plots of averages and standard deviation of Fe and Ti atoms per 3 oxygen atoms of samples Pailin4, Di Linh_O1 and Di Linh_H from recalculated analytical results of LA-ICP-MS and EPMA.

Table 5.1 Comparison of atomic proportions of Al component and other trace elements based on 3 oxygen atoms between LA-ICP-MS and EPMA.

Atomic Proportions (3O)	Pailin4					
	Core		Arm		Growth sector	
Elements	LA-ICP-MS	EPMA	LA-ICP-MS	EPMA	LA-ICP-MS	EPMA
Al	1.9577±0.0000	1.9938±0.0005	1.9577±0.0000	1.9932±0.0010	1.9577±0.0000	1.9929±0.0010
Si	0.0035±0.0010	0.0000±0.0000	0.0028±0.0004	0.0001±0.0001	0.0020±0.0009	0.0001±0.0001
Ti	0.0006±0.0002	0.0001±0.0001	0.0008±0.0002	0.0005±0.0003	0.0010±0.0007	0.0007±0.0006
Cr	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
Ga	0.0002±0.0000	0.0003±0.0001	0.0002±0.0000	0.0003±0.0001	0.0002±0.0000	0.0003±0.0001
V	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0001±0.0002	0.0000±0.0000	0.0001±0.0001
Fe	0.0054±0.0003	0.0056±0.0003	0.0053±0.0003	0.0055±0.0004	0.0053±0.0001	0.0055±0.0002
Ca	0.0000±0.0000	0.0000±0.0000	0.0000±0.0001	0.0001±0.0001	0.0000±0.0000	0.0000±0.0000
Mg	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
Mn	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
K	0.0001±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0000±0.0000
Total	1.9675±0.0008	2.0000±0.0000	1.9669±0.0010	1.9998±0.0001	1.9662±0.0013	1.9998±0.0002

Table 5.2 Comparison of atomic proportions of Al component and other trace elements based on 3 oxygen atom between LA-ICP-MS and EPMA.

Atomic Proportions (3O)	Di Linh_O1					
	Core		Arm		Growth sector	
Elements	LA-ICP-MS	EPMA	LA-ICP-MS	EPMA	LA-ICP-MS	EPMA
Al	1.9577±0.0000	1.9813±0.0018	1.9577±0.0000	1.9840±0.0008	1.9577±0.0000	1.9837±0.0008
Si	0.0024±0.0007	0.0002±0.0002	0.0024±0.0002	0.0001±0.0001	0.0023±0.0002	0.0001±0.0001
Ti	0.0003±0.0001	0.0002±0.0002	0.0002±0.0001	0.0002±0.0002	0.0002±0.0000	0.0002±0.0001
Cr	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0001±0.0000	0.0000±0.0000	0.0000±0.0001
Ga	0.0003±0.0000	0.0003±0.0002	0.0002±0.0000	0.0002±0.0001	0.0002±0.0000	0.0003±0.0001
V	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0000±0.0001
Fe	0.0179±0.0011	0.0176±0.0016	0.0145±0.0004	0.0152±0.0006	0.0148±0.0002	0.0154±0.0006
Ca	0.0000±0.0001	0.0001±0.0001	0.0001±0.0001	0.0001±0.0000	0.0000±0.0000	0.0001±0.0001
Mg	0.0001±0.0000	0.0001±0.0002	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0001±0.0002
Mn	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
K	0.0001±0.0000	0.0000±0.0001	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
Total	1.9787±0.0017	2.0000±0.0001	1.9752±0.0007	2.0000±0.0001	1.9753±0.0002	2.0000±0.0001

Table 5.3 Comparison of atomic proportions of Al component and other trace elements based on 3 oxygen atoms between LA-ICP-MS and EPMA.

Atomic Proportions (3O)	Di Linh_H					
	Core		Arm		Growth sector	
Elements	LA-ICP-MS	EPMA	LA-ICP-MS	EPMA	LA-ICP-MS	EPMA
Al	1.9577±0.0000	1.9798±0.0018	1.9577±0.0000	1.9840±0.0008	1.9577±0.0000	1.9817±0.0021
Si	0.0027±0.0009	0.0001±0.0001	0.0024±0.0001	0.0001±0.0002	0.0021±0.0004	0.0001±0.0001
Ti	0.0003±0.0002	0.0002±0.0003	0.0001±0.0001	0.0001±0.0002	0.0001±0.0001	0.0002±0.0001
Cr	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000	0.0000±0.0000
Ga	0.0002±0.0000	0.0003±0.0001	0.0003±0.0000	0.0003±0.0001	0.0003±0.0000	0.0003±0.0001
V	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0001±0.0001
Fe	0.0198±0.0018	0.0191±0.0017	0.0152±0.0005	0.0151±0.0006	0.0165±0.0017	0.0173±0.0020
Ca	0.0001±0.0001	0.0001±0.0001	0.0000±0.0001	0.0001±0.0001	0.0000±0.0000	0.0001±0.0000
Mg	0.0001±0.0000	0.0001±0.0002	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0000±0.0001
Mn	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0000±0.0000
K	0.0000±0.0000	0.0001±0.0001	0.0000±0.0000	0.0000±0.0001	0.0000±0.0000	0.000100.0001
Total	1.9808±0.0019	2.0000±0.0002	1.9758±0.0005	2.0000±0.0001	1.9767±0.0016	2.0000±0.0001

5.2 Trace Element Analyses of the Trapiche Sapphires

Twenty-five samples of trapiche sapphire from Thailand, Cambodia and Vietnam were selected for quantitative analysis by EPMA technique. Oxide contents of major element (Al_2O_3) and some trace elements (SiO_2, TiO_2, Cr_2O_3, Ga_2O_3, V_2O_3, Fe_2O_3, CaO, MgO, MnO and K_2O) of trapiche sapphires were analyzed about 5-19 points for each sample depending on sizes and shape of core, arm and growth sector appearing in the sample. In general, at least three analytical points were obtained for each particular part. These oxide contents were subsequently recalculated into atomic proportions on the basis of 3 oxygen atoms as in the typical formula of corundum (Al_2O_3). All EPMA analytical data of trace analyses are tabulated in Appendix I. In this study, means and standard deviations of EPMA analyses are also used for discussion and interpretation. However, only iron (Fe) and titanium (Ti) atomic proportions obtained from core, arm and growth sector are selected for graphical presentation because the other trace elements are fluctuated and negligible.

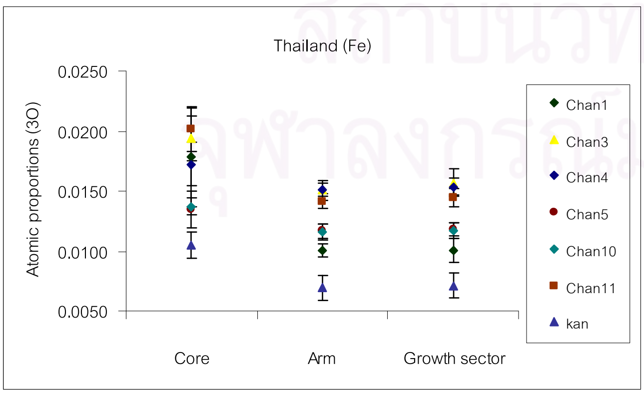
In addition, X-ray mapping, another application of EPMA technique, was also applied to distinguish trace geochemistry between core, arm and growth sector in all the samples. In this study the element mapping technique was carried out for the following trace elements, namely Fe, Ti, Cr, Ga, Si, Mg and V. However, only Fe and Ti distribution maps, because of their relatively high concentrations, show significant variation in some particular areas, whereas the other elements do not show any variation in the maps due to their low concentrations. Hence only Fe and Ti maps will be used for further discussion. In those maps the color variation is applied to distinguish level of element concentration which is in the sequence from low to high concentrations as violet, blue, green, yellow and red, respectively. The results will be presented in individual country of origin (i.e., Thailand, Cambodia and Vietnam).

5.2.1 Trapiche Sapphires from Thailand

Major and trace element analyses of fourteen trapiche sapphire samples from Thailand are described below. They are eleven samples from Chanthaburi deposit, one sample from Kanchanaburi (Bo Phloi) deposit and two samples from Phrae deposit.

5.2.1.1 Quantitative Point Analysis

Representative chemical compositions of Thai trapiche sapphires observed within 3 individual parts (i.e., core, arm and growth sector) are summarized in Tables 5.2.1 to 5.2.3 and all the analyses are included in Appendix I. Based on the result, iron and titanium concentrations can clearly differentiate into four different trends of geochemistry. The first sample group includes 6 samples (i.e., Chan1, Chan3, Chan4, Chan5, Chan10 and Chan11) from Chanthaburi deposit and one sample from Kanchanaburi deposit (Kan). These samples yield decreasing trends of Fe and Ti from core to growth sector and arm, respectively (see Figure 5.2.1 and Table 5.2.1). For example, sample Chan1 contains 0.0190, 0.0106 and 0.0100 Fe atom and 0.0018, 0.0007 and 0.0004 Ti atom at core, growth sector and arm, respectively (see Table 5.2.1). The second group includes three samples (i.e., Chan2, Chan7 and Chan9) from Chanthaburi deposit. These samples have the highest Fe and Ti concentration at core and their concentrations at arm are higher than those obtained from growth sector (Figure 5.2.2). As summarized in Table 5.2.2, sample Chan 9 contains about 0.0246, 0.0175 and 0.0166 Fe atom and 0.0006, 0.0004 and 0.0003 Ti atom at core, arm and growth sector, representatively.



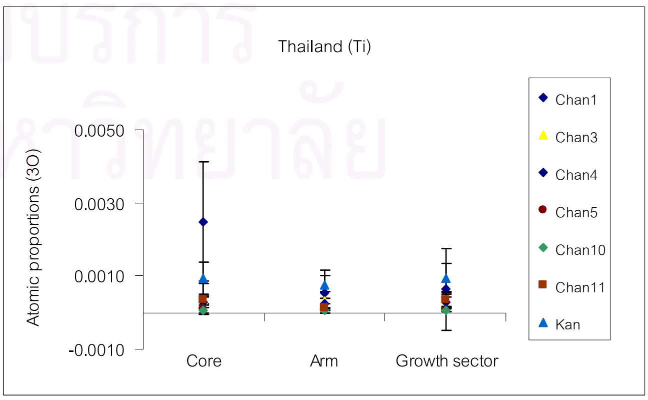


Figure 5.2.1 Plots of averages and standard deviations of Fe and Ti atoms in the core, arm and growth sector of the first sample group of Thailand that appears to have decreasing Fe and Ti trends from core to growth sector and arm.

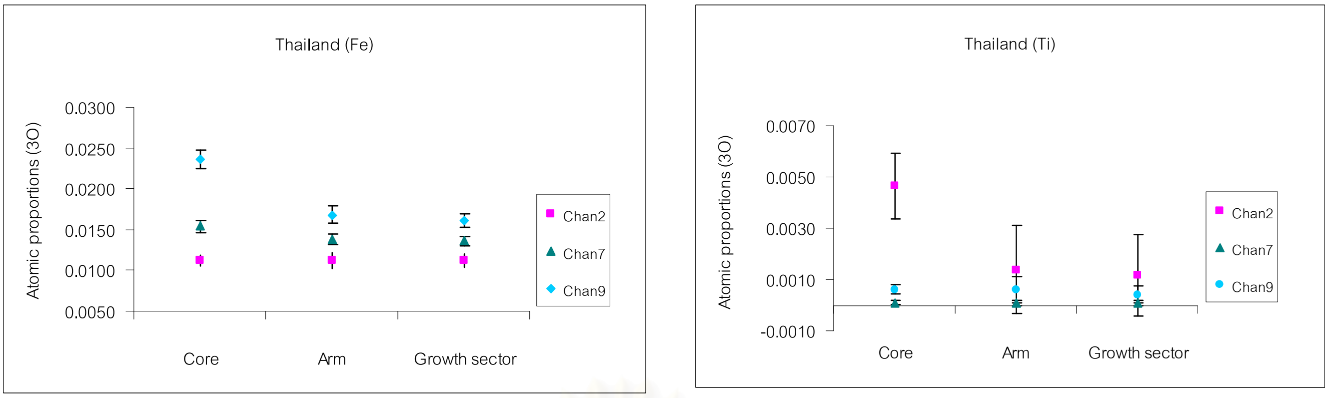


Figure 5.2.2 Plots of averages and standard deviations of Fe and Ti atoms in the core, arm and growth sector of the second sample group of Thailand that appears to have decreasing Fe and Ti trends from core to arm and growth sector.

Only sample Chan8 from Chanthaburi deposit is recognized as the third group that has the lowest concentrations of Fe (0.0128 atom) and Ti (0.0001 atom) at core. Besides, both concentrations of Fe and Ti at arm (0.0151 and 0.0003 atom) appear to be higher than those of growth sector (0.0149 and 0.0002 atom) (Figure 5.2.3 and Table 5.2.3).

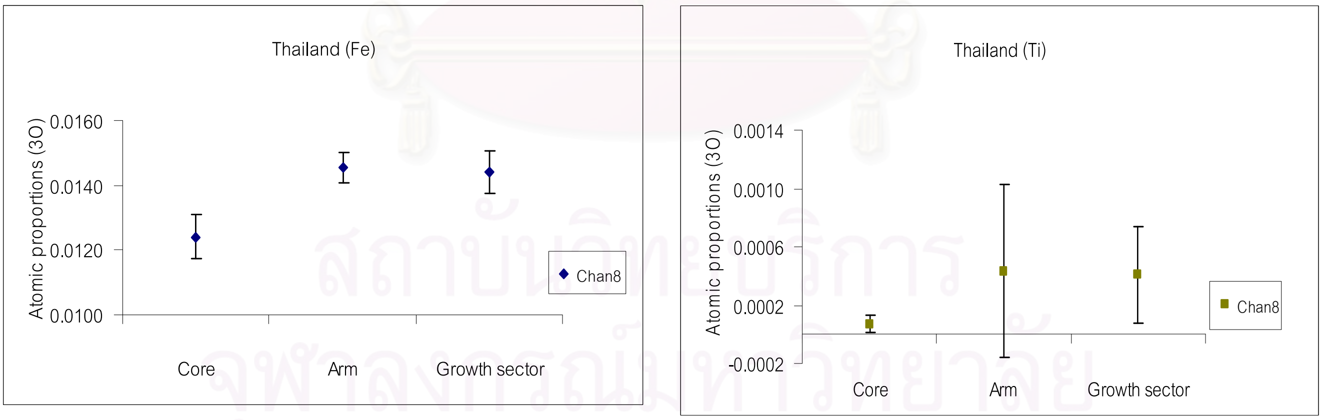


Figure 5.2.3 Plots of averages and standard deviations of Fe and Ti atoms of the third group (Chan 8) showing highest Fe and Ti proportions at arm and decreasing to growth sector and core, respectively.

The last group includes Chan6 from Chanthaburi deposit, Phrae1 and Phrae2 from Phrae deposit. Unlike the former groups, this group appears to have dissimilar geochemical trends of Fe and Ti (Figure 5.2.4.). They are likely combination between the second group and the third group which Fe concentrations decreases from core to arm and growth sector whereas Ti concentrations increases from core to growth sector and arm, respectively (Figure 5.2.4). For example, sample Phrae 1 contains 0.0153 Fe atom at core, 0.0119 Fe atom at arm and 0.0108 Fe atom at growth sector and it yields about 0.0024, 0.0016 and 0.0006 atom of Ti at arm, growth sector and core, respectively (Table 5.2.4).

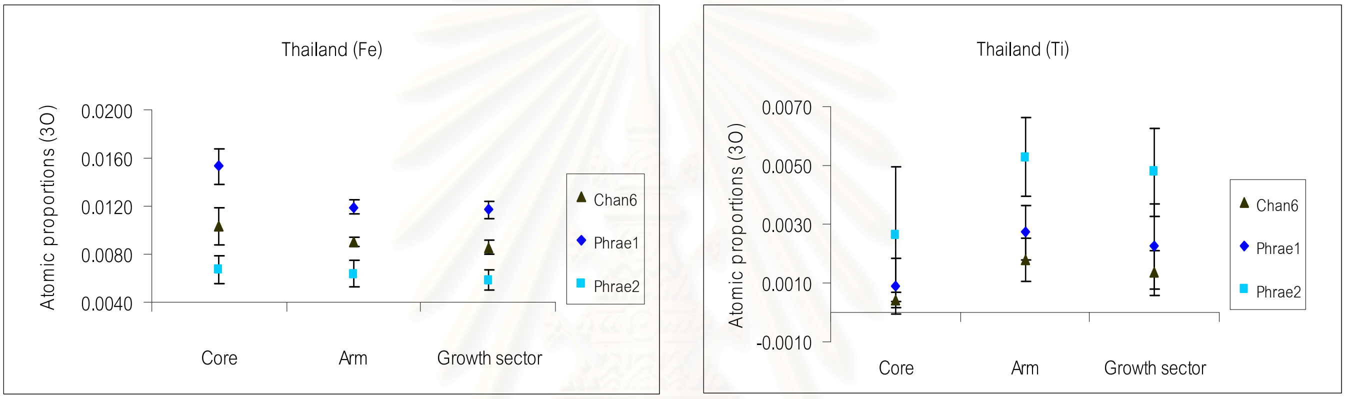


Figure 5.2.4 Plots of averages and standard deviations of Fe and Ti atoms along core, arm and growth sector of the last sample group of Thailand that appears to have decreasing Fe trends from core to arm and growth sector, increasing Ti trend from core to growth sector and arm.

Table 5.2.1 EPMA analyses of the first group of trapiche sapphire samples from Thailand and their atomic proportions of main Al component and other trace elements.

	Chan1			Chan3			Chan4			Chan5			Chan10			Chan11			Kan		
	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector
Al_2O_3	97.76	99.14	99.06	98.48	97.86	99.43	98.07	98.83	98.67	98.82	99.12	98.91	98.91	100.00	98.95	98.20	98.85	98.66	98.70	99.31	98.48
SiO_2	0.01	0.00	0.01	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.00	0.00
TiO_2	0.14	0.03	0.05	0.03	0.01	0.03	0.03	0.02	0.02	0.03	0.01	0.01	0.01	0.00	0.01	0.05	0.01	0.02	0.12	0.04	0.08
Cr_2O_3	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.04	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.04	0.03	0.01	0.02	0.03	0.03	0.05	0.02	0.04	0.04	0.02	0.03
V_2O_3	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.03	0.00	0.01
Fe_2O_3	1.48	0.78	0.83	1.42	1.20	1.30	1.42	1.17	1.25	1.09	0.85	0.98	1.07	0.86	0.92	1.68	1.09	1.21	0.96	0.61	0.65
CaO	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00
MgO	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.46	99.98	99.98	99.98	99.11	100.81	99.57	100.05	99.97	100.03	100.01	99.95	100.02	100.91	99.93	99.99	99.98	99.99	99.87	99.99	99.26
Formula 3(O)																					
Al	1.9774	1.9892	1.9879	1.9804	1.9838	1.9823	1.9806	1.9843	1.9832	1.9844	1.9886	1.9866	1.9858	1.9885	1.9874	1.9768	1.9854	1.9827	1.9845	1.9911	1.9897
Si	0.0002	0.0000	0.0001	0.0005	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0000	0.0001	0.0000	0.0001	0.0000	0.0005	0.0000	0.0000	0.0000
Ti	0.0018	0.0004	0.0007	0.0004	0.0002	0.0003	0.0004	0.0002	0.0003	0.0004	0.0001	0.0002	0.0002	0.0000	0.0001	0.0006	0.0001	0.0003	0.0016	0.0006	0.0011
Cr	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0005	0.0003	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0002	0.0004	0.0003	0.0001	0.0003	0.0003	0.0003	0.0005	0.0002	0.0004	0.0004	0.0002	0.0003
V	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0002	0.0001	0.0002	0.0000	0.0004	0.0000	0.0002
Fe	0.0190	0.0100	0.0106	0.0183	0.0155	0.0166	0.0183	0.0150	0.0160	0.0139	0.0109	0.0126	0.0137	0.0109	0.0118	0.0215	0.0140	0.0156	0.0123	0.0079	0.0084
Ca	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0002	0.0000	0.0000	0.0000
Mg	0.0002	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0008	0.0000	0.0000	0.0001	0.0000	0.0003	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0001	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
Total*	1.9994	1.9999	1.9998	1.9997	2.0000	2.0000	1.9999	1.9999	1.9999	2.0002	2.0000	1.9999	2.0000	2.0000	2.0001	1.9998	2.0000	1.9999	1.9996	1.9999	1.9997

Table 5.2.2 EPMA analyses of the second group of trapiche sapphire samples from Thailand and their atomic proportions of main Al component and other trace elements.

	Chan2			Chan7			Chan9		
	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector
Al_2O_3	98.53	99.03	99.40	98.76	98.85	98.89	98.19	98.32	98.60
SiO_2	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
TiO_2	0.36	0.06	0.02	0.02	0.00	0.01	0.05	0.03	0.02
Cr_2O_3	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01
Ga_2O_3	0.06	0.00	0.04	0.03	0.01	0.02	0.04	0.04	0.01
V_2O_3	0.06	0.01	0.01	0.00	0.02	0.00	0.01	0.00	0.00
Fe_2O_3	0.92	0.88	0.80	1.16	1.08	1.06	1.92	1.36	1.29
CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MgO	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.98	99.98	100.27	99.98	99.98	99.98	100.21	99.75	99.94
Formula 3(O)									
Al	1.9798	1.9875	1.9889	1.9843	1.9856	1.9860	1.9738	1.9815	1.9826
Si	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Ti	0.0046	0.0007	0.0003	0.0002	0.0001	0.0001	0.0006	0.0004	0.0003
Cr	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001
Ga	0.0007	0.0000	0.0004	0.0003	0.0002	0.0002	0.0004	0.0004	0.0001
V	0.0008	0.0001	0.0001	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000
Fe	0.0118	0.0113	0.0102	0.0149	0.0139	0.0135	0.0246	0.0175	0.0166
Ca	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Mg	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9987	1.9998	1.9999	1.9999	2.0000	2.0000	1.9998	1.9999	1.9999

Table 5.2.3 EPMA analyses of the third group of trapiche sapphire samples from Thailand and their atomic proportions of main Al component and other trace elements.

	Chan8		
	Core	Arm	Growth sector
Al_2O_3	99.32	98.78	99.61
SiO_2	0.00	0.00	0.00
TiO_2	0.01	0.03	0.01
Cr_2O_3	0.00	0.00	0.01
Ga_2O_3	0.03	0.04	0.02
V_2O_3	0.02	0.00	0.00
Fe_2O_3	1.00	1.18	1.17
CaO	0.00	0.00	0.00
MgO	0.00	0.00	0.00
MnO	0.00	0.00	0.01
K_2O	0.00	0.00	0.00
Total	100.38	100.02	100.83
Formula 3(O)			
Al	1.9864	1.9840	1.9846
Si	0.0000	0.0000	0.0000
Ti	0.0001	0.0003	0.0002
Cr	0.0000	0.0000	0.0001
Ga	0.0003	0.0004	0.0002
V	0.0002	0.0000	0.0000
Fe	0.0128	0.0151	0.0149
Ca	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0001
K	0.0000	0.0000	0.0000
Total*	1.9999	1.9999	2.0000

Table 5.2.4 EPMA analyses of the last group of trapiche sapphire samples from Thailand and their atomic proportions of main Al component and other trace elements.

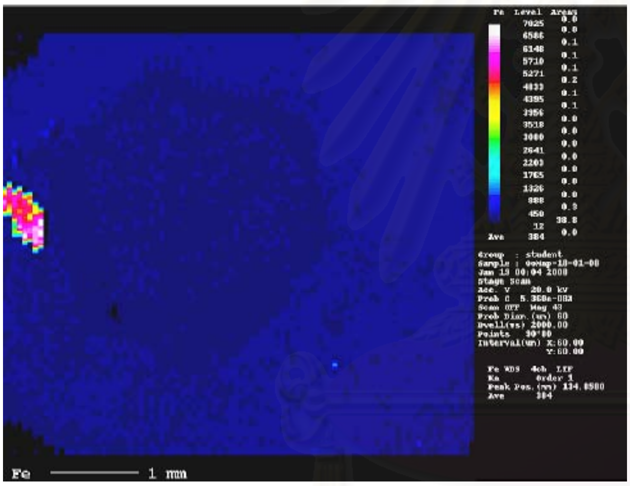
	Chan6			Phrae1			Phrae2		
	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector
Al_2O_3	99.04	98.91	99.43	98.34	99.34	98.47	99.23	98.94	99.07
SiO_2	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.00
TiO_2	0.04	0.21	0.11	0.04	0.19	0.12	0.15	0.40	0.33
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.02	0.02	0.02	0.01	0.03	0.01	0.02	0.03	0.01
V_2O_3	0.02	0.00	0.00	0.01	0.02	0.00	0.03	0.06	0.06
Fe_2O_3	0.80	0.70	0.58	1.19	0.94	0.84	0.59	0.56	0.54
CaO	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Total	99.91	99.85	100.16	99.61	100.54	99.47	100.01	100.02	100.01
Formula 3(O)									
Al	1.9886	1.9871	1.9902	1.9833	1.9838	1.9865	1.9893	1.9844	1.9865
Si	0.0000	0.0000	0.0000	0.0002	0.0002	0.0003	0.0000	0.0001	0.0000
Ti	0.0005	0.0027	0.0014	0.0006	0.0024	0.0016	0.0019	0.0052	0.0042
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Ga	0.0002	0.0003	0.0003	0.0001	0.0003	0.0001	0.0002	0.0004	0.0001
V	0.0003	0.0000	0.0000	0.0002	0.0003	0.0001	0.0004	0.0009	0.0008
Fe	0.0102	0.0089	0.0074	0.0153	0.0119	0.0108	0.0075	0.0072	0.0068
Ca	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
Mg	0.0001	0.0000	0.0001	0.0002	0.0002	0.0000	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000
Total*	1.9999	1.9991	1.9996	1.9999	1.9993	1.9995	1.9994	1.9984	1.9986

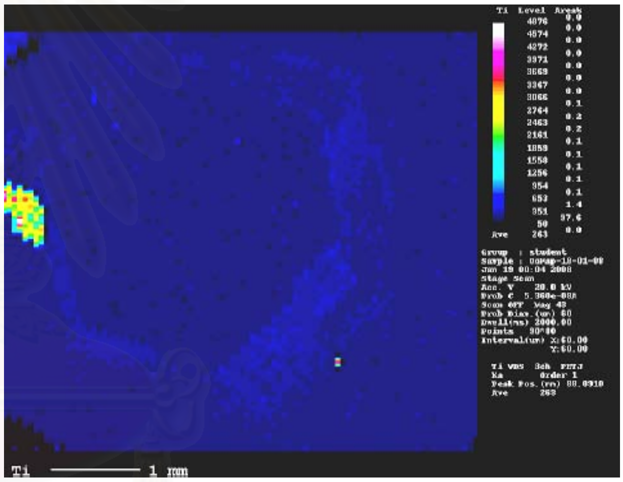
5.2.1.2 Element Mapping

Element mapping was carried out on most of the trapiche sapphire samples from Thailand but only the maps of samples Chan8, Chan9 and Phrae2 show noticeable trace element variations. The maps of the other samples show unclear variation because the contrast of the Fe and Ti concentrations among the core, arm and growth sector in those samples was not high enough to be detected by this analytical technique. The Fe and Ti maps of three samples are described below.

Map of sample Chan8 shows Fe concentration at core area lower than the other parts but Ti concentration at the core is similar to the other parts. Except the outer side of the core transitional to the arm, the highest Ti concentration appears to have cumulated around these areas that may be caused by the cloud of Ti-bearing inclusions (Figure 5.2.5).

Outer Appearance of Chan8



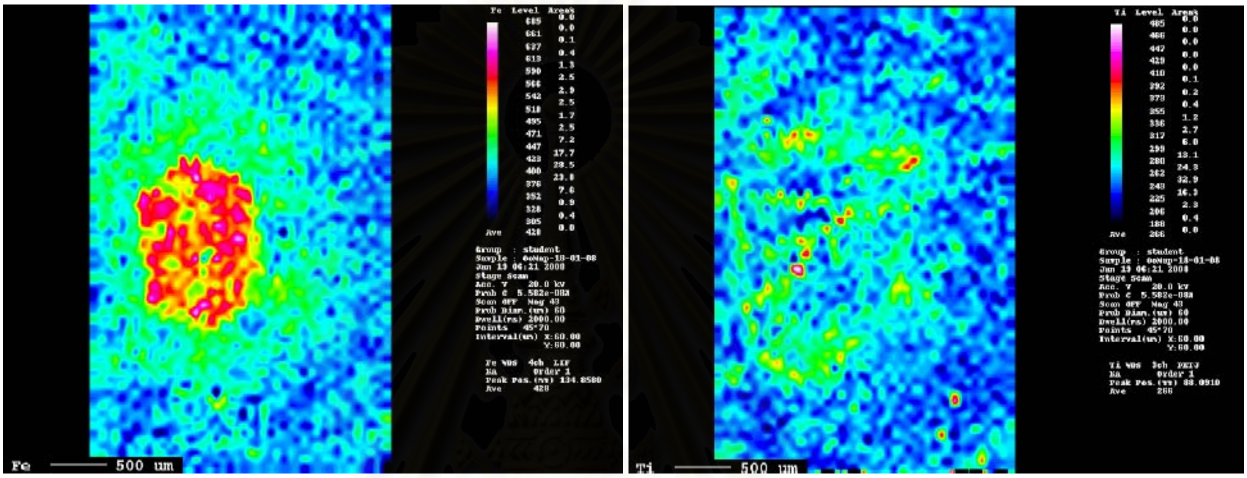


Fe Map Ti Map

Figure 5.2.5 Fe and Ti distribution mapping of the sample Chan8 from Chanthaburi deposit, Eastern Thailand.

Maps of sample Chan9 shows the Fe and Ti concentrations in the core area higher than those of the other parts. Fe concentration appears to decrease gradually outward from the core; on the contrary, Ti concentration reveals unclear difference. However, transitional area between core and arm yields lower Fe content than the core but similar Ti content to the core. This appearance may suggest that the core may contain Fe-Ti-bearing nano-inclusions (Figure 5.2.6).

Outer appearance of Chan9

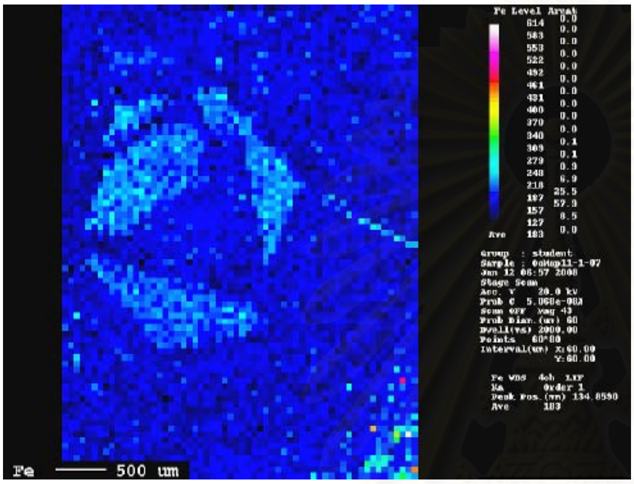


Fe Map Ti Map

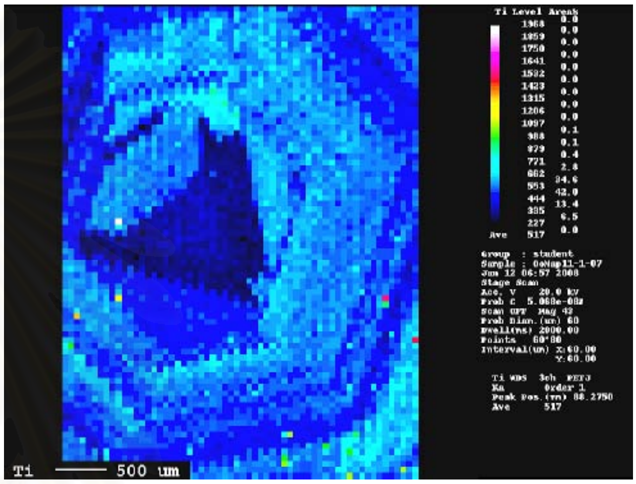
Figure 5.2.6 Fe and Ti distribution mapping of the sampleChan9 from Chanthaburi deposit, Eastern Thailand.

The element maps of Phrae2 clearly separates hexagonal core into two different parts that have inhomogeneous Fe and Ti distributions (Figure 5.2.7). They are consequently distinguished as triangular center and three triangles developed from each face of triangular center. The triangular center likely yields lower concentrations of both Fe and Ti than those along surrounding triangles. In addition, they also show zonal distributions of Fe and Ti; however, Ti map present more obvious zonal distribution outward the core. The geochemical distribution of this sample may be resulted by inhomogeneous source of crystallization.

Outer Appearance of Phrae2



Fe Map



Ti Map

Figure 5.2.7 Fe and Ti distribution mapping of sample Phrae2 from Phrae deposit, Northern Thailand.

.

5.2.2 Trapiche Sapphires from Cambodia

Major and trace element analyses of eight trapiche sapphire samples from Cambodia are described below.

5.2.2.1 Quantitative Point Analysis

Based on iron concentrations, the samples can be divided into 2 groups; the first group includes Pailin1, Pailin2, Pailin3, Pailin4, Pailin5 and Pailin6 which show Fe contents decreasing from core to growth sector and arm whereas Ti concentrations increase from core to arm and growth sector (Figure 5.2.8). For example, sample Pailin3 contains 0.0054, 0.0041 and 0.0038 Fe atom at the core, growth sector and arm and 0.0001, 0.0004 and 0.0006 Ti atom at the core, arm and growth sector, respectively (Table 5.2.5).

The second group is Pailin7 and Pailin8 which shows Fe content decreasing from the core to arm and growth sector but Ti concentrations increase from the core to arm and growth sector similar to that of the first group (Figure 5.2.9). For example, sample Pailin7 contains 0.0067, 0.0048 and 0.0045 Fe atom at the core, arm and growth sector and 0.0001, 0.0002 and 0.0005 Ti atom at core, arm and growth sector, respectively (Table 5.2.6).

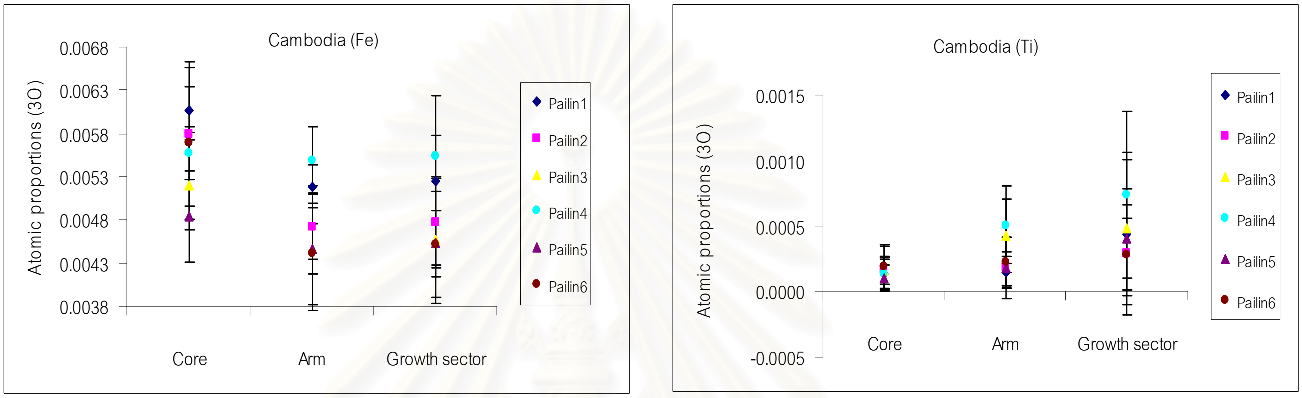


Figure 5.2.8 Plots of averages and standard deviations of Fe and Ti atoms along core, arm and growth sector of the first sample group of Cambodia that appears to have Fe contents decreasing from the core to growth sector and arm but increasing Ti contents from the core to arm and growth sector.

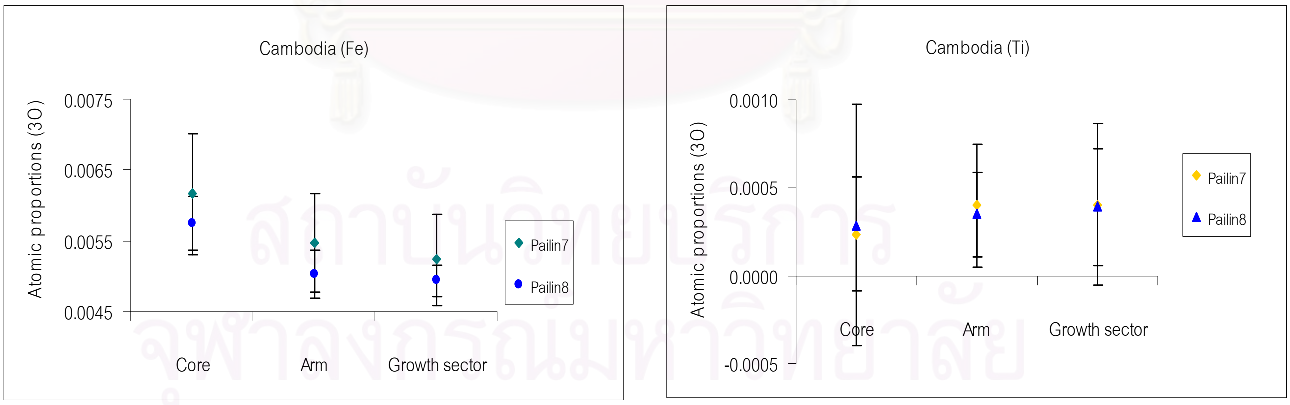


Figure 5.2.9 Plots of averages and standard deviations of Fe and Ti atoms along core, arm and growth sector of the second sample group of Cambodia that appears to have Fe contents decreasing from the core to arm and growth sector but increasing Ti contents from the core to arm and growth sector.

Table 5.2.5 EPMA analyses of the first group of trapiche sapphire samples from Cambodia and their atomic proportions of main Al component and other trace elements.

	Pailin1			Pailin2			Pailin3			Pailin4			Pailin5			Pailin6		
	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector
Al_2O_3	99.10	99.54	99.51	99.50	99.59	99.57	99.53	99.61	99.61	98.63	98.73	98.90	99.57	98.87	99.59	100.11	99.62	99.61
SiO_2	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
TiO_2	0.01	0.02	0.03	0.01	0.01	0.03	0.01	0.03	0.05	0.02	0.03	0.06	0.00	0.01	0.03	0.00	0.02	0.03
Cr_2O_3	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Ga_2O_3	0.04	0.03	0.03	0.05	0.03	0.02	0.02	0.04	0.01	0.03	0.01	0.04	0.01	0.04	0.03	0.04	0.03	0.03
V_2O_3	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00
Fe_2O_3	0.49	0.40	0.43	0.45	0.36	0.36	0.43	0.30	0.32	0.45	0.41	0.42	0.38	0.34	0.34	0.38	0.32	0.33
CaO	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Total	99.65	100.01	100.02	100.03	100.01	100.01	99.99	100.00	100.00	99.13	99.21	99.43	100.00	99.26	100.00	100.57	100.00	100.00
Formula 3(O)																		
Al	1.9930	1.9937	1.9934	1.9933	1.9946	1.9943	1.9941	1.9948	1.9947	1.9936	1.9937	1.9930	1.9946	1.9949	1.9946	1.9941	1.9950	1.9948
Si	0.0000	0.0002	0.0000	0.0002	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001
Ti	0.0002	0.0003	0.0004	0.0001	0.0002	0.0004	0.0001	0.0004	0.0006	0.0002	0.0004	0.0008	0.0001	0.0002	0.0004	0.0001	0.0002	0.0004
Cr	0.0000	0.0000	0.0001	0.0000	0.0002	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Ga	0.0004	0.0003	0.0003	0.0005	0.0003	0.0002	0.0003	0.0004	0.0001	0.0003	0.0001	0.0004	0.0002	0.0004	0.0003	0.0004	0.0003	0.0003
V	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0002	0.0001	0.0000
Fe	0.0062	0.0052	0.0055	0.0057	0.0046	0.0047	0.0054	0.0038	0.0041	0.0058	0.0053	0.0054	0.0048	0.0043	0.0044	0.0049	0.0040	0.0042
Ca	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000
Mg	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
K	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	2.0000	1.9999	1.9999	2.0000	2.0000	1.9999	2.0000	1.9998	1.9999	2.0000	2.0000	1.9998	2.0000	1.9999	1.9998	1.9999	1.9999	1.9999

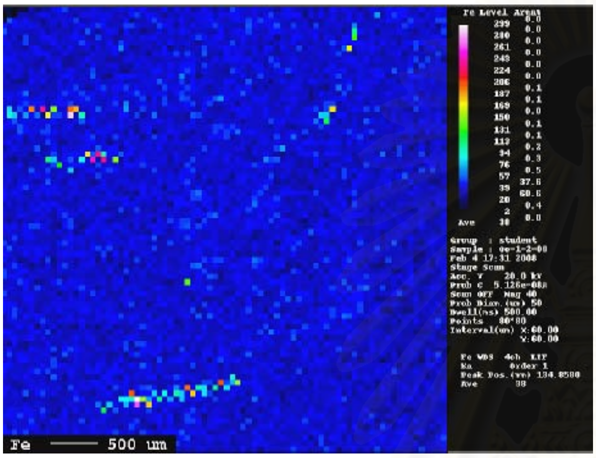
Table 5.2.6 EPMA analyses of the second group of trapiche sapphire samples from Cambodia and their atomic proportions of main Al component and other trace elements.

	Pailin7			Pailin8		
	Core	Arm	Growth sector	Core	Arm	Growth sector
Al_2O_3	99.62	99.65	100.07	99.51	99.93	100.17
SiO_2	0.00	0.00	0.01	0.01	0.00	0.00
TiO_2	0.01	0.02	0.04	0.01	0.02	0.03
Cr_2O_3	0.01	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.05	0.03	0.02	0.02	0.03	0.03
V_2O_3	0.01	0.02	0.01	0.01	0.00	0.01
Fe_2O_3	0.53	0.38	0.35	0.45	0.41	0.39
CaO	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.00
MnO	0.00	0.00	0.00	0.01	0.01	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.22	100.10	100.50	100.01	100.41	100.63
Formula 3(O)						
Al	1.9923	1.9943	1.9944	1.9936	1.9940	1.9941
Si	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000
Ti	0.0001	0.0002	0.0005	0.0001	0.0002	0.0004
Cr	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001
Ga	0.0005	0.0004	0.0002	0.0003	0.0003	0.0003
V	0.0001	0.0002	0.0001	0.0001	0.0000	0.0001
Fe	0.0067	0.0048	0.0045	0.0057	0.0052	0.0049
Ca	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001
Mn	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	2.0000	2.0000	1.9998	2.0000	1.9999	1.9999

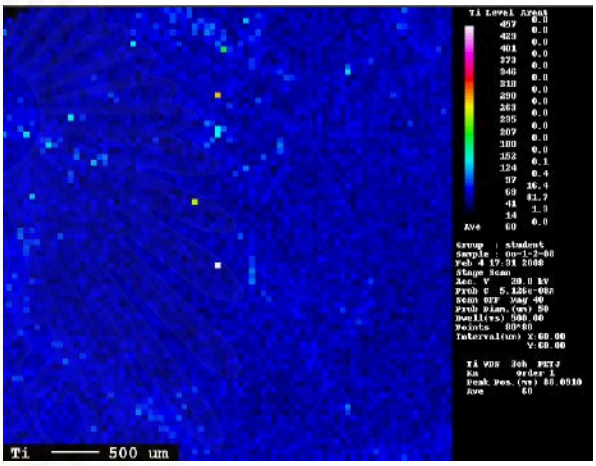
5.2.2.2 Element Mapping

The element mapping was also carried out on most of trapiche sapphire samples from Cambodia but only sample Pailin3 show some noticeable trace element variations. In this sample (Figure 5.2.10), the map shows unclear variation of Fe concentration. But the hexagonal zones of white cloud seem to correspond to the high Ti concentration zone cutting both arm and growth sector. This may be caused by Ti-bearing micro inclusions.

Outer appearance of Pailin3



Fe Map



Ti Map

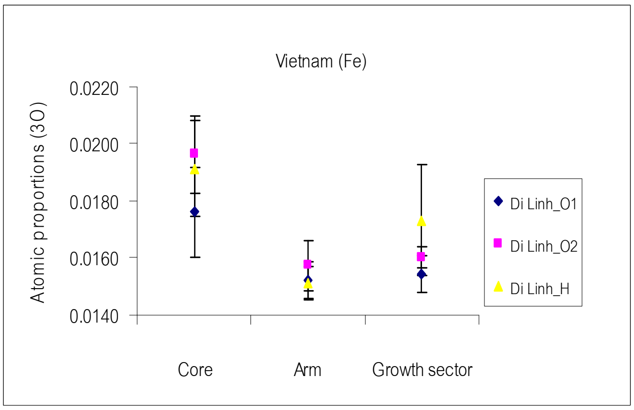
Figure 5.2.10 Fe and Ti distribution mapping of sample Pailin3 from Pailin deposit, Cambodia.

5.2.3 Trpiche Sapphires from Vietnam

Major and trace element analyses of the three samples of trapiche sapphire from Vietnam are described below.

5.2.3.1 Quantitative Point Analysis

As shown in Figures 5.2.11, iron and titanium concentrations of all samples decrease from core to growth sector and arm. For example, sample Di Linh_H contains 0.0193, 0.0179 and 0.0149 Fe atom and 0.0005, 0.0002 and 0.0001 Ti atom at the core, growth sector and arm, respectively (Table 5.2.7).



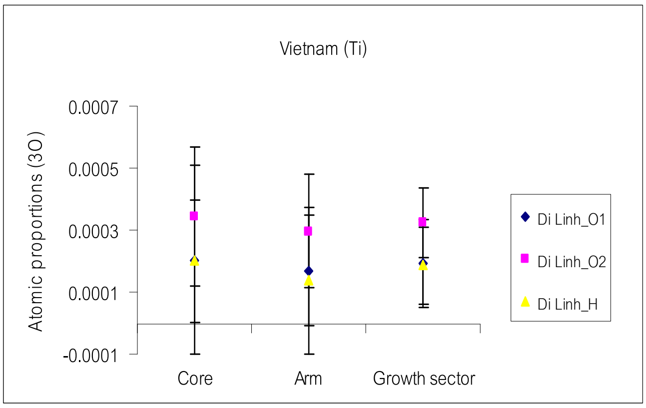


Figure 5.2.11 Plots of averages and standard deviations of Fe atom along core, arm and growth sector that appears to have Fe contents decreasing from core to growth sector and arm, and Ti contents decreasing from core to growth sector and arm.

5.2.3.2 Element Mapping

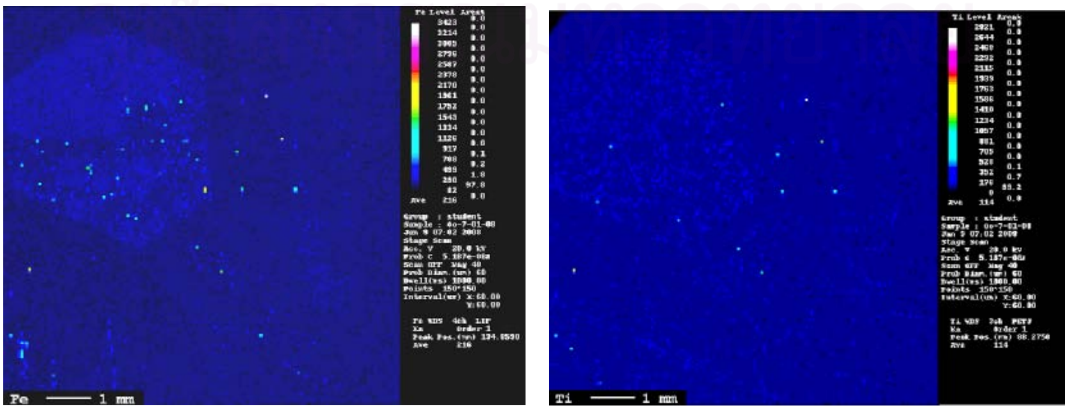
Element mapping was also carried out on all samples from Vietnam (Di Linh_O1, Di Linh_O2 and Di Linh_H). As shown in Figures 5.2.12 and 5.2.14, the maps of samples Di Linh_O1 and Di Linh_O2 show Fe and Ti concentrations in the core higher than the other parts. This evidence indicates conclusively that short needles and small black inclusions found in the core (as reported in Chapter 4) are Fe and/or Fe-Ti phases.

For the sample Di Linh_H, the Fe map shows Fe concentrations at the core higher than the other parts. On the contrary, the Ti map shows no obvious difference of Ti concentration throughout the stone, although the core area appears to have a slightly higher concentration. Nonetheless, the quantitative point analysis can be used to confirm the mentioned finding. This result also suggests that short needles and small black inclusions found in the core (as reported in Chapter 4) are Fe and/or Fe-Ti bearing.

Table 5.2.7 EPMA analyses of the of trapiche sapphire samples from Vietnam and their atomic proportions of main Al component and other trace elements.

	Di Linh_O1			Di Linh_O2			Di Linh_H		
	Core	Arm	Growth sector	Core	Arm	Growth sector	Core	Arm	Growth sector
Al_2O_3	98.46	98.75	98.72	98.35	98.73	99.08	98.15	98.91	98.51
SiO_2	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.05	0.01	0.02	0.03	0.02	0.02	0.04	0.01	0.01
Cr_2O_3	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Ga_2O_3	0.03	0.00	0.03	0.03	0.03	0.03	0.05	0.03	0.04
V_2O_3	0.02	0.00	0.01	0.02	0.00	0.01	0.01	0.00	0.02
Fe_2O_3	1.44	1.17	1.22	1.55	1.19	1.25	1.50	1.16	1.40
CaO	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
MnO	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.03	99.96	100.02	99.98	99.98	100.42	99.76	100.11	99.98
Formula 3(O)									
Al	1.9798	1.9841	1.9834	1.9789	1.9838	1.9829	1.9791	1.9846	1.9810
Si	0.0000	0.0004	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Ti	0.0006	0.0001	0.0002	0.0004	0.0002	0.0003	0.0005	0.0001	0.0002
Cr	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001
Ga	0.0004	0.0000	0.0003	0.0003	0.0004	0.0003	0.0005	0.0003	0.0004
V	0.0003	0.0000	0.0002	0.0002	0.0001	0.0002	0.0001	0.0000	0.0002
Fe	0.0185	0.0150	0.0156	0.0199	0.0152	0.0159	0.0193	0.0149	0.0179
Ca	0.0002	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001
Mg	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000	0.0001
Mn	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9999	1.9999	2.0000	2.0000	2.0000	2.0000	1.9998	1.9999	2.0000

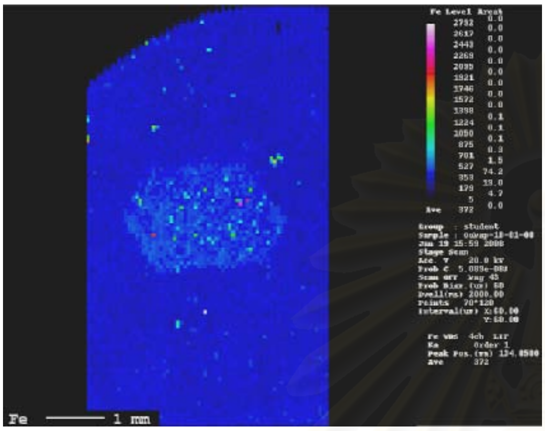
Outer Appearance of Di Linh_O1



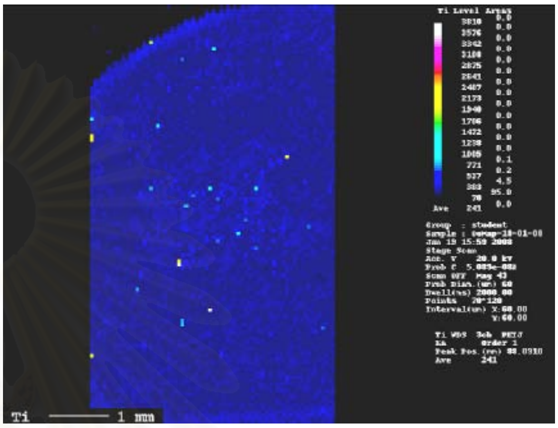
Fe Map Ti Map

Figure 5.2.12 Fe and Ti distribution mapping of sample Di Linh_O1 from Di Linh deposit, Vietnam.

Outer Appearance of Di Linh_O2

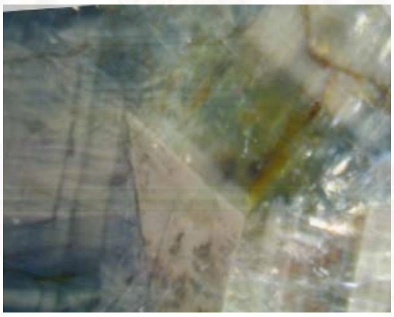


Fe Map

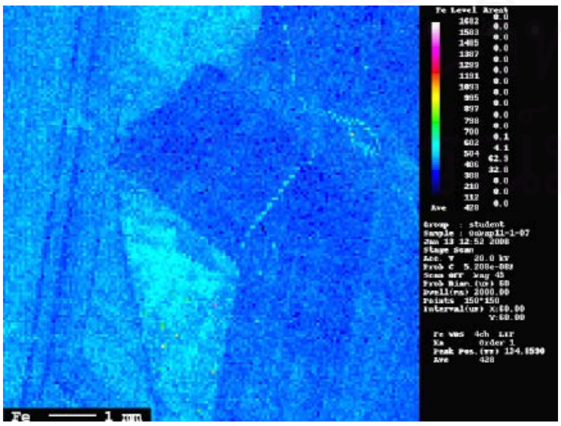


Ti Map

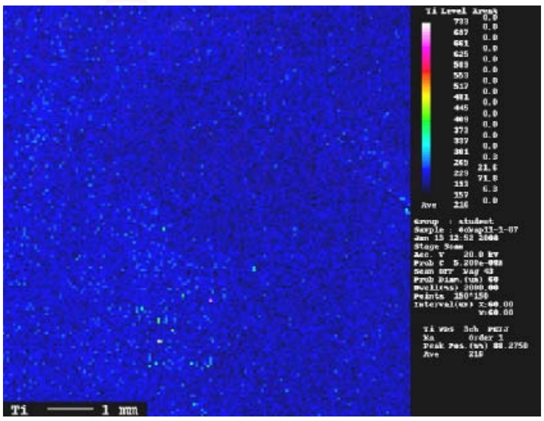
Figure 5.2.13 Fe and Ti distribution mapping of sample Di Linh_O2 from Di Linh deposit, Vietnam.



Outer Appearance of Di Linh_H



Fe Map



Ti Map

Figure 5.2.14 Fe and Ti distribution mapping of sample Di Linh_H from Di Linh deposit, Vietnam.

CHAPTER VI
DISCUSSION AND CONCLUSIONS

6.1 Core Formations

Based on the results obtained from this study, core of trapiche sapphire samples can be subdivided into 5 groups as summarized in Table 6.1. Although, they have quite similar appearance, their internal features are somewhat different. In fact, the cores of all trapiche sapphires contain thin-film fluid inclusions as the most common significant feature. Other internal features including minute particles, short needles and black mineral inclusions are sometimes occurred along with thin-film fluid inclusions that lead to five different groups of core (C1 to C5) as described in Table 6.1.

Table 6.1 Summary of five different groups of core based on their internal features.

Group	Internal Features	Samples
C1	thin-film fluid inclusions + minute particles + black inclusions	Chan4, Chan9, Kan, Pailin1, Pailin3, Pailin4, Pailin5, Pailin6, Pailin8
C2	thin-film fluid inclusions + minute particles	Chan1, Chan5, Chan6, Phrae1, Pailin2, Pailin7
C3	thin-film fluid inclusions + black inclusions	Chan8, Chan10, Chan11
C4	thin-film fluid inclusions + short needles + black inclusions	Chan2, Chan3, Chan7, Di Linh_O1, Di Linh_O2, Di Linh_H
C5	thin-film fluid inclusions, the inner trigonal core also contains cloudy minute particles	Phrae2

When taken chemical fingerprints into consideration, the differences of internal features also reflect in trace element contents in different parts of trapiche sapphire samples. For examples, Fe concentrations in the cores of most samples are higher than those of the other parts. Exception is the Chan8 sample from Chanthaburi deposit in which its core is occupied by essentially thin-film fluid inclusions and only small amount of tiny black inclusions; in contrast, columbite inclusions are detected in arm whereas growth zone contains some iron-stained fracture. These features can explain the lower Fe concentrations at the core area than those of the other parts (as reported in Chapter V). In addition, high Fe concentrations are also found in the core regions for the sample Di Linh_O1 from Southern Vietnam (as reported in Chapter V), that usually contain short needles and black inclusions. This information suggest that they are Fe-or Fe-Ti-bearing inclusions.

For Ti concentration of the core, the studied samples show either highest Ti or lowest Ti concentrations at core compared to arm and growth sector. Lower Ti concentrations at the core are found in samples Chan6 and Chan8 from Eastern Thailand, Phrae1 and Phrae2 from Northern Thailand, and all trapiche sapphire samples from Pailin, Cambodia. For example, Phrae2 has distinctively higher Ti concentrations in the growth sectors and arms than that at the inner trigonal core; this may be due to the fact that the inner trigonal core contains lesser amount of cloudy minute particles of probably Ti-bearing inclusions than that of the other areas. However, the outer core of the same sample shows somewhat higher Ti concentration comparable to that in the growth sector. Because of the fact that the outer core area has no minute particles, hence the higher Ti concentration is probably reflected by stronger Fe-Ti charge transfer causing dark blue in this area. In addition, Ti map also presents obvious zonal distribution outward from the core which indicates inhomogeneous source of geochemical condition during the crystallization. When ever there is higher Ti content in the core area, Chan9 for example, it usually contains some minute particles and black inclusions of probably Ti-bearing phases. In conclusion, the samples with lower Ti core are mostly categorized into C1, C2 and C5 groups whereas all samples of C4 and most of C3 have higher Ti core. This information may additionally indicate that short needle inclusions are mainly found in C4 group and some black inclusions in both C3 and C4 would be related to higher Ti concentration recorded at the core area.

Based on above information it can generally be postulated that the distinctly well developed core of a trapiche sapphire crystal might have formed from a unique physical and chemical (eutectic?) growth condition that allowed co-precipitation and/or incorporation of many phases during the crystallization of such a core. Subsequently, the environment either pressure, temperature or composition had changed abruptly that may lead to development of arm and growth sector in somewhat different growth condition.

6.2 Developments of Arm and Growth Sector

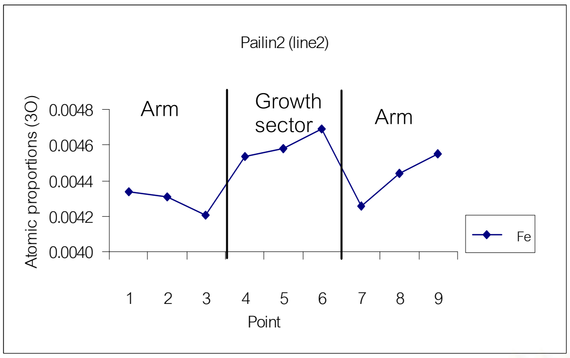
The arms of all trapiche sapphire samples in this study extend outward from poorly to well developed hexagonal core, along the direction perpendicular to $\{11\bar{2}0\}$ faces. They can be separated, based on internal features, into 5 groups as summarized in Table 6.2. On the other hand, growth sector of all trapiche sapphire samples are quite similar to each other. They are clearly partitioned by the arm and composed mainly of thin-film fluid inclusions. White cloudy hexagonal zone and/or blue zone are clearly developed outward from the core region covering both arms and growth sectors.

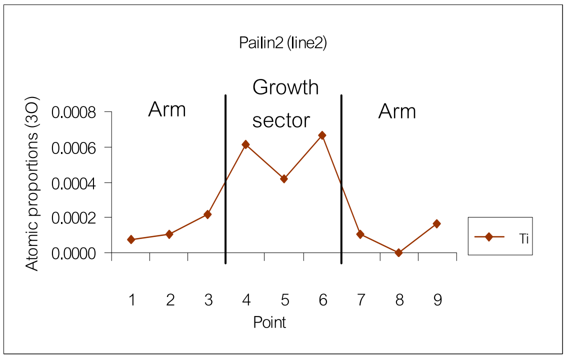
Table 6.2 Summary of different groups of arm based on their internal features.

Group	Internal features	Sample
A1	thin-film fluid inclusions + minute particles + black inclusions	Chan4, Chan6
A2	thin-film fluid inclusions + minute particles	Chan1, Chan9, Kan, Phrae2
A3	thin-film fluid inclusions + black inclusions	Pailin1 to Pailin8
A4	thin-film fluid inclusions + short needles + black inclusions	Chan2, Chan3, Chan7, Chan8, Phrae1, DiLinh_O1, Di Linh_O2, Di Linh_H
A5	thin-film fluid inclusions	Chan5, Chan10, Chan11

As shown in Table 6.2, the arms contain the similar kinds of internal features that are not entirely different from those found in the core and growth sector. The difference between the arm and growth sector is even more subtle with respect to the nature of inclusions and chemical variation. However, only the amount and the way in which the inclusions were formed (i.e., as random versus oriented) as also reflected in the chemical variation are different. In fact, the physical appearance of the arm is mainly due to the presence of abundant thin-film fluid inclusions or 2-3 phase inclusions that are oriented mainly in the direction perpendicular to $\{11\bar{2}0\}$ faces and in many samples with accompanying short needles, small black inclusions and minute particles. Hence, the arm could be merely a place (perpendicular to $\{11\bar{2}0\}$ faces) in the growth sector where fluids and most of the impurities were likely to be concentrated. This is also confirmed by the fact that the boundary between arm and growth sector is mostly gradational without a sharp contact.

With regard to the chemical fingerprints, although X-ray mapping could not clearly show any difference between arm and growth sector, quantitative analyses as reported in Chapter V show some differences of trace element geochemistry, particularly on the Fe and Ti profiles. Based on quantitative profile along arm and growth sector developed from the core at about the same distance, Fe and Ti concentrations between arms and growth sectors can be divided into 2 groups. The first group contains higher Fe and Ti concentrations in growth sectors than those of the arms; these samples are Chan1, Chan3, Chan4, Chan5, Chan10, Chan11 and Kan from Thailand, most samples of Pailin (Pailin1 to Pailin6) from Cambodia and all samples from Southern Vietnam. For example, the Pailin2 sample shows Fe and Ti contents at arm clearly lower than the adjacent growth sectors (Figure 6.1). As for the Pailin7 and Pailin8 samples from Cambodia, although their arms and growth sectors contains somewhat similar Ti contents as mentioned above, the Fe profile is in the opposite direction (Figure 6.2). That is the arm shows slightly higher Fe concentration than the growth sector. Nonetheless, both samples are also grouped into the first group due to such the rare case found in this study and the fact that Fe concentrations are not obvious different. For the second group, Fe and Ti analyses across arm and growth sectors show complete opposite profile as observed in the first group. They have higher Fe and Ti concentrations at arms; this geochemical characteristic is found in samples Chan2, Chan6, Chan7, Chan8, Chan9, Phrae1 and Phrae2 from Thailand (Figure 6.3).





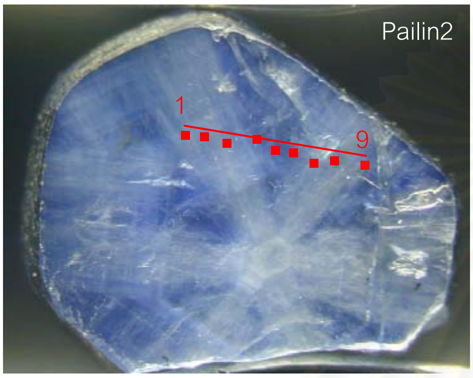
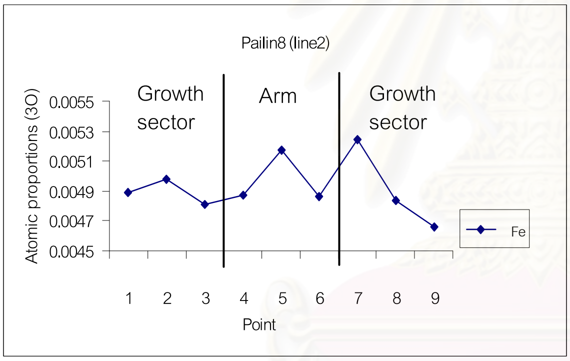
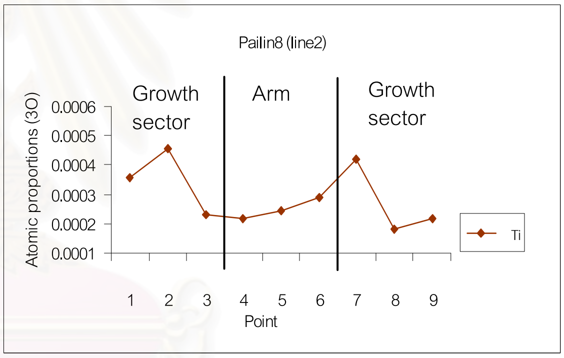


Figure 6.1 Quantitative profile analysis along arm and growth sector of trapiche sapphire (Pailin2) from Cambodia showing higher Fe and Ti concentrations in growth sectors than the arms.





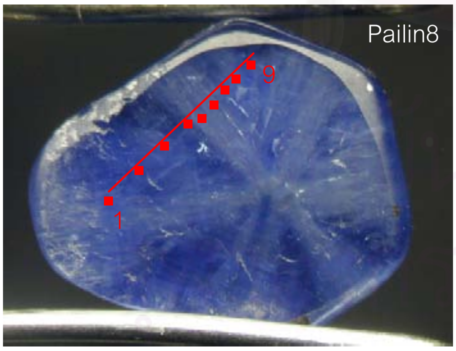
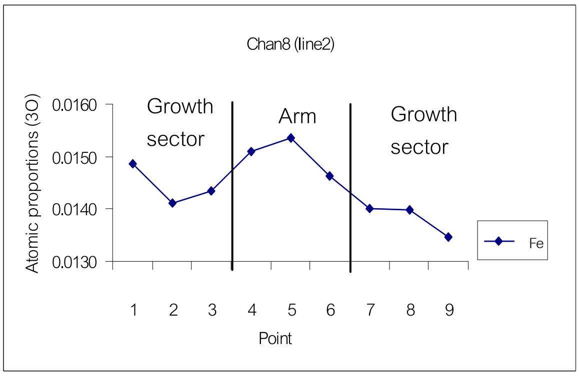
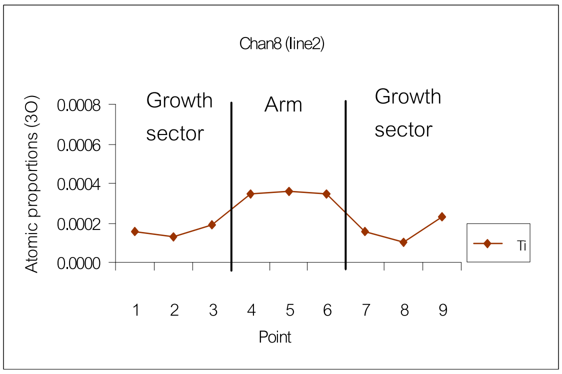


Figure 6.2 Quantitative profile analysis along arm and growth sector of trapiche sapphire (Pailin8) from Cambodia showing lower Fe and higher Ti in the surrounding growth sector than the arm.





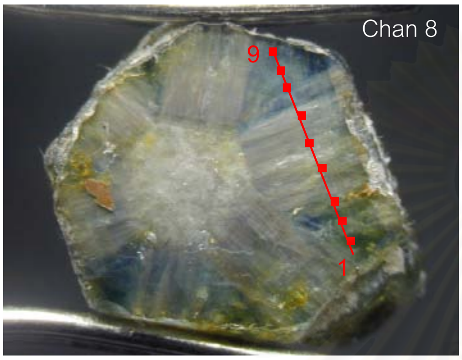


Figure 6.3 Quantitative profile analysis along arm and growth sector of trapiche sapphire (Chan8) from Thailand showing higher Fe and Ti concentrations in the arms than the surrounding growth sectors.

Although, both groups of different Fe-Ti profiles are unclearly related to classification of the arm as earlier described as A1 to A5 (Table 6.2), there are some statistic signatures. For example, many samples in the second group, particularly samples Chan2, Chan7, Chan8 and Phrae1, are grouped in A4 that contains short needles and black inclusions. These internal features, probably Fe/Fe-Ti bearing components, may cause higher Fe and Ti concentrations at the arm than those at the growth sectors. On the other hand, arms of samples Chan5, Chan10 and Chan11 grouped as A5, contain only thin-film fluid inclusions that would explain the lower Fe-Ti concentration of the arms than the surrounding growth sectors.

For the rest of the samples, they scatter in most arm groups A1 to A4 but do not show such similar profiles; this may reflect different proportion of some particular Fe-Ti bearing inclusions (e.g., black inclusions and short needle inclusions) between arm and growth sector. Arms of all samples from Southern Vietnam also contain short needles and black inclusions and they are grouped as A4 as well as some samples in A1 and A2 containing minute particles with or without black inclusions but their Fe and Ti concentrations in these arms are still lower than the growth sectors. In addition, all of

Pailin samples in A3 show small black inclusions at arm but their arms mostly contain lower Fe and Ti contents than the surrounding growth sectors, except Pailin7 and Pailin8. This contradictory evidence leads to the speculation that there could be micro-to-nano-sized inclusions of probably Fe-Ti-bearing phases that could not be observed using conventional gem microscope. These invisible inclusions may spread in any parts of corundum (Wathanakul et al., 2004) which can cause high Fe and Ti concentrations.

Regarding to combination between core types (C1 to C5) and arm types (A1 to A5), trapiche sapphires in this study can be distinguished into 12 patterns as shown in Table 6.3. Most of trapiche sapphire samples fall within 2 main characteristics; 1) cores contain thin-film fluid inclusions, minute particles and black inclusions with six arms containing thin-film fluid inclusions and black inclusions (C1A3); 2) cores contain thin-film fluid inclusions, short needles and black inclusions and six arms containing all the same types as core (C4A4). In general, these combinations reveal quite good relation between core and arm formation in which arms appear to form following the core formation. Consequently, inclusion types found within the arm should be similar to those in the core (i.e., C1A1, C2A2 and C4A4) or some inclusions, particularly minute particles and black inclusions, found in the core are missing in arms (i.e., C1A2, C1A3, C2A5 and C3A5). Just small amount of the sample are not corresponding to the mentioned characteristics. Hence, based on these results, arm formation would originate in the association with core formation.

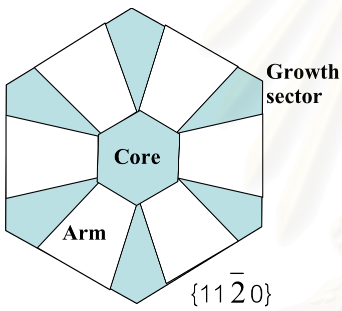
6.3 Crystallizations of Trapiche Sapphire

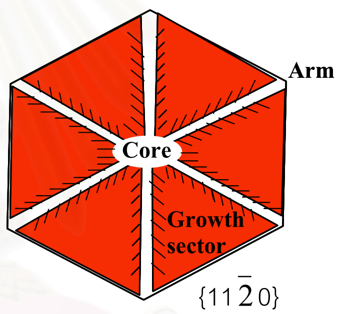
Because of the fact that all the trapiche sapphires used in this study contains sifnificant thin-film fluid inclusions or 2-3 phase inclusions in all parts of the crystals that are rarely found in normal sapphires occur in those localities. It is therefore likely that the trapiche sapphire was crystallized from in a peraluminous melt that was exceptionally enriched with volatile component. Such the highly volatile-rich melt could be the main cause of the development of the trapiche texture.

Table 6.3 Summary of the internal features as found in different types of core and arm in trapiche sapphire samples.

Core	Arm	Samples	Significant Note
C1	A1	Chan4	Similar types of inclusion
C1	A2	Chan9, Kan	Black inclusion missing in arm
C1	A3	Pailin1, Pailin3, Pailin4, Pailin5, Pailin6, Pailin8	Minute particle missing in arm
C2	A1	Chan6	Black inclusion adding in arm
C2	A2	Chan1	Similar types of inclusion
C2	A3	Pailin2, Pailin7	Minute particle missing but black inclusion adding in arm
C2	A4	Phrae1	Short needle adding but minute particle missing in arm
C2	A5	Chan5	Minute particle missing in arm
C3	A4	Chan8	Short needle adding in arm
C3	A5	Chan10, Chan11	Black inclusion missing in arm
C4	A4	Chan2, Chan3, Chan7, DiLinh_O1, Di Linh_O2, Di Linh_H	Similar types of inclusion
C5	A2	Phrae2	Minute particle adding in arm

Based on the information reported above, the cores should be formed first within the environments which may be different in compositions from place to place; these are indicated by different inclusions and trace element geochemistry found within the core. It could be a unique physical and chemical (eutectic?) growth condition that allowed co-precipitation and/or incorporation of many phases during the crystallization of such a core. Subsequently, the environmental conditions could have changed abruptly and led to the formations of the arms and growth sectors simultaneously. As such, hexagonal growth zone could be developed continuously covering both arms and growth sector with slight difference in trace element geochemistry recorded along these areas. The arms had formed as band of multi phase impurities following the basal (a) axes perpendicular to the {11$\bar{2}$0} faces which may be a specific direction forming defects of the crystal, where fluids inclusions and most of the impurities were heavily segregated and formed. These arms are combined by clearer area of growth sectors intercepting the {11$\bar{2}$0} faces (see Figure 6.4) which is the growth directions of the {10$\bar{1}$0} faces but these faces could not be properly developed in corundum crystal. Consequently, the growth sectors formed apparently as corners of hexagonal faces but they mainly develop clear blue texture with less inclusions, mainly thin-film fluid inclusions. Sequence of crystallization of trapiche sapphire is quite different from that reported from trapiche ruby. Indeed, one important different fact is that in the trapiche sapphire, the arms develop in the direction perpendicular to {11$\bar{2}$0} faces (or parallel to the a-axes) whereas in the trapiche ruby, the arms develop in the direction along the bisecting of a-axes (see Figure 6.4).





Trapiche sapphire

(This study)

Trapiche ruby

(Modified from Sunagawa et al,1999)

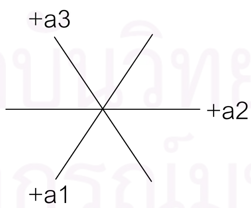


Figure 6.4 Schematic illustration of textures of trapiche sapphire observed under this study and trapiche ruby reported in the previous work.

According to Sunagawa et al. (1999) the main skeleton of trapiche ruby was constructed rapidly by dendritic growth around the arms, under high driving force. Following this stage, lowering driving force had led growth sector forming along the interstices of already formed skeletons. Trapiche ruby has tube-like inclusions originating from the arms (called branch), orientated at 30º to the arm direction which is perpendicular to the $\{11\bar{2}0\}$ faces. As for the arms of trapiche sapphire, they are significantly occupied by thin-film fluid inclusion and other inclusions that would also be formed within the same direction to the branch of trapiche ruby. That supports high driving force toward these directions. However, trapiche ruby formation originated in solid metamorphic condition whereas trapiche sapphire appear to have crystallized within the melt that may lead to fluid-rich inclusions and many defects in their arms.

As also observed during the crystallization of trapiche sapphire, many mineral inclusions found within these trapiche sapphires such as magnetite, columbite, pyrochlore, monazite, zircon and feldspar appear to have been crystallized from peraluminous felsic magma. Besides, nepheline usually occurs in low-silica intrusive rocks and associated pegmatite. This is comparable to some evidences published by previous studies (e.g., Coenraads et al., 1995; Gao et al., 1996: Sutherland et al., 1998; Pisutha-Arnond et al., 1999; Intasopa et al., 2000; Sutthirat et al., 2001) that reported similar group of mineral inclusions (e.g., ferrocolumbite, zircon, monazite, feldspar, pyrochlore) in basaltic sapphires from the same deposits under this study.

Poorly to well developed hexagonal cores of the trapiche sapphires may depend on the time of crystallization. Subsequently, the environment of the melt would have changed immediately; consequently, after crystallization of Fe-Ti containing mineral as some of them found as mineral inclusions (mainly magnetite), residual melts might have Al component richer than original melt hence clearer corundum texture started to crystallize toward the arms and growth sectors, simultaneously.

Table 6.4 Mineral inclusions found in each part of trapiche sapphire from Thailand, Cambodia and Vietnam deposits.

Mineral Inclusions			
Part	Thailand deposits	Cambodia deposit	Vietnam deposit
Core	Magnetite	-	Magnetite
Arm	Magnetite	-	Magnetite
	Columbite	Columbite	-
	Pyrochlore	Pyrochlore	Pyrochlore
	Zircon	-	Feldspar
	Monazite	-	-
Growth sector	Nepheline	Columbite	-
	Feldspar	Pyrochlore	-
	Calcite	-	-
	Zircon	-	-

6.4 Conclusions

6.4.1 Cores of trapiche sapphires contain the most significant feature as thin-film fluid inclusion combined with the other internal features, including minute particles, short needles and black inclusions.

6.4.2 Formation of arm appears to have developed following the core formation which is indicated by similar types of internal features found in both areas of the same samples.

6.4.3 The arms are formed toward the basal (a) axes as rectangular bands of multi phase impurities perpendicular to the $\{11\bar{2}0\}$ faces. Formations of the arms and growth sectors were started simultaneously.

6.4.4 Geochemical fingerprint observed along the different parts of trapiche sapphire significantly indicates Fe-Ti-richer core. The other cases seem to be minority. Some areas containing high Fe, Ti concentrations, may be caused by some inclusions and/or Fe-Ti charge transfer reaction making blue color in growth sector.

6.4.5 Trapiche sapphires appear to have crystallized in partial melt of peraluminous felsic rocks.

REFERENCES

Aspen, P., Upton, B.G.J., and Dicken, A.P. 1990. Anorthoclase, sanidine and associated megacrysts in Scottish alkali basalts: high-pressure syenitic debris from upper mantle sources?. Eur J Mineral 2: 503-517.

Barr, S.M., and Madonald, A.S. 1978. Geochemistry and Petrogenesis of Late Cenozoic alkaline basalts of Thailand. Geol. Soc. Malaysia, Bulletin: 25-52.

Barr, S.M., and Madonald, A.S. 1981. Geochemistry and geochronology of Late Cenozoic basalts of Southeast Asia. Geological Society of America Bulletin, 92: 1069-1142.

Bernauer, F. 1926. Die sog. Smaragddrillinge von Muzo und ihre optischen Anomalien. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Supplemental, 54, Part A: 205-242.

Bertrand, E.1879. Compte-rendu de la séance du 13 Février 1879 (Report of the meeting of February 13, 1879). Bulletin de la Société Minéralogique de France. 2: 31.

Bunopas, S, and Bunjitadulya, S. 1975. Geology of Amphoe Bo Phloi, north Kanchanaburi, with special notes on the Kanchanaburi Series: Jour. Geol. Soc. Thailand 1: 51-67.

Choowong, M. 2002. Quaternary geology and sapphire deposits from the Bo Phloi gem field, Kanchanaburi Province, Western Thailand. Journal of Asian Earth Sciences 20: 119-125.

Choudhary, G., and Golecha, C. 2006. Trapiche-the fixed star. Hands-on Gemmology Gems & Jewellery. December: 122-123.

Christopher, P.S., Robert, C. K., Alice, S.K., Peretti, A., Scarratt, K.V., Nguyen, D.K., and Repetto, S. 1995. Sapphires from Southern Vietnam. Gems & Gemology. 31, 3: 168-186.

Coenraads, R.R., Sutherland, F.L., and Kinny,P. 1990. The origin of sapphires: U-Pb dating of zircon inclusions sheds new light. Mineralogical Magazine. 54: 113-122.

Coenraads, R.R., Vichit, P., and Sutherland, F.L. 1995. An unusual sapphire-zircon-magnetite xenolith from the Chanthaburi gem province, Thailand. Journal of Gemmology 25, 8: 590-591.

Garnier, V., Ohnenstetter, D., Giuliani, G., Blanc, P., and Schwarz, D. 2002. Trace - element contents and cathodoluminescence of “trapiche” rubies from Mong Hsu, Myanmar (Burma): geological significance. Mineralogy and Petrology. 76: 179-193.

Garnier V., Ohnenstetter D., Giuliani G., Fallick A.E., Phan Trong T., Hoàng Quang V., Pham Van L., Schwarz D. 2005. Basalt petrology, zircon ages and sapphire genesis from Dak Nong, southern Vietnam. Mineralogical Magazine. February, 69, 1: 21-38.

Gemmological Association of Great Britain (GAGTL). 2001. Manual of Preliminary, section 6. UK: 1-14.

Guo, J., O’Reilly, S.Y., and Griffin, W.L. 1996. Corundum from basaltic terrains: a mineral inclusion approach to the enigma. Contributions to mineralogy and petrology. 122: 368-386.

Hoang, N., and Flower, M. 1998. Petrogenesis of Cenozoic basalts from Vietnam: implications for origins of a diffuse igneous province. Journal of Petrology 39, 3: 369-395.

Hughes, R. W. 1997. Ruby&Sapphire. Colorado USA: RWH Publishing, Boulder. 511pp.

Intasopa, S., Atichat, W., Pisutha-Arnond, V., Sriprasert, B., Narudeesombat, N., Puttarat, T. 2000. Inclusion in Chantaburi-Trat Corundums: A Clue to Their Genesis. Proceedings of Symposium on Mineral, Energy, and Water Resources of Thailand: Towards the Year 2000, Bangkok, Thailand: 471-483.

Irving, A.J. 1986. Polybaric magma mixing in alkali basalts and kimberlites: Evidence from corundum, zircon and ilmenite megacrysts. In: Smith, C.B. (compl.) Fourth International Kimberlite Conference Extended Abstracts, Perth, Western Australia, August 11-15, 1986. Geological Society of Australia Abstracts Series. 16: 262-264.

Jobbins, E.A., and Berrange, J.P. 1981. The pailin ruby and sapphire gemfield, Cambodia. Journal of Gemmology 16, 8: 555-567.

Jungyusuk, N., and Khoisitanont, S. 1992. Volcanic rocks and associated mineralization in Thailand. In Piancharoen, C. (ed.), Proceedings of a National Conference on Geologic Resources of Thailand: Potential for Future Development DMR, Thailand: 522-538.

Leelawatanasuk, T. Relationship between magnesium and iron content in some olivine and Raman Spectroscopy. M.Sc. Thesis (unpublished), Chulalongkorn University, Thailand, 2004.

Levinson A.A., and Cook F.A. 1994. Gem corundum in alkali basalt: origin and occurrence. Gems & Gemology. 30: 253–262.

Limtrakun, P., Khin, Z., Ryan, C.G., and Mernagh, T.P. 2001. Formation of the Denchai gem sapphires, northern Thailand: evidence from mineral chemistry and fluid/melt inclusion characteristics. Mineralogical Magazine. 65: 725-735.

Muhlmeister, S., and Quinn, E. 2004. Trapiche rubies displaying asterism. http://www.gia.edu [2007, March 16].

Nassau, K., and Jackson, K.A. 1970. Trapiche emeralds from Chivor and Muzo, Colombia. The American Mineralogist. 55: 416-427.

Oakes, G.M., Barron, L.M., and Lishmond, S.R. 1996. Alkali basalts and associated volcaniclastic rocks as a source of sapphire in eastern Australia. Austral. J. Earth Sci. 43: 289-298.

Pisutha-Arnond, V., Wathanakul, P., and Intasopa, S. 1999. New evidences on the origin of Kanchanaburi sapphire. Proceedings of Symposium on Mineral, Energy, and Water Resources of Thailand: Towards the Year 2000. Bangkok, Thailand (abstract).

Pisutha-Arnond, V., Wathanakul, P., Atichat, W., Sutthirat, C., Sriprasert, B., Leelawattanasuk, T., and Somboon, C. 2007. Unusual sapphire assemblages from the Kanchanaburi gem field, western Thailand. 30th International Gemmological Conference 2007, Moscow, Russia: 79 (abstract).

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

Schmetzer, K., Hänni, H.A., Bernhardt, H.-J., and Schwarz, D. 1996. Trapiche Rubies. Gems&Gemology. 32: 242-250.

Schmetzer, K., Zhang, B.L., Gao, Y., Bernhardt, H.-J., and Hänni, H.A. 1998. Element mapping of trapiche rubies. Journal of Gemmology 26, 5: 289-301.

Sinkankas, J. 1981. Trapiche emeralds. Emerald and other beryls: 262-264.

Smith, C.P., Kammerling, R.C., Keller, A.S., Peretti, A., Scarratt, K.V., Khoa, N.D.,and Repetto,S.1995. Sapphires from southern Vietnam. Gems&Gemology: 168-186.

Sunagawa, I., Bernhardt, H.-J., and Schmetzer, K. 1999. Texture formation and element partitioning in trapiche ruby. Journal of Crystal Growth 206: 322-330.

Sutherland, F. L., and Coenraads R.R. 1996. An unusual ruby-sapphire-saphirine-spinel assemblage from the Tertiary Barrington volcanic province, New South Wales, Australia. Mineralogical Magazine. 60: 623-638.

Sutherland, F. L., and Schwarz, D. 2000. Rubies and sapphires from Thailand and Cambodia. 31st IGC, Rio de Janeiro, Brazil, August 2000.

Sutherland, F. L., and Schwarz, D. 2001. Origin of gem corundums from basaltic fields. Australian Gemmologist. 21: 30-33.

Sutherland, F.L., Schwarz D., Jobbins, E.A., Coenraads, R.R., and Webb, G. 1998a. Distinctive gem corundum suits from discrete basalt fields: a comparative study of Barrington, Australia, and West Pailin, Cambodia, gemfields. Journal of Gemology 26: 65– 85.

Sutthirat, C. Petrochemistry of basalts in Amphoe Sop Prab and Amphoe Ko Kha, Changwat Lampang. M.Sc. Thesis (unpublished), Chulalongkorn University, Thailand, 1995.

Sutthirat, C., Charusiri, P., Farrar, E., and Clark, A.H. 1994. New 40Ar/39Ar geochronology and characteristics of some Cenozoic basalts in Thailand. Proceedings of the International Symposium on: Stratigraphic Correlation of Southeast Asia. Bangkok, Thailand: 306-321.

Sutthirat, C., Pisutha-Arnond, V., Hauzenberger, C., Chualaowanich, T., Wathanakul, P., Atichat, W., and Sriprasert, B. 2007. Ruby and sapphire formations in basaltic fields, Thailand. 30th International Gemmological Conference 2007, Moscow, Russia: 116-117 (abstract).

Sutthirat, C., Saminpanya, S., Droop, G.T.R., Henderson, C.M.B., and Manning, D.A.C. 2001. Clinopyroxene-corundum assemblages from alkali basalt and alluvium, eastern Thailand: Constraint on the origin of Thai rubies. Mineralogical Magazine. 65, 2: 277-295.

Vichit P. 1992. Gemstones in Thailand. In Piancharoen, C. (ed.), Proceedings of a National Conference on Geologic Resources of Thailand: Potential for Future Development DMR, Thailand: 124-150.

Vichit P., Vudhichativanich S., Hansawek R. 1978. The distribution and some characteristics of corundum-bearing basalts in Thailand. Journal Geological Soc. Thailand, Spec. Iss. For GEOSEA III, 3, M4-1-M4-38.

Wathanakul, P., Atichat, W., Pisutha-Arnond, V., Win, TT., and Singbamroong, S. 2004. Evidences on the unusually high Be, Sn, Nb, and Ta content in some trapiche-like sapphires from basaltic origins. The 29th International Gemmological Conference 2004, Wuhan, China, 114-118.

Win, K.K. 2005. Trapiche of Myanmar. Australian Gemmologist. 22: 269-270.

http://www.anpa.ualr.edu/digital_library/narratives/VietMap_large.jpg [2008, January 22].

http://www. crystal-treasure.com [2008, February 5].

http://www.lib.utexas.edu/maps/middle_east_and_asia/cambodia_pol_97.jpg [2008, January 22].

http://www. usuarious.lycos.es [2008, January 10].

APPENDICES

APPENDIX I

Table A.1 EPMA analyses of trapiche sapphire samples from Thailand and recalculated atomic proportions based on 3(O).

Table A.2 EPMA analyses of trapiche sapphire samples from Cambodia and Recalculated atomic proportions based on 3(O).

Table A.3 EPMA analyses of trapiche sapphire samples from Vietnam and recalculated atomic proportions based on 3(O).

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan1

	Core						Arm										
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	98.02	97.92	97.92	97.76	98.60	98.61	99.01	99.15	99.14	98.89	99.13	98.98	98.95	98.67	98.66	98.94	98.91
SiO_2	0.00	0.00	0.06	0.01	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.01	0.02
TiO_2	0.16	0.13	0.21	0.14	0.08	0.44	0.07	0.02	0.03	0.14	0.04	0.02	0.05	0.03	0.01	0.03	0.01
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Ga_2O_3	0.05	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.01	0.03	0.04	0.03	0.02	0.02	0.03
V_2O_3	0.03	0.02	0.03	0.01	0.02	0.02	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.02	0.00	0.00
Fe_2O_3	1.61	1.74	1.50	1.48	0.89	1.10	0.83	0.76	0.78	0.87	0.79	0.78	0.79	0.80	0.73	0.75	0.72
CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.06	0.08	0.07	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.95	99.95	99.84	99.46	99.66	100.22	99.98	99.98	99.98	99.97	99.98	99.82	99.82	99.55	99.46	99.74	99.69
Formula 3(O)																	
Al	1.9744	1.9731	1.9736	1.9774	1.9859	1.9774	1.9872	1.9894	1.9892	1.9855	1.9890	1.9891	1.9887	1.9886	1.9895	1.9895	1.9898
Si	0.0000	0.0001	0.0009	0.0002	0.0002	0.0001	0.0003	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0003	0.0001	0.0003
Ti	0.0021	0.0016	0.0028	0.0018	0.0011	0.0056	0.0009	0.0002	0.0004	0.0018	0.0006	0.0002	0.0006	0.0004	0.0002	0.0003	0.0002
Cr	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Ga	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0001	0.0003	0.0004	0.0003	0.0002	0.0002	0.0004
V	0.0004	0.0003	0.0004	0.0002	0.0003	0.0003	0.0000	0.0001	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000
Fe	0.0207	0.0223	0.0193	0.0190	0.0115	0.0141	0.0107	0.0098	0.0100	0.0111	0.0101	0.0100	0.0101	0.0103	0.0095	0.0096	0.0092
Ca	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0014	0.0021	0.0018	0.0002	0.0002	0.0003	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0002	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
K	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	1.9999	2.0002	1.9995	1.9994	1.9997	1.9982	1.9997	1.9999	1.9999	1.9994	1.9998	1.9999	1.9998	1.9999	1.9999	1.9999	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan1

Growth sector																
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Al_2O_3	99.06	99.03	99.14	99.13	99.06	98.46	98.43	98.17	99.01	99.03	98.79	98.63	98.78	98.82	98.51	98.81
SiO_2	0.02	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.02	0.01	0.00
TiO_2	0.04	0.05	0.00	0.01	0.05	0.02	0.01	0.35	0.02	0.02	0.04	0.05	0.04	0.02	0.01	0.02
Cr_2O_3	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00
Ga_2O_3	0.03	0.02	0.03	0.02	0.02	0.01	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.02	0.02	0.02
V_2O_3	0.00	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Fe_2O_3	0.82	0.84	0.78	0.79	0.83	0.73	0.69	1.02	0.76	0.76	0.76	0.76	0.74	0.81	0.70	0.71
CaO	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MgO	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.98	99.98	99.98	99.98	99.98	99.23	99.16	99.58	99.82	99.86	99.62	99.49	99.60	99.72	99.27	99.57
Formula 3(O)																
Al	1.9879	1.9876	1.9892	1.9891	1.9879	1.9901	1.9906	1.9805	1.9895	1.9893	1.9891	1.9886	1.9894	1.9882	1.9900	1.9902
Si	0.0004	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0003	0.0000	0.0003	0.0002	0.0000
Ti	0.0005	0.0006	0.0000	0.0002	0.0007	0.0002	0.0001	0.0045	0.0002	0.0002	0.0004	0.0007	0.0004	0.0003	0.0001	0.0003
Cr	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000
Ga	0.0003	0.0002	0.0004	0.0002	0.0002	0.0001	0.0002	0.0004	0.0003	0.0004	0.0003	0.0002	0.0002	0.0002	0.0003	0.0002
V	0.0000	0.0003	0.0001	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0001
Fe	0.0105	0.0108	0.0100	0.0101	0.0106	0.0094	0.0089	0.0131	0.0097	0.0097	0.0098	0.0098	0.0096	0.0104	0.0090	0.0091
Ca	0.0002	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Mg	0.0000	0.0004	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Total*	1.9998	2.0000	1.9999	2.0000	1.9998	2.0000	2.0000	1.9986	1.9999	1.9999	1.9999	1.9997	1.9999	1.9999	1.9999	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan2																	
	Core						Arm										
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	98.39	98.53	98.74	99.08	98.60	99.06	98.60	98.59	98.82	98.81	99.03	99.88	100.07	99.65	99.81	99.56	99.63
SiO_2	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.00	0.01	0.03	0.00	0.00	0.01	0.01	0.01	0.01	0.02
TiO_2	0.51	0.36	0.25	0.33	0.45	0.29	0.40	0.32	0.02	0.19	0.06	0.02	0.02	0.08	0.02	0.04	0.03
Cr_2O_3	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01
Ga_2O_3	0.05	0.06	0.02	0.02	0.02	0.03	0.00	0.01	0.04	0.04	0.00	0.03	0.03	0.02	0.03	0.03	0.03
V_2O_3	0.07	0.06	0.03	0.01	0.00	0.02	0.06	0.05	0.01	0.04	0.01	0.02	0.01	0.02	0.01	0.00	0.00
Fe_2O_3	0.93	0.92	0.88	0.88	0.82	0.82	0.90	0.96	1.05	0.85	0.88	0.80	0.81	0.82	0.83	0.92	0.84
CaO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.03	0.04	0.02	0.00	0.00	0.02	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Total	99.98	99.98	99.98	100.36	99.89	100.23	99.98	99.98	99.98	99.98	99.98	100.76	100.97	100.59	100.72	100.57	100.56
Formula 3(O)																	
Al	1.9773	1.9798	1.9828	1.9820	1.9816	1.9837	1.9803	1.9806	1.9849	1.9840	1.9875	1.9888	1.9885	1.9876	1.9884	1.9870	1.9880
Si	0.0002	0.0001	0.0001	0.0003	0.0000	0.0002	0.0002	0.0000	0.0002	0.0005	0.0000	0.0000	0.0001	0.0002	0.0002	0.0001	0.0003
Ti	0.0065	0.0046	0.0031	0.0041	0.0057	0.0037	0.0051	0.0041	0.0002	0.0025	0.0007	0.0002	0.0003	0.0010	0.0002	0.0005	0.0003
Cr	0.0002	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
Ga	0.0005	0.0007	0.0002	0.0003	0.0002	0.0003	0.0000	0.0001	0.0005	0.0005	0.0000	0.0003	0.0004	0.0002	0.0003	0.0004	0.0003
V	0.0009	0.0008	0.0005	0.0001	0.0000	0.0002	0.0008	0.0007	0.0001	0.0005	0.0001	0.0003	0.0001	0.0002	0.0001	0.0000	0.0000
Fe	0.0120	0.0118	0.0113	0.0112	0.0105	0.0105	0.0116	0.0123	0.0135	0.0109	0.0113	0.0102	0.0103	0.0104	0.0105	0.0117	0.0106
Ca	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Mg	0.0001	0.0008	0.0009	0.0004	0.0000	0.0001	0.0005	0.0012	0.0007	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001
Total*	1.9978	1.9987	1.9992	1.9986	1.9981	1.9988	1.9984	1.9990	2.0001	1.9990	1.9998	2.0000	1.9999	1.9996	1.9999	1.9999	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan2																
Growth sector																
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Al_2O_3	98.99	99.02	98.98	99.33	99.57	99.53	99.28	98.39	99.17	99.73	99.40	99.54	99.79	99.49	99.80	99.40
SiO_2	0.01	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.01	0.01	0.01	0.00
TiO_2	0.03	0.08	0.00	0.02	0.03	0.03	0.10	0.51	0.23	0.03	0.06	0.04	0.10	0.13	0.03	0.02
Cr_2O_3	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01
Ga_2O_3	0.02	0.00	0.01	0.01	0.01	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.02	0.04
V_2O_3	0.01	0.02	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.01	0.00	0.01
Fe_2O_3	0.91	0.84	0.96	0.97	0.86	0.83	0.83	0.90	0.81	0.79	0.99	0.94	0.87	0.86	0.82	0.80
CaO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
MnO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Total	99.98	99.99	99.98	100.37	100.49	100.43	100.25	99.86	100.25	100.59	100.52	100.59	100.81	100.53	100.70	100.27
Formula 3(O)																
Al	1.9871	1.9873	1.9871	1.9865	1.9881	1.9883	1.9871	1.9789	1.9853	1.9890	1.9855	1.9863	1.9865	1.9861	1.9884	1.9889
Si	0.0002	0.0002	0.0002	0.0004	0.0000	0.0000	0.0002	0.0001	0.0001	0.0000	0.0000	0.0004	0.0002	0.0002	0.0002	0.0000
Ti	0.0004	0.0010	0.0000	0.0002	0.0004	0.0004	0.0012	0.0065	0.0029	0.0004	0.0008	0.0005	0.0013	0.0016	0.0003	0.0003
Cr	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0002	0.0001
Ga	0.0002	0.0000	0.0001	0.0001	0.0002	0.0003	0.0003	0.0003	0.0002	0.0003	0.0003	0.0003	0.0003	0.0004	0.0003	0.0004
V	0.0001	0.0002	0.0000	0.0001	0.0001	0.0001	0.0000	0.0002	0.0001	0.0000	0.0002	0.0001	0.0000	0.0001	0.0000	0.0001
Fe	0.0116	0.0108	0.0123	0.0124	0.0110	0.0105	0.0107	0.0116	0.0103	0.0101	0.0126	0.0119	0.0110	0.0109	0.0104	0.0102
Ca	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0003	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0002	0.0000
Mn	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9998	1.9997	2.0000	1.9999	1.9999	1.9999	1.9996	1.9979	1.9990	2.0000	1.9999	1.9997	1.9995	1.9994	1.9999	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan3

	Core					Arm							
Analysis no.	1	2	3	4	5	1	2	3	4	5	6	7	8
Al_2O_3	98.48	97.66	98.33	98.51	97.94	97.88	97.86	97.95	98.05	98.23	98.98	99.67	99.03
SiO_2	0.03	0.04	0.02	0.01	0.01	0.01	0.00	0.03	0.03	0.01	0.02	0.02	0.02
TiO_2	0.03	0.02	0.00	0.08	0.01	0.02	0.01	0.06	0.06	0.03	0.07	0.00	0.11
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.02	0.04	0.03	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.02	0.03	0.03
V_2O_3	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01
Fe_2O_3	1.42	1.51	1.32	1.67	1.62	1.18	1.20	1.20	1.25	1.12	1.27	1.10	1.30
CaO	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01
MgO	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.02	0.00	0.02	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.98	99.27	99.71	100.31	99.63	99.14	99.11	99.31	99.42	99.45	100.37	100.83	100.52
Formula 3(O)													
Al	1.9804	1.9787	1.9821	1.9764	1.9780	1.9834	1.9838	1.9820	1.9819	1.9841	1.9819	1.9851	1.9804
Si	0.0005	0.0007	0.0003	0.0002	0.0002	0.0002	0.0001	0.0004	0.0005	0.0001	0.0003	0.0003	0.0003
Ti	0.0004	0.0002	0.0000	0.0011	0.0002	0.0003	0.0002	0.0007	0.0007	0.0003	0.0009	0.0000	0.0014
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
Ga	0.0002	0.0004	0.0003	0.0004	0.0003	0.0002	0.0002	0.0004	0.0003	0.0003	0.0002	0.0004	0.0003
V	0.0000	0.0001	0.0001	0.0000	0.0002	0.0002	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001
Fe	0.0183	0.0195	0.0170	0.0214	0.0209	0.0152	0.0155	0.0155	0.0161	0.0145	0.0162	0.0140	0.0166
Ca	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001
Mg	0.0000	0.0000	0.0001	0.0001	0.0002	0.0001	0.0002	0.0004	0.0000	0.0004	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9997	1.9997	2.0000	1.9996	2.0000	1.9999	2.0000	1.9998	1.9996	2.0000	1.9996	1.9999	1.9995

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan3

Growth sector																	
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Al_2O_3	97.82	98.03	97.96	98.04	98.17	98.41	98.62	98.65	98.37	98.54	99.61	99.54	99.43	98.69	98.79	98.55	98.50
SiO_2	0.04	0.03	0.04	0.03	0.03	0.02	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.01
TiO_2	0.05	0.05	0.05	0.03	0.00	0.04	0.04	0.04	0.04	0.08	0.01	0.03	0.03	0.04	0.01	0.04	0.04
Cr_2O_3	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.03	0.03	0.03	0.05	0.01	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.04
V_2O_3	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02
Fe_2O_3	1.25	1.23	1.20	1.16	1.08	1.33	1.29	1.27	1.33	1.38	1.13	1.14	1.30	1.30	1.25	1.29	1.28
CaO	0.00	0.01	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00
MgO	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.19	99.39	99.33	99.34	99.30	99.85	99.99	100.02	99.78	100.04	100.80	100.76	100.81	100.08	100.11	99.92	99.90
Formula 3(O)																	
Al	1.9816	1.9821	1.9816	1.9829	1.9852	1.9812	1.9823	1.9824	1.9815	1.9804	1.9848	1.9842	1.9823	1.9819	1.9829	1.9824	1.9818
Si	0.0007	0.0004	0.0008	0.0006	0.0004	0.0003	0.0000	0.0001	0.0003	0.0002	0.0001	0.0002	0.0001	0.0003	0.0002	0.0000	0.0002
Ti	0.0006	0.0006	0.0006	0.0004	0.0000	0.0006	0.0006	0.0005	0.0005	0.0010	0.0001	0.0003	0.0003	0.0005	0.0002	0.0005	0.0005
Cr	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
Ga	0.0004	0.0004	0.0003	0.0005	0.0001	0.0002	0.0003	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004
V	0.0000	0.0000	0.0002	0.0001	0.0001	0.0002	0.0000	0.0002	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0002
Fe	0.0161	0.0159	0.0155	0.0149	0.0140	0.0170	0.0166	0.0163	0.0171	0.0177	0.0144	0.0146	0.0166	0.0166	0.0160	0.0166	0.0164
Ca	0.0001	0.0001	0.0000	0.0003	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Mg	0.0001	0.0000	0.0005	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Mn	0.0000	0.0002	0.0002	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001
Total*	1.9996	1.9998	1.9998	1.9998	1.9999	1.9998	1.9999	1.9999	1.9998	1.9996	2.0000	1.9999	2.0000	1.9998	2.0000	1.9999	1.9998

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan4

	Core						Arm								
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9
Al_2O_3	97.84	98.21	98.37	98.03	98.07	98.48	98.50	98.54	98.19	97.98	98.84	98.56	99.04	98.83	98.82
SiO_2	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.00	0.02
TiO_2	0.03	0.02	0.00	0.03	0.03	0.01	0.02	0.01	0.02	0.04	0.02	0.03	0.03	0.02	0.00
Cr_2O_3	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Ga_2O_3	0.03	0.03	0.04	0.02	0.03	0.03	0.00	0.02	0.02	0.00	0.01	0.02	0.03	0.03	0.03
V_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
Fe_2O_3	1.44	1.14	1.22	1.50	1.42	1.31	1.13	1.12	1.13	1.18	1.20	1.25	1.18	1.17	1.24
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MgO	0.00	0.00	0.04	0.00	0.00	0.00	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total	99.38	99.43	99.71	99.59	99.57	99.85	99.70	99.74	99.39	99.23	100.09	99.91	100.29	100.05	100.12
Formula 3(O)															
Al	1.9797	1.9839	1.9827	1.9797	1.9806	1.9823	1.9843	1.9845	1.9845	1.9835	1.9839	1.9824	1.9837	1.9843	1.9833
Si	0.0006	0.0005	0.0001	0.0000	0.0000	0.0002	0.0002	0.0001	0.0001	0.0003	0.0002	0.0003	0.0003	0.0000	0.0003
Ti	0.0004	0.0003	0.0000	0.0004	0.0004	0.0002	0.0003	0.0001	0.0002	0.0005	0.0002	0.0004	0.0003	0.0002	0.0000
Cr	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000
Ga	0.0003	0.0003	0.0004	0.0003	0.0003	0.0003	0.0000	0.0002	0.0002	0.0000	0.0001	0.0002	0.0003	0.0003	0.0003
V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0001	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000
Fe	0.0186	0.0147	0.0157	0.0194	0.0183	0.0168	0.0145	0.0144	0.0145	0.0152	0.0154	0.0161	0.0151	0.0150	0.0159
Ca	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0002
Mg	0.0001	0.0000	0.0009	0.0000	0.0000	0.0000	0.0007	0.0006	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
K	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
Total*	1.9998	1.9998	2.0003	1.9999	1.9999	1.9999	2.0002	2.0002	2.0001	1.9998	1.9999	1.9999	1.9998	1.9999	2.0000

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan4

Growth sector																			
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Al_2O_3	98.06	98.23	98.10	97.89	98.02	98.30	97.74	98.20	98.37	98.46	98.41	98.51	98.58	98.86	98.67	98.94	98.79	98.67	98.70
SiO_2	0.02	0.01	0.02	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00
TiO_2	0.00	0.02	0.04	0.04	0.02	0.03	0.03	0.03	0.00	0.03	0.02	0.02	0.01	0.03	0.02	0.03	0.02	0.01	0.02
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Ga_2O_3	0.02	0.03	0.02	0.02	0.03	0.02	0.04	0.02	0.03	0.03	0.02	0.01	0.03	0.02	0.02	0.02	0.03	0.02	0.03
V_2O_3	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01
Fe_2O_3	1.18	1.23	1.18	1.16	1.14	1.14	1.21	1.18	1.08	1.24	1.28	1.27	1.13	1.23	1.25	1.27	1.24	1.16	1.15
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.30	99.56	99.37	99.16	99.22	99.49	99.03	99.44	99.50	99.76	99.76	99.83	99.79	100.16	99.97	100.27	100.09	99.86	99.90
Formula 3(O)																			
Al	1.9838	1.9827	1.9834	1.9833	1.9845	1.9846	1.9830	1.9839	1.9856	1.9832	1.9826	1.9829	1.9845	1.9831	1.9832	1.9828	1.9833	1.9847	1.9845
Si	0.0003	0.0002	0.0003	0.0003	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0003	0.0000	0.0000	0.0000
Ti	0.0000	0.0003	0.0005	0.0005	0.0003	0.0003	0.0004	0.0003	0.0000	0.0003	0.0003	0.0003	0.0001	0.0003	0.0003	0.0003	0.0002	0.0001	0.0002
Cr	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
Ga	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003	0.0004	0.0002	0.0003	0.0003	0.0002	0.0001	0.0004	0.0002	0.0002	0.0002	0.0003	0.0002	0.0003
V	0.0002	0.0002	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0002	0.0000	0.0000	0.0002	0.0000	0.0001
Fe	0.0152	0.0158	0.0152	0.0150	0.0147	0.0147	0.0156	0.0153	0.0139	0.0160	0.0165	0.0163	0.0145	0.0158	0.0160	0.0162	0.0159	0.0149	0.0147
Ca	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0004	0.0000	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Total*	1.9999	2.0000	1.9998	1.9999	2.0000	1.9999	1.9998	1.9999	2.0002	1.9999	1.9999	1.9999	2.0000	1.9998	1.9999	1.9998	1.9999	2.0000	2.0000

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan5

	Core						Arm										
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	98.78	98.82	98.75	99.00	98.90	99.12	99.78	99.76	98.94	99.00	99.06	99.12	99.09	99.10	99.09	100.07	99.06
SiO_2	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
TiO_2	0.00	0.03	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Ga_2O_3	0.02	0.04	0.03	0.03	0.03	0.01	0.02	0.04	0.05	0.02	0.03	0.03	0.01	0.01	0.01	0.03	0.03
V_2O_3	0.01	0.00	0.01	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.00	0.00
Fe_2O_3	1.15	1.09	1.18	0.99	1.04	0.86	0.89	0.97	1.01	0.97	0.91	0.85	0.89	0.86	0.87	0.92	0.90
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01
MgO	0.05	0.03	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.02	100.03	100.02	100.02	100.02	100.01	100.70	100.80	100.01	100.01	100.01	100.01	100.02	100.02	100.01	101.02	100.02
Formula 3(O)																	
Al	1.9840	1.9844	1.9835	1.9869	1.9855	1.9883	1.9883	1.9868	1.9862	1.9870	1.9879	1.9886	1.9881	1.9882	1.9880	1.9880	1.9877
Si	0.0000	0.0001	0.0002	0.0000	0.0002	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0002
Ti	0.0000	0.0004	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001
Cr	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000
Ga	0.0002	0.0004	0.0003	0.0003	0.0003	0.0001	0.0002	0.0004	0.0006	0.0003	0.0003	0.0003	0.0001	0.0001	0.0001	0.0003	0.0003
V	0.0001	0.0000	0.0001	0.0000	0.0005	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0003	0.0004	0.0001	0.0000	0.0000
Fe	0.0147	0.0139	0.0152	0.0126	0.0134	0.0110	0.0113	0.0123	0.0129	0.0124	0.0117	0.0109	0.0114	0.0110	0.0111	0.0116	0.0115
Ca	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001
Mg	0.0012	0.0008	0.0006	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Mn	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	2.0005	2.0002	2.0002	2.0000	2.0000	1.9999	2.0000	2.0001	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan5

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	98.91	99.08	99.53	99.64	99.76	98.99	99.10	99.11	99.08	99.07	99.08	99.06	99.01	99.08	99.06	99.07	99.08	99.06
SiO_2	0.02	0.00	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.00	0.00	0.03	0.00	0.01	0.00	0.01	0.01	0.02
TiO_2	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01
Cr_2O_3	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
Ga_2O_3	0.01	0.01	0.05	0.03	0.02	0.04	0.01	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.04	0.03	0.03	0.01
V_2O_3	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01
Fe_2O_3	0.98	0.96	1.02	0.96	0.93	0.97	0.86	0.86	0.89	0.90	0.91	0.90	0.95	0.89	0.90	0.90	0.88	0.92
CaO	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.95	100.07	100.65	100.66	100.74	100.02	100.02	100.02	100.01	100.01	100.02	100.02	100.02	100.02	100.02	100.02	100.02	100.03
Formula 3(O)																		
Al	1.9866	1.9874	1.9857	1.9870	1.9875	1.9867	1.9881	1.9883	1.9880	1.9880	1.9880	1.9875	1.9872	1.9880	1.9878	1.9877	1.9879	1.9873
Si	0.0003	0.0000	0.0001	0.0002	0.0003	0.0002	0.0003	0.0003	0.0001	0.0000	0.0000	0.0004	0.0000	0.0001	0.0000	0.0002	0.0002	0.0003
Ti	0.0002	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001
Cr	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Ga	0.0001	0.0002	0.0006	0.0003	0.0002	0.0004	0.0001	0.0003	0.0002	0.0002	0.0002	0.0002	0.0005	0.0003	0.0005	0.0003	0.0004	0.0001
V	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0002
Fe	0.0126	0.0122	0.0130	0.0122	0.0118	0.0125	0.0111	0.0110	0.0114	0.0115	0.0116	0.0116	0.0122	0.0114	0.0115	0.0115	0.0113	0.0117
Ca	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
Mg	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000
Mn	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001
K	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Total*	1.9999	2.0000	2.0001	1.9999	1.9999	1.9999	1.9999	1.9999	2.0000	2.0000	2.0000	1.9999	2.0000	1.9999	2.0000	2.0000	2.0000	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan6															
	Core						Arm								
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9
Al_2O_3	98.72	98.45	98.15	99.08	99.04	99.04	98.46	98.91	98.59	98.92	99.04	98.87	99.34	98.42	99.13
SiO_2	0.06	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.01	0.02	0.02	0.02
TiO_2	0.07	0.02	0.03	0.03	0.01	0.04	0.22	0.21	0.09	0.10	0.07	0.16	0.12	0.10	0.20
Cr_2O_3	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00
Ga_2O_3	0.02	0.05	0.02	0.01	0.02	0.02	0.06	0.02	0.03	0.02	0.01	0.03	0.01	0.03	0.02
V_2O_3	0.02	0.00	0.01	0.01	0.02	0.02	0.03	0.00	0.02	0.02	0.00	0.01	0.00	0.00	0.00
Fe_2O_3	1.03	0.76	0.78	0.77	0.68	0.80	0.73	0.70	0.74	0.67	0.66	0.70	0.68	0.74	0.72
CaO	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
MgO	0.04	0.01	0.05	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.03	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.99	99.30	99.05	99.93	99.78	99.91	99.52	99.85	99.49	99.74	99.80	99.80	100.17	99.35	100.08
Formula 3(O)															
Al	1.9827	1.9889	1.9879	1.9889	1.9904	1.9886	1.9854	1.9871	1.9879	1.9890	1.9900	1.9873	1.9887	1.9873	1.9868
Si	0.0010	0.0001	0.0001	0.0002	0.0000	0.0000	0.0002	0.0000	0.0003	0.0000	0.0000	0.0002	0.0003	0.0003	0.0003
Ti	0.0009	0.0003	0.0004	0.0004	0.0002	0.0005	0.0028	0.0027	0.0012	0.0013	0.0009	0.0021	0.0015	0.0013	0.0025
Cr	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0002	0.0000
Ga	0.0003	0.0005	0.0002	0.0001	0.0002	0.0002	0.0007	0.0003	0.0003	0.0002	0.0001	0.0003	0.0001	0.0003	0.0002
V	0.0003	0.0000	0.0002	0.0001	0.0003	0.0003	0.0004	0.0000	0.0002	0.0002	0.0000	0.0002	0.0000	0.0000	0.0000
Fe	0.0132	0.0098	0.0101	0.0099	0.0087	0.0102	0.0094	0.0089	0.0095	0.0086	0.0085	0.0090	0.0087	0.0095	0.0092
Ca	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0000
Mg	0.0010	0.0004	0.0013	0.0002	0.0000	0.0001	0.0000	0.0000	0.0002	0.0002	0.0000	0.0000	0.0001	0.0007	0.0001
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9998	2.0000	2.0003	1.9999	2.0000	1.9999	1.9990	1.9991	1.9997	1.9996	1.9998	1.9993	1.9995	1.9997	1.9991

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan6															
Growth sector															
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Al_2O_3	98.32	98.50	98.14	98.75	99.03	99.11	99.43	99.21	99.22	98.72	99.06	99.03	98.68	98.75	98.72
SiO_2	0.00	0.02	0.00	0.03	0.02	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
TiO_2	0.09	0.05	0.15	0.02	0.00	0.04	0.11	0.11	0.14	0.10	0.15	0.16	0.19	0.16	0.20
Cr_2O_3	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.03	0.04	0.02	0.02	0.03	0.02	0.02	0.03	0.01	0.03	0.03	0.04	0.02	0.01	0.03
V_2O_3	0.02	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.03	0.01	0.03	0.00	0.01
Fe_2O_3	0.77	0.69	0.70	0.64	0.58	0.60	0.58	0.63	0.64	0.68	0.70	0.67	0.73	0.72	0.72
CaO	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
MgO	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.27	99.32	99.06	99.48	99.67	99.77	100.16	100.00	100.04	99.54	99.97	99.91	99.66	99.65	99.68
Formula 3(O)															
Al	1.9873	1.9891	1.9875	1.9903	1.9917	1.9913	1.9902	1.9893	1.9889	1.9890	1.9877	1.9881	1.9866	1.9877	1.9867
Si	0.0000	0.0003	0.0000	0.0005	0.0003	0.0002	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Ti	0.0012	0.0006	0.0019	0.0003	0.0000	0.0004	0.0014	0.0014	0.0018	0.0013	0.0019	0.0020	0.0024	0.0020	0.0026
Cr	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Ga	0.0003	0.0004	0.0002	0.0003	0.0003	0.0002	0.0003	0.0003	0.0001	0.0003	0.0003	0.0004	0.0003	0.0001	0.0003
V	0.0003	0.0000	0.0004	0.0000	0.0001	0.0000	0.0000	0.0000	0.0002	0.0001	0.0004	0.0002	0.0003	0.0000	0.0002
Fe	0.0099	0.0089	0.0091	0.0082	0.0075	0.0077	0.0074	0.0081	0.0082	0.0087	0.0089	0.0086	0.0094	0.0093	0.0092
Ca	0.0000	0.0000	0.0002	0.0002	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Mg	0.0006	0.0004	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0001
Mn	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	1.9998	1.9998	1.9995	1.9998	1.9999	1.9998	1.9996	1.9995	1.9994	1.9996	1.9994	1.9993	1.9993	1.9994	1.9992

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan7																
	Core						Arm									
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10
Al_2O_3	97.79	97.87	97.88	98.75	98.76	98.77	98.89	98.83	97.85	98.78	98.87	98.88	98.90	98.84	98.85	98.99
SiO_2	0.01	0.00	0.02	0.00	0.00	0.01	0.01	0.03	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00
TiO_2	0.01	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.00
Cr_2O_3	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.03	0.01	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.03	0.03	0.01	0.02
V_2O_3	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.02	0.00
Fe_2O_3	1.26	1.27	1.15	1.17	1.16	1.16	1.05	1.10	1.11	1.16	1.06	1.05	1.03	1.10	1.08	0.98
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.01	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MnO	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.13	99.20	99.08	99.97	99.98	99.97	99.99	99.99	99.02	99.99	99.97	99.98	99.98	99.98	99.98	99.98
Formula 3(O)																
Al	1.9826	1.9826	1.9843	1.9844	1.9843	1.9845	1.9859	1.9849	1.9846	1.9845	1.9857	1.9860	1.9861	1.9854	1.9856	1.9873
Si	0.0001	0.0000	0.0003	0.0000	0.0000	0.0001	0.0002	0.0005	0.0004	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
Ti	0.0001	0.0001	0.0000	0.0001	0.0002	0.0001	0.0000	0.0001	0.0002	0.0003	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000
Cr	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Ga	0.0003	0.0001	0.0003	0.0003	0.0003	0.0002	0.0002	0.0001	0.0002	0.0001	0.0003	0.0002	0.0003	0.0003	0.0002	0.0002
V	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0002	0.0002	0.0000	0.0002	0.0000
Fe	0.0163	0.0164	0.0149	0.0150	0.0149	0.0148	0.0135	0.0141	0.0144	0.0148	0.0136	0.0135	0.0132	0.0141	0.0139	0.0125
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mg	0.0002	0.0012	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0000
Mn	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	2.0001	2.0004	1.9999	2.0000	1.9999	2.0001	1.9999	1.9998	1.9999	1.9999	2.0000	2.0001	2.0000	2.0001	2.0000	2.0000

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan7

Growth sector															
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Al_2O_3	97.84	98.81	98.82	98.92	98.86	98.88	98.89	98.82	98.87	98.91	98.91	98.91	98.89	98.80	98.89
SiO_2	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.07	0.00	0.00	0.01	0.01	0.00	0.01	0.01
TiO_2	0.01	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00
Cr_2O_3	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
Ga_2O_3	0.04	0.04	0.03	0.02	0.01	0.02	0.02	0.05	0.02	0.04	0.01	0.01	0.02	0.02	0.01
V_2O_3	0.01	0.00	0.01	0.01	0.01	0.02	0.00	0.01	0.02	0.00	0.02	0.00	0.00	0.00	0.00
Fe_2O_3	1.13	1.12	1.08	1.02	1.08	1.04	1.05	1.02	1.05	1.03	1.03	1.01	1.06	1.13	1.07
CaO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.04	99.99	99.97	99.97	99.97	99.97	99.98	99.98	99.98	99.97	99.97	99.97	99.98	99.97	99.98
Formula 3(O)															
Al	1.9845	1.9849	1.9851	1.9864	1.9857	1.9859	1.9859	1.9847	1.9859	1.9864	1.9862	1.9862	1.9860	1.9848	1.9860
Si	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0002	0.0012	0.0001	0.0000	0.0002	0.0001	0.0000	0.0001	0.0002
Ti	0.0001	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0002	0.0000
Cr	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000
Ga	0.0005	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002	0.0005	0.0003	0.0004	0.0001	0.0001	0.0002	0.0002	0.0002
V	0.0001	0.0000	0.0002	0.0001	0.0001	0.0002	0.0001	0.0001	0.0003	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000
Fe	0.0146	0.0144	0.0138	0.0130	0.0139	0.0134	0.0134	0.0130	0.0134	0.0131	0.0131	0.0130	0.0135	0.0145	0.0137
Ca	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Total*	2.0000	2.0000	1.9999	2.0000	2.0000	2.0001	2.0000	1.9998	2.0000	2.0000	1.9999	2.0000	2.0000	1.9999	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan8

	Core								Arm							
Analysis no.	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Al_2O_3	99.92	99.00	98.96	99.88	99.34	99.20	99.32	99.57	98.61	98.78	98.79	98.76	98.85	98.78	98.91	98.87
SiO_2	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.00
TiO_2	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.16	0.03	0.05	0.04	0.00	0.03	0.01	0.00
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Ga_2O_3	0.03	0.00	0.03	0.02	0.04	0.03	0.03	0.03	0.05	0.06	0.02	0.01	0.03	0.04	0.02	0.02
V_2O_3	0.01	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.94	0.97	1.01	0.87	1.05	0.97	1.00	0.98	1.15	1.14	1.14	1.18	1.11	1.18	1.08	1.10
CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MgO	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.93	100.01	100.02	100.79	100.45	100.20	100.38	100.61	100.02	100.01	100.02	100.01	100.01	100.02	100.02	100.02
Formula 3(O)																
Al	1.9873	1.9868	1.9865	1.9883	1.9859	1.9873	1.9864	1.9868	1.9811	1.9842	1.9839	1.9836	1.9851	1.9840	1.9858	1.9853
Si	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0001	0.0003	0.0000	0.0000	0.0000	0.0000
Ti	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0002	0.0021	0.0003	0.0007	0.0006	0.0000	0.0003	0.0001	0.0000
Cr	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0002
Ga	0.0003	0.0000	0.0004	0.0002	0.0004	0.0003	0.0003	0.0004	0.0005	0.0006	0.0002	0.0001	0.0003	0.0004	0.0002	0.0003
V	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0002	0.0001	0.0003	0.0001	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
Fe	0.0119	0.0124	0.0129	0.0111	0.0134	0.0124	0.0128	0.0125	0.0147	0.0146	0.0146	0.0151	0.0143	0.0151	0.0138	0.0141
Ca	0.0002	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Mg	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	2.0001	2.0004	2.0000	2.0000	2.0000	2.0000	1.9999	2.0000	1.9994	1.9999	1.9998	1.9998	2.0000	1.9999	2.0000	2.0000

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan8

Growth sector																	
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Al_2O_3	98.72	98.89	98.74	99.58	99.45	99.44	99.21	99.48	99.61	99.67	99.72	98.84	99.66	98.76	98.85	98.87	98.90
SiO_2	0.00	0.01	0.01	0.02	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.00
TiO_2	0.05	0.00	0.06	0.01	0.02	0.06	0.09	0.06	0.01	0.06	0.02	0.04	0.01	0.03	0.01	0.01	0.02
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.00
Ga_2O_3	0.04	0.05	0.02	0.03	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.02	0.03	0.04	0.03	0.02	0.04
V_2O_3	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.03	0.01	0.01	0.00	0.00	0.01
Fe_2O_3	1.11	1.07	1.17	1.10	1.13	1.04	1.19	1.20	1.17	1.21	1.17	1.08	1.11	1.16	1.09	1.09	1.05
CaO	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.95	100.02	100.02	100.75	100.64	100.59	100.56	100.76	100.83	100.98	100.95	100.01	100.84	100.01	100.02	100.02	100.02
Formula 3(O)																	
Al	1.9842	1.9855	1.9831	1.9850	1.9848	1.9850	1.9821	1.9834	1.9846	1.9831	1.9843	1.9848	1.9849	1.9838	1.9850	1.9852	1.9856
Si	0.0000	0.0001	0.0002	0.0003	0.0001	0.0001	0.0005	0.0000	0.0000	0.0001	0.0000	0.0000	0.0003	0.0001	0.0002	0.0001	0.0000
Ti	0.0006	0.0000	0.0008	0.0001	0.0002	0.0008	0.0012	0.0007	0.0002	0.0007	0.0003	0.0005	0.0001	0.0003	0.0002	0.0001	0.0002
Cr	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0002	0.0003	0.0000
Ga	0.0005	0.0005	0.0002	0.0003	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0005	0.0003	0.0002	0.0004
V	0.0002	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0003	0.0004	0.0001	0.0001	0.0000	0.0000	0.0001
Fe	0.0143	0.0137	0.0150	0.0140	0.0143	0.0133	0.0152	0.0153	0.0149	0.0154	0.0148	0.0138	0.0141	0.0149	0.0140	0.0140	0.0135
Ca	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001
Mg	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9999	2.0000	1.9999	2.0000	2.0000	1.9997	1.9995	1.9998	2.0000	1.9998	1.9999	1.9998	1.9999	1.9999	1.9999	1.9999	2.0000

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan9

	Core								Arm										
Analysis no.	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	97.45	98.33	97.94	97.97	98.16	98.57	98.19	98.19	99.16	99.53	98.79	99.15	99.55	98.29	98.46	97.98	98.35	98.07	98.32
SiO_2	0.02	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.00	0.01	0.03	0.00	0.01	0.00	0.00	0.01	0.00
TiO_2	0.08	0.04	0.03	0.03	0.06	0.05	0.05	0.04	0.01	0.03	0.05	0.06	0.02	0.03	0.11	0.01	0.02	0.13	0.03
Cr_2O_3	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Ga_2O_3	0.05	0.02	0.04	0.04	0.03	0.04	0.04	0.03	0.02	0.02	0.03	0.02	0.04	0.02	0.03	0.03	0.02	0.04	0.04
V_2O_3	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.03	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
Fe_2O_3	1.82	1.74	1.90	1.88	1.95	1.77	1.92	1.74	1.24	1.36	1.37	1.41	1.18	1.30	1.44	1.31	1.19	1.27	1.36
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Total	99.43	100.18	99.93	99.94	100.22	100.44	100.21	100.02	100.45	100.94	100.26	100.68	100.84	99.65	100.04	99.36	99.59	99.52	99.75
Formula 3(O)																			
Al	1.9738	1.9761	1.9743	1.9746	1.9734	1.9759	1.9738	1.9763	1.9833	1.9819	1.9811	1.9802	1.9834	1.9824	1.9792	1.9822	1.9840	1.9807	1.9815
Si	0.0004	0.0002	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0003	0.0001	0.0001	0.0002	0.0004	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000
Ti	0.0010	0.0005	0.0004	0.0004	0.0007	0.0007	0.0006	0.0005	0.0001	0.0004	0.0006	0.0008	0.0003	0.0004	0.0014	0.0002	0.0003	0.0016	0.0004
Cr	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Ga	0.0005	0.0005	0.0005	0.0001	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0002	0.0002	0.0004
V	0.0001	0.0002	0.0001	0.0000	0.0001	0.0002	0.0001	0.0004	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000
Fe	0.0236	0.0223	0.0244	0.0242	0.0251	0.0226	0.0246	0.0223	0.0158	0.0172	0.0176	0.0180	0.0150	0.0167	0.0185	0.0169	0.0153	0.0164	0.0175
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	1.9996	2.0002	2.0000	1.9995	1.9998	1.9996	1.9996	1.9998	1.9999	2.0000	1.9997	1.9996	1.9997	1.9999	1.9995	1.9999	2.0000	1.9992	1.9999

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan9

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.44	99.37	98.73	99.52	98.76	98.76	98.62	98.38	98.60	98.49	99.04	99.18	99.05	99.12	98.90	99.22	98.57	98.25
SiO_2	0.01	0.00	0.02	0.03	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
TiO_2	0.05	0.01	0.04	0.02	0.01	0.02	0.02	0.04	0.02	0.14	0.02	0.02	0.05	0.03	0.05	0.01	0.05	0.02
Cr_2O_3	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.02	0.03	0.03	0.02	0.01	0.03	0.03	0.02	0.01	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02
V_2O_3	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.03	0.01	0.00	0.00
Fe_2O_3	1.29	1.26	1.28	1.25	1.20	1.16	1.15	1.29	1.29	1.35	1.25	1.16	1.27	1.27	1.41	1.20	1.32	1.22
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01
MgO	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Total	100.82	100.68	100.14	100.88	100.01	99.97	99.83	99.75	99.94	100.03	100.35	100.41	100.42	100.46	100.42	100.49	99.97	99.53
Formula 3(O)																		
Al	1.9821	1.9832	1.9815	1.9822	1.9838	1.9843	1.9844	1.9824	1.9826	1.9793	1.9832	1.9842	1.9823	1.9829	1.9804	1.9836	1.9819	1.9834
Si	0.0001	0.0000	0.0003	0.0005	0.0002	0.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	0.0001	0.0002
Ti	0.0007	0.0002	0.0005	0.0002	0.0002	0.0003	0.0002	0.0006	0.0003	0.0017	0.0003	0.0003	0.0006	0.0004	0.0006	0.0002	0.0006	0.0002
Cr	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0002	0.0002	0.0002	0.0002	0.0004	0.0003	0.0003	0.0003	0.0001	0.0001	0.0003	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003
V	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0001	0.0001	0.0000	0.0004	0.0002	0.0001	0.0000
Fe	0.0165	0.0161	0.0164	0.0159	0.0154	0.0148	0.0148	0.0166	0.0166	0.0173	0.0160	0.0148	0.0162	0.0163	0.0181	0.0153	0.0169	0.0157
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001
Mg	0.0000	0.0000	0.0010	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0002
Total*	1.9998	1.9998	2.0000	2.0000	2.0001	1.9999	2.0000	1.9999	1.9999	1.9992	2.0001	1.9998	1.9998	1.9999	2.0000	1.9999	1.9998	2.0001

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan10

	Core					Arm					Growth sector										
Analysis no.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	98.57	98.81	98.95	98.95	98.91	98.98	99.01	98.74	99.07	100.00	98.97	99.08	99.04	99.07	99.10	99.09	99.06	99.10	99.09	98.95	99.01
SiO_2	0.02	0.02	0.00	0.01	0.00	0.01	0.02	0.00	0.03	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.03	0.01	0.00	0.00
TiO_2	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.01	0.02	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.01	0.02	0.03	0.03	0.03	0.02	0.03	0.01	0.02	0.03	0.02
V_2O_3	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
Fe_2O_3	1.15	1.09	1.03	1.01	1.07	0.98	0.93	0.91	0.87	0.86	1.03	0.91	0.91	0.89	0.87	0.90	0.92	0.86	0.87	0.92	0.97
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.04	0.03	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	99.80	99.97	100.02	100.01	100.02	100.01	100.02	99.67	100.02	100.91	100.01	100.02	100.02	100.02	100.02	100.02	100.02	100.02	100.02	99.93	100.02
Formula 3(O)																					
Al	1.9838	1.9848	1.9863	1.9864	1.9858	1.9868	1.9868	1.9880	1.9875	1.9885	1.9867	1.9879	1.9875	1.9877	1.9883	1.9879	1.9878	1.9879	1.9881	1.9874	1.9870
Si	0.0004	0.0003	0.0001	0.0002	0.0000	0.0002	0.0004	0.0001	0.0006	0.0001	0.0000	0.0002	0.0001	0.0002	0.0000	0.0003	0.0000	0.0005	0.0002	0.0000	0.0001
Ti	0.0001	0.0000	0.0000	0.0001	0.0002	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Ga	0.0001	0.0002	0.0003	0.0002	0.0003	0.0002	0.0003	0.0002	0.0002	0.0003	0.0001	0.0002	0.0003	0.0003	0.0003	0.0002	0.0003	0.0001	0.0003	0.0003	0.0002
V	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000
Fe	0.0147	0.0140	0.0132	0.0129	0.0137	0.0126	0.0119	0.0117	0.0112	0.0109	0.0132	0.0116	0.0117	0.0115	0.0111	0.0115	0.0118	0.0111	0.0111	0.0118	0.0124
Ca	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0009	0.0006	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0001
Mn	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Total*	2.0002	2.0001	2.0000	2.0000	2.0000	2.0000	1.9999	2.0000	1.9999	2.0000	2.0000	2.0000	2.0000	1.9999	2.0000	1.9999	2.0001	1.9999	1.9999	2.0001	2.0000

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Chan11

	Core						Arm							Growth sector							
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
Al_2O_3	98.20	98.22	98.22	98.34	98.56	98.26	98.75	98.85	98.89	98.84	98.85	98.87	98.80	98.66	98.73	98.70	98.89	97.88	98.68	98.57	98.78
SiO_2	0.01	0.00	0.03	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.03	0.02	0.01	0.00	0.00	0.00	0.01	0.02
TiO_2	0.05	0.02	0.04	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.00	0.03	0.02	0.02	0.01	0.02	0.01	0.05	0.03	0.07
Cr_2O_3	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.05	0.02	0.01	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.04	0.01	0.03	0.03	0.02	0.03	0.02	0.03
V_2O_3	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.03
Fe_2O_3	1.68	1.73	1.66	1.42	1.37	1.55	1.20	1.09	1.06	1.12	1.09	1.08	1.10	1.21	1.18	1.11	1.06	1.08	1.17	1.11	1.06
CaO	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00
MgO	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.99	99.99	99.99	99.86	99.97	99.86	99.99	99.98	99.99	99.98	99.99	99.99	99.98	99.99	99.99	99.89	99.99	99.00	99.95	99.75	99.98
Formula 3(O)																					
Al	1.9768	1.9772	1.9767	1.9804	1.9819	1.9793	1.9840	1.9854	1.9860	1.9853	1.9853	1.9858	1.9845	1.9827	1.9836	1.9846	1.9859	1.9855	1.9834	1.9847	1.9841
Si	0.0001	0.0000	0.0005	0.0002	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000	0.0001	0.0000	0.0002	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	0.0002	0.0003
Ti	0.0006	0.0002	0.0005	0.0003	0.0003	0.0003	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0004	0.0003	0.0002	0.0001	0.0002	0.0002	0.0006	0.0003	0.0008
Cr	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Ga	0.0005	0.0002	0.0001	0.0004	0.0002	0.0003	0.0003	0.0002	0.0004	0.0002	0.0002	0.0003	0.0002	0.0004	0.0001	0.0003	0.0003	0.0002	0.0003	0.0002	0.0003
V	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0004	0.0000	0.0000	0.0003	0.0000	0.0004
Fe	0.0215	0.0222	0.0213	0.0183	0.0176	0.0199	0.0153	0.0140	0.0136	0.0144	0.0139	0.0138	0.0141	0.0156	0.0151	0.0143	0.0135	0.0140	0.0151	0.0143	0.0136
Ca	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001
Mg	0.0000	0.0000	0.0007	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Mn	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Total*	1.9998	1.9999	2.0000	1.9999	1.9999	1.9999	1.9999	2.0000	2.0000	2.0000	1.9999	2.0000	1.9998	1.9999	2.0000	2.0000	1.9999	2.0000	1.9998	1.9999	1.9997

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Kan

	Core								Arm									
Analysis no.	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10
Al_2O_3	99.05	98.81	98.70	99.11	98.24	98.42	98.33	98.80	98.41	98.95	99.30	99.31	99.23	99.97	99.94	99.90	99.87	99.84
SiO_2	0.00	0.00	0.00	0.02	0.06	0.02	0.00	0.02	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00
TiO_2	0.05	0.07	0.12	0.06	0.12	0.02	0.08	0.07	0.11	0.04	0.03	0.04	0.03	0.09	0.06	0.07	0.13	0.07
Cr_2O_3	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Ga_2O_3	0.03	0.02	0.04	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.00	0.02	0.01	0.03	0.01	0.02	0.02	0.04
V_2O_3	0.02	0.01	0.03	0.01	0.02	0.02	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.02
Fe_2O_3	0.89	0.88	0.96	0.77	0.76	0.74	0.82	0.71	0.63	0.63	0.64	0.61	0.64	0.49	0.50	0.51	0.57	0.51
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MnO	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	100.07	99.79	99.87	99.99	99.22	99.25	99.26	99.65	99.19	99.66	100.01	99.99	99.95	100.61	100.53	100.52	100.61	100.49
Formula 3(O)																		
Al	1.9867	1.9871	1.9845	1.9884	1.9862	1.9891	1.9877	1.9886	1.9894	1.9906	1.9908	1.9911	1.9906	1.9916	1.9922	1.9919	1.9901	1.9915
Si	0.0000	0.0000	0.0000	0.0003	0.0011	0.0003	0.0001	0.0003	0.0003	0.0002	0.0002	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0001
Ti	0.0006	0.0008	0.0016	0.0007	0.0015	0.0002	0.0011	0.0009	0.0014	0.0006	0.0003	0.0006	0.0004	0.0011	0.0007	0.0009	0.0016	0.0009
Cr	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Ga	0.0003	0.0002	0.0004	0.0002	0.0001	0.0002	0.0002	0.0003	0.0001	0.0002	0.0000	0.0002	0.0001	0.0003	0.0001	0.0002	0.0002	0.0004
V	0.0003	0.0002	0.0004	0.0001	0.0002	0.0002	0.0000	0.0002	0.0002	0.0001	0.0001	0.0000	0.0001	0.0001	0.0002	0.0001	0.0000	0.0002
Fe	0.0114	0.0113	0.0123	0.0098	0.0098	0.0095	0.0106	0.0091	0.0081	0.0080	0.0082	0.0079	0.0082	0.0062	0.0064	0.0065	0.0073	0.0065
Ca	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000
Mg	0.0005	0.0001	0.0004	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0000	0.0000	0.0001
Total*	2.0000	1.9997	1.9996	1.9997	1.9992	2.0000	1.9996	1.9997	1.9995	1.9998	1.9999	1.9999	1.9999	1.9998	1.9998	1.9997	1.9995	1.9997

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Kan																
Growth sector																
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Al_2O_3	98.61	98.34	98.48	98.49	99.26	99.11	98.51	99.31	99.81	99.35	99.84	100.06	99.73	100.17	99.41	100.19
SiO_2	0.00	0.01	0.00	0.03	0.00	0.00	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01
TiO_2	0.13	0.14	0.08	0.04	0.04	0.03	0.07	0.09	0.06	0.05	0.08	0.03	0.08	0.07	0.09	0.08
Cr_2O_3	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Ga_2O_3	0.04	0.00	0.03	0.02	0.03	0.01	0.01	0.02	0.01	0.02	0.02	0.00	0.02	0.02	0.02	0.02
V_2O_3	0.03	0.02	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.03	0.00	0.02
Fe_2O_3	0.70	0.69	0.65	0.66	0.49	0.55	0.57	0.56	0.52	0.55	0.55	0.50	0.48	0.44	0.49	0.49
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01
MgO	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
MnO	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.52	99.21	99.26	99.27	99.83	99.74	99.19	100.00	100.40	99.98	100.51	100.60	100.34	100.74	100.01	100.81
Formula 3(O)																
Al	1.9878	1.9880	1.9897	1.9896	1.9925	1.9918	1.9909	1.9908	1.9922	1.9917	1.9911	1.9929	1.9918	1.9926	1.9920	1.9918
Si	0.0000	0.0001	0.0000	0.0004	0.0001	0.0001	0.0003	0.0002	0.0001	0.0000	0.0002	0.0002	0.0002	0.0000	0.0000	0.0001
Ti	0.0017	0.0018	0.0011	0.0005	0.0006	0.0003	0.0008	0.0011	0.0007	0.0006	0.0010	0.0004	0.0010	0.0009	0.0012	0.0010
Cr	0.0001	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
Ga	0.0004	0.0000	0.0003	0.0002	0.0003	0.0001	0.0001	0.0002	0.0001	0.0002	0.0002	0.0000	0.0002	0.0002	0.0002	0.0002
V	0.0004	0.0002	0.0002	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0004	0.0000	0.0002
Fe	0.0090	0.0089	0.0084	0.0086	0.0063	0.0071	0.0073	0.0072	0.0066	0.0070	0.0070	0.0063	0.0062	0.0056	0.0062	0.0062
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	0.0000	0.0002
Mg	0.0000	0.0003	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
Mn	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
K	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9995	1.9995	1.9997	1.9998	1.9998	2.0000	1.9997	1.9996	1.9997	1.9998	1.9997	1.9999	1.9997	1.9997	1.9996	1.9997

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Phrae1

	Core						Arm					
Analysis no.	1	2	3	4	5	6	1	2	3	4	5	6
Al_2O_3	99.10	98.56	99.21	97.97	98.61	98.34	99.69	99.47	99.34	98.45	98.57	98.47
SiO_2	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.01
TiO_2	0.07	0.07	0.21	0.01	0.02	0.04	0.16	0.22	0.19	0.13	0.15	0.14
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Ga_2O_3	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.01	0.01
V_2O_3	0.00	0.02	0.03	0.01	0.00	0.01	0.02	0.04	0.02	0.00	0.02	0.01
Fe_2O_3	1.28	1.34	1.03	1.23	1.10	1.19	0.92	0.98	0.94	0.85	0.94	0.87
CaO	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00
MnO	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.46	100.01	100.51	99.25	99.77	99.61	100.81	100.75	100.54	99.46	99.72	99.53
Formula 3(O)												
Al	1.9823	1.9811	1.9826	1.9835	1.9848	1.9833	1.9850	1.9828	1.9838	1.9865	1.9843	1.9856
Si	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0001	0.0002	0.0002	0.0000	0.0004	0.0002
Ti	0.0009	0.0009	0.0027	0.0001	0.0002	0.0006	0.0020	0.0028	0.0024	0.0017	0.0020	0.0018
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
Ga	0.0001	0.0001	0.0002	0.0001	0.0002	0.0001	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001
V	0.0000	0.0002	0.0004	0.0001	0.0000	0.0002	0.0003	0.0006	0.0003	0.0000	0.0003	0.0001
Fe	0.0163	0.0172	0.0132	0.0159	0.0142	0.0153	0.0116	0.0125	0.0119	0.0109	0.0120	0.0113
Ca	0.0000	0.0002	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0002	0.0002	0.0002	0.0000	0.0001	0.0002	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Total*	1.9997	1.9998	1.9991	2.0001	2.0000	1.9999	1.9993	1.9991	1.9993	1.9994	1.9993	1.9993

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Phrae1

Growth sector											
Analysis no.	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	99.41	99.74	99.88	99.31	99.60	98.30	98.22	98.43	98.47	98.08	98.61
SiO_2	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.01	0.00
TiO_2	0.12	0.05	0.07	0.13	0.05	0.27	0.11	0.13	0.12	0.20	0.05
Cr_2O_3	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Ga_2O_3	0.01	0.03	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.02	0.01
V_2O_3	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fe_2O_3	0.85	0.84	0.89	0.93	0.89	0.93	0.95	0.95	0.84	0.89	0.86
CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
MgO	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total	100.44	100.66	100.87	100.46	100.56	99.53	99.31	99.56	99.47	99.22	99.54
Formula 3(O)											
Al	1.9863	1.9881	1.9871	1.9848	1.9877	1.9831	1.9854	1.9848	1.9865	1.9844	1.9877
Si	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	0.0002	0.0003	0.0002	0.0000
Ti	0.0015	0.0006	0.0009	0.0016	0.0006	0.0035	0.0014	0.0017	0.0016	0.0026	0.0007
Cr	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Ga	0.0001	0.0003	0.0002	0.0004	0.0001	0.0003	0.0001	0.0003	0.0001	0.0002	0.0001
V	0.0003	0.0000	0.0000	0.0003	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0002
Fe	0.0108	0.0107	0.0113	0.0119	0.0113	0.0120	0.0123	0.0122	0.0108	0.0115	0.0111
Ca	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Mg	0.0004	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000
Total*	1.9997	1.9998	1.9997	1.9994	1.9999	1.9989	1.9995	1.9995	1.9995	1.9992	1.9998

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Phrae2

	Core									Arm					
Analysis no.	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6
Al_2O_3	98.77	100.01	99.23	99.29	99.32	99.41	98.92	98.94	99.39	98.71	98.86	98.94	99.21	99.17	99.28
SiO_2	0.01	0.01	0.00	0.01	0.00	0.02	0.02	0.01	0.04	0.01	0.00	0.01	0.00	0.02	0.02
TiO_2	0.40	0.16	0.15	0.22	0.21	0.14	0.52	0.50	0.14	0.60	0.45	0.40	0.36	0.39	0.29
Cr_2O_3	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Ga_2O_3	0.00	0.02	0.02	0.01	0.02	0.00	0.01	0.01	0.01	0.02	0.03	0.03	0.02	0.01	0.01
V_2O_3	0.07	0.03	0.03	0.00	0.00	0.00	0.00	0.01	0.00	0.09	0.06	0.06	0.00	0.00	0.01
Fe_2O_3	0.75	0.57	0.59	0.48	0.46	0.43	0.55	0.57	0.43	0.57	0.59	0.56	0.42	0.43	0.42
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
MgO	0.02	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total	100.02	100.84	100.01	100.02	100.02	100.02	100.03	100.03	100.02	100.02	100.01	100.02	100.03	100.02	100.02
Formula 3(O)															
Al	1.9821	1.9888	1.9893	1.9897	1.9901	1.9914	1.9834	1.9837	1.9909	1.9805	1.9834	1.9844	1.9881	1.9874	1.9891
Si	0.0002	0.0001	0.0000	0.0001	0.0000	0.0004	0.0003	0.0002	0.0007	0.0001	0.0001	0.0001	0.0001	0.0003	0.0003
Ti	0.0051	0.0021	0.0019	0.0029	0.0027	0.0018	0.0067	0.0064	0.0018	0.0076	0.0057	0.0052	0.0046	0.0049	0.0036
Cr	0.0000	0.0001	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000
Ga	0.0000	0.0002	0.0002	0.0001	0.0002	0.0000	0.0001	0.0001	0.0001	0.0002	0.0004	0.0004	0.0002	0.0001	0.0001
V	0.0010	0.0004	0.0004	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0012	0.0009	0.0009	0.0000	0.0000	0.0002
Fe	0.0095	0.0073	0.0075	0.0061	0.0058	0.0055	0.0071	0.0072	0.0055	0.0073	0.0076	0.0072	0.0054	0.0055	0.0054
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0001	0.0000
Mg	0.0004	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0001	0.0000	0.0008	0.0000	0.0001	0.0001	0.0001	0.0000
Mn	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
Total*	1.9984	1.9994	1.9994	1.9990	1.9992	1.9993	1.9977	1.9978	1.9992	1.9977	1.9981	1.9984	1.9985	1.9983	1.9987

Table A.1 EPMA analyses of trapiche sapphire samples each part of Thailand and recalculated atomic proportions based on 3(O).

Phrae2

Growth sector										
Analysis no.	1	2	3	4	5	6	7	8	9	10
Al_2O_3	98.88	99.07	99.04	99.19	98.92	99.20	99.46	99.17	99.34	99.28
SiO_2	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.01	0.01	0.02
TiO_2	0.45	0.33	0.37	0.22	0.42	0.38	0.17	0.42	0.25	0.31
Cr_2O_3	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.01	0.01	0.01	0.02	0.04	0.01	0.01	0.00	0.02	0.01
V_2O_3	0.07	0.06	0.05	0.05	0.06	0.01	0.01	0.01	0.00	0.01
Fe_2O_3	0.57	0.54	0.53	0.49	0.55	0.42	0.36	0.41	0.39	0.40
CaO	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00
MnO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Total	100.02	100.01	100.01	100.02	100.02	100.02	100.01	100.02	100.02	100.02
Formula 3(O)										
Al	1.9834	1.9865	1.9860	1.9883	1.9840	1.9878	1.9922	1.9872	1.9902	1.9890
Si	0.0001	0.0000	0.0000	0.0003	0.0004	0.0000	0.0001	0.0001	0.0001	0.0003
Ti	0.0058	0.0042	0.0047	0.0028	0.0053	0.0048	0.0021	0.0054	0.0032	0.0040
Cr	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Ga	0.0001	0.0001	0.0001	0.0002	0.0004	0.0001	0.0001	0.0000	0.0002	0.0001
V	0.0009	0.0008	0.0007	0.0007	0.0009	0.0001	0.0001	0.0002	0.0000	0.0001
Fe	0.0073	0.0068	0.0068	0.0063	0.0070	0.0054	0.0046	0.0052	0.0050	0.0051
Ca	0.0001	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0003	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0000	0.0003	0.0000
Mn	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9982	1.9986	1.9985	1.9991	1.9982	1.9984	1.9993	1.9982	1.9990	1.9986

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin1

Core									
Analysis no.	1	2	3	4	5	6	7	8	9
Al_2O_3	99.51	99.50	99.48	99.47	100.29	99.92	99.95	98.93	99.10
SiO_2	0.01	0.01	0.00	0.01	0.00	0.01	0.02	0.00	0.00
TiO_2	0.00	0.02	0.00	0.02	0.01	0.01	0.00	0.01	0.01
Cr_2O_3	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00
Ga_2O_3	0.01	0.02	0.02	0.04	0.03	0.07	0.05	0.05	0.04
V_2O_3	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01
Fe_2O_3	0.46	0.46	0.50	0.45	0.50	0.49	0.49	0.45	0.49
CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
K_2O	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.02	100.02	100.84	100.51	100.52	99.45	99.65
Formula 3(O)									
Al	1.9935	1.9933	1.9932	1.9929	1.9930	1.9924	1.9927	1.9934	1.9930
Si	0.0002	0.0002	0.0000	0.0002	0.0001	0.0002	0.0003	0.0000	0.0000
Ti	0.0000	0.0003	0.0000	0.0003	0.0002	0.0001	0.0001	0.0002	0.0002
Cr	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0001	0.0000
Ga	0.0001	0.0002	0.0002	0.0004	0.0003	0.0007	0.0006	0.0006	0.0004
V	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001
Fe	0.0059	0.0058	0.0064	0.0057	0.0063	0.0062	0.0062	0.0058	0.0062
Ca	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Mn	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	2.0001	1.9999	2.0000	1.9999	2.0000	1.9999	1.9999	2.0000	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin1

Arm																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.56	99.50	99.53	99.50	99.56	99.51	99.56	99.54	99.51	99.56	99.77	99.79	99.08	98.76	98.75	99.79	99.36	99.38
SiO_2	0.01	0.01	0.01	0.02	0.01	0.00	0.00	0.01	0.01	0.02	0.01	0.02	0.00	0.01	0.02	0.02	0.03	0.00
TiO_2	0.00	0.03	0.02	0.01	0.00	0.04	0.01	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00
Cr_2O_3	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00
Ga_2O_3	0.04	0.02	0.01	0.04	0.01	0.03	0.02	0.03	0.06	0.04	0.04	0.01	0.02	0.03	0.04	0.02	0.03	0.03
V_2O_3	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.01
Fe_2O_3	0.39	0.45	0.43	0.42	0.41	0.42	0.40	0.40	0.40	0.39	0.44	0.40	0.38	0.42	0.39	0.39	0.37	0.39
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
K_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total	100.01	100.01	100.01	100.01	100.01	100.02	100.01	100.01	100.01	100.01	100.28	100.23	99.52	99.25	99.21	100.26	99.80	99.83
Formula 3(O)																		
Al	1.9941	1.9934	1.9937	1.9933	1.9941	1.9934	1.9943	1.9937	1.9936	1.9941	1.9935	1.9943	1.9943	1.9937	1.9939	1.9938	1.9941	1.9944
Si	0.0002	0.0001	0.0002	0.0003	0.0002	0.0000	0.0000	0.0002	0.0001	0.0003	0.0001	0.0003	0.0001	0.0001	0.0003	0.0003	0.0004	0.0000
Ti	0.0000	0.0003	0.0003	0.0002	0.0000	0.0005	0.0001	0.0003	0.0002	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
Cr	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0000
Ga	0.0004	0.0003	0.0001	0.0004	0.0001	0.0003	0.0002	0.0003	0.0006	0.0004	0.0004	0.0001	0.0002	0.0004	0.0004	0.0002	0.0003	0.0003
V	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0002	0.0000	0.0000	0.0002	0.0001	0.0002
Fe	0.0049	0.0057	0.0055	0.0054	0.0052	0.0054	0.0051	0.0052	0.0051	0.0050	0.0056	0.0052	0.0049	0.0054	0.0050	0.0050	0.0048	0.0050
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000
Mg	0.0001	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
Mn	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
K	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
Total*	2.0000	1.9999	1.9999	1.9999	2.0001	1.9999	2.0000	1.9999	1.9999	1.9999	1.9999	1.9999	2.0001	2.0000	1.9999	1.9999	1.9999	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin1

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.55	99.51	99.47	99.44	99.59	100.05	98.85	99.41	99.23	100.01	99.64	99.86	99.86	99.50	100.01	99.47	99.78	99.41
SiO_2	0.00	0.00	0.03	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01
TiO_2	0.00	0.03	0.00	0.06	0.02	0.20	0.05	0.16	0.13	0.01	0.00	0.02	0.02	0.01	0.00	0.05	0.03	0.02
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Ga_2O_3	0.02	0.03	0.04	0.03	0.03	0.01	0.03	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.02
V_2O_3	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.03	0.02	0.00	0.01	0.00	0.00	0.01	0.02	0.01	0.00	0.00
Fe_2O_3	0.44	0.43	0.45	0.44	0.37	0.44	0.50	0.55	0.54	0.42	0.43	0.47	0.37	0.40	0.38	0.37	0.40	0.33
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00
MgO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
K_2O	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.02	100.02	100.02	100.01	100.72	99.44	100.19	99.97	100.48	100.11	100.37	100.28	99.95	100.43	99.99	100.25	99.81
Formula 3(O)																		
Al	1.9941	1.9934	1.9928	1.9922	1.9947	1.9907	1.9921	1.9893	1.9899	1.9940	1.9941	1.9934	1.9946	1.9942	1.9946	1.9927	1.9939	1.9947
Si	0.0000	0.0000	0.0004	0.0004	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0008	0.0000	0.0002
Ti	0.0000	0.0004	0.0000	0.0008	0.0002	0.0025	0.0006	0.0021	0.0017	0.0002	0.0000	0.0003	0.0002	0.0001	0.0000	0.0007	0.0004	0.0003
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
Ga	0.0002	0.0003	0.0005	0.0003	0.0003	0.0001	0.0003	0.0003	0.0002	0.0002	0.0003	0.0002	0.0003	0.0003	0.0002	0.0002	0.0003	0.0003
V	0.0000	0.0001	0.0002	0.0002	0.0000	0.0002	0.0000	0.0004	0.0003	0.0000	0.0001	0.0000	0.0000	0.0001	0.0003	0.0001	0.0000	0.0000
Fe	0.0056	0.0055	0.0058	0.0057	0.0048	0.0056	0.0064	0.0070	0.0069	0.0053	0.0055	0.0059	0.0047	0.0051	0.0048	0.0047	0.0051	0.0043
Ca	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0000
Mg	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
K	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	2.0000	1.9999	2.0000	1.9996	1.9999	1.9992	1.9997	1.9994	1.9995	2.0000	2.0000	1.9999	1.9999	2.0000	2.0001	1.9997	2.0000	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin2

Core										
Analysis no.	1	2	3	4	5	6	7	8	9	10
Al_2O_3	99.50	99.41	99.49	99.44	99.54	99.43	99.38	99.58	99.60	99.54
SiO_2	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00
TiO_2	0.01	0.04	0.00	0.03	0.01	0.00	0.03	0.01	0.00	0.02
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
Ga_2O_3	0.05	0.04	0.03	0.01	0.03	0.05	0.03	0.02	0.02	0.02
V_2O_3	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01
Fe_2O_3	0.45	0.53	0.47	0.45	0.41	0.51	0.56	0.37	0.37	0.41
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Total	100.03	100.03	100.01	100.02	100.01	100.01	100.01	100.01	100.01	100.01
Formula 3(O)										
Al	1.9933	1.9920	1.9934	1.9921	1.9939	1.9927	1.9919	1.9944	1.9947	1.9939
Si	0.0002	0.0001	0.0000	0.0000	0.0002	0.0001	0.0001	0.0003	0.0001	0.0000
Ti	0.0001	0.0005	0.0001	0.0004	0.0001	0.0000	0.0003	0.0001	0.0000	0.0003
Cr	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000
Ga	0.0005	0.0004	0.0003	0.0001	0.0003	0.0005	0.0004	0.0003	0.0002	0.0002
V	0.0001	0.0000	0.0001	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001
Fe	0.0057	0.0067	0.0060	0.0057	0.0053	0.0066	0.0071	0.0047	0.0047	0.0053
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001
Mg	0.0000	0.0001	0.0000	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	2.0000	1.9999	2.0000	2.0006	1.9999	2.0000	1.9999	2.0000	2.0000	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin2

Arm														
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Al_2O_3	99.55	99.54	99.52	99.39	99.57	99.54	99.55	99.59	99.62	99.61	99.60	99.62	99.62	99.59
SiO_2	0.00	0.00	0.03	0.00	0.01	0.01	0.01	0.00	0.02	0.01	0.02	0.02	0.01	0.00
TiO_2	0.02	0.02	0.02	0.04	0.01	0.03	0.02	0.00	0.01	0.01	0.02	0.01	0.00	0.01
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Ga_2O_3	0.03	0.03	0.03	0.01	0.03	0.03	0.04	0.02	0.02	0.03	0.04	0.01	0.02	0.03
V_2O_3	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Fe_2O_3	0.41	0.40	0.42	0.36	0.39	0.40	0.39	0.38	0.34	0.34	0.33	0.33	0.35	0.36
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Total	100.01	100.01	100.02	99.81	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01
Formula 3(O)														
Al	1.9941	1.9939	1.9933	1.9945	1.9942	1.9938	1.9940	1.9947	1.9948	1.9949	1.9946	1.9948	1.9950	1.9946
Si	0.0000	0.0000	0.0004	0.0000	0.0002	0.0002	0.0002	0.0000	0.0003	0.0001	0.0003	0.0004	0.0001	0.0001
Ti	0.0002	0.0003	0.0002	0.0005	0.0001	0.0003	0.0002	0.0000	0.0001	0.0001	0.0002	0.0001	0.0000	0.0002
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0002
Ga	0.0003	0.0003	0.0003	0.0001	0.0003	0.0003	0.0004	0.0003	0.0002	0.0003	0.0004	0.0001	0.0002	0.0003
V	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
Fe	0.0052	0.0051	0.0053	0.0046	0.0049	0.0051	0.0050	0.0048	0.0043	0.0043	0.0042	0.0043	0.0044	0.0046
Ca	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001
Mg	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0001
Total*	1.9999	1.9999	1.9998	1.9999	1.9999	1.9998	1.9999	2.0000	1.9999	2.0000	1.9998	1.9999	2.0001	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin2

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.55	99.48	99.52	99.54	99.51	99.61	99.58	99.52	99.53	99.50	99.57	99.66	99.69	99.61	99.59	99.57	99.47	99.57
SiO_2	0.00	0.00	0.02	0.01	0.03	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.01
TiO_2	0.00	0.07	0.03	0.05	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.06	0.04
Cr_2O_3	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Ga_2O_3	0.04	0.02	0.03	0.02	0.02	0.01	0.03	0.04	0.03	0.04	0.04	0.02	0.03	0.02	0.02	0.02	0.01	0.01
V_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.02	0.00	0.01	0.00
Fe_2O_3	0.40	0.43	0.40	0.38	0.44	0.34	0.38	0.40	0.41	0.45	0.35	0.31	0.29	0.36	0.35	0.36	0.42	0.37
CaO	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MgO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.01	100.02	100.02	99.99	100.03	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01	100.01
Formula 3(O)																		
Al	1.9941	1.9929	1.9935	1.9936	1.9932	1.9951	1.9944	1.9937	1.9939	1.9936	1.9944	1.9956	1.9960	1.9949	1.9945	1.9943	1.9928	1.9941
Si	0.0000	0.0000	0.0003	0.0002	0.0004	0.0000	0.0000	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0002
Ti	0.0001	0.0009	0.0003	0.0007	0.0002	0.0002	0.0000	0.0002	0.0000	0.0000	0.0002	0.0001	0.0001	0.0002	0.0002	0.0004	0.0008	0.0005
Cr	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001
Ga	0.0005	0.0002	0.0003	0.0003	0.0003	0.0001	0.0003	0.0004	0.0003	0.0004	0.0004	0.0003	0.0003	0.0002	0.0003	0.0002	0.0001	0.0001
V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000
Fe	0.0052	0.0055	0.0051	0.0049	0.0056	0.0043	0.0048	0.0052	0.0052	0.0058	0.0045	0.0039	0.0037	0.0046	0.0045	0.0047	0.0054	0.0047
Ca	0.0001	0.0000	0.0000	0.0000	0.0000	0.0003	0.0002	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000
Mg	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Mn	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
K	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	2.0001	1.9997	1.9998	1.9998	1.9998	2.0001	2.0001	2.0001	2.0000	2.0001	2.0000	2.0000	2.0000	2.0000	1.9999	1.9999	1.9997	1.9998

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin3

Core									
Analysis no.	1	2	3	4	5	6	7	8	9
Al_2O_3	99.50	99.49	99.42	99.55	99.55	99.53	100.44	99.60	100.40
SiO_2	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00
TiO_2	0.01	0.02	0.03	0.01	0.00	0.01	0.01	0.01	0.01
Cr_2O_3	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.04	0.04	0.06	0.01	0.02	0.02	0.04	0.03	0.03
V_2O_3	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.41	0.43	0.49	0.41	0.41	0.43	0.36	0.36	0.37
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.02	99.99	99.99	99.99	100.87	100.00	100.82
Formula 3(O)									
Al	1.9934	1.9931	1.9924	1.9943	1.9944	1.9941	1.9946	1.9948	1.9947
Si	0.0003	0.0003	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Ti	0.0002	0.0003	0.0004	0.0002	0.0000	0.0001	0.0001	0.0001	0.0001
Cr	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0004	0.0005	0.0006	0.0001	0.0002	0.0003	0.0004	0.0003	0.0004
V	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Fe	0.0052	0.0055	0.0062	0.0052	0.0052	0.0054	0.0046	0.0046	0.0047
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
K	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Total*	1.9999	1.9998	2.0001	2.0000	2.0000	2.0000	1.9999	2.0000	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin3

Arm															
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Al_2O_3	99.53	99.52	99.54	99.54	99.55	99.45	99.46	100.23	99.52	100.52	99.63	99.63	99.64	100.60	99.61
SiO_2	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.01
TiO_2	0.05	0.02	0.03	0.04	0.01	0.05	0.03	0.01	0.08	0.07	0.02	0.03	0.01	0.01	0.03
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.01	0.03	0.02	0.03	0.02	0.05	0.05	0.03	0.04	0.03	0.04	0.02	0.04	0.03	0.04
V_2O_3	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.03	0.01	0.00	0.00	0.02	0.01	0.02
Fe_2O_3	0.40	0.42	0.39	0.38	0.42	0.41	0.42	0.30	0.33	0.30	0.30	0.31	0.29	0.29	0.30
CaO	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.01	99.99	100.00	99.99	99.99	100.58	100.01	100.95	100.00	100.00	100.00	100.95	100.00
Formula 3(O)															
Al	1.9934	1.9934	1.9939	1.9940	1.9942	1.9930	1.9931	1.9955	1.9933	1.9941	1.9952	1.9951	1.9954	1.9955	1.9948
Si	0.0002	0.0005	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0003	0.0001	0.0002	0.0000	0.0001	0.0001
Ti	0.0007	0.0002	0.0004	0.0005	0.0001	0.0006	0.0004	0.0002	0.0010	0.0009	0.0003	0.0004	0.0002	0.0001	0.0004
Cr	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
Ga	0.0002	0.0003	0.0003	0.0004	0.0003	0.0006	0.0005	0.0004	0.0004	0.0003	0.0004	0.0002	0.0004	0.0003	0.0004
V	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0001	0.0000	0.0004	0.0001	0.0000	0.0000	0.0002	0.0002	0.0002
Fe	0.0051	0.0053	0.0050	0.0049	0.0053	0.0053	0.0054	0.0038	0.0042	0.0038	0.0038	0.0039	0.0037	0.0037	0.0038
Ca	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	1.9997	1.9998	1.9999	1.9998	2.0000	1.9998	2.0000	2.0000	1.9996	1.9996	2.0000	1.9998	2.0000	2.0000	1.9998

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin3

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.57	99.52	99.56	99.49	99.30	99.52	99.49	99.47	99.44	99.64	99.61	99.61	100.48	100.58	99.66	100.58	100.52	99.56
SiO_2	0.01	0.00	0.01	0.02	0.02	0.01	0.00	0.01	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01
TiO_2	0.02	0.02	0.02	0.05	0.19	0.01	0.02	0.03	0.07	0.01	0.05	0.02	0.02	0.01	0.02	0.02	0.03	0.08
Cr_2O_3	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.02	0.03	0.00	0.04	0.03	0.03	0.04	0.04	0.03	0.04	0.01	0.03	0.03	0.03	0.02	0.02	0.03	0.02
V_2O_3	0.00	0.01	0.00	0.00	0.03	0.01	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.02
Fe_2O_3	0.38	0.42	0.41	0.41	0.45	0.39	0.41	0.42	0.44	0.30	0.32	0.33	0.30	0.30	0.30	0.31	0.29	0.31
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
K_2O	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.02	100.02	100.01	99.99	99.99	99.99	99.99	100.00	100.00	100.00	100.84	100.95	100.00	100.95	100.88	100.00
Formula 3(O)																		
Al	1.9941	1.9937	1.9939	1.9929	1.9899	1.9940	1.9935	1.9932	1.9927	1.9952	1.9947	1.9949	1.9954	1.9952	1.9955	1.9952	1.9954	1.9940
Si	0.0002	0.0000	0.0002	0.0003	0.0004	0.0002	0.0000	0.0001	0.0000	0.0003	0.0001	0.0000	0.0001	0.0001	0.0001	0.0002	0.0000	0.0002
Ti	0.0003	0.0002	0.0002	0.0007	0.0024	0.0002	0.0003	0.0004	0.0009	0.0001	0.0006	0.0002	0.0002	0.0002	0.0003	0.0002	0.0004	0.0010
Cr	0.0001	0.0000	0.0002	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0002	0.0003	0.0000	0.0004	0.0003	0.0004	0.0004	0.0004	0.0003	0.0004	0.0001	0.0003	0.0003	0.0003	0.0002	0.0002	0.0003	0.0002
V	0.0000	0.0002	0.0000	0.0000	0.0004	0.0001	0.0002	0.0002	0.0001	0.0001	0.0000	0.0001	0.0000	0.0002	0.0000	0.0001	0.0000	0.0003
Fe	0.0049	0.0054	0.0053	0.0052	0.0057	0.0050	0.0052	0.0054	0.0056	0.0038	0.0041	0.0042	0.0037	0.0038	0.0039	0.0039	0.0037	0.0040
Ca	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0003	0.0002	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
K	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9999	2.0000	1.9999	1.9998	1.9991	2.0000	2.0000	1.9999	1.9998	1.9999	1.9999	2.0000	1.9999	2.0000	1.9999	1.9999	1.9999	1.9997

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

pailin4

	Core			Arm						Growth sector													
Analysis no.	1	2	3	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Al_2O_3	98.63	98.54	98.66	98.73	98.72	98.82	98.58	98.68	99.51	98.68	99.32	98.51	98.44	98.90	98.62	98.68	99.41	99.50	99.44	98.84	98.76	98.75	98.93
SiO_2	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.02	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
TiO_2	0.02	0.02	0.00	0.03	0.03	0.04	0.03	0.08	0.02	0.02	0.18	0.03	0.10	0.06	0.00	0.07	0.13	0.02	0.04	0.03	0.03	0.09	0.01
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.03	0.04	0.02	0.01	0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.04	0.02
V_2O_3	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.03	0.00	0.02	0.01	0.00	0.02	0.00	0.00	0.03	0.01	0.01	0.02	0.00	0.01	0.02	0.01
Fe_2O_3	0.45	0.44	0.40	0.41	0.41	0.43	0.40	0.48	0.42	0.40	0.45	0.44	0.44	0.42	0.44	0.44	0.42	0.42	0.45	0.44	0.42	0.46	0.40
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.13	99.05	99.10	99.21	99.19	99.33	99.04	99.34	99.99	99.15	99.99	99.01	99.03	99.43	99.09	99.25	99.99	99.99	99.99	99.35	99.25	99.36	99.37
Formula 3(O)																							
Al	1.9936	1.9934	1.9944	1.9937	1.9938	1.9933	1.9938	1.9912	1.9936	1.9938	1.9904	1.9934	1.9920	1.9930	1.9939	1.9924	1.9921	1.9937	1.9928	1.9934	1.9935	1.9918	1.9944
Si	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001	0.0003	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
Ti	0.0002	0.0002	0.0000	0.0004	0.0004	0.0005	0.0004	0.0011	0.0002	0.0002	0.0023	0.0004	0.0013	0.0008	0.0000	0.0009	0.0016	0.0002	0.0005	0.0004	0.0004	0.0011	0.0002
Cr	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000
Ga	0.0003	0.0005	0.0002	0.0001	0.0002	0.0004	0.0003	0.0004	0.0003	0.0003	0.0002	0.0003	0.0003	0.0004	0.0002	0.0004	0.0002	0.0004	0.0004	0.0003	0.0003	0.0004	0.0002
V	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0005	0.0000	0.0003	0.0001	0.0000	0.0003	0.0001	0.0000	0.0004	0.0001	0.0001	0.0002	0.0000	0.0002	0.0003	0.0001
Fe	0.0058	0.0057	0.0052	0.0053	0.0053	0.0056	0.0052	0.0062	0.0053	0.0052	0.0057	0.0057	0.0057	0.0054	0.0056	0.0056	0.0054	0.0053	0.0058	0.0056	0.0054	0.0059	0.0051
Ca	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Total*	2.0000	2.0000	2.0000	2.0000	1.9999	1.9998	1.9999	1.9997	1.9999	1.9999	1.9992	1.9999	1.9996	1.9998	2.0000	1.9997	1.9996	1.9999	1.9998	1.9999	1.9999	1.9997	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin5

Core											
Analysis no.	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	99.57	99.19	99.06	99.97	99.61	99.48	98.90	98.88	99.82	99.69	99.55
SiO_2	0.01	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00
TiO_2	0.00	0.00	0.01	0.02	0.01	0.02	0.00	0.00	0.01	0.01	0.01
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.01	0.05	0.02	0.00	0.01	0.04	0.03	0.05	0.03	0.03	0.03
V_2O_3	0.01	0.02	0.00	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.01
Fe_2O_3	0.38	0.40	0.36	0.42	0.36	0.44	0.36	0.41	0.32	0.32	0.34
CaO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
MnO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.00	99.69	99.46	100.45	100.01	99.99	99.29	99.36	100.20	100.05	99.94
Formula 3(O)											
Al	1.9946	1.9936	1.9947	1.9939	1.9949	1.9934	1.9948	1.9938	1.9952	1.9953	1.9950
Si	0.0001	0.0002	0.0003	0.0000	0.0001	0.0000	0.0002	0.0001	0.0002	0.0000	0.0000
Ti	0.0001	0.0000	0.0001	0.0002	0.0001	0.0003	0.0000	0.0001	0.0001	0.0002	0.0001
Cr	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
Ga	0.0002	0.0005	0.0002	0.0000	0.0001	0.0004	0.0003	0.0005	0.0003	0.0003	0.0003
V	0.0001	0.0003	0.0000	0.0002	0.0001	0.0001	0.0000	0.0000	0.0002	0.0000	0.0001
Fe	0.0048	0.0052	0.0046	0.0053	0.0045	0.0056	0.0046	0.0053	0.0041	0.0040	0.0043
Ca	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Mn	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	2.0000	2.0000	1.9999	2.0001	2.0000	1.9999	2.0000	2.0000	1.9999	2.0000	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin5

Arm															
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Al_2O_3	99.61	99.60	99.59	99.58	99.58	99.14	98.73	99.61	98.87	99.41	100.30	100.56	100.20	100.14	99.67
SiO_2	0.01	0.02	0.03	0.02	0.03	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00
TiO_2	0.00	0.01	0.00	0.01	0.00	0.00	0.07	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Ga_2O_3	0.02	0.01	0.02	0.01	0.03	0.02	0.02	0.00	0.04	0.04	0.05	0.02	0.03	0.01	0.02
V_2O_3	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Fe_2O_3	0.37	0.37	0.36	0.38	0.36	0.35	0.38	0.37	0.34	0.34	0.33	0.32	0.33	0.31	0.34
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MnO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Total	100.01	100.01	100.01	100.01	100.01	99.53	99.22	100.00	99.26	99.82	100.71	100.94	100.61	100.49	100.04
Formula 3(O)															
Al	1.9948	1.9945	1.9944	1.9944	1.9943	1.9949	1.9934	1.9950	1.9949	1.9948	1.9947	1.9951	1.9947	1.9954	1.9952
Si	0.0002	0.0003	0.0005	0.0003	0.0004	0.0002	0.0000	0.0001	0.0001	0.0000	0.0002	0.0001	0.0002	0.0000	0.0000
Ti	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0010	0.0001	0.0002	0.0001	0.0002	0.0003	0.0003	0.0002	0.0001
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000
Ga	0.0002	0.0001	0.0002	0.0001	0.0003	0.0002	0.0003	0.0000	0.0004	0.0004	0.0005	0.0002	0.0003	0.0001	0.0002
V	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Fe	0.0047	0.0047	0.0046	0.0049	0.0046	0.0045	0.0049	0.0047	0.0043	0.0044	0.0041	0.0041	0.0042	0.0039	0.0044
Ca	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000
Mn	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001
Total*	1.9999	1.9999	1.9999	1.9999	1.9999	1.9999	1.9997	1.9999	1.9999	2.0000	1.9999	1.9999	1.9999	2.0000	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin5

Growth sector																
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Al_2O_3	99.55	99.49	99.50	99.60	99.50	99.67	99.33	99.72	99.52	99.41	99.34	100.10	100.22	99.79	99.59	100.11
SiO_2	0.02	0.00	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00
TiO_2	0.02	0.07	0.03	0.02	0.05	0.01	0.05	0.01	0.01	0.14	0.02	0.02	0.02	0.02	0.03	0.00
Cr_2O_3	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Ga_2O_3	0.04	0.03	0.03	0.02	0.05	0.02	0.05	0.03	0.02	0.03	0.02	0.02	0.04	0.02	0.03	0.03
V_2O_3	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Fe_2O_3	0.38	0.40	0.41	0.35	0.41	0.36	0.38	0.36	0.31	0.37	0.33	0.33	0.31	0.31	0.34	0.34
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MnO	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.01	100.01	100.02	100.07	99.82	100.14	99.87	99.95	99.71	100.48	100.62	100.18	100.00	100.49
Formula 3(O)																
Al	1.9939	1.9931	1.9932	1.9946	1.9933	1.9949	1.9934	1.9945	1.9955	1.9925	1.9952	1.9950	1.9948	1.9948	1.9946	1.9952
Si	0.0003	0.0000	0.0003	0.0003	0.0000	0.0000	0.0002	0.0002	0.0000	0.0000	0.0000	0.0002	0.0003	0.0003	0.0001	0.0000
Ti	0.0003	0.0009	0.0004	0.0002	0.0006	0.0002	0.0007	0.0001	0.0001	0.0018	0.0002	0.0002	0.0002	0.0003	0.0004	0.0001
Cr	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001
Ga	0.0004	0.0003	0.0004	0.0002	0.0005	0.0002	0.0005	0.0003	0.0002	0.0003	0.0002	0.0002	0.0004	0.0003	0.0003	0.0003
V	0.0000	0.0003	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Fe	0.0049	0.0051	0.0052	0.0044	0.0052	0.0046	0.0048	0.0046	0.0040	0.0047	0.0042	0.0042	0.0040	0.0040	0.0044	0.0043
Ca	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Mn	0.0000	0.0000	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Total*	1.9998	1.9997	1.9998	1.9999	1.9998	2.0000	1.9997	2.0000	2.0000	1.9995	2.0000	1.9999	1.9999	1.9999	1.9998	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin6

	Core											Arm										
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	99.48	99.43	99.42	99.43	99.35	99.50	99.46	100.28	100.45	100.11	99.59	99.50	99.54	99.84	99.62	99.43	100.45	99.65	99.58	99.67	100.56	99.62
SiO_2	0.03	0.03	0.02	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.02	0.03	0.02	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01
TiO_2	0.02	0.04	0.00	0.01	0.01	0.00	0.01	0.03	0.01	0.00	0.01	0.05	0.00	0.04	0.00	0.02	0.01	0.01	0.03	0.01	0.02	0.02
Cr_2O_3	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.02	0.03	0.03	0.04	0.03	0.02	0.04	0.03	0.04	0.04	0.03	0.02	0.04	0.03	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03
V_2O_3	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.00	0.01	0.01
Fe_2O_3	0.45	0.49	0.51	0.51	0.53	0.48	0.51	0.41	0.34	0.38	0.35	0.41	0.41	0.33	0.38	0.40	0.32	0.31	0.32	0.29	0.32	0.32
CaO	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
MgO	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
K_2O	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.02	100.02	100.03	100.02	99.93	100.01	100.06	100.75	100.85	100.57	100.00	100.02	100.02	100.25	100.06	99.89	100.83	100.00	100.00	100.00	100.94	100.00
Formula 3(O)																						
Al	1.9928	1.9919	1.9921	1.9924	1.9926	1.9935	1.9923	1.9939	1.9948	1.9941	1.9945	1.9929	1.9936	1.9947	1.9945	1.9940	1.9952	1.9954	1.9943	1.9958	1.9950	1.9950
Si	0.0005	0.0004	0.0004	0.0000	0.0000	0.0000	0.0003	0.0001	0.0001	0.0002	0.0003	0.0005	0.0004	0.0001	0.0002	0.0001	0.0000	0.0001	0.0002	0.0000	0.0001	0.0001
Ti	0.0003	0.0006	0.0000	0.0002	0.0001	0.0000	0.0001	0.0004	0.0001	0.0001	0.0002	0.0006	0.0000	0.0005	0.0001	0.0002	0.0001	0.0001	0.0004	0.0001	0.0003	0.0002
Cr	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0002	0.0003	0.0003	0.0004	0.0003	0.0002	0.0004	0.0004	0.0004	0.0004	0.0003	0.0002	0.0004	0.0003	0.0003	0.0002	0.0002	0.0003	0.0002	0.0003	0.0002	0.0003
V	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0000	0.0005	0.0000	0.0001	0.0001
Fe	0.0058	0.0063	0.0065	0.0065	0.0067	0.0061	0.0065	0.0052	0.0043	0.0049	0.0045	0.0053	0.0053	0.0041	0.0049	0.0051	0.0040	0.0040	0.0041	0.0037	0.0041	0.0040
Ca	0.0000	0.0000	0.0001	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001
Mg	0.0000	0.0003	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
K	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	1.9997	1.9998	1.9999	2.0002	2.0000	2.0000	1.9999	1.9999	2.0000	1.9999	1.9999	1.9997	1.9999	1.9999	2.0001	1.9999	2.0000	2.0000	1.9999	2.0001	1.9999	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin6

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.57	99.30	99.60	99.57	99.66	99.37	99.61	99.62	99.53	100.56	99.61	99.61	99.64	100.44	99.65	100.61	99.52	99.59
SiO_2	0.01	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.00
TiO_2	0.02	0.13	0.00	0.02	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.01	0.01	0.07	0.06
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.00
Ga_2O_3	0.03	0.05	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02
V_2O_3	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00
Fe_2O_3	0.38	0.48	0.37	0.39	0.41	0.39	0.38	0.41	0.41	0.33	0.34	0.33	0.32	0.32	0.32	0.30	0.34	0.33
CaO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.05	100.01	100.03	100.14	99.80	100.04	100.07	100.02	100.95	100.00	100.00	100.00	100.81	100.00	100.95	100.01	100.00
Formula 3(O)																		
Al	1.9942	1.9894	1.9948	1.9940	1.9939	1.9946	1.9945	1.9943	1.9937	1.9952	1.9949	1.9948	1.9952	1.9952	1.9955	1.9956	1.9933	1.9945
Si	0.0002	0.0011	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0002	0.0000	0.0000	0.0001	0.0003	0.0000
Ti	0.0002	0.0016	0.0000	0.0003	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0004	0.0001	0.0003	0.0001	0.0002	0.0009	0.0008
Cr	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0003	0.0000
Ga	0.0004	0.0006	0.0003	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
V	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0003	0.0000
Fe	0.0049	0.0061	0.0048	0.0050	0.0052	0.0050	0.0049	0.0052	0.0052	0.0041	0.0044	0.0042	0.0041	0.0040	0.0040	0.0038	0.0044	0.0042
Ca	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9999	1.9992	2.0000	1.9999	1.9999	2.0000	2.0000	2.0000	2.0002	2.0000	2.0000	1.9999	1.9999	1.9999	2.0000	1.9999	1.9996	1.9997

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin7

Core											
Analysis no.	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	99.41	99.27	99.62	99.02	99.34	99.43	100.06	100.26	100.04	99.84	99.79
SiO_2	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.00
TiO_2	0.00	0.09	0.01	0.02	0.00	0.01	0.02	0.01	0.00	0.02	0.02
Cr_2O_3	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00
Ga_2O_3	0.04	0.02	0.05	0.02	0.04	0.05	0.03	0.04	0.03	0.04	0.03
V_2O_3	0.00	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01
Fe_2O_3	0.50	0.60	0.53	0.52	0.51	0.53	0.38	0.40	0.44	0.43	0.47
CaO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MnO	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.97	100.01	100.22	99.62	99.91	100.03	100.52	100.74	100.56	100.36	100.32
Formula 3(O)											
Al	1.9929	1.9901	1.9923	1.9921	1.9928	1.9923	1.9942	1.9938	1.9933	1.9933	1.9931
Si	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0002	0.0003	0.0003	0.0000
Ti	0.0000	0.0012	0.0001	0.0002	0.0000	0.0002	0.0003	0.0001	0.0000	0.0002	0.0003
Cr	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000
Ga	0.0005	0.0002	0.0005	0.0003	0.0004	0.0005	0.0004	0.0004	0.0003	0.0004	0.0003
V	0.0000	0.0003	0.0001	0.0000	0.0000	0.0000	0.0001	0.0002	0.0002	0.0000	0.0001
Fe	0.0063	0.0077	0.0067	0.0067	0.0066	0.0068	0.0048	0.0051	0.0056	0.0055	0.0060
Ca	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
Mg	0.0001	0.0001	0.0001	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Mn	0.0001	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0001	0.0000	0.0001	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	2.0000	1.9996	2.0000	2.0001	2.0000	2.0000	1.9999	2.0000	1.9999	1.9999	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin7																
Arm																
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Al_2O_3	99.45	99.35	99.31	99.42	99.46	99.34	99.29	99.35	99.38	99.24	99.47	99.51	99.72	99.68	99.37	99.65
SiO_2	0.05	0.05	0.03	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00
TiO_2	0.03	0.03	0.05	0.01	0.00	0.01	0.02	0.02	0.01	0.02	0.03	0.05	0.03	0.01	0.05	0.02
Cr_2O_3	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Ga_2O_3	0.04	0.05	0.03	0.02	0.04	0.04	0.04	0.05	0.02	0.02	0.03	0.04	0.04	0.02	0.03	0.03
V_2O_3	0.01	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.02
Fe_2O_3	0.39	0.51	0.51	0.52	0.50	0.43	0.44	0.45	0.47	0.42	0.38	0.39	0.34	0.37	0.41	0.38
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
MnO	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.97	100.01	99.96	100.02	100.01	99.82	99.82	99.91	99.88	99.73	99.91	100.04	100.16	100.08	99.88	100.10
Formula 3(O)																
Al	1.9928	1.9910	1.9913	1.9921	1.9930	1.9939	1.9932	1.9928	1.9936	1.9937	1.9942	1.9930	1.9943	1.9949	1.9933	1.9943
Si	0.0009	0.0009	0.0004	0.0005	0.0000	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0003	0.0000	0.0000	0.0000	0.0000
Ti	0.0003	0.0004	0.0006	0.0001	0.0000	0.0001	0.0002	0.0003	0.0002	0.0002	0.0003	0.0007	0.0004	0.0001	0.0007	0.0002
Cr	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Ga	0.0004	0.0005	0.0004	0.0002	0.0004	0.0004	0.0004	0.0005	0.0002	0.0003	0.0003	0.0005	0.0004	0.0003	0.0003	0.0004
V	0.0001	0.0001	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0003	0.0000	0.0001	0.0002
Fe	0.0050	0.0066	0.0066	0.0067	0.0064	0.0056	0.0056	0.0058	0.0060	0.0054	0.0049	0.0049	0.0043	0.0047	0.0052	0.0048
Ca	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000
Mg	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
Mn	0.0001	0.0002	0.0002	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	1.9996	1.9996	1.9997	1.9999	2.0000	2.0000	1.9999	2.0002	1.9999	1.9999	1.9999	1.9997	1.9999	2.0000	1.9998	2.0000

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin7

Growth sector																	
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Al_2O_3	99.44	99.45	99.41	99.05	99.48	98.99	99.27	99.31	99.79	99.64	99.75	100.07	99.48	99.30	99.58	99.44	99.47
SiO_2	0.02	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.00	0.01	0.01	0.02	0.01	0.02	0.01	0.02
TiO_2	0.03	0.03	0.03	0.01	0.02	0.02	0.02	0.01	0.02	0.00	0.02	0.04	0.13	0.11	0.02	0.03	0.01
Cr_2O_3	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Ga_2O_3	0.04	0.04	0.05	0.03	0.05	0.04	0.03	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.03	0.04
V_2O_3	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.03
Fe_2O_3	0.48	0.48	0.50	0.46	0.45	0.44	0.36	0.39	0.38	0.42	0.35	0.35	0.40	0.38	0.37	0.38	0.37
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.01	100.01	100.01	99.57	100.02	99.49	99.70	99.78	100.23	100.10	100.17	100.50	100.05	99.84	100.03	99.89	99.94
Formula 3(O)																	
Al	1.9925	1.9927	1.9923	1.9933	1.9930	1.9936	1.9945	1.9938	1.9942	1.9941	1.9946	1.9944	1.9919	1.9925	1.9940	1.9940	1.9938
Si	0.0003	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0004	0.0002	0.0000	0.0002	0.0001	0.0004	0.0002	0.0003	0.0002	0.0003
Ti	0.0003	0.0004	0.0003	0.0001	0.0003	0.0003	0.0002	0.0001	0.0002	0.0000	0.0002	0.0005	0.0017	0.0015	0.0002	0.0004	0.0001
Cr	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
Ga	0.0004	0.0004	0.0005	0.0003	0.0005	0.0004	0.0003	0.0004	0.0004	0.0003	0.0003	0.0002	0.0002	0.0003	0.0003	0.0003	0.0004
V	0.0000	0.0000	0.0001	0.0002	0.0001	0.0001	0.0000	0.0002	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0004
Fe	0.0062	0.0062	0.0064	0.0059	0.0058	0.0056	0.0046	0.0049	0.0048	0.0053	0.0045	0.0045	0.0051	0.0049	0.0048	0.0048	0.0047
Ca	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Mn	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
K	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	1.9999	1.9999	1.9999	2.0000	2.0000	1.9999	1.9999	1.9998	1.9999	2.0000	2.0000	1.9998	1.9993	1.9995	1.9999	1.9999	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin8									
Core									
Analysis no.	1	2	3	4	5	6	7	8	9
Al_2O_3	99.41	100.04	98.77	99.20	98.85	99.68	99.51	99.51	99.25
SiO_2	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
TiO_2	0.03	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.19
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.07	0.05	0.03	0.04	0.05	0.03	0.02	0.02	0.02
V_2O_3	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Fe_2O_3	0.45	0.44	0.41	0.44	0.47	0.42	0.45	0.46	0.52
CaO	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00
MgO	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.00
MnO	0.00	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.01
K_2O	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	100.04	100.55	99.23	99.71	99.38	100.15	100.01	100.01	100.01
Formula 3(O)									
Al	1.9915	1.9935	1.9941	1.9934	1.9933	1.9939	1.9936	1.9936	1.9895
Si	0.0009	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001
Ti	0.0004	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0002	0.0024
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0008	0.0005	0.0003	0.0004	0.0005	0.0003	0.0003	0.0003	0.0002
V	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
Fe	0.0058	0.0056	0.0053	0.0057	0.0061	0.0053	0.0057	0.0058	0.0066
Ca	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001
Mg	0.0000	0.0001	0.0001	0.0000	0.0000	0.0004	0.0001	0.0000	0.0000
Mn	0.0000	0.0001	0.0002	0.0002	0.0000	0.0000	0.0001	0.0000	0.0001
K	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	1.9996	2.0001	2.0002	2.0000	2.0001	2.0001	2.0000	2.0000	1.9992

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin8

Arm																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.58	99.57	99.50	99.52	99.56	99.59	99.56	99.93	99.37	99.54	100.08	100.07	100.41	99.51	99.53	100.52	99.59	99.52
SiO_2	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.02
TiO_2	0.07	0.02	0.04	0.05	0.01	0.01	0.02	0.02	0.05	0.03	0.04	0.00	0.02	0.04	0.03	0.02	0.00	0.02
Cr_2O_3	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.00	0.03	0.04	0.00	0.03	0.05	0.04	0.03	0.04	0.03	0.02	0.03	0.02	0.02	0.04	0.03	0.02	0.04
V_2O_3	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.02
Fe_2O_3	0.36	0.39	0.41	0.44	0.41	0.35	0.37	0.41	0.40	0.44	0.38	0.38	0.36	0.42	0.39	0.38	0.37	0.38
CaO	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MnO	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.02	100.01	100.02	100.02	100.03	100.01	100.01	100.41	99.88	100.06	100.55	100.50	100.83	100.00	100.00	100.97	100.00	100.01
Formula 3(O)																		
Al	1.9940	1.9943	1.9933	1.9934	1.9937	1.9945	1.9941	1.9940	1.9933	1.9934	1.9937	1.9946	1.9945	1.9935	1.9938	1.9942	1.9947	1.9936
Si	0.0001	0.0000	0.0000	0.0000	0.0004	0.0002	0.0001	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0003
Ti	0.0009	0.0002	0.0005	0.0006	0.0002	0.0001	0.0002	0.0002	0.0007	0.0004	0.0005	0.0000	0.0003	0.0005	0.0004	0.0003	0.0000	0.0002
Cr	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0000	0.0003	0.0004	0.0000	0.0003	0.0005	0.0004	0.0003	0.0004	0.0003	0.0002	0.0004	0.0002	0.0003	0.0004	0.0003	0.0002	0.0004
V	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0001	0.0000	0.0001	0.0001	0.0003	0.0002
Fe	0.0046	0.0050	0.0053	0.0056	0.0052	0.0044	0.0048	0.0052	0.0052	0.0056	0.0048	0.0048	0.0045	0.0054	0.0050	0.0049	0.0047	0.0049
Ca	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001
Mn	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001
K	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	1.9997	2.0000	2.0000	1.9999	1.9998	2.0000	2.0000	1.9999	1.9999	2.0000	1.9999	2.0001	1.9999	1.9999	1.9999	2.0000	2.0000	1.9999

Table A.2 EPMA analyses of trapiche sapphire samples each part of Cambodia and recalculated atomic proportions based on 3(O).

Pailin8

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	99.58	99.46	99.46	99.48	99.47	99.57	100.15	100.17	100.03	99.72	99.92	99.54	99.58	99.42	99.59	100.57	99.57	99.56
SiO_2	0.01	0.03	0.03	0.01	0.02	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.00	0.04	0.04	0.08	0.08	0.02	0.04	0.03	0.03	0.01	0.04	0.04	0.02	0.14	0.02	0.02	0.02	0.01
Cr_2O_3	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.03	0.05	0.06	0.03	0.02	0.04	0.02	0.03	0.04	0.04	0.01	0.02	0.02	0.02	0.03	0.01	0.02	0.03
V_2O_3	0.00	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Fe_2O_3	0.39	0.43	0.41	0.43	0.42	0.38	0.39	0.39	0.37	0.40	0.39	0.38	0.38	0.41	0.37	0.38	0.38	0.38
CaO	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	100.02	100.03	100.03	100.05	100.01	100.03	100.63	100.63	100.50	100.20	100.38	100.01	100.00	100.01	100.00	101.00	100.01	100.01
Formula 3(O)																		
Al	1.9944	1.9923	1.9925	1.9923	1.9925	1.9941	1.9936	1.9941	1.9938	1.9938	1.9941	1.9939	1.9944	1.9920	1.9947	1.9946	1.9944	1.9943
Si	0.0001	0.0005	0.0005	0.0002	0.0003	0.0001	0.0001	0.0000	0.0003	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ti	0.0000	0.0005	0.0005	0.0010	0.0010	0.0002	0.0005	0.0004	0.0004	0.0002	0.0005	0.0004	0.0003	0.0018	0.0002	0.0003	0.0002	0.0002
Cr	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0003	0.0001	0.0000	0.0001	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
Ga	0.0003	0.0005	0.0007	0.0003	0.0002	0.0004	0.0002	0.0003	0.0004	0.0004	0.0002	0.0003	0.0002	0.0003	0.0003	0.0002	0.0002	0.0004
V	0.0000	0.0003	0.0001	0.0002	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000
Fe	0.0049	0.0054	0.0052	0.0055	0.0054	0.0049	0.0050	0.0049	0.0047	0.0051	0.0050	0.0049	0.0049	0.0052	0.0047	0.0048	0.0049	0.0049
Ca	0.0002	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mg	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Mn	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	2.0000	1.9997	1.9997	1.9996	1.9996	1.9999	1.9998	1.9999	1.9998	1.9999	1.9999	1.9998	1.9999	1.9995	2.0000	1.9999	1.9999	2.0000

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_O1

Core														
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Al_2O_3	98.53	98.59	98.65	98.31	98.64	98.64	98.90	98.99	98.36	98.75	98.59	98.46	99.44	98.46
SiO_2	0.01	0.02	0.03	0.03	0.03	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00
TiO_2	0.00	0.00	0.01	0.03	0.00	0.01	0.01	0.02	0.02	0.01	0.01	0.04	0.02	0.05
Cr_2O_3	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.05	0.02	0.03	0.05	0.03	0.00	0.02	0.05	0.04	0.02	0.02	0.03	0.02	0.03
V_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.02
Fe_2O_3	1.34	1.31	1.21	1.53	1.23	1.28	1.29	1.58	1.53	1.23	1.39	1.48	1.41	1.44
CaO	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
MgO	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.01
K_2O	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.94	99.96	99.96	99.96	99.96	99.95	100.25	100.65	100.02	100.02	100.02	100.02	100.90	100.03
Formula 3(O)														
Al	1.9819	1.9823	1.9830	1.9785	1.9828	1.9833	1.9826	1.9789	1.9785	1.9837	1.9816	1.9797	1.9813	1.9798
Si	0.0001	0.0003	0.0005	0.0005	0.0005	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001	0.0000
Ti	0.0000	0.0000	0.0002	0.0003	0.0000	0.0001	0.0001	0.0002	0.0002	0.0001	0.0001	0.0006	0.0002	0.0006
Cr	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Ga	0.0006	0.0002	0.0003	0.0006	0.0003	0.0000	0.0002	0.0005	0.0004	0.0002	0.0002	0.0004	0.0002	0.0004
V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0003
Fe	0.0172	0.0168	0.0156	0.0196	0.0158	0.0164	0.0165	0.0201	0.0197	0.0157	0.0178	0.0190	0.0179	0.0185
Ca	0.0002	0.0001	0.0002	0.0001	0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002
Mg	0.0000	0.0001	0.0002	0.0001	0.0000	0.0000	0.0003	0.0000	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000	0.0001
K	0.0000	0.0002	0.0000	0.0000	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	2.0000	2.0001	1.9999	1.9998	2.0000	2.0002	2.0002	2.0000	2.0001	2.0000	2.0000	1.9998	1.9999	1.9999

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_O1

Arm															
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Al_2O_3	98.66	98.73	98.74	98.75	98.63	99.58	99.62	99.75	98.66	98.71	98.79	98.86	98.78	98.85	98.83
SiO_2	0.01	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
TiO_2	0.00	0.02	0.02	0.01	0.05	0.00	0.02	0.01	0.02	0.01	0.00	0.00	0.03	0.00	0.00
Cr_2O_3	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00
Ga_2O_3	0.05	0.00	0.02	0.00	0.03	0.02	0.02	0.00	0.03	0.02	0.03	0.02	0.03	0.03	0.02
V_2O_3	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.01	0.01	0.00	0.03	0.00	0.02
Fe_2O_3	1.22	1.18	1.15	1.17	1.23	1.21	1.25	1.22	1.27	1.25	1.17	1.12	1.14	1.12	1.13
CaO	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.95	99.95	99.95	99.96	99.96	100.83	100.93	100.99	100.02	100.02	100.01	100.02	100.02	100.02	100.02
Formula 3(O)															
Al	1.9834	1.9842	1.9843	1.9841	1.9827	1.9842	1.9833	1.9841	1.9826	1.9831	1.9844	1.9852	1.9840	1.9851	1.9847
Si	0.0002	0.0002	0.0003	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0002
Ti	0.0000	0.0003	0.0002	0.0001	0.0006	0.0000	0.0003	0.0002	0.0002	0.0002	0.0000	0.0000	0.0004	0.0000	0.0000
Cr	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
Ga	0.0005	0.0000	0.0002	0.0000	0.0003	0.0002	0.0002	0.0000	0.0004	0.0002	0.0003	0.0002	0.0003	0.0003	0.0003
V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002	0.0001	0.0000	0.0001	0.0002	0.0000	0.0004	0.0000	0.0002
Fe	0.0157	0.0151	0.0147	0.0150	0.0158	0.0154	0.0158	0.0155	0.0163	0.0161	0.0149	0.0144	0.0146	0.0144	0.0145
Ca	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001
Mg	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0002	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000
Total*	2.0000	2.0000	1.9999	1.9999	1.9998	2.0000	2.0000	2.0000	2.0001	2.0000	2.0001	2.0001	1.9999	2.0001	2.0000

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_O1

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	98.71	98.66	98.79	98.65	98.68	98.61	98.80	98.78	98.79	98.81	98.76	98.78	98.72	98.69	98.69	98.81	98.76	98.77
SiO_2	0.01	0.03	0.02	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.01
TiO_2	0.02	0.01	0.00	0.01	0.02	0.00	0.00	0.02	0.01	0.01	0.02	0.03	0.02	0.03	0.04	0.01	0.02	0.01
Cr_2O_3	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Ga_2O_3	0.05	0.02	0.02	0.05	0.03	0.06	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.01	0.03	0.01	0.04	0.03
V_2O_3	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Fe_2O_3	1.17	1.22	1.12	1.22	1.26	1.33	1.19	1.18	1.17	1.15	1.20	1.17	1.22	1.27	1.26	1.18	1.19	1.17
CaO	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.96	99.96	99.96	99.97	100.01	100.03	100.01	100.02	100.02	100.02	100.02	100.02	100.02	100.02	100.02	100.02	100.01	100.02
Formula 3(O)																		
Al	1.9839	1.9831	1.9849	1.9831	1.9827	1.9818	1.9845	1.9841	1.9841	1.9844	1.9838	1.9841	1.9834	1.9827	1.9828	1.9845	1.9838	1.9840
Si	0.0002	0.0004	0.0003	0.0000	0.0003	0.0000	0.0000	0.0000	0.0002	0.0001	0.0001	0.0000	0.0000	0.0003	0.0000	0.0001	0.0000	0.0002
Ti	0.0002	0.0001	0.0000	0.0001	0.0002	0.0000	0.0000	0.0002	0.0001	0.0002	0.0002	0.0004	0.0002	0.0004	0.0005	0.0001	0.0003	0.0002
Cr	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000
Ga	0.0005	0.0002	0.0003	0.0006	0.0004	0.0006	0.0002	0.0003	0.0003	0.0003	0.0002	0.0003	0.0003	0.0001	0.0003	0.0001	0.0004	0.0004
V	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001
Fe	0.0150	0.0157	0.0144	0.0157	0.0162	0.0170	0.0152	0.0151	0.0150	0.0147	0.0153	0.0150	0.0156	0.0162	0.0162	0.0151	0.0152	0.0150
Ca	0.0001	0.0002	0.0001	0.0002	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000
Mg	0.0000	0.0001	0.0000	0.0000	0.0000	0.0006	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total*	1.9999	2.0000	1.9999	2.0002	1.9999	2.0002	2.0000	2.0000	2.0000	1.9999	2.0000	1.9999	2.0000	1.9998	1.9998	2.0000	2.0000	1.9999

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_O2

	Core								Arm												
Analysis no.	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12	13
Al_2O_3	98.43	98.37	98.79	98.35	98.41	97.54	98.50	98.35	98.75	98.73	97.82	98.56	98.85	97.84	98.71	98.68	98.83	98.61	98.63	98.62	97.76
SiO_2	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01
TiO_2	0.00	0.01	0.04	0.05	0.05	0.02	0.02	0.03	0.00	0.02	0.02	0.04	0.03	0.03	0.04	0.03	0.00	0.07	0.06	0.05	0.07
Cr_2O_3	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.04	0.03	0.04	0.05	0.02	0.04	0.04	0.03	0.04	0.03	0.05	0.02	0.06	0.03	0.03	0.03	0.02	0.02	0.04	0.02	0.02
V_2O_3	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Fe_2O_3	1.42	1.49	1.75	1.51	1.50	1.60	1.42	1.55	1.17	1.19	1.26	1.33	1.33	1.21	1.19	1.22	1.14	1.27	1.24	1.28	1.28
CaO	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MnO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.95	99.93	100.64	99.98	99.98	99.23	99.99	99.98	99.99	99.98	99.17	99.96	100.30	99.10	99.99	99.99	99.99	99.98	99.99	99.98	99.15
Formula 3(O)																					
Al	1.9804	1.9799	1.9761	1.9790	1.9796	1.9781	1.9810	1.9789	1.9842	1.9838	1.9826	1.9820	1.9813	1.9836	1.9835	1.9831	1.9852	1.9820	1.9824	1.9823	1.9817
Si	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001
Ti	0.0000	0.0001	0.0006	0.0006	0.0006	0.0003	0.0002	0.0004	0.0000	0.0002	0.0003	0.0004	0.0004	0.0003	0.0006	0.0004	0.0000	0.0009	0.0008	0.0007	0.0008
Cr	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
Ga	0.0005	0.0004	0.0005	0.0005	0.0003	0.0005	0.0004	0.0003	0.0004	0.0004	0.0005	0.0002	0.0006	0.0003	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0002
V	0.0000	0.0001	0.0001	0.0002	0.0000	0.0002	0.0001	0.0002	0.0002	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Fe	0.0182	0.0191	0.0223	0.0193	0.0193	0.0207	0.0182	0.0199	0.0150	0.0152	0.0164	0.0171	0.0170	0.0157	0.0152	0.0157	0.0146	0.0163	0.0159	0.0164	0.0166
Ca	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001
Mg	0.0005	0.0004	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0002	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Mn	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
K	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Total*	2.0002	2.0001	1.9998	2.0000	2.0001	2.0000	1.9999	2.0000	2.0000	2.0000	1.9999	1.9999	1.9999	1.9999	1.9998	1.9999	2.0000	1.9997	1.9996	1.9998	1.9998

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_O2

Growth sector																			
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Al_2O_3	99.08	97.82	98.84	98.65	98.73	98.65	98.71	98.69	98.65	98.62	97.85	97.68	98.62	97.71	98.67	98.75	98.59	98.62	98.61
SiO_2	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00
TiO_2	0.02	0.01	0.02	0.03	0.01	0.02	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.07	0.07	0.07	0.05
Cr_2O_3	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Ga_2O_3	0.03	0.00	0.02	0.03	0.03	0.01	0.04	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.02
V_2O_3	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.02	0.01	0.01	0.00	0.00
Fe_2O_3	1.25	1.28	1.27	1.25	1.20	1.26	1.19	1.21	1.26	1.25	1.25	1.27	1.26	1.29	1.22	1.34	1.28	1.26	1.28
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01
MgO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
MnO	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Total	100.42	99.12	100.17	99.97	99.97	99.98	99.98	99.98	99.98	99.98	99.17	99.02	99.98	99.12	99.98	100.23	99.98	99.98	99.98
Formula 3(O)																			
Al	1.9829	1.9831	1.9829	1.9829	1.9841	1.9828	1.9837	1.9834	1.9829	1.9825	1.9828	1.9825	1.9824	1.9816	1.9831	1.9806	1.9819	1.9822	1.9822
Si	0.0001	0.0000	0.0000	0.0001	0.0000	0.0003	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0002	0.0002	0.0000	0.0002	0.0000	0.0000	0.0000
Ti	0.0003	0.0002	0.0002	0.0004	0.0001	0.0003	0.0003	0.0005	0.0004	0.0004	0.0004	0.0005	0.0004	0.0005	0.0005	0.0009	0.0009	0.0009	0.0007
Cr	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
Ga	0.0003	0.0000	0.0002	0.0003	0.0003	0.0001	0.0004	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.0004	0.0003	0.0003	0.0002	0.0004	0.0004
V	0.0002	0.0000	0.0002	0.0000	0.0000	0.0001	0.0001	0.0002	0.0000	0.0003	0.0000	0.0000	0.0001	0.0000	0.0002	0.0001	0.0002	0.0000	0.0000
Fe	0.0159	0.0166	0.0162	0.0160	0.0154	0.0161	0.0153	0.0156	0.0162	0.0161	0.0162	0.0164	0.0162	0.0168	0.0156	0.0171	0.0164	0.0161	0.0164
Ca	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0001	0.0000	0.0001
Mg	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0002	0.0000	0.0000	0.0003	0.0000	0.0000	0.0001
Mn	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000	0.0001	0.0001	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Total*	2.0000	2.0000	2.0000	1.9999	2.0000	1.9999	1.9999	1.9999	1.9999	1.9999	2.0000	1.9998	2.0000	1.9999	1.9999	1.9998	1.9998	1.9997	2.0001

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_H											
Core											
Analysis no.	1	2	3	4	5	6	7	8	9	10	11
Al_2O_3	98.29	98.30	98.53	98.16	97.93	97.97	98.15	98.16	98.73	98.88	99.00
SiO_2	0.00	0.01	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.01	0.01
TiO_2	0.00	0.01	0.00	0.02	0.01	0.01	0.04	0.00	0.01	0.02	0.00
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Ga_2O_3	0.03	0.03	0.02	0.03	0.04	0.03	0.05	0.02	0.03	0.04	0.04
V_2O_3	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00
Fe_2O_3	1.53	1.43	1.53	1.75	1.48	1.55	1.50	1.40	1.42	1.43	1.38
CaO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total	99.86	99.79	100.09	99.98	99.50	99.58	99.76	99.60	100.20	100.40	100.43
Formula 3(O)											
Al	1.9799	1.9808	1.9799	1.9766	1.9796	1.9791	1.9791	1.9815	1.9812	1.9804	1.9818
Si	0.0000	0.0001	0.0001	0.0000	0.0004	0.0002	0.0000	0.0000	0.0000	0.0002	0.0001
Ti	0.0000	0.0002	0.0000	0.0003	0.0001	0.0001	0.0005	0.0000	0.0001	0.0003	0.0000
Cr	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000
Ga	0.0004	0.0003	0.0003	0.0004	0.0004	0.0004	0.0005	0.0004	0.0003	0.0004	0.0004
V	0.0000	0.0001	0.0001	0.0000	0.0000	0.0002	0.0001	0.0002	0.0000	0.0001	0.0000
Fe	0.0197	0.0184	0.0196	0.0225	0.0191	0.0200	0.0193	0.0180	0.0182	0.0183	0.0176
Ca	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000
Mg	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000
Total*	2.0000	1.9999	2.0000	2.0000	1.9999	2.0001	1.9998	2.0003	2.0000	1.9999	1.9999

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O).

Di Linh_H

Arm																	
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Al_2O_3	98.72	98.70	98.68	98.69	98.73	98.57	98.38	98.91	98.89	99.09	99.01	98.91	99.37	99.35	99.45	99.45	99.27
SiO_2	0.01	0.01	0.02	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.02	0.01	0.00	0.00	0.02
TiO_2	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.08	0.01	0.01	0.00	0.00
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Ga_2O_3	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.03
V_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00
Fe_2O_3	1.19	1.21	1.21	1.20	1.16	1.29	1.15	1.17	1.23	1.22	1.16	1.16	1.17	1.11	1.15	1.15	1.12
CaO	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	99.97	99.96	99.95	99.96	99.96	99.96	99.61	100.13	100.15	100.35	100.27	100.11	100.70	100.52	100.65	100.62	100.45
Formula 3(O)																	
Al	1.9840	1.9838	1.9835	1.9839	1.9842	1.9823	1.9842	1.9841	1.9838	1.9840	1.9836	1.9846	1.9826	1.9851	1.9848	1.9851	1.9849
Si	0.0002	0.0001	0.0004	0.0000	0.0001	0.0000	0.0000	0.0003	0.0000	0.0001	0.0005	0.0000	0.0004	0.0001	0.0000	0.0000	0.0003
Ti	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	0.0002	0.0002	0.0001	0.0000	0.0001	0.0001	0.0010	0.0001	0.0001	0.0000	0.0000
Cr	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
Ga	0.0003	0.0003	0.0003	0.0004	0.0005	0.0004	0.0004	0.0002	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002	0.0003	0.0002	0.0003
V	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0000
Fe	0.0153	0.0156	0.0156	0.0154	0.0149	0.0166	0.0148	0.0149	0.0158	0.0156	0.0149	0.0149	0.0149	0.0141	0.0146	0.0146	0.0143
Ca	0.0002	0.0001	0.0000	0.0002	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001
Mg	0.0001	0.0000	0.0000	0.0002	0.0000	0.0003	0.0003	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
Mn	0.0000	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000
K	0.0000	0.0000	0.0000	0.0001	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Total*	2.0001	2.0001	1.9999	2.0003	1.9999	2.0003	2.0000	1.9999	2.0000	2.0000	2.0000	1.9999	1.9997	2.0001	2.0000	2.0000	1.9999

Table A.3 EPMA analyses of trapiche sapphire samples each part of Vietnam and recalculated atomic proportions based on 3(O)

Di Linh_H

Growth sector																		
Analysis no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Al_2O_3	98.56	99.28	99.07	99.22	97.65	97.76	97.70	98.51	98.25	99.03	98.46	98.23	98.44	98.39	98.97	98.66	99.22	98.95
SiO_2	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.03	0.01	0.00
TiO_2	0.03	0.01	0.02	0.01	0.04	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01
Cr_2O_3	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Ga_2O_3	0.01	0.02	0.02	0.02	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.03	0.04	0.03	0.02	0.04	0.03
V_2O_3	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.02	0.02	0.02	0.01	0.00	0.01	0.01	0.00	0.00	0.00
Fe_2O_3	1.33	1.10	1.12	1.25	1.61	1.43	1.46	1.40	1.38	1.32	1.46	1.47	1.51	1.37	1.14	1.21	1.18	1.12
CaO	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00
Total	99.95	100.42	100.24	100.50	99.35	99.25	99.23	99.98	99.72	100.43	99.99	99.78	100.02	99.84	100.18	99.95	100.47	100.12
Formula 3(O)																		
Al	1.9819	1.9855	1.9850	1.9835	1.9778	1.9806	1.9801	1.9810	1.9811	1.9821	1.9803	1.9800	1.9796	1.9813	1.9845	1.9833	1.9840	1.9851
Si	0.0002	0.0000	0.0000	0.0001	0.0001	0.0002	0.0001	0.0000	0.0000	0.0001	0.0000	0.0002	0.0001	0.0001	0.0001	0.0005	0.0001	0.0000
Ti	0.0004	0.0001	0.0002	0.0001	0.0006	0.0001	0.0002	0.0002	0.0002	0.0001	0.0002	0.0003	0.0003	0.0001	0.0001	0.0000	0.0002	0.0001
Cr	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000
Ga	0.0002	0.0002	0.0002	0.0003	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003	0.0003	0.0004	0.0003	0.0002	0.0004	0.0003
V	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0002	0.0003	0.0003	0.0002	0.0001	0.0000	0.0001	0.0002	0.0001	0.0000	0.0000
Fe	0.0171	0.0140	0.0144	0.0159	0.0208	0.0185	0.0189	0.0179	0.0178	0.0169	0.0187	0.0189	0.0194	0.0177	0.0146	0.0155	0.0151	0.0143
Ca	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001
Mg	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
Mn	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001
K	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0001	0.0001	0.0001	0.0002	0.0000	0.0001	0.0002	0.0000	0.0000
Total*	1.9999	2.0000	2.0000	2.0000	1.9999	1.9999	1.9999	2.0000	2.0001	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	2.0000	1.9999	2.0000

BIOGRAPHY

Miss Sureeporn Pumpang was born in March 16, 1979, at Nakornpathom. She graduated with a bachelor degree in geology from the Department of Geology, Faculty of Science, Chulalongkorn University in 2001. At present, she works at Gem Testing Laboratory, The Gem and Jewelry Institute of Thailand and also studies in a Master program in geology at Chulalongkorn University.