RACHADAPISEKSOMPOJ RESEARCH FUND

RESEARCH REPORT

Petrochemistry of Probable Gem-Bearing Basalts in Sop Prap-Ko Kha Area, Changwat Lampang

By

Punya Charusiri, Wasant Pongsapich, and Chakkaphan Sutthirat

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The landsat image showing the middle dark patch of basaltic flow in some part of Sop Prap-Ko Kha area

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ชื่อโครงการวิจัย : การศึกษาลักษณะศิลาเคมีของหินบะซอลต์ที่คาดว่าจะให้พลอย บริเวณพื้นที่ อำเภอสบปราบ อำเภอเกาะคา จังหวัดลำปาง

ชื่อผู้วิจัย : ปัญญา จารุศิริ วสันต์ พงศาพิชญ์ และ จักรพันธ์ สุทธิรัตน์

เดือนและปีที่ทำวิจัยเสร็จ : มกราคม 2539

บทคัดย่อ

พื้นที่ทำการวิจัยครอบคลุมประมาณ 300 ตร.กม. ในบริเวณอำเภอสบปราบ อำเภอเกาะคา และอำเภอแม่ทะ จังหวัดลำปาง ลักษณะทางธรณีวิทยาบริเวณกว้างประกอบไปด้วย หินตะกอน (และหินแปร) ในยุคเพอร์เมียน ยุคไทยแอสซิก ยุคเทอร์เชียรี และยุคควอเทอร์นารี หินยุคไทรแอสซิกประกอบด้วย หน่วยหินพระธาตุ หน่วยหินผาก้าน และหน่วยหินฮ่องหอย ในกลุ่มหินลำปาง ส่วนหินอัคนีประกอบด้วย หินภูเขาไฟ และตะกอนภูเขาไฟ ในยุคเพอร์โมไทรแอสซิก หินแกรโนไดออไรต์ ยุคไทรแอสซิก และหินบะซอลต์ของมหายุคซีโนโซอิค

พลอยแซปไฟร์มักพบในลักษณะการสะสมตัวแบบตะกอนน้ำพัดและสะสมตัวอยู่กับที่ ซึ่งพบมากในบริเวณหินบะซอลต์ แซปไฟร์ที่พบโดยทั่วไปทั้งสองพื้นที่มักมีสีฟ้า น้ำเงิน ฟ้าอมเขียว น้ำตาลเข้มและแสดงรูปร่างเหลี่ยมถึงกึ่งเหลี่ยมขนาดตั้งแต่ 0.5 ถึง 6 ซม. หินบะซอลต์ในพื้นที่แบ่งออกเป็น 2 บริเวณ คือ ทางตอนเหนือ (ชุดน้ำโจ้) และหินทางตอนใต้ (ชุดสบปราบ-เกาะคา) หินทั้งสองปะทุในแอ่งตะกอนสบปราบ-เกาะคา บะซอลต์ชุดน้ำโจ้คลุมพื้นที่ 3 ตร.กม. ในตำบลน้ำโจ้ อำเภอแม่ทะ หินบะซอลต์บริเวณนี้แสดงการไหลลงตามความลาดชันของเขา ประกอบด้วยหินที่มีรูพรุน สีน้ำตาลแดง (ตอนบน) และหินเนื้อแน่นสีดำ (ตอนล่าง) มีลักษณะเม็ดละเอียดและเนื้อดอกและมักพบแปลกปลอมจำพวกอัลตราเมฟิก เช่น เลอร์โซไลต์ผลึกขนาดใหญ่ ซึ่งประกอบด้วยแร่โอลิวีน ไพรอกซีน และสปิเนล เป็นส่วนใหญ่ จากลักษณะจุลภาคหินแสดงเนื้อดอกขนาดเล็กถึงเนื้อดอกและผลึกขนาดเล็กมาก โดยมีผลึกแร่ดอกที่สำคัญ ได้แก่ แร่โอลิวีนและไพรอกซีน พบอยู่ระหว่างเพลจิโอเคลสขนาดเล็กและแก้ว จากการศึกษาองค์ประกอบทางแร่ พบว่า หินทางตอนเหนือส่วนใหญ่มีเนื้อชั้นการไหลชั้นเดียวประกอบด้วยเนื้อผลึกดอกที่เนื้อพื้นเนียน ผลึกแร่ดอกของโอลิวีนและไพรอกซีนพบอยู่ระหว่างผลึกขลุยแพลจิโอเคสขนาดเล็กและแก้ว หินบะซอลต์นี้ส่วนใหญ่ ประกอบด้วย แพลจิโอเคลส โอลิวีน แร่ทึบแสง และแร่

ประกอบอื่นๆ ขนาดแร่โดยเฉลี่ยเล็กกว่าที่พบในหินบะซอลต์ทางตอนใต้ จากการศึกษาภาคสนามพบว่าหินบะซอลต์ทางตอนใต้ แบ่งออกเป็น 5 ชั้นทางไหล ซึ่งปรากฏให้เห็นบริเวณหลักกิโลเมตร 568-569 บนถนนพหลโยธินและอยู่ใกล้ปากปล่องภูเขาไฟ โดยครอบคลุมพื้นที่ประมาณ 5 ตร.กม. ในเขตอำเภอสบปราบและอำเภอเกาะคา หินบะซอลต์ทั้ง 5 ชั้นทางไหลมีลักษณะเนื้อที่เป็นรูพรุนเนื้อแน่น ผลึกเนื้อดอกขนาดเล็กถึงเนื้อดอกขนาดเล็กถึงเล็กมาก สำหรับแร่ดอกโอลิวีนพบอยู่โดยทั่วไปในทุกชั้น ลักษณะภายใต้กล้องจุลทรรศน์ แสดงว่าชั้นการไหลมีลักษณะคล้ายกันโดยประกอบด้วยแร่แพลจิโอเคลส ไพรอกซีน โอลิวีน แร่ทึบแสง และแร่ประกอบอื่น ๆ ลักษณะเนื้อหินจำพวก interstitial และ subophitic ปรากฏให้เห็นทั่วไปและไม่ค่อยพบหินแปลกปลอมชนิดอัลตราเมฟิก

น้ำโจ้บะซอลต์และสบปราบ-เกาะคาบะซอลต์ สามารถแยกได้โดยลักษณะทางธรณีเคมีได้เด่นชัด โดยแสดงความแตกต่างของทั้งธาตุหลักและธาตุพบน้อย แม้ว่าในหลายๆ ไดอะแกรมจะแสดงแนวการเปลี่ยนแปลงในทางเดียวกัน ในที่นี้ได้จัดให้น้ำโจ้บะซอลต์อยู่ในกลุ่มยาซาไนต์ ขณะที่สบปราบ-เกาะคาละซอลต์จัดอยู่ในประเภทอัลคาไลน์โอลิวีนบะซอลต์ โดยใช้นอร์มของแพลจิโอเคลสและไฮเปอร์สทีนหรือเนฟฟีลลิน จากการศึกษาธาตุหายากเมื่อเทียบกับหินอุกาบาตพบว่า รูปแบบทอดตัวลดลงจากธาตุเบาไปธาตุหนักเหมือนกัน ส่วนค่าแมกนีเซียมที่คำนวนได้บ่งบอกถึงการตกผลึกลำดับส่วนจากหินหนืดสืบทอด

การหาอายุโดยวิธี $^{40}Ar/^{39}Ar$ พอสรุปได้ว่าสบปราบ-เกาะคาบะซอลต์มีอายุตั้งแต่ อ่อนกว่า 2.30 จนถึง 2.41 ล้านปี ในขณะที่น้ำโจ้บะซอลต์ มีอายุที่อ่อนกว่า คือประมาณ 2.02 ล้านปี

อาจสรุปได้ว่าหินบะซอลต์ทั้งสองบริเวณคือ กำเนิดมาจากหินหนืดสืบทอดที่ผ่านขบวนการคล้ายกัน เช่น การตกผลึกลำดับส่วนโดยมีการปนเปื้อนจากชั้นผิวโลกบ้าง แต่หินหนืดสืบทอดนี้ คงเปลี่ยนแปลงมาจากต้นกำเนิดที่ต่างกัน และจากหินหนืดปฐมภูมิที่ผ่านการหลอมละลายบางส่วนที่ไม่เท่ากันในชั้นเนื้อโลก ร่องรอยของแซปไฟร์นี้อาจชี้ให้เห็นถึงการหลอมละลายบางส่วนของหินหนืดปฐมภูมิ ณ ระดับลึก หรือที่ความดันสูง (มากกว่า 5 กิโลบาร์) อาจกล่าวได้ว่าบะซอลต์ชุดน้ำโจ้น่าจะสัมพันธ์กับพลอยแซปไฟร์มากกว่าบะซอลต์ชุดสบปราบ-เกาะคา เนื่องจากองค์ประกอบของแหล่งต้นกำเนิดที่แตกต่างจากสบปราบ-เกาะคาบะซอลต์

Project Title : Petrochemistry of Probable Gem-Bearing Basalts in Sop Prap-Ko Kha Area, Changwat Lampang

Name of Investigators : Punya Charusiri, Wasant Pongsapich, and Chakkaphan Sutthirat

Year : 1996

Abstract

The project area covers approximately 300 km^2 encompassing parts of Amphoe Sop Prap, Amphoe Ko Kha, and Amphoe Mae Tha of Changwat Lampang. The area is mainly occupied by sedimentary (and metamorphic) rocks of Permian, Triassic, Tertiary, and Quaternary ages. The Triassic rocks include the Phra That, the Pha Kan, and the Hong Hoi Formations of the Lampang Group. Igneous rocks comprise Permo-Triassic volcanics, Triassic granodiorite, and Cenozoic basalts.

Sapphires are frequently found in alluvial and residual deposits, particularly in the northern basaltic area. Sapphires in the south terrain are also encountered in stream channels flowing from nearby Cenozoic basaltic crater. Sapphires are normally blue, dark blue, greenish blue, and dark brown, and occur as angular to subangular forms, ranging in size from 0.5 to 6 cm.

Basalts in the project area can be geographically subdivided into 2 terrains - the north and the south. The northern terrain (Nam Cho Basalt) covers approximately 3 km^2 in Thambon Nam Cho, Amphoe Mae Tha. The basalts occur as one major flow layer, that flowed following the hill slope. The rocks are characterized by reddish

brown vesicular rocks (top), and black dense rocks (bottom). They are generally present as fine-grained and porphyritic. Ultramafic nodules of lherzolite comprising olivine, pyroxene and spinel and megacrysts of olivine, and pyroxene, are often observed in this terrain. Microscopically, the northern basalts invariably occur as microporphyritic to porphyritic, aphanitic. Phenocrysts of olivine and pyroxene are generally surrounded by small plagioclase- microlite groundmass and glass. The basalts are typically composed of plagioclase, pyroxene, olivine, opaque minerals, and other accessories. Average grain size is relatively smaller than that of the south basalts. The southern terrain (Sop Prap-Ko Kha Basalt) can be subdivided into 5 flow layers. Good exposures are typically present at road cut quarries between kms 586-569 on the highway number 1, nearby the volcanic crater. The area covers approximately 55 km^2 between Amphoe Ko Kha and Amphoe Sop Prap. These five basaltic flows are similarly characterized by vesicular, or massive, microporphyritic-porphyritic, fine-grained to aphanitic rocks. Phenocrysts of olivine frequently occur in most flows. These basalt flows microscopically comprise similar characteristics, mostly they always contain plagioclase, pyroxene, olivine, opaque minerals, and other accessories. Intersertal, interstitial, and subophitic textures are frequently present in these basalts. Ultramafic nodules are rarely found in this basaltic terrain.

Geochemically, that Nam Cho and Sop Prap-Ko Kha Basalts can be clearly divided by difference in major and trace-element contents. Though several variation diagrams display similar trend. The Nam Cho basalts are mainly classified as basanite, where as the Sop Prap-Ko Kha basalts are dominantly alkaline-olivine basalt based on normative plagioclase and hyperstene and/or nepheline. Rare-earth element concentrations show similar chondrite-normalized patterns for most basalt groups. Calculated Mg-values indicate crystal fractionation process of the derivative magmas.

$^{40}Ar/^{39}Ar$ geochronological data are clearly concluded that Sop Prap-Ko Kha Basalts, ranging in age from younger than 2.30 to 2.41 Ma, are older than Nam Cho Basalts (ca. 2.02 Ma).

Therefore, it is tentatively inferred that basalts from both terrains were probably originated from derivative magmas, which are evolved by similar processes, as crystal fraction with subsequent crystal contamination process. However, these derivative magmas may have been derived from different originated sources and primary magmas with low degree of partial melting in mantle. The occurrence of sapphires possibly indicates partial melting of primary magma at high depth and pressure, and crystal fractionations of derivative magma route to 8-10 kbar. Then Nam Cho Basalt can be regarded as gem-related and formed from different derivative magma from mantle source region.

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CHAPTER I

INTRODUCTION

1.1 General Statement

Gems are the important economic minerals and parts of nation' s significant annual revenue comes from exporting them. Thailand exported gem to the high amount of about 34,877.9 million baht, 35,925.9 million baht and 36,681.8 million baht respectively in 1990, 1991, and 1992, and the trend of exporting increases every years. Gem-quality corundum can be originated from different genesis in each area. Therefore Thai corundum (comprising ruby and sapphires) always associates with basaltic area. The investigation of individual basalt can be led to inform the general characteristic of corundum in that basaltic area, which this information is useful for the corundum exploration.

Most of the exposed basaltic rocks in Thailand are recongnized to have occurred in Late Cenozoic. mainly Upper Tertiary to Quaternary (Barr and Macdonald, 1981) and some of these basalts are prime sources of gems, such as corundum, garnet, zircon, spinel, etc. Recently the occurrences of several gem-quality minerals (corundum, spinel, pyroxene, olivine) in this study area are reported by Gem Exploration Section of Economic Geology Division, Department of Mineral Resources (DMR), all of which occur relatively in basaltic area. The basalts are distributed into two areas - the Nam Cho basalt in the northern area and the Sop Prap - Ko Kha basalt in the southern area. The Nam Cho basalt was first discovered by air-borne magnetic interpretation and follow-up field investigation and was first done by geoscientists of Airborne Geophysical Data Interpretation Section, DMR. A more detailed study was carried out by Geological Survey

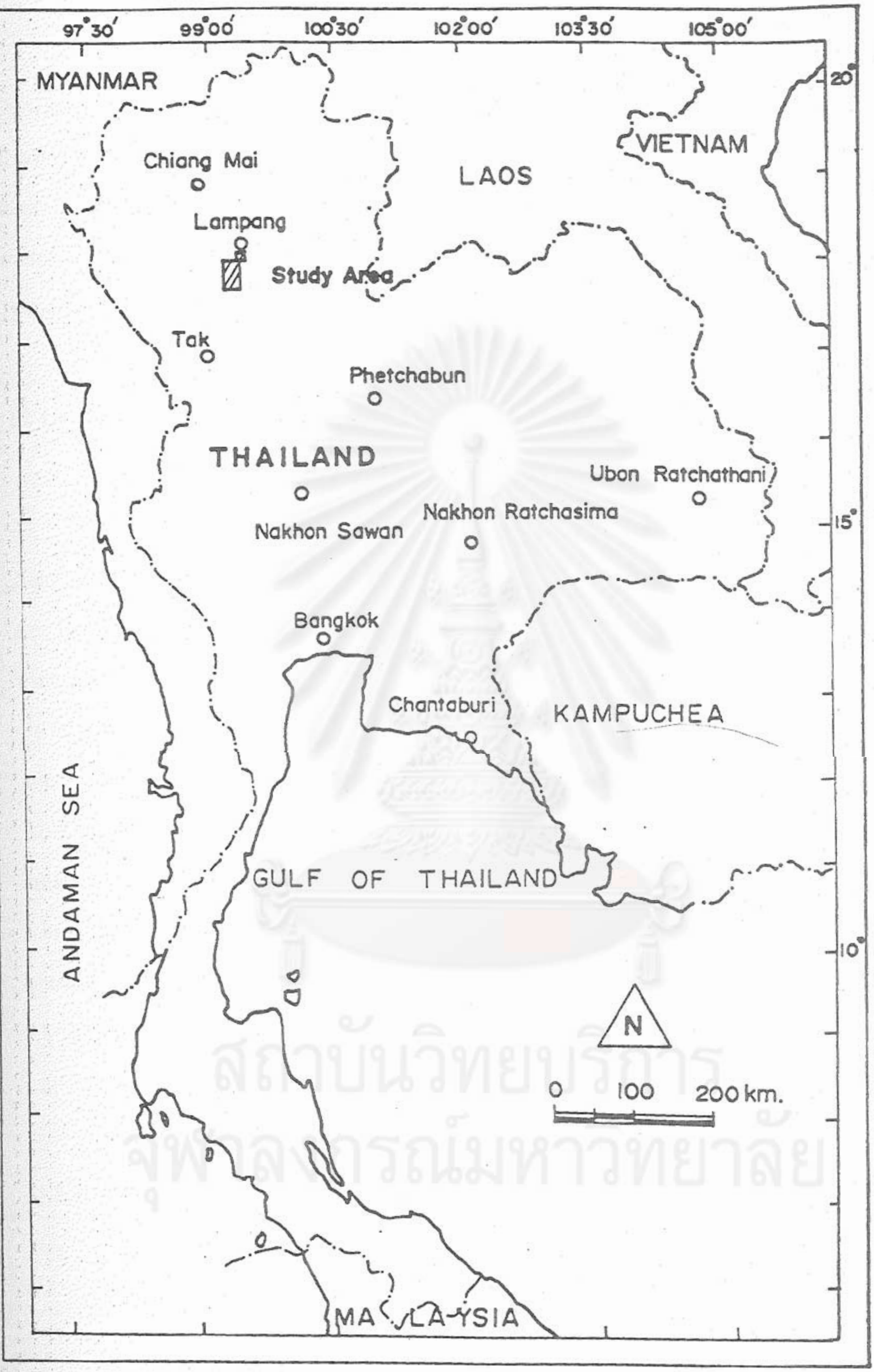


Figure 1.1 Index map of Thailand showing locality of the study area in Changwat Lampang northern Thailand.

Division (Charoenprawat et al. 1986) and subsequently by geologists of Gemstone Exploration Section (Thayapink and Sutthirat, 1993). This study area may become a good target for developing as a new gem deposit, and the basalts are believed to be corundum-related. This area is quite geologically interesting since detailed informations on geology, petrogenesis, and geochemistry of these basalts have never been reported.

1.2 Location

The study area is located in Amphoe Ko Kha, Amphoe Sop Prap, and Ban Nong, Amphoe Mae Tha, Changwat Lampang in northern Thailand (Figure 1.1). The area lies in two topographic maps at the scale of 1:250,000, sheet NE 47-7 (Changwat Lampang) and sheet NE 47-11 (Changwat Uttaradit), and in the topographic maps, scale 1 : 50,000, series L7017, sheet 4845 II (Amphoe Ko Kha) and sheet 4844 I (Amphoe Sop Prap). It comprises geographically 2 subareas (Figure 1.2) as Amphoe Sop Prap - Ko Kha (larger area) and Ban Nong, Thambon Nam Cho, Amphoe Mae Tha (smaller area), covering the total area of about 300 km^2. The northern part of the study area is located about 10 km south of Amphoe Ko Kha, whereas the southern part is situated about 8 km north of Amphoe Sop Prap. These two subareas are bounded by latitudes 18°10'N and 18°55'N and longitudes 99°18' E and 99°28'E, and is occupied by basalts approximately covering an area of about 60 km^2 (or about 20% of the total area).

1.3 Accessibility

Accessibility to the study area is accomplished by several routes. From Bangkok it is accessible by using many convenient routes to Changwat Nakhon Sawan. Then turn northwest following Highway no. 1 to Changwat Tak, Amphoe Thurn, Amphoe Sop Prap, and Amphoe Ko Kha, Changwat Lampang. The total distance from Bangkok to the study area is approximately 570 km. Highway no. 1 from Changwat Lampang to Amphoe Sop Prap cut across a volcanic crater in southern Amphoe Ko Kha. Many routes for forestation and agricultures in the area can be conveniently used only in the dry season, however, some may be possibly used in the rainy season.

1.4 Physiography

The study area is located in the southern part of Changwat Lampang, and its topography is composed largely of flat plains, small hills, and mountain ranges (Figure 1.2). Flat plains are also present with small hills in the north and south of the area. The high-altitude, N- and NE- trending mountains, with elevations ranging from 250 m to about 540 m (above the mean sea level, m.s.l), are located along the western and eastern edges of the study area. The basaltic plateau covers about 55 km^2 in the central area, with elevations ranging from 200 m to higher than 350 m (m.s.l), the rest (5 km^2) form as flat plains mixed with Quaternary sediments. The highest elevation (380 m above m.s.l) is located along the volcanic crater in the central part.

The principal drainage of the area is Mae Nam Wang which flows roughly from north to south, though in some parts it flows partially northwest along a fault zone. Radial drainage pattern is found around the volcanic crater. Other small intermitten streams generally distribute through out in the entired study area.

1.5 Climate and Vegetation

Changwat Lampang has a tropical savanna climate. The cold dry season with the mean temperatures 18° to 20°c usually starts in November and lasts until February,

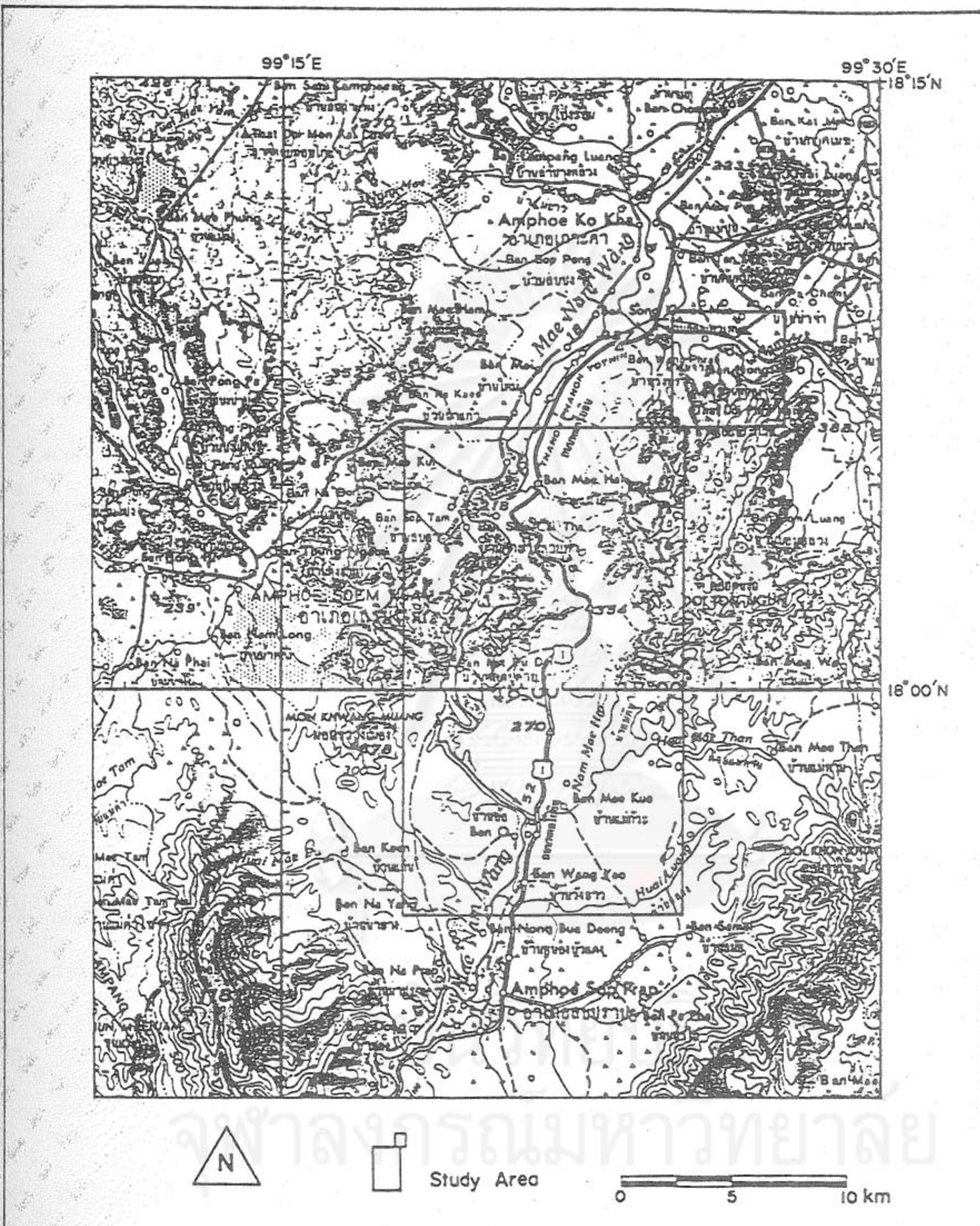


Figure 1.2 Topographic map of the study and adjacent areas showing some accessibility and physiography (Map sheet index NE 47-7 and NE 47-11).

which the lowest temperature frequently occurs in December. The area has been influenced by northeasterly prevailing wind. The summer is relatively short, with the mean temperatures 25° to 30°c in March to May. The highest temperature is in April. The rainy season commonly ranges from June to October under the influence of southwest monsoon. The mean annual rainfall is approximately 700 to 1,200 mm^3.

Vegetations in the area comprise shrubs and trees. The cultivated crops include sugarcane, rice, tamarind, and corn. They are grown extensively in flat plains of alluviums and colluviums. The wilds are generally timber forests, composed largely of Teetona grandis (teak tree), Dipterocarpaceae, inferior trees, and other non-economic trees. Some of these area are disturbed severely by deforestation.

1.6 Previous works

Previous geological data of the study area were reported by some researchers. Geologic maps used as reference maps herein were complied by Geological Survey Division, Department of Mineral Resources (DMR). The regional geology of the study and adjacent areas were performed on the geologic maps scale 1:250000, sheet NE47-7 (Changwat Lampang), and sheet NE47-11 (Changwat Uttaradit) by Piyasin (1971 and 1974). Charoenprawat et al. (1986) partially reported geological information of this area on the geologic map scale (1:50000), sheet 4844I (Amphoe Sop Prap). These geologic data were mentioned in Chapter 2.

Petrochemical informations of basalts from this study area were rarely reported. Barr and Macdonald (1978 and 1981) suggested from one basaltic sample from this area that the basalt was geochemically classified as hawaiite, whereas basalts from east of Lampang (Mae Tha basalts) were generally defined as basanite and hawaiite. Later investigation on geochemistry, including major- and trace- element contents in this basaltic area was reported by Barr and Jamest (1990), which one sample was classified as trachybasalt. They further suggested that trachybasalts are chemically similar to basanites, but with somewhat higher silica and lower alkali contents.

Barr et al. (1976) also investigated paleomagnetism and age of the underlying pebble tools in the Lampang basalts. These results indicated that ages of Lampang basalts range from 0.69 to 0.95 Ma. K/Ar ages of 0.6±0.2Ma and 0.8±0.3 Ma were suggested by Sasada et al. (1987). Recently, Sutthirat et al. (1994) reported $^{40}Ar/^{39}Ar$ age of 0.59±0.05 Ma from Mae Tha basalts.

Recently Sutthirat (1995), made a detailed geological study on basaltic rocks in the study area. Part of this research is taken from his study, however these exists some difference in dating data and interpretation on tectonic setting.

1.7 Purposes

The objectives of this investigation are :

1. To study petrographic features and geochemical compositions of these basalts;
2. To classify types of these basalts;
3. To study origins of these basalts and associated gems;
4. To establish the relationship between these basalts and associated gem;
5. To study general geology, structural geology, distribution of basalt, and gem occurrence using sattellite image and aerial photograph; and
6. To serve as a case study for future exploration of corundum-bearing basalts and their associated gems.

1.8 Methods of Investigation

Field mapping and sampling are regarded as preliminary works. They were carried out during mid 1992. The geologic maps (scale 1:50,000), sheet 4845II and 4844I, series L7017 were reinterpreted, and sample locations were plotted on these maps. This field study was cooperated with the Gemstone Exploration Division, Economic Geology Division, DMR. The aerial photographs and satellite images were also used to guide ground survey mapping, and to delineate rock boundaries and structural geology of the study area.

The basalt samples and some associated minerals were prepared for petrographic investigation and chemical analyses. Sixty-five fresh basaltic samples were selected and powder samples were ground using jaw crusher and disc mill. Before grinding, contamination of samples are avoided by getting rid of weathered surfaces, megacrysts, xenoliths, and amygdules. These powdered products were prepared for chemical analyses. About 120 thin-sections for petrographic description under polarizing microscope were prepared from these 65 basalt samples.

Mineralogy and textures of samples were studied in standard thin-sections using the petrographic microscope. Major elements and some trace elements were analyzed using X-ray fluorescence (XRF) by Mr. Somsak Sangsila, Mrs. Suchada Sripairojthikoon, and Miss Sasithon Panthong, and FeO contents were analysed using volumetric method by Miss Piyanun Amnachskul, Mineral Resources Analysis Division, DMR. Some rare earth elements, including La, Ce, Nd, Sm, Eu, Tb, Dy, Yb, and Lu, were analyzed using neutron activation analysis by Mr. Chanchai Asvavijnijkulchai, staff of the Physics Division, Office of Atomic Energy for Peace. Six duplicate basalt samples were cross-checked for rare earth elements, using the same method, by Chemex Labs Ltd., Canada.

The determinations of megacrysts and xenoliths were also carried out by X-ray diffraction (XRD) method, at X-ray Lab of Department of Geology, Chulalongkorn University.

Five selected basalt samples were dated using $^{40}Ar/^{39}Ar$ incremental step-wise heating analysis, using labs of the Mc Master University and Queen's University, by Professor Dr. Edward Farrar and Robin Landgridge, Department of Geological Sciences, Queen's University, Canada.

CHAPTER II

REVIEWS OF LATE CENOZOIC BASALTS IN MAINLAND SOUTHEAST ASIA

2.1 Introduction

Occurrences of basalts in Southeast Asia are considered to be late Cenozoic in age. They form a large continental volcanic province comparable to those in eastern Australia and western United States (Barr and Macdonald, 1981). These basalts generally occur as small provinces and scattering in Thailand and western Kampuchea, though those in eastern Kampuchea, southern Laos, and Vietnam tend to be larger (Figure. 2.1). Basalts of similar age are also found in Malaysia (Hutchison, 1973), southern China (Barr and Macdonald, 1981), and central Burma (Bender, 1983). These basalts are varied in geochemistry and geochronology. Their ages range from 24 Ma to recent. The origins of these basalts may be a result of complex regional tectonic phenomena in Southeast Asia. It is also regarded that basalts of Southeast Asia are main source of gem-quality ruby , sapphire , and zircon , particularly those in Thailand and Kampuchea.

2.2 Distribution

The late Cenozoic basalts in northern and eastern Thailand and western Kampuchea are relatively small and scattered, whereas those in eastern Kampuchea, southern Laos, and Vietnam form larger and more extensive bodies. Basalts of similar

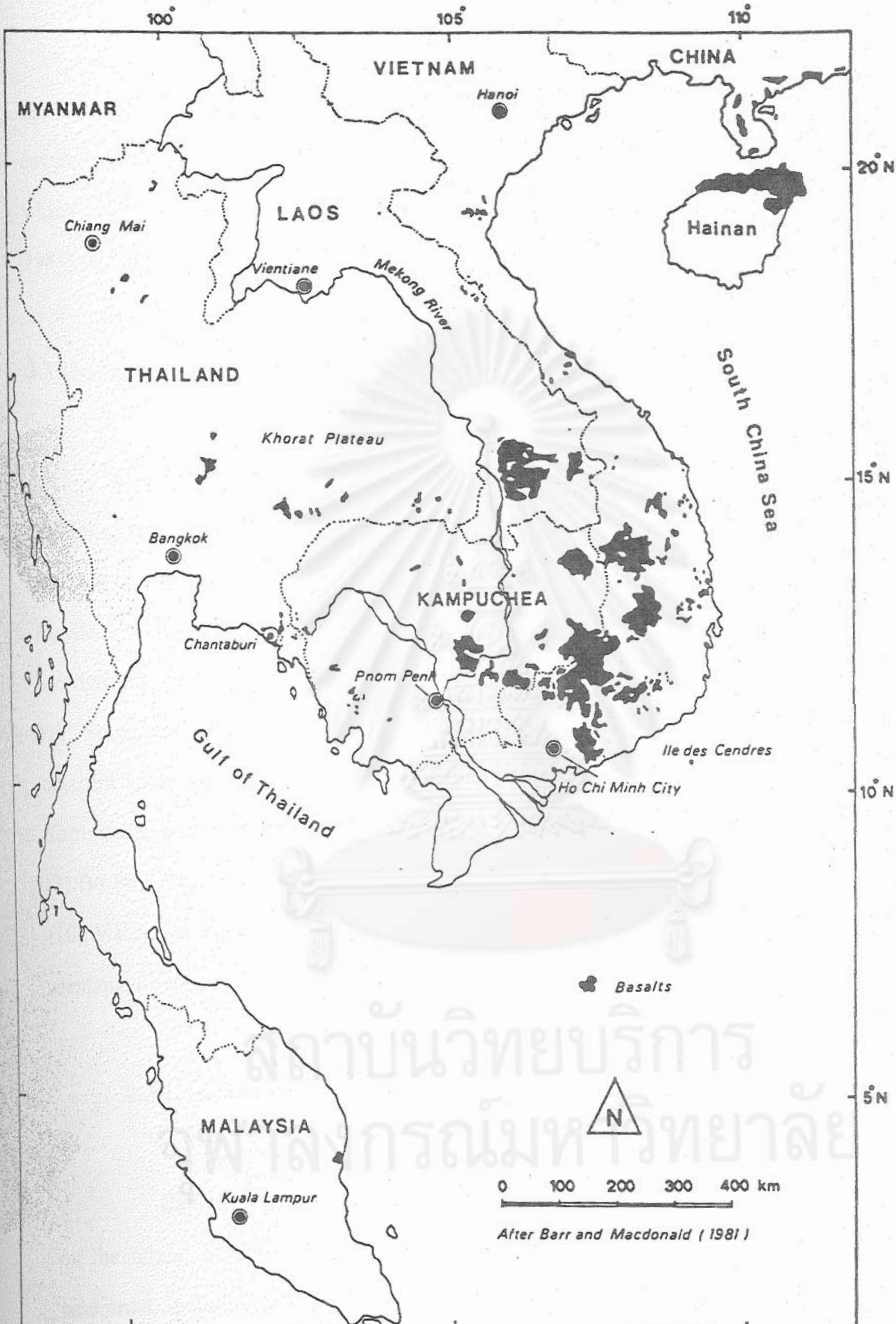


Figure 2.1 Map showing the distribution of Cenozoic basalts in parts of mainland Southeast Asia (Barr and Macdonald, 1981).

age also occur in Malaysia and southern China (Figure. 2.1). Some basalts may be covered by thick, reddish-brown latosols and are interpreted to be older than those which retain vents, craters, and other volcanic landforms (Barr and Macdonald, 1981). Details of basalts in these locations are presented in the next section.

2.3 Geology and Petrochemistry

A review paper was earlier performed by Barr and Macdonald (1981) regarding several aspects of Cenozoic basalts of Southeast Asia (Figure. 2.3). Most geology and petrochemistry of basalts described herein were taken from Barr and Macdonald (op. cit.). According to their studies, mainland Southeast Asian basalts are divided, based upon geographical locations as, into 10 areas (Figure. 2.1) - (1) Southern China and northern Vietnam, (2) Northern and central Vietnam and adjacent areas, (3) Bolovens and Kasseng Plateaus, (4) Bokeo Plateau, (5) Eastern Kampuchea and southern Vietnam, (6) Western Kampuchea and eastern Thailand, (7) Bo Ploi area, Thailand, (8) Khorat Plateau, Thailand, (9) Northern Thailand, and (10) Malaysian Peninsula. In addition, Cenozoic basalts of central Burma were also mentioned herein.

2.3.1. Southern China and northern Vietnam

Cenozoic basalts of this area occur in the Kouang Tcheou Wan area and on the island of Hainan (see Figure. 2.1). These basalts show typical volcanic landforms, including crater lakes, although lateritic red soil is extensively developed (Hoffet, 1933b). Chemical analyses of two samples (Lacroix, 1933) indicate that the basalts are tholeiitic and similar to tholeiitic basalts in central Vietnam.

2.3.2. Northern and central Vietnam and adjacent areas

This area includes small scattered basalt bodies in the north and large basaltic plateaus in the south. These basalts include older flows, on which extensive lateritic red soils are developed, as well as younger volcanic cones, occurring on these older flows. They occur in Pleiku, Darlac, Haut Chhlong, and Djiring Plateaus, all of which are high-level plateaus. Pleiku and Darlac are shield-like in form. They always show primary volcanic landforms such as cones, crater lakes, volcanic mountains, and lava flows. Haut Chhlong and Djiring Plateaus are largely covered by basaltic lavas, but they are not commonly presented as primary volcanic landforms. However, the younger basalts in the east may show some basaltic flows and volcanic cones. Basalts of these areas range in composition from tholeiite to alkali basalt, such as alkali olivine basalt, hawaiite, and mugearite. The petrochemical results indicate that older basalts are generally tholeiitic, whereas alkali basalts are younger than tholeiitic basalts. Three samples from the Djiring Plateau (Barr and Macdonald, 1981) yeilded relatively old K/Ar ages of 8.8 $\pm$ 0.3 Ma, 13.3 $\pm$ 1.1 Ma, and 11.6 $\pm$ 0.3 Ma. Hawaiites from Pleiku and Darlac Plateaus have K/Ar ages of 2.1 $\pm$ 0.1 and 3.4 $\pm$ 0.2 Ma, respectively.

2.3.3. Bolovens and Kasseng Plateaus

In northern Vietnam, basalt flows cap the Bolovens Plateau at an elevation of 1,000 to 1,200 m and occupy valleys descending radially from the center of the plateau nearly to sea level (Hoffet, 1933a). Hoffet (op. cit.) considered these flows to be Quaternary, occupying pre-existing valleys. Age of 1.36 $\pm$ 0.09 Ma obtained for a zircon crystal from this plateau is apparently similar to basalts nearby Kasseng

Plateau (Hoffet, 1933a). Petrological data are not available for basalts of these plateaus. Zircons from the Bolovens Plateau were observed to be geochemically similar to those from nearby Bokeo Plateau (Carbonnel et al., 1973). Age (1.36 $\pm$ 0.09 Ma) of basalts from this area is similar to that (1.29 $\pm$ 0.23 Ma) reported for zircon from Bokeo Plateau (Carbonnel et al., 1972). Then these are assumed that basalts of the Bolovens and Kasseng Plateaus are similar to those of Bokeo.

2.3.4. Bokeo Plateau

The Bokeo Plateau (100 to 500 m from msl) consists of basalt flows (with the maximum thickness of 40 m) capping older volcanic and surrounding metamorphic rocks. The basalts formed volcanic landforms such as cones and crater lakes (Lacombe, 1970). Flows are largely covered by laterictic red earths. Gems, predominantly zircons in association with large crystals of corundum, garnet, titanomagnetite, chromopicotite, picotite, and anorthoclase, are found mainly in the basalt terrane. But most products are results of explosive eruption and weathering. It may also be implied that the magacrysts are more abundant in younger basalts. Paleomagnetic data (Lacombe, 1970) was used to divide these basalts into 2 groups : reversed magnetic polarity of older basalts (0.7 - 2.3 Ma) and normal polarity of younger ones (younger than 0.7 Ma). Compositions of basalts vary geochemically from tholeiitic to highly alkalic - tholeiites, hawaiites, mugearites, alkali olivine basalts, nepheline mugearites, nepheline hawaiites, and basanites.

2.3.5. Eastern Kampuchea and southern Vietnam

These basalts form a series of low plateaus (Kompong Cham, Suong, Mimot, Snoul, and Xuan Loc) in eastern Kampuchea and southern Vietnam. They always show primary volcanic landforms, such as flows, craters, and cones, that form hills rising above the reddish-brown latosols formed on the flatter basaltic areas. Gems, primarily zircons, are mined from basaltic gravels on Xuan Loc Plateau (Carbonnel et al., 1972). Age data are also available from only the Xuan Loc Plateau. Fission-track dating from four different zircon crystals yielded an average age of 0.63 $\pm$ 0.09 Ma. However, K/Ar age of 2.6 $\pm$ 0.2 Ma (Barr and Macdonald, 1981) from a whole-rock basalt is actually concordant with zircon ages from Pailin basalt. Although the K/Ar age may be inaccurate. The younger basalts have been weathered rapidly, forming gem-bearing gravel deposits. Paleomagnetic data from the Kompong Cham Plateau indicate normal magnetic polarity (Carbonnel et al., 1973). That is in agreement with young zircon ages from basalts of the Xuan Loc Plateau. Chemical compositions of these basalts range from tholeiitic to strongly alkalic. They comprise nepheline hawaiite, tholeiite, basanite, and hawaiite.

2.3.6. Western Kampuchea and eastern Thailand

Basalts of this area always occur as small scattering volcanic bodies. Most of them are especially intriguing to be major source of ruby and sapphire. Cardamomes Massif's basalts form small bodies in the SSE trend. They are largely covered by red lateritic soil, but remnants of craters can be recognized (Carbonnel et al., 1973). Sapphire and zircon are mined from eluvial and alluvial deposits associated with some of these flows. Chemical compositions indicate a wide range of silica content, but they are not highly alkalic. They include basanite, hawaiite, mugearite, and tholeiite. The basalts of Pailin area occur in metamorphic rocks of Pre-Cambrian age , and greywackes of Triassic age. They form four separated hills rising above the surrounding plain. Three of the hills, Phnum O Tang, Phnum Ko Ngoap, and Phnum Yat, are considered to be eroded remnants of volcanic cones with associated lobes of lavas. The Pailin area is a rich gem field where ruby, sapphire, and other megacrysts (zircon, garnet, etc.) are mined from eluvial, colluvial, and alluvial materials derived from the three larger basalt bodies. Fission-track ages of 2.42 $\pm$ 0.18 Ma (Carbonnel et al., 1973) are determined from Phnum Yat. Four K/Ar ages are available from the other volcanic hills in the Pailin area : Phnum O Tang (1.09 $\pm$ 0.13 Ma), O Chra (1.30 $\pm$ 0.17 Ma), and Phnum Ko Ngoap (1.43 $\pm$0.10 and 1.42 $\pm$ 0.08 Ma). All of these ages are significantly younger than basalts from Phnum Yat. Basalts from Pailin are generally highly alkalic and low in silica. They comprise mainly basanite and nepheline hawaiite, whereas Phum Yat basalts are hawaiite. Geochronological and chemical data indicated that younger basalts are more alkalic and undersaturated than older flows. Basalts from Chanthaburi area are generally similar to those nearby Pailin, with volcanic vents and associated flows. Gems, dominantly corundum, are mined from eluvial, colluvial, and alluvial deposits associated with most basalts in this area. K/Ar age of 1.13 $\pm$ 0.17 Ma has been obtained for basalts from Nong Bon Basalt, north of Trat (Barr and Macdonald, 1981), whereas Carbonnel et al. (1972) reported a fission-track age of 2.57 $\pm$ 0.02 Ma from the same area. Bignell and Snelling (1977) reported a K/Ar age of 8.5 $\pm$ 1.0 Ma for a basalt from Ko Kut island, south of Trat. Basalt from Tha Mai, Chanthaburi yielded a young K/Ar age of 0.44 $\pm$ 0.11 Ma. Whereas Sutthirat et al. (1994) reported a Ar/Ar age of 2.38 $\pm$ 0.16 Ma for basalt from Nong Bon, and 3.0 $\pm$ 0.19 Ma for basalt from Khao Wua. Chemical compositions are similar to basalts from Pailin; i.e., highly alkalic and low in silica (Barr and Macdonald, 1981). They always comprise basanitoid and nephelinite.

2.3.7. Bo Phloi area

Basalt at Bo Ploi forms a small, plug-like body covering about 1 km^2 in a fracture zone in quartzite of Silurian-Devonian age. K/Ar age of 3.14 $\pm$ 0.17 Ma was reported by Barr and Macdonald (1981). Sutthirat et al. (1994) reported Ar/Ar age of 4.17$\pm$0.11 Ma for a basalt from the same area. This basalt is a source of quality gems of Thailand. Gems, dominantly corundum, are mined from alluvial and colluvial deposits. Basalt is extremely fine-grained with microlites scattered within a glassy, analcime-bearing groundmass. Megacrysts of olivine, nepheline, anorthoclase, clinopyroxene, and spinel are abundant. Chemical compositions show highly alkalic nepheline hawaiite with very high Na and low Al. They are very similar to nepheline hawaiite from Pailin in Kampuchea.

2.3.8. Khorat Plateau

The Khorat Plateau is underlain by sedimentary rocks of Mesozoic age. Scattered small outcrops of basalts occur in southern part of plateau (called as E-sarn Tai) and west of western edge of plateau. The age of basalt from Khao Kradong, Burirum was reported to be 0.92 $\pm$ 0.30 Ma using K-Ar method by Barr and Macdonald (1981). A sample of basalt from Phu Fai, Kantharalak, Sri Sa Ket, has yielded a K/Ar age of 3.28 $\pm$ 0.48 Ma (Barr and Macdonald, 1981). Basalt from Lam Narai was reported K/Ar age of 11.29 $\pm$ 0.64 Ma by Barr and Macdonald (1981), whereas Ar/Ar age of 18.1$\pm$0.7 Ma and 24.1$\pm$1.0 Ma were reported by Intasopa (1993). However Wichianburi basalts have yielded Ar/Ar ages of 8.82$\pm$0.09 Ma and 11.03$\pm$0.03 Ma (Sutthirat et al., 1994) and 9.08 $\pm$0.29 Ma (Intasopa, 1993). These basalts are always covered by lateritic soil. Khao Phu Fai forms gabbroic plug that may represent a "feeder" source of basalts which form volcanic landforms nearby (Sutthirat et al., 1995). Gem deposits occur in the southern part of plateau nearby Phanom Dongrak range. Gems in this area comprise mainly corundum, zircon, and garnet. Khao Phu Fai is also a major source of garnet. Khao Phu Fai gabbroid is Ne-mugearite in composition, whereas the other basalts from southern Khorat Plateau are mainly hawaiites (Barr and Macdonald, 1981). Sutthirat (1992) and Sutthirat et al. (1995) suggested that garnet at Khao Phu Fai were carried from upper-mantle source region, and that hypabyssal basaltic rock is of Ne-Hawaiite in composition. Chemical compositions of basalts from west of the western edge of the plateau, e.g. Lam Narai and Wichianburi , comprise tholeiite , alkali olivine basalt and hawaiite.

2.3.9. Northern Thailand

Seven basalt flows from Denchai area form a thin layer on Mesozoic (meta) sedimentary rocks. They are very dissected, but appear to form three lobes radiation from a subdued topographic feature inferred to represent the vent area (Barr and Macdonald, 1981). The uppermost flow has a K/Ar age of 5.64 ± 0.28 Ma. Zircon and corundum are mined from eluvial and alluvial deposits associated with these basalts. Geochemistry indicates that four types of basalts are present in this area. They range from tholeiitic (oldest basalt) to hawaiite and basanite (youngest basalt). Basalts from Lampang area depict volcanic vents and flows in east and southwest of Lampang. They are generally poorly exposed due to thick covers of alluvial materials and soils. Laterite underlies the basalt in some areas. Paleomagnetic studies and fission - track datings (Barr and Macdonald, 1981) have indicated that the age of the Lampang basalt is about 0.69 or 0.95 Ma. The K/Ar ages of 0.8 ± 0.3 and 0.6 ± 0.2 Ma are reported by Sasada et al. (1987) which are similar to the $^{40}Ar/^{39}Ar$ age of 0.59±0.05 Ma as reported by Sutthirat et al. (1994). Basalts are generally basanites and similar in composition to those of Denchai. Some basalts are hawaiites. Mae Lama and Ban Chang Khian areas are found as other small and separated basalt occurrences. They are grouped together because of petrographic and chemical similarities. Chemical analyses point to tholeiitic composition. K/Ar age of 1.69 ± 1.25 Ma was obtained for a basalt from Ban Chang Khian (Barr and Macdonald, 1981). Basalt in Chiang Khong is exposed on the banks of the Maekong River. This basalt is crowed with vitreous, black clinopyroxene crystals similar to those at Bo Ploi and Tha Mai. Zircon and corundum are mined from gravel deposits in Laos sides of the river (Ban Huai Sai, Laos). Lacroix (1933) presented an analysis of an alkali olivine basalt from Ban Huai Sai, whereas Barr and Macdonald (1981) reported a basanitic basalt for basalts of Thai side. K/Ar age of 1.74 ± 0.12 Ma was reported by Barr and Macdonald (op. cit.).

2.3.10. Malaysian Peninsula

Basalts occur in the Segamat and Kuantan areas of the eastern Malaysian Peninsula. The Segamat basalts are highly potassic. K/Ar dating has indicated an age of at least 62 Ma (Bignell and Snelling, 1977). The Kuantan basalts have been described by Fitch (1952), Hutchison (1973), and Chakraborty (1977). No volcanic landforms are present, but a K-Ar age of only 1.6 ± 0.2 Ma has been obtained (Bignell and Snelling, 1977). The basalts apparently include an older "alkali olivine basalt" series and a younger "nephelinite" series (Chakraborty, 1977). Chemical data show that they range from alkalic to highly alkalic. They include hawaiite, nepheline hawaiite, basanite, and nephelinite.

2.3.11. Central Plain of Burma

The Central plain of Burma consists of a wide range of volcanic suits occurring during (Late) Cretaceous and Tertiary to sub-Recent intrusive and extrusive which follows the N-S strike almost parallel to the Tertiary Basin. This is commonly called by Bender (1983) as inner volcanic arc of the inner-Burmar Tertiary basin, which runs from W Sumatra via the volcanic islands of Barren Island and Narcondam Island though the Gulf of Mataban as far as northern Burma. This arc is characterized by a discontinuous chain of mafic to felsic volcanic suits. Major rocks include serpentinized olivine dolerite, andesite, tuff, rhyolite, picritic basalt, olivine basalts and ashes. Craters cone-shaped volcanoes with plugs and some pillow structures are characteristic volcanic features.

2.4 Gem - Bearing Basalts in Thailand

Distributions of late Cenozoic basalts are widespread in northern, eastern, and central Thailand (Figure. 2.2). Late Cenozoic basalts of Thailand can be further subdivided into 2 major groups based on occurrence of gems (mainly corundum) as corundum-bearing and corundum - barren basalts (Vichit, 1992). These basalts can be geochemically subdivided into basanitoids and hawaiite basalts (Barr and Macdonald, 1978). The basanitoids comprise nephelinite, basanite, nepheline hawaiite and nepheline mugearite whereas the hawaiite basalts comprise alkali olivine basalt, hawaiite and mugearite. It is expected that gem-quality corundum is typically associated with basanitoid basalts (Sutthirat, 1992, Jungyusuk and Khositanont, 1992).

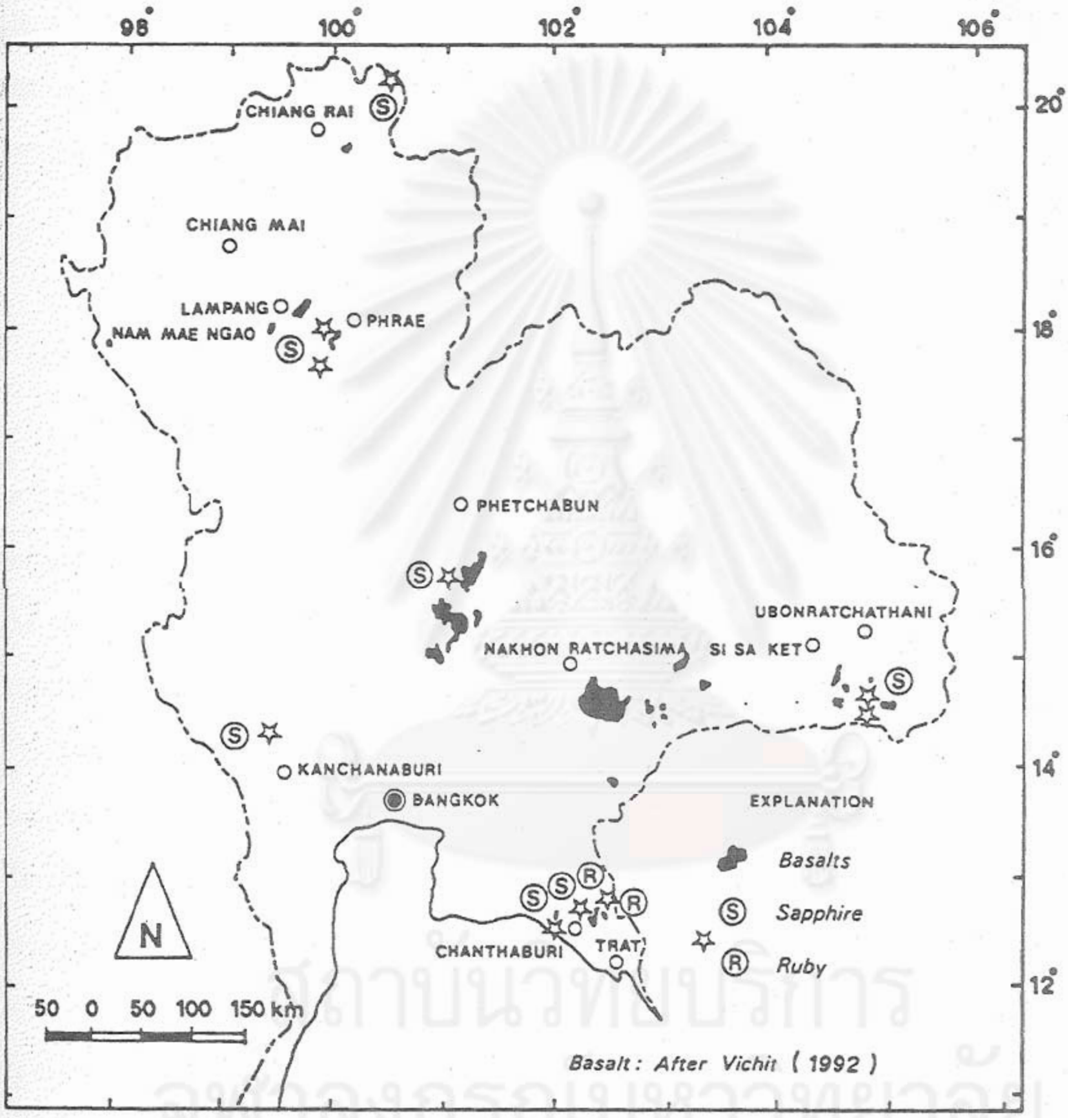


Figure 2.2 Map showing distribution of Cenozoic basalts and locations of ruby and sapphire deposits in Thailand (Vichit, 1992).

Gem-bearing corundum deposits in Thailand are generally found as secondary deposits such as eluvial or alluvial placers and residual soils (Vichit, 1992). Most gem-bearing corundum deposits can be geographically subdivided into 6 areas, such as Chanthaburi-Trat area, Bo Phloi area, Phrae-Sukhothai area, Wichian Buri area, Ubon Ratchathani-Si Sa Ket area, and Chiang Khong area. Distributions of basalts and corundum deposits in Thailand are presented in Figure 2.2. The details of these basalts and gem deposits are described below.

2.4.1. Chanthaburi - Trat area :

Basalts of this area occur in Amphoe Khlung, Amphoe Pong Nam Ron in Changwat Chanthaburi, and Amphoe Bo Rai in Changwat Trat. They generally formed low relief flat plains and have commonly been weathered to red soils with the exceptional Khao Ploi Waen basalt which occurs as a small hill of dominant volcanic landform. These basaltic rocks can be identified as nephelinite (Barr and Macdonald, 1981). They can be described as black to dark grey, fined-grained rock containing ultramafic nodules, clinopyroxene megacrysts and spinel. K/Ar age determination yielded an age of 0.44 ± 0.11 Ma for a basalt from Khao Phloi Waen area (Barr and Macdonald, 1981). The older age (3.0 ± 0.19 Ma) was reported for a basalt from Khao Wua using Ar/Ar dating method (Sutthirat et al., 1994) which is also in Khao Ploi Waen range. Fine-grained porphyritic hawaiite is suggested for basalts found in the northern part of this area at Ban Saphan Hin (Sirinawin, 1981) whereas the southern part is mainly occupied by gem-bearing basanite in Ban We Lu, Ban Ang Et and Ban I Ram (Jungyusuk and Sirinawin, 1983). The age of 2.57 ± 0.2 Ma was obtained from a basalt sample from east of Chanthaburi using fission-track age determination (Carbonnel et al., 1972). Nong Bon basalts extruded thick beds of sandstone and shale of Carboniferous and Triassic ages, were identified as dark grey to black, fine-grained porphyritic basanitoid (Vichit et al., 1978). Megacrysts of clinopyroxene, garnet, spinel, and ilmenite and ultramafic modules can be generally observed. Olivine and clinopyroxene phenocrysts were encountered in groundmass of clinopyroxene, nepheline and opaque minerals. K/Ar age of 1.13 $\pm$ 0.7 Ma was reported by Barr and Macdonald (1981) whereas $^{40}Ar/^{39}Ar$ age of 2.38 $\pm$ 0.16 Ma was determined by Sutthirat et al. (1994). Basalt from Ko Kut is as old as 8.5 $\pm$ 1.0 Ma and obtained from K/Ar method (Bingell and Snelling,1977).

2.4.2. Bo Phloi area

Bo Phloi basalt may be called gem-quality blue sapphire carrier and is found at Khao Wong Chinda Ram, Amphoe Bo Ploi, Changwat Kanchanaburi. It is generally fine-grained, porphyritic, dark and dense rock. This basalt can be characterized by occurrence of numerous spinel- lherzolite nodules, clinopyroxene megacrysts, spinel, sanidine and olivine. The basalts were called nepheline-olivine basalt by Bunopas and Bunjitradulya (1975), however, Barr and Macdonald (1981) and Yamniyom (1982) geochemically identified these basalts as nepheline hawaiite. K/Ar method yielded an age of 3.14 $\pm$ 0.17 Ma (Barr and Macdonald, 1981), and $^{40}Ar/^{39}Ar$ age of 4.17$\pm$0.11 Ma is recently reported by Sutthirat et al. (1994). Aranyakanon (1988) suggests that the area of Bo Phloi was once used to be covered by basalts. They extruded Silurian - Devonian rocks in the east to central plains and the west of the area, such as Ban Chong Dan. Volcanic layers are commonly present, particularly those underlying gem-bearing unconsolidated deposit.

2.4.3. Phrae-Sukhothai area

Basalt is found in Ban Bo Khaew, Amphoe Den Chai, Changwat Phrae. Several basalt flows are overlying Permo-Triassic volcanic and Permo-Carboniferous sedimentary rocks. Den Chai basalt can be subdivided into 7 flows (Barr and Macdonald, 1981). This basalt was geochemically classified as transition hawaiite (Flow 1 to Flow 4), hawaiite (Flow 5 and Flow 6) and basanite (Flow 7). Basalts in Flow 1 to Flow 6 are fine-grained to medium-grained, with abundant olivine phenocrysts. Layers of spinel lherzolite nodules (1 m thick) are typically concentrated in the bottom of Flow 6. Occurrence of columnar jointing in Flow 7 makes it different from the others. Basalt in Flow 7 also contains abundant lherzolite nodules and megacrysts of aluminous clinopyroxene and black spinel. Each flow shows vesicular texture in the upper part. These vesicular textures can be used as an indicator of sharp contact between layers. Occurrences of gem-quality corundum and zircon in this area are considered to be related to the Flow 7 basalt (Vichit et al., 1978, and Barr and Macdonald, 1981). Age of these basalts which was obtained by K/Ar method is 5.64 ± 0.28 Ma (Barr and Macdonald, op. cit.).

2.4.4. Wichianburi area

Wichianburi basalt in Changwat Phetchabun is exposed as high-relief hilly terrane with outstanding volcanic plugs. Columnar jointing can be commonly found. These basalts set on the sequence of Permian and Tertiary sedimentary rocks (Jungyusuk et al., 1989). They are always present as black, fine-grained, porphyritic rocks, locally containing ultramafic nodules and black spinel. Plagioclase frequently occurs as laths of oligoclase. Diabase dikes crosscut this basaltic flow in many locations. This basalt can be geochemically classified as alkali basalt, including alkali olivine basalt, hawaiite, nepheline hawaiite, and basanite (Vichit et al. , 1988). In addition, gem-quality corundum can be occasionally discovered in this rock. Ar/Ar age dating method of this basalt yield an age of 9.08 $\pm$ 0.29 Ma (Intasopa, 1993), 8.82$\pm$0.09 Ma and 11.03 $\pm$ 0.03 Ma (Sutthirat et al., 1994).

2.4.5. Ubon Ratchathani-Sri Sa Ket area

Basaltic rocks in Sri Sa Ket are mostly recognized as volcanic cones and can be found at Phu Ngoen, Phu Kom and Phu Khamint. Phu Ngoen basalts are typically vesicular rocks containing xenoliths of sandstone, siltstone and ultramafic rocks in the middle layers. Phu Khamint basalts are characteristically dark grey with fine-grained to medium-grained, diabasic textures. Both basalts were geochemically classified as hawaiite. Phu Fai rocks are identified as shallow intrusive (subvolcanic) basalts, and can be divided into 3 groups (Sutthirat, 1992), namely coarsed-grained gabbroid, medium-grained gabbroid, and fine-grained gabbroid with transitional boundaries. They commonly contain plagioclase, clinopyroxene, olivine, apatite ilmenite. They are present geochemically as nepheline mugearite by Barr and Macdonald (1981), however, they are classified as nepheline hawaiite by Sutthirat, (1992). K/Ar age of 3.28 $\pm$ 0.48 Ma is reported by Barr and Macdonald (1981). Garnet (pyrope : almadine ratio = 7 : 3) and other associated minerals imply an upper-mantle source (Sutthirat, 1992).

Basaltic rocks occurring in the southern part of Ubon Ratchathani can be sporadically found in Ban Nong Khun and at Khao Noi Keereebunpot, Amphoe Nam Yun. These basalts are dark grey, fine-grained, and vesicular. They consist mainly of olivine and titanoaugite microphenocrysts in intergranular groundmass of plagioclase, clinopyroxene, magnetite and sphene. Zeolite filling can be occasionally observed in vesicular basalts. The basalts are geochemically regarded to be hawaiite. Corundum deposits are locally found in Ban Nam Yun nearby outcrops of hawaiite. It is noticeable that corundum is usually associated with basanitoid basalt. An absence of basanitoid basalt in this area was probably a result of erosion (Jungyusuk and Khositanont, 1992).

2.4.6. Chiang Khong area

Basalts are exposed along Mae Khong river bank, Changwat Chiang Rai and can be traced southward across the Mae Khong River into Laos. These basalts can be identified as black , fine-grained rocks with black spinel, olivine and plagioclase phenocrysts (Sukvattananunt and Assavapatchara, 1989). A sample from the outcrop on the Thai side of the river bank shows higher potash and more undersaturation and is classified as basanite (Barr and Macdonald, 1981). An age of 1.74 ± 0.12 Ma was obtained by K/Ar method (Barr and Macdonald, 1981). Gem-quality corundum has been mined only in Laos.

2.5 Chronology of Thai Cenozoic Basaltic Volcanism.

Sutthirat et al. (1994) used $^{40}Ar/^{39}Ar$ geochronological data and previous age information of Thai basalts (Table 2.1), and suggest that several distinct episodes of volcanism which may have been related to and caused by modifying patterns of tectonic regimes. They concluded that the Cenozoic volcanic activities in Thailand may have been inferred to be episodic rather than continuous and have involved at least 6 events.

Table 2.1 Age determination of basalts in Thailand (after Sutthirat et al.,1994).

Localities	Age (Ma)			
	Fiss. Track	K\Ar	Ar/Ar (t_p)	Plaleomag
1. Ban Chang Khian (Chiang Rai)		1.69 ± 1.25[A]		
2. Chiang Khong (Chiang Rai)		1.05 ± 0.81[A]		
3. Mae Tha (Lampang)		0.80 ± 0.3[E] 0.60 ± 0.2[E]	0.59 ± 0.05[F]	0.69 - 0.95[A]
4. Den Chai (Phrae)		5.64 ± 0.28[A]		
5. Lam Narai (Lop Buri)		11.29 ± 0.64[A]	18.10± 0.7[D] 24.10 ± 1.0[D]	
6. Wichianburi (Phetchabun)			9.08 ± 0.29[D] 8.82 ± 0.09[F] 11.03 ± 0.03[F]	
7. Bo Phloi (Kanchana Buri)		3.14 ± 0.17[A]	4.17± 0.11[F]	
8. Khao Kradong (Buri Rum)		0.92 ± 0.3[A]		
9. Phu Fai		3.28 ± 0.48[A]		
10. E. Chanthaburi	2.57 ± 0.2[C]			
11. Khao Phloi Waen (Chanthaburi)		0.44 ± 0.11[A]		
12. Khao Wua (Chanthaburi)			3.00 ± 0.19[F]	
13. Nong Bon (Trat)		1.31± 0.17[A]	2.38 ± 0.16[F]	
14. Ko Kut (Trat)		8.50 ± 1.0[B]		

References

A Barr and Macdonald (1981)
B Bignell and Snelling (1977)
C Carbonel et al. (1972)
D Intasopa (1993)
E Sasada et al. (1987)
F Sutthirat et al. (1994)

2.5.1. Late Oligocene Episode (22 - 24 Ma)

The probable oldest Cenozoic basaltic rocks were in Lopburi area. The $^{40}Ar/^{39}Ar$ age data of weaky alkali basalts from this area indicate that the rocks were emplaced during Late Oligocene to Early Miocene (24 Ma). The rhyolite from southern Chao Phra plain was dated as Early Miocene (22.5Ma ; Hooper,1969). These age data correspond to the displacement event of the Ailao Shan/Red River metamorphic belt along the sinistral Red-River Fault which occurred at appoximately 23 Ma (K-Ar age) (Tapponnier et al., 1990). Rapid extension of the Lopburi area, therefore, may have occurred in the Oligocene epoch and closed in the Early Miocene. Extension of Mergui basin may have closed also during Early Miocene (Polachan , 1988). However , no gem-bearing basalts of the Epoch were encountered.

2.5.2. Early Miocene Episode (18 - 20 Ma)

The Lopburi area still acted as the locus of the volcanism. The second episode of volcanic activity (alkali-basaltic-andesitic-rhyolitic series), as dated recently by Intasopa (1993) using $^{40}Ar/^{39}Ar$ method, was Early Miocene (18-20 Ma). Again no gem-bearing volcanism has been reported yet.

2.5.3. Middle to Late Miocene Episode (8 - 14 Ma)

The third episode of basaltic activity occurred during Miocene. Although no basaltic rocks of Middle Miocene were encountered. The emplacement of basaltic volcanics occurred later at about 5-11 Ma. Alkali basalts from Lopburi area yield respectively the age of 11.3 Ma (K/Ar, Barr and Macdonald, 1981) and 9.1 Ma ($^{40}Ar/^{39}Ar$, Intasopa, 1993). It is interpreted that the rhyolite-associated basalts have not given rise to gem generation.The locus of Neogene volcanism appears to extend northwards along the Late Paleozoic suture zone.

Wichian Buri basalts in the Phetchabun area were emplaced later at approximately 8-11 Ma ($^{40}Ar/^{39}Ar$ method, Sutthirat et al., 1994). These alkali basalts were proved to be temporally and spatially associated with gems. This basaltic volcanism can be regarded as the first episode of gem-bearing basalt in Thailand. In addition, a basalt sample from the Phitsanulok basin was dated as 10.3 Ma using K/Ar method (Knox and Wakefield, 1983). Such event may have taken into account the generation of Ko Kra Ridge which may extend northward from the eastern Gulf of Thailand to this tectonic-related volcanic belt.

The occurrence of Ko Kra ridge can be regarded as the indication of the rapid uplift of this volcanic belt. Similar age (i.e. 11 Ma) is interpreted by Charusiri et al. (1991) to represent the reactivation of the NNE - trending Pranburi - Hua Hin Fault. This major event, therefore, marks the regional and rapid tectonic uplift and the cessation of the main extensional phase. It is quite probable that once the culmination of extension was reached, the first episode of gem-bearing basalt commenced. Voluminous supply of terrigeneous sediments in the Gulf of Thailand and the Phitsanulok Basin, which also indicated rapid regional uplift, were also reported to have occurred during Middle to Late Miocene (Polachan, 1988).

2.5.4. Early Pliocene Episode (4 - 5.3 Ma)

This episode of basaltic volcanism took place during 4 to 5.3 Ma (Early Miocene). This event was evidenced from dated basalts at Phrae (K/Ar method, Barr and Macdonald, 1981) and Kanchanaburi areas ($^{40}Ar/^{39}Ar$ method, Sutthirat et al.,1994). This event is also inferred as gem-related and is characterized by the emplacement of basanitoid basalt.

2.5.5. Late Pliocene Episode (1.6 - 3.6 Ma)

The fifth episode of Cenozoic basalt occurs during 1.6 to 3.6 Ma. These basalts are found in Chiang Rai (K/Ar, Barr and Macdonald, 1981), Chantaburi and Trat (fission track, Carbonel et al., 1977, and $^{40}Ar/^{39}Ar$, Sutthirat, 1994). They are inferred to be also related to gem. The volcanic activity is characterized by the appearance of tholeiite and basanitoid. This episode represents the last episode of gem - bearing basalts. Sutthirat (1992) found, based upon geochemical constituents, that gem - bearing gabbroid hypabyssal rock at Phu Fai is probably contaminated by thick crustal materials, possibly during the culmination of extension tectonics.

2.5.6. Quaternary Episode (Less than 1.6 Ma)

The youngest episode of basalt volcanism in Thailand occurred in 1.6 Ma until recent. The basalts are mainly basanitoid and hawaiite. They are found in Lampang (Mae Tha) and Burirum (e.g. Khao Phanom Rung, see Plathong, 1994) areas. However, several lines of evidences suggest that they are not regarded as gem -bearing basalts, eventhough the basalts also occurred as a result of tectonic extensional rifting mechanism (Charusiri et al., 1995).

CHAPTER III

GEOLOGIC SETTING

3.1 Regional Geology

Regional geology of Lampang - Sop Prap area is summarized from the previous works performed earlier by Piyasin (1971 and 1974), Bunopas and Vella (1983), and Bunopas (1992 and 1994). The area is in the central part of northern region. General geology of the regional area mainly includes sedimentary rocks of Silurian-Devonian, Permian, and Triassic. Igneous rocks as well as unconsolidated Quaternary sediments are also exposed in this area. A synoptic view of the regional geology is illustrated in Figure 3.1. The sedimentary rocks are herein described in the order of ages from the oldest to the youngest, below.

3.1.1. Silurian - Devonian

Rocks in Silurian-Devonian distribute in the southern region (Figure 3.1). They are characterized by quartzite, quartzo-feldspathic schist, phyllite, chloritic phyllite, calcsilicate phyllite, and chert. These rocks have been grouped into the Donchai Group (Piyasin, 1971). The type section was located at Nam Mae Bon Stream near Ban Donchai, Amphoe Mae Tha, east Lamphun. Thickness of the sequence was not given, but is estimated later by Bunopas (1981) to be more than 1,500 m. These rocks have experienced low-grade metamorphism and their strata are mesoscopically folded.

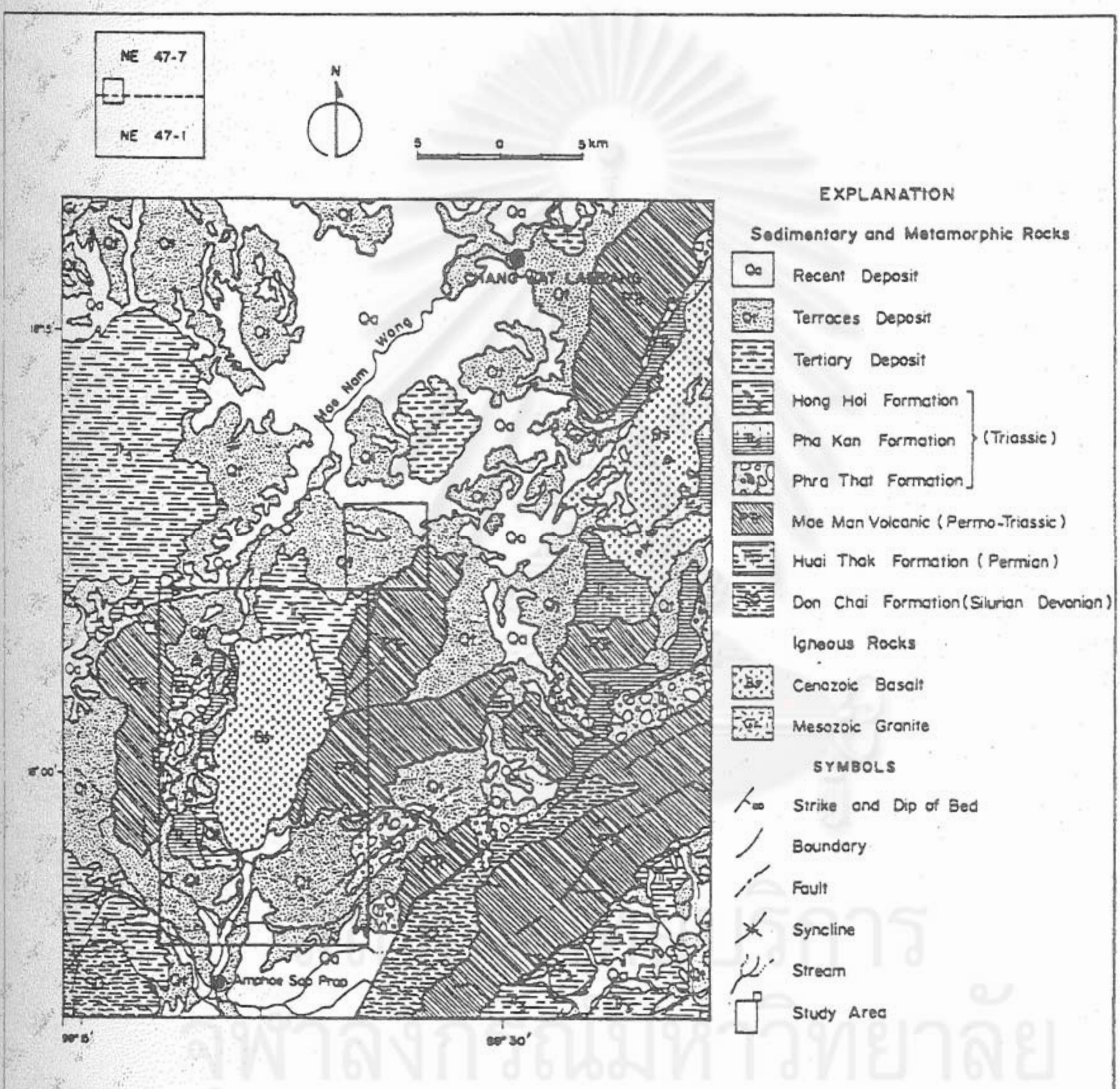


Figure 3.1 Regional geologic map of the Lampang-Sop Prap area (Piyasin, 1971 and 1974).

3.1.2. Permian

Permian rocks occur nearby the this project area. They are relatively present as small exposures, and have been grouped into the Huai Tak Formation of the Ngao Group (Piyasin, 1971, and 1974). The Huai Tak Formation consists mainly of fossiliferous shale and thin intercalations of sandstone, limestone and intraformational conglomerate, with the overall thickness of least 760 m and possibly up to 1,500 m. Late Permian lyttonid faunas from the formation are correlated with the lower Changing fauna of south China (Bunopas and Vella, 1983).

3.1.3. Permo - Triassic

Permo-Triassic rocks in the study area comprise volcanic rocks as rhyolite, andesite, tuff and agglomerate (Piyasin, 1971, and 1974). They are collectively called as Mae Man volcanics by Charusiri et al. (1994). These rocks with the estimated thickness of 100 m are unconformably underlain by clastics of the Huai Tak Formation. The Mae Man rocks have been grouped equivalent to or as part of the Phare-Lampang volcanic province in northern highland volcanic rocks (Jungyusuk and Khositanont, 1992).

3.1.4. Triassic

Triassic rocks are dominantly marine sedimentary rocks. They have been grouped into the Lampang Group by Piyasin (1971). This marine Triassic sequence conformably or disconformably overlies Permo - Triassic volcanics and Permian rocks. The Lampang Group is inferred to have been deposited in the Upper Paleozoic back-arc basin (Charusiri et al., 1994). The Lampang Group comprises 5 formations, however only 3 formations are recognized in the study area. Description of 5 formations in an ascending order is below.

Phra That Formation : The Phra That Formation consists chiefly of epiclastic rocks including sandstones, siltstones, conglomerates, breccias, and minor limestones. These rocks are generally coarse-grained and red in color at the base, and gradually become finer-grained and green to gray in color upwards.They are believed to have been deposited in near-shore and partly continental environments (Chonglakmani, 1983) with source materials mainly from the Permo-Triassic Mae Man volcanic rocks (Charusiri et al., 1994). This formation is from 100 to 840 m thick and contains bivalves, ammonoids, and brachiopods which indicate an age ranging from Upper Griesbachian (Early Triassic) to Middle Carnian (early Late Triassic).

Pha Kan Formation : This formation overlies the Phra That Formation and comprises predominantly grey limestones with minor grey to green shales and sandstones. The formation is 80 to 500 m thick and conformably underlies the Hong Hoi Formation . It contains characteristic fauna of ammonoids, bivalves, and gastropods, indicative of an age range from Upper Anisian (early Middle Triassic) to Upper Carnian (early Late Triassic) (Chonglakmani, 1983).

Hong Hoi Formation : The Hong Hoi Formation overlies the Pha Kan Formation and is the upper formation of the Lampang Group in this study area. It consists chiefly of a flysch sequence with predominantly grey to greenish grey shales, sandstones, siltstones, and conglomerates, and minor interbedded argillaceous limestones. This formation which is based on the macrofauna, ranges in age from Scythian (Early Triassic) to Lower Norian (Late Triassic) (Chonglakmani, 1983).

Doi Long Formation : This formation has not exposed in this research area , because of its limited geographic distribution. The Doi Long Formation is 230 m thick comprising grey to light grey finely crystalline limestones, which lies between the Pha Daeng Formation and the Hong Hoi Formation. The unit contains an indeterminated fauna of bivalves, serpulid worms, brachiopods, and gastropods, however, the formation is considered to be Middle Carnian (early Late Triassic) (Chonglakmani, 1983).

Pha Daeng Formation : The Pha Daeng Formation is the uppermost unit of the Lampang Group with thickness of about 500 to 600m. This formation cannot be found in the study area. It is invariably composed of well beded red micaceous siltstone, sandstone, shale and thin coguina limestone; the basal part is calcareous conglomerate with clasts of grey limestone, rare rhyolite and less common quartzite and slaty shale. Siltstone above the basal conglomerate contains the fossil, Hettangia (Bunopas, 1992). Charusiri et al. (1995) interpreted this red bed equivalent to that of the Mesozoic Khorat Group. The age of this formation is inferred to be Jurassic.

3.1.5. Tertiary

Tertiary deposits expose only in few parts of this regional area. They are characterized by conglomerate, sandstone, shale, limestone, carbonaceous shale, and lignite (Piyasin, 1974). Tertiary deposits in northern Thailand always developed from intermontane basins. They frequently serve as major sources of coal and clay minerals.

3.1.6. Quaternary

Quaternary terrace and alluvial sediments are developed around the regional area. They comprise gravels, sands, silts, muds and clays. They always occur as floodplains along the Mae Nam Wang River. Quaternary deposits are covered by basaltic rocks in some places.

3.1.7. Igneous Rocks

Igneous rocks of both extrusive and intrusive affinities are observed in the regional area and its adjacency. These include granitic and volcanic rocks. The granitic rocks occur as small and scattered stocks and are characterized by biotite-hornblende granite, porphyritic granite, leucogranite, and pegmatite. They are inferred to be Mesozoic in age. Mostly these felsic plutons are found in the northwestern part of this regional area.

The volcanic rocks are composed largely of felsic and mafic rocks. The more felsic volcanic rocks have been grouped into Permo-Triassic volcanic rocks, which are described previously. Mafic volcanic rocks are characterized by basalts. They occur mostly in the project area and the northeastern part of the region. The basalts are dark grey, vesicular and fine-grained. Chemical compositions of the Lampang basalts denote basanites and hawaiite (Barr and Macdonald, 1981). K/Ar ages of 0.8 ± 0.3 and 0.6 ± 0.2 Ma are reported by Sasada et al. (1987), whereas $^{40}Ar/^{39}Ar$ dating, published very recently by Sutthirat et al. (1994) yielded an age of 0.59 ± 0.05 Ma. Paleomagnetic studies and fission-track dating (Barr and Macdonald, 1981) have indicated the age of the Mae Tha basalt at about 0.69 or 0.95 Ma.

3.2 Geology of the Study Area

The geologic map of the study area is illustrated in Figure 3.2. Rocks in the study area comprise mainly (meta-) sedimentary and igneous rocks. Physiographically the area forms a large basin with lower altitude in the center enveloped by higher-relief terrane. Structurally, the older rock units including the Permo-Triassic and the Phra That Formations are encountered in the east, the west, and the south. As a result, the area forms a large structural syncline flanked by the older rock units. The synclinal axis is in the N-NNE direction with a low-angle plunge due north. A small anticlinal structure with similar trend is found in the southwestern part of the study area. The outpouring of basalts occurs in the middle portion of the syncline, possibly along the axis. Two other fracture systems are also recognized; one in the NW-WNW direction, and the other in the E-W direction, the former being more or less related to the late Triassic felsic intrusion. Sedimentary rocks include Permian clastics and Triassic-Jurassic clastics/carbonates. Igneous rocks comprise both intrusive and volcanic rocks, including Permo-Triassic volcanic rocks, Triassic granodiorites, and Cenozoic basalts. The details of these rocks are given below.

3.2.1. Permain metamorphic rocks

Metamorphic rocks of the Permian age are regarded as the oldest rock unit in the study area. They are generally composed principally of quartzite with some pale brown sandstone. They occur as a small, remnant but high, hills, covering an area of about 1 km^2 located at the north of Mae Than reservoir , Ban Mae Kua. These rocks were cut by NE- and NW-trending faults. The occurrence of metamorphosed sandstone leads Charoenprawat et al. (1986) to assign the rock sequence older than the others in the study area. The bedding strikes N-S and dips at 60° to W. The estimated thickness

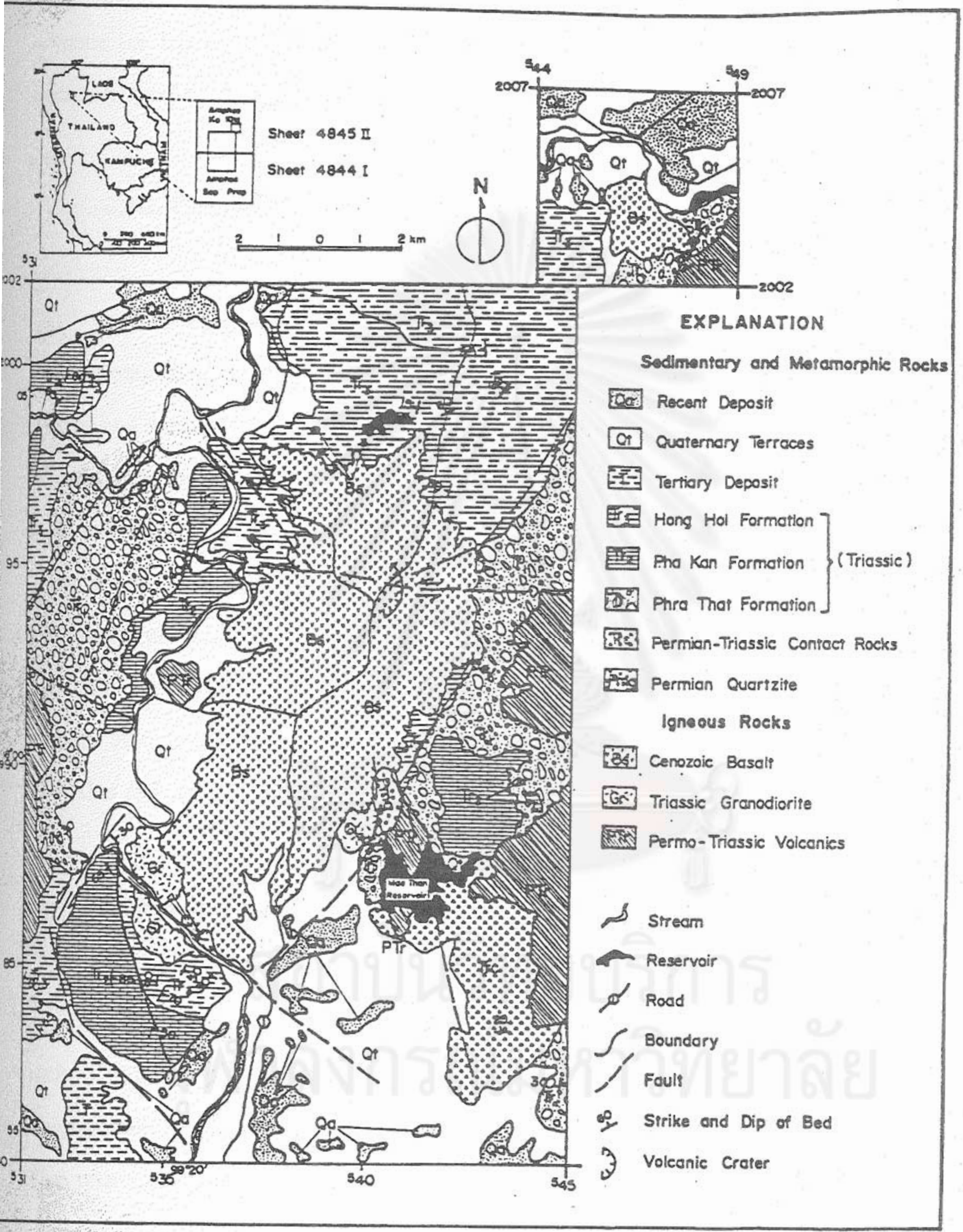


Figure 3.2 Geologic map of the study area (modified after Charoenprawat et al., 1986, and Tiyapairach and Mahapum, 1991), showing the distribution of the Nam Cho basalt and the Sop Prap-Ko Kha basalt.

is not less than 100 m. Recently, quartzite in this study area is classified as metatuffaceous siltstone (or felsite) by Sirimongkolkitti (1996), which this rock may be possibly metamorphosed from the Triassic rock.

3.2.2. Permo-Triasic rocks

The Permo-Triassic volcanics comprise rhyolites, andesites, tuffs, and agglomerates, they generally form as high , steep-slope hills, and can be found in the eastern and western edges of the area. Typical locations include Doi Ton, Doi Mon Khamin, and Doi Lak Kai. Rhyolites are characterized by pale grey to pink, fine-grained rocks and containing quartz and plagioclase crystals. Andesites are always green to deep green, fine-grained rocks, with abundant phenocrysts of plagioclase, hornblende, biotite, and pyrite. Tuffs and agglomerates are also associated with rhyolites and andesites, which they cannot be clearly differentiated. In some places, the rocks show distinctive layers with the attitude of E70°S / 70°SW and are difficult to distinguish from the overlying Phra That rock unit.

3.2.3. Upper Permian-Lower Triassic contact rocks.

Contact rocks contain association of igneous, sedimentary, and metamorphic rocks. Those comprise quartzites, rhyolites, sandstones, shales, and conglomerates. Geographically, they always show as small hills continually distributed in southeast of Mae Than reservoir. The average thickness of this unit is 300 m. The attitude of bedding varies considerably in strikes from N5°W to N90°E and dips from 20° to 25° due NE.

3.2.4. Triassic sedimentary rock.

Triassic rocks are characterized by clastic and marine carbonate sedimentary rocks of the Lampang Group, including Phra That, Pha Kan, and Hong Hoi Formations. They widely distribute in this area. Total thickness is about 800 m.

The Phra That Formation is the lowermost and oldest part of the Lampang Group in Lower Triassic age. Typical locations comprise Doi Ton, Doi Ngoen, and Doi Kaeo in the western and eastern ranges. Thickness is approximately 300 m. These rocks commonly consist of sandstones, shales , siltstones, agglomerates, and tuffaceous sandstones, with reddish brown and gray. The conglomerates in the lowest part comprise gravels of cherts, andesites, and rhyolites with silica cements.

These conglomerates generally show poorly sorting, and gravels often occur as angular to subround, with size of less than 16 cm to more than 25cm. The upper rocks are brown to reddish brown sandstone alternated with siltstones and shales, limestone lens and scattered tuffs. Their attitude generally strikes N10^{o} E to N70^{o}E and dip 15^{o}-85^{o}SE. The Phra That rocks rest unconformably over the Permo-Triassic rocks. These rocks occur as hills, mostly present in east and west of the investigated area.

The Pha Kan Formation is characterized by limestone, massive to well-bedded, light grey to dark grey, with interbedded black shales. Strike is mainly in N- to NNW- trending with 70^{o}-85^{o} dip. These rocks occur as moderate high hill in the west and the east. The average thickness of this unit is 100 m. The Pha Kan Formation is defined as Middle Triassic in age.

The Hong Hoi Formation is composed of greenish grey to light grey shales, with interbedded sandstones and dark grey limestone lens. Sandstones are characterized by fine- to medium- grained size, with high sphericity , good roundness, and good sorting. They are in N10°W to N70°W trend with 60°-80° dip. The rocks also distribute in northern and western parts, with typical locations at Huai Rai, Huai Na Saeng, and Doi Chadi. This unit is about 400 m thick. They are partially covered by younger basalts and Quaternary unconsolidated sediments.

3.2.5. Tertiary sedimentary rocks

Tertiary sedimentary rocks include sandstones, shales, conglomerates, and limestones. They may occur as semiconsolidated deposits in some parts. In the study area, the Tertiary deposits, especially white claystone, can be found in the south. Tertiary deposits, containing lignite and ball clay are economically exposed in the adjacent area.

3.2.6. Quaternary sediments

Quaternary sediments comprise unconsolidated and semiconsolidated sediments. The semiconsolidated deposits are mainly characterized by terrace sediments comprising clays, sands, and gravels in the moderately high area. These gravels include generally shale, rhyolite, andesite, chert, granite, and quartz, etc. The unconsolidated sediments are frequently characterized by recent deposits, as alluviums and colluviums.

3.2.7. Granodiorites

The granodiorites are found as small, isolated stocks in the south, such as both sides of Mae Nam Wang and north of Mae Than reservoir. They are generally characterized by porphyritic, coarse-grained, hornblende-biotite affinity. Feldspar phenocrysts are mostly plagioclase ranging in length from 1 to 2 cm. These granodiorites may probably occur in Upper Triassic (to Cretaceous) periods. Quartz veins (up to 20cm thick) are also found in and around the granitic rocks.

3.2.8. Basalts

Basalts widely distribute in the study area and its adjacency. They are classified as olivine basalts based upon field investigation. Mostly the basalts show a distinct volcanic crater (Figure 3.2). The basalts always contain phenocrysts of olivine, pyroxene and spinel, with the average size of 0.2 to 2 cm. Basalts frequently exhibit vesicular texture, exfoliation and columnar - liked jointings. They are assigned to be Late Cenozoic in age. In the study area, basalts can be geographically divided into 2 parts as the Nam Cho basalt or Northern basalt and the Sop Prap-Ko Kha basalt or southern basalt. In the field, the basalts are found as volcanic flows lying over the Triassic rock sequence (Figure 3.3) and some are observed as gravel deposits to highly weathered flows (Figures 3.4, 3.5, and 3.6) lying on tops of unconsolidated Quaternary deposits. These evidences imply that these basaltic flows are quite young (see the details in the discussion chapter). Petrographic descriptions of these rocks are described in the next chapter.

Figure 3.3 Volcanic flows of the Sop Prap-Ko Kha basalt (top) lying on the Triassic rock sequence (bottom).

Figure 3.4 Thick basaltic soil covering gravel bed in the southern edge of the Sop Prap-Ko Kha basaltic area (grid reference 362854).

Figure 3.5 Residual weathered basalts overling gravel deposit of the Triassic sediments at the western edge of the Sop Prap-Ko Kha basaltic area (grid reference 357914).

Figure 3.6 Characteristic of gravels of the old Mae Nam Wang River at the south edge of the Sop Prap-Ko Kha basaltic area near the recent Mae Nam Wang River (grid reference 371856).

Figure 3.7 Foldings of the Hong Hoi **Formation showing** NE-trending fold axis.

3.3 Regional Structural Geology

Regional geological structures generally comprise several small sub-basins within the major Lampang basin. These sub-basins are significantly controlled or bounded by faults and unconformity. The former are of oblique-slip normal type. These faults align in at least 2 directions, NE and NW. The NE-trending fault may have preceeded the NW-trending fault. Many joints and fractures frequently align in NW-, E-, and NE-directions. Those are often associated with major fault zones which may have occurred during Upper Permian to Upper Triassic . Foldings (Figure 3.7) are also present , including inclined, recumbent and overturned folds, with NE-trending folding axis. These folds frequently overprinted the Triassic rocks, and can be encountered at both sides of Mae Nam Wang and in the eastern part of the study area. The foldings may have formed contemporaneously with faultings.

3.4 Sapphire Occurrences

The gem exploration project launched by DMR was planned to cover basalts in this area. At least 15 test pittings were designed in the north basaltic area, and 65 pittings in the south basaltic area. Sapphires were discovered in 4 pittings in the north, and 12 pittings in the south (Figure 3.8). Occurrences of sapphires are always along stream and residual deposits in both basaltic areas. The sapphire-bearing layers of the Nam Cho (northern) basalt are frequently present as grayish brown, yellowish brown, moderate yellowish brown, and dark yellowish brown in color, whereas that of the Sop Prap-Ko Kha (southern) basalt is always characterized by moderate brown to greyish black, dusky yellowish brown, brownish grey, greyish black, and brownish black.

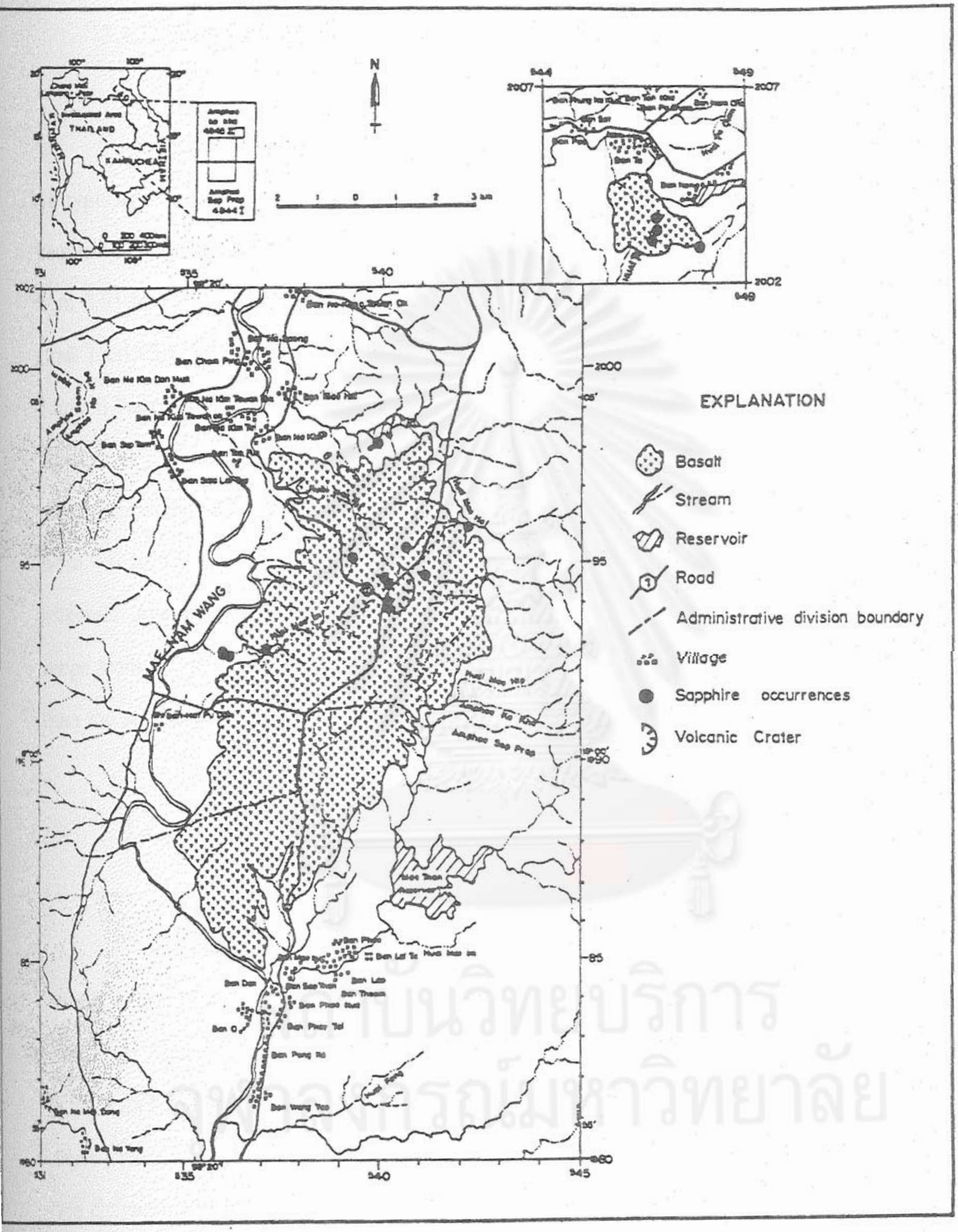


Figure 3.8 Map showing the aereal extent of basalts and locations of sapphire occurrences in the study area (Sutthirat et al., 1995).

3.4.1. Nam Cho Basaltic Area

Sapphires generally disperse in layers of gravel, sand, and clay. Most of gravels are typically basalt, and moderately andesite, rhyolite, sandstone, and tuff. Sapphires frequently occur in the level of 0-2.20 m depth. Gem bearing - layer ranges in thickness from 0.65 to 1.3 m. Sapphires in this terrane were found along Huai Khi, Huai Ta Sua, Huai Teen Cha, Huai Hua Ma, and Huai Khi Tud, and some are located in Ban Nong, Tambon Nam Cho, Amphoe Mae Tha. These sapphires are characterized by sky - blue, greenish sky - blue, blue, and brownish blue sapphires.They generally show angular to subangular shape, with transparent to translucent properties. The average grain size ranges from 1.0 to 5.0 mm. Associated minerals comprise pyroxene, spinel, and iron oxide minerals. Average grain size of these minerals are 0.5 to 1 cm, though they invariably range from 0.2 to 7.0 cm. They also form subangular shape, which are relatively larger than the southern area.

3.4.2. Sop Prap - Ko Kha Basaltic Area

Sapphires in this terrane frequently disperse around a volcanic crater, that is locally called "Lung Thum". The occurrences are in the Huai Mae Pad, Huai Mae Heap, and Huai Mae Hi, Ban Tao Poon, and Ban Mae Hi, Tambon Noosing, Amphoe Ko Kha. Sapphires always occur at the level of 1.5 m depth, with 0.2 to 0.8 m thick. The layer generally comprises gravels, sands, and weathered basalts. Sapphires of this terrane are characterized by sky-blue, brownish sky-blue, blue and brown star sapphires. They range from 2.5 to 6 mm in size, generally occur as angular to subangular shape, and are transparent to translucent. Associated minerals frequently contain olivine, spinel, pyroxene, iron oxide, and rarely zircon. They generally range from 1.0 to 6.0 mm in size, with an average grain size of 4.0 ± 1.0 mm.

CHAPTER IV

PETROGRAPHY

Sutthirat (1995) investigated the petrographic features of these research basalts, those are present as following. Based solely upon geographical distribution, basalts of the study area (Figure 3.2) can be subdivided into 2 distinctive masses, namely the north basaltic mass or Nam Cho basalt and the south basaltic mass or Sop Prap-Ko Kha basalt. The Nam Cho basalt covers an area of approximately 3 km^2 at Ban Nong, Thambon Nam Cho, Amphoe Mae Tha, Changwat Lampang (Figure 4.1), and the Sop Prap - Ko Kha basalt covers approximately 55 km^2 of the area in between Amphoe Ko Kha and Amphoe Sop Prap, Changwat Lampang (Figure 4.2). Its type section is located between kms 559 to 571 on Highway number 1 (Phahonyothin Road).

4.1 Nam Cho Basalt

The Nam Cho basalt extruded Permo-Triassic volcanic/volcaniclastic rocks and covered parts of Quaternary sediments. It occurs as east-west flows following hill slopes (Figure 4.1) of the Triassic rocks of the Phra That Formation. The reddish brown soils (weathered basalts) frequently cover Quaternary sediments. The basalt is megascopically characterized by thin reddish brown vesicular layer on the top, and black dense layer at the bottom. It is generally dark, dense, fine-grained, and porphyritic textures. The rock specimens of the Nam Cho basalt collected from exposures are relatively fresher than those from the Sop Prap - Ko Kha basalt. Ultramafic nodules of lherzolites (Figure 4.3) containing aggregates of olivine, pyroxene, and spinel are rather common. Megacrysts

Figure 4.1 Flow of Nam Cho basalt following hill slope of the Phra That Formation to the bottom plain.

Figure 4.2 Typical location at kms 568 to 569 on the Highway number 1 comprising 5 basaltic flows with total thickness of about 20 m thick of the Sop Prap-Ko Kha basalt.

of olivine, pyroxene, and spinel are often found in this basalt. Lherzolite nodules vary in size from 1 to 5 cm, and size of megacrysts ranges from 0.2 to larger than 2 cm. The total thickness of this basaltic flow is at least 2 m.

Microscopically, the Nam Cho basalt is generally hypocrystalline. Average grain size is virtually smaller than that of the Sop Prap - Ko Kha basalt. It always shows aphanitic granularity and locally grades to microporphyritic and porphyritic textures (Figure 4.4). Trachytic texture is moderately found, whereas subophitic and skeletal textures rarely occur in this basalt. Calcite, as large as 0.5 cm in diameter, is often present as amygdules. Mineral compositions essentially contain plagioclase, pyroxene, olivine, and opaque minerals. The secondary minerals are often composed of calcite, and zeolite.

Plagioclase frequently contains about 10 to 15%. It always occurs as microlite habits, with small subhedral crystal. Average grain size range is between 0.01 and 0.06 mm, which is relatively smaller than plagioclase of the Sop Prap - Ko Kha basalt. Plagioclase in groundmass can be hardly identified under microscope. When occurring as phenocrysts, plagioclase exhibits both Carlsbad-albite and albite twins. Its An - content appears to be ranging from andesine (An_{40}-An_{50}) to rarely labradorite (An_{51}-An_{55}). Plagioclase is found to be slightly or strongly altered.

Pyroxene is commonly in average range of 20 to 25% (up to 40%) of the total volume. It frequently occurs in groundmass and as phenocryst. In groundmass the size of the pyroxene is less than 0.01 to 0.02 mm, whereas phenocrystic pyroxene ranges from 0.1 to 1 mm. Pyroxene always shows anhedral and subhedral crystals, though some phenocrysts may form euhedral crystals, frequently with pale green to brown colours. Pyroxene in groundmass frequently forms short prismatic to rounded grains. It

Figure 4.3 A specimen of the Nam Cho basalt contains lherzolite nodule and showing general characteristics of this rock.

4.4 a

4.4 b

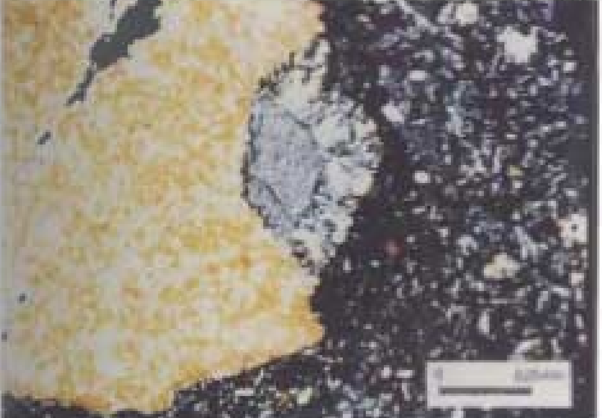


Figure 4.4 Photomicrographs of the Nam Cho basalt showing large phenocrysts of olivine (Ol) and pyroxene (Py) in groundmass of plagioclase microlite, pyroxene, and opaque mineral (4.4a: uncross nicols, 4.4b: cross nicols).

also shows crack, and one-direction cleavage is always prominent (Figure 4.4). Almost pyroxenes are characterized by clinopyroxene (mainly augite). Reaction rims are also present in pyroxene phenocrysts and megacrysts.

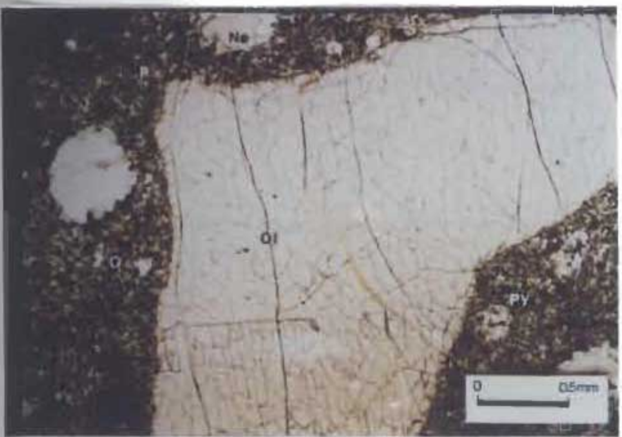
Olivine ranges from 10 to 15% of the total volume and occurs as anhedral to subhedral crystals (Figure 4.4). It is mainly present as phenocrysts and megacrysts (Figures 4.4, 4.5). Size of its phenocryst varies from 0.1 to larger than 1 mm, whereas in groundmass it ranges from 0.01 to 0.06 mm. Cracks and cleavages were frequently developed in olivine crystals. Skeletal texture is also encountered in olivine phenocryst. Some olivines are altered to be deep yellow to orange brown iddingsites. Olivine is optically negative very high, closed to 90°.

Opaque minerals frequently comprise up to 15% of the total volume. Their average grain size commonly ranges from less than 0.01 to 0.02 mm, and rarely larger than 0.03 mm. They always occur as anhedral to subhedral crystals, with rounded and polygonal shapes. Most opaque minerals generally accompany in groundmass.

The secondary minerals are characterized by calcite and zeolite. Though calcite is rarely found in this basalt, but in some specimens calcite can contain up to 5% of total volume, with average grain size about 0.1 to 0.5 mm. Calcite frequently occurs as anhedral crystals along fractures and vugs. Zeolite occurs as small crystals (mostly 0.1 mm) and is much less abundant than calcite.

Xenoliths (Figure 4.6) are always characterized by ultramafic nodules, frequently containing dark green pyroxene, green olivine, and black spinel. Size of these xenolith nodules are ranging from 1 to 5 cm. Microscopically, these lherzolites show equigranular,

4.5 a



4.5 b

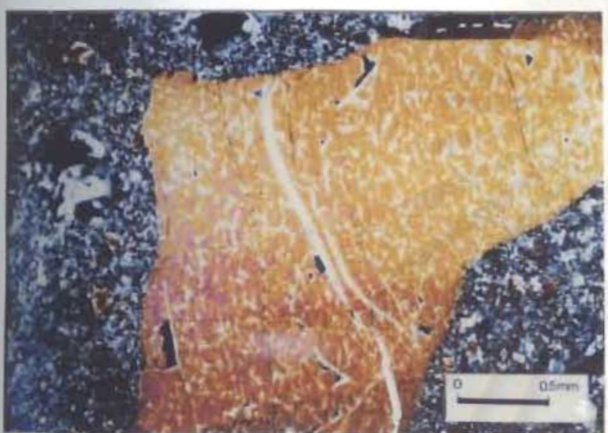


Figure 4.5 Olivine megacryst (Ol) in aphanitic opaque (O), pyroxene (Py), and plagioclase, and showing occurrences of anhedral zeolite in vesicle (4.5 a: uncross nicols, 4.5b: cross nicols).

4.6 a

4.6 b

Figure 4.6 Spinel-lherzolite nodule comprises olivine (Ol), pyroxene (Py), and spinel (Sp), with equigranular, fine-grained holocrystalline (4.6a: uncross nicols, 4.6b: cross nicols).

intergranular, and sugary-liked textures with fine-grained holocrystalline. They contain olivine and pyroxene as the major constituents with minor amount of spinel (Figure 4.6). Olivine commonly forms anhedral crystals. Pyroxene is also present as anhedral crystals with one-direction perfect cleavage. It is characterized by the presence of clinopyroxene (frequently augite). Spinel always exhibits anhedral to subhedral forms with brown isometric outline. Pyroxene megacryst moderately occurs nearby xenoliths. These ultramafic nodules are frequently altered along rims and sometimes whole nodules are totally replaced by secondary minerals.

Glass generally contains about 30 to 40%, and always distributes in vesicles and vugs. Glass frequently shows some devitrification.

The other minerals, as apatite and zircon, are rarely found. It is interesting to note that ultramafic nodule, pyroxene and opaque minerals are relatively more abundant than those of the Sop Prap - Ko Kha basalt.

4.2 Sop Prap-Ko Kha Basalt

The Sop Prap-Ko Kha basalt is enclosed by rocks of the Permo-Triassic to Triassic age and the Quaternary sediments (see Figure 3.2). Volcanic crater in this area has been identified by using both landsat image- and aerial photograph- interpretations and field investigation. Volcanic bomb (Figure 4.7) and scoriaceous spatter materials (Figure 4.8) can be found nearby this crater. Five successive basaltic flows have been recognized with typical location at the road-cut quarry between kms 568 to 569 on the Highway number 1 (Figure 4.2).This road-cut shows that the volcanic crater comprises these 5 flows with at least the total thickness of about 20 m thick. All the flows bear similarity

Figure 4.7 Characteristic of volcanic bomb occurring in the volcanic crater (grid reference 403944).

Figure 4.8 Scoriaceous spatter materials are found in volcanic crater (grid reference 403944).

in texture and mineralogy. They are characterized by vesicular to massive, microporphylitic-porphyritic, and fine-grained textures. Phenocrysts (up to 0.3 cm) of olivine frequently occur in most flows. The vesicular texture is commonly present in the upper parts of all flows. The channel-like structures, always present as yellowish brown weathered basaltic soils within cavities, are usually found between the second and the third basaltic flows. The columnar-like jointings predominantly appear in the second basaltic flow, and are sometimes found in the first and the fourth flows. The parting is quite distinctive, they are present in the lower parts of the second, the third and the fifth flows. The ropy structure (Figure 4.9) indicating the "pahoehoe" flow (Figure 4.10), always exposes around the lowest part of the first flow along steep slopes of this basaltic area.

4.2.1. The First Basaltic Flow

The first flow, the lowermost part of the Sop Prap - Ko Kha basalt, is at least 2 to 3 m thick. This basalt commonly shows layer vesiculars in the upper parts. The vesicles are about 0.5 to 2 cm. Vesicles tend to form alignment indicating local flow direction. It is always characterized by dark grey to black colour fine-grained, porphyritic textures (Figure 4.11). It sometimes shows ropy or (pahoehoe) structure (Figures 4.9, 4.10) implying flowages away from crater. Pahoehoe is mainly found along slopes in the eastern and western regions. Microscopically, this basalt always exhibits porphyritic, interstitial, and intersertal textures. Plagioclase is partially enclosed by pyroxene, forming subophitic texture. This basalt frequently exhibits hypocrystalline with aphanitic to granularity textures. Mineral composition comprises 30 to 35% plagioclase, 10 to 20% pyroxene, 15 to 20% olivine, 10 to 15% opaques, 5 to 10% accessories, and 25 to 30% glassy materials.

Figure 4.9 Ropy structure is frequently shown in the lower flows of the Sop Prap-Ko Kha basaltic area.

Figure 4.10 Pahoehoe flow comprising ropy structures along the slopes in the eastern and western Sop Prap-Ko Kha area.

Plagioclase (Figures 4.13. 4.14) is more abundant than other minerals. It generally occurs as lath and microlite forms, with subhedral crystals. These crystals are generally ranging in size from 0.01x0.1 to 0.01x0.6 mm. Carlsbad-albite twins are more abundant than albite twins. Plagioclase is optically determined in terms of An content to range from andesine (An_{40}-An_{50}) to labradorite (An_{52}-An_{65}) with rare bytownite(An_{71}-An_{76}).

Pyroxene (Figures 4.13, 4.14) appears to be anhedral to subhedral crystals, though short prismatic form is frequently present as euhedral habits. It is always assembled in groundmass, whereas pyroxene phenocryst rarely occurs. Pyroxene commonly occurs as rounded grains, and is often clustered, forming glomeroporphyritic texture. Cracks are better developed than cleavages. Pyroxene typically occurs as clinopyroxene (mostly augite).

Olivine (Figures 4.12, 4.13) always occurs as anhedral to subhedral crystals, the latter being present as phenocryst rather than groundmass. Olivine in groundmass is ranging in size from 0.01 to 0.08 mm, whereas phenocrystic olivine is ranging from 0.2 to larger than 1 mm in size. It frequently develops skeletal texture. Deuteric alteration often occurs along rims and cracks of olivine crystals. Olivine is often cracked, and normally filled with iddingsite. It optically appears large 2V negative (nearly 90°).

Opaque minerals (Figures 4.13, 4.14) always occur as fine-grained, anhedral to subhedral crystals. Average grain size varies from 0.01 to 0.04 mm. It frequently forms skeletal shape, with rounded to polygonal forms.

Figure 4.11 A specimen of the first flow of the Sop Prap-Ko Kha basalt showing fine-grained, porphyritic, olivine basalt.

4.12 a

4.12 b

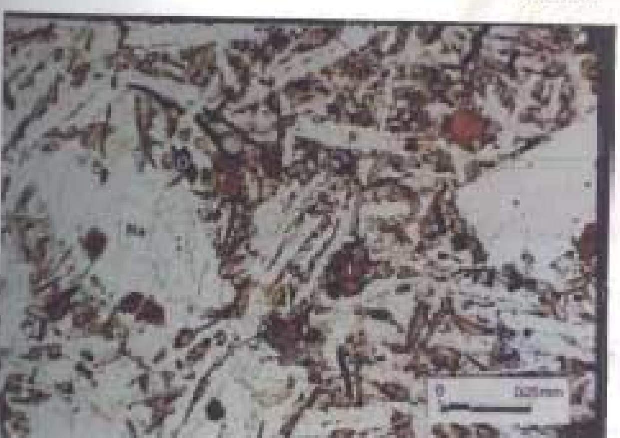
Figure 4.12 Photomicrographs show olivine phenocryst (Ol) in trachytic plagioclase (P) microlites, interstitial of pyroxene (Py) and opaque, intersertal of glass, and some iddingsite (I) crystals (4.12a: uncross nicols, 4.12b: cross nicols).

4.13 a

4.13 b

Figure 4.13 Interstitial of anhedral-subhedral pyroxene (Py) in plagioclase (P) lath, interstitial texture of glass (G), skeletal texture of opaque, short prismatic apatite, subhedral olivine (Ol) phenocryst, and iddingsite (I) in first basaltic flow (4.13a: uncross nicols, 4.13b: cross nicols).

4.14 a



4.14 b

Figure 4.14 Iddingsite (I), anhedral-subhedral opaque (O), rare prismatic apatite, lath of plagioclase is partially enclosed by pyroxene (Py) forming subophitic texture, with intersertal texture (4.14a: uncross nicols, 4.14b: cross nicols).

The accessory minerals include apatite, zeolite, and calcite. Apatite (1 to 3%) is less abundant in this flow. It always occurs as subhedral short prismatic, that generally enclosed in grains of plagioclase. Zeolite, an uncommon secondary mineral, is always present in vugs and along veinlets. It commonly shows radiation of short prismatic forms, with small grain sizes. Calcite, a more common secondary mineral, frequently occurs as subhedral to anhedral crystals. It is mostly associated with pyroxene, olivine, and plagioclase. It sometimes fills in spaces between laths of plagioclase. Its content is about 5 to 10%.

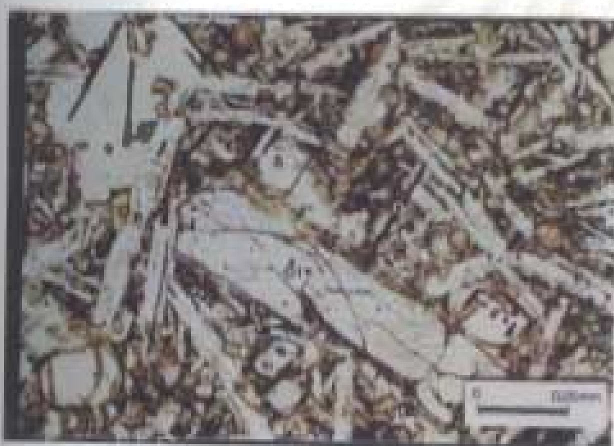
Glass (Figures 4.12, 4.13, and 4.14) comprises of 25 to 30 % by total volume and is always associated with opaque and pyroxene. Glass frequently fills in voids among plagioclase lathes, forming intersertal texture, and sometimes exhibits mild devitrification.

4.2.2. The Second Basaltic Flow

Overlying the first flow is the second basaltic flow (Figure 4.2), about 3 to 4 meter thick or more. Megascopically, the upper surface is also indicated by vesicular olivine basalts followed by those with columnar-like jointings. The lower surface frequently appears as more massive olivine basalt, with parting almost parallel to the flow layer. This basaltic flow is always characterized by dark grey to black, fine-grained to aphanitic, porphyritic textures (Figure 4.15). The channel-like structure averages 1 m x 2 m in diameters, indicating that flow direction can be traced as far as at least 200 m in this basaltic flow. Microscopically, this basalt generally appears to be holocrystalline (Figure 4.18), with aphanitic granularity texture. Porphyritic, intersertal, interstitial, and subophitic textures (Figures 4.16, 4.17, and 4.18) are also present under microscopic investigation.

Figure 4.15 **A specimen of the second flow of the Sop Prap-Ko Kha basalt showing fine-grained,** porphyritic, olivine **basalt, with** vesicular **texture.**

4.16 a



4.16 b

Figure 4.16 **Photomicrographs show phenocryst of subhedral olivine (Ol), skeletal opaque (O), with pyroxene (Py) form interstitial between plagioclase (P) laths,** and some **subophitic texture** (4.16a: **uncross nicols, 4.16b:** cross **nicols**).

The alignment of microlites indicating trachytic texture are present in some samples. Mineral composition always contains 25 to 30% plagioclase, 10 to 15% pyroxene, 10 to 15% olivine, 5 to 15% opaques, 5 to 10% accessories, and 25 to 35 % glass.

Plagioclase is generally more abundant than other minerals. Its grains are frequently subhedral, with long rectangular outlines (Figures 4.16, 4.17). These plagioclase grains occurring as lath form are more abundant than microlite form. The average grain size ranges from 0.02 x 0.3 mm to 0.2 x 0.6 mm. Both Carlsbad-albite and albite twins are equally present in this flow. Plagioclase ranges in composition from andesine (An_{38}-An_{49}) to labradorite (An_{53}-An_{70}). Laths of plagioclase always show interlocking, indicating intersertal or interstitial textures. Some plagioclase grains may be partially enclosed by pyroxene, representing subophitic texture.

Pyroxene averages from 0.01 to 0.08 mm in size. Its crystals always occur as anhedral to subhedral (Figures 4.17, 4.18), colourless to pale green and brownish green. Phenocrysts of pyroxene are rarely found, when occur, they are ranging in size from 0.1 to 0.3 mm. Pyroxene is commonly assembled in groundmass. Rare euhedral crystals are present as short prismatic form. Pyroxene is predominantly clinopyroxene (mostly augite).

Olivine is typical phenocryst (Figures 4.16, 4.18) of this basalt. Phenocryst is about 0.1 to 2 mm in size, whereas in groundmass olivine averages in size from 0.02 to 0.08 mm. It occurs as anhedral to subhedral crystals. It frequently shows skeletal texture. Cracks often develop in olivine crystals. Olivine is sometimes fresh, though deuteric alteration feature is always prominent along rims and cracks of crystal. It is optically found negative with large 2V angle.

4.17 a

4.17 b

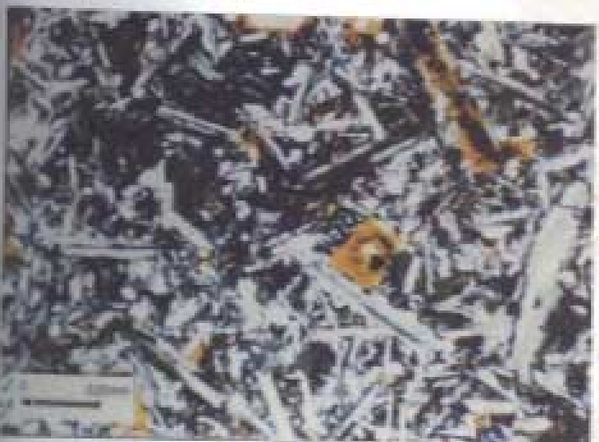


Figure 4.17 Iddingsite (I) altered from olivine, anhedral-subhedral pyroxene (Py), subhedral plagioclase (P), which form subophitic and interstitial with some intersertal textures (4.17 a: uncross nicols, 4.17b: cross nicols).

4.18 a

4.18 b

Figure 4.18 Subhedral phenocrysts of olivine (Ol), skeletal opaque, pyroxene groundmass, and glass (G) in vug, those show porphyritic, intersertal, interstitial, and subophitic texture (4.18a: uncross nicols, 4.18b: cross nicols).

Opaque minerals (Figures 4.16, 4.18) always occur as anhedral to subhedral crystals, whose average grain size is ranging from less than 0.01 to 0.1 mm. Petrographic description indicated that opaque is always associated with pyroxene in groundmass. Skeletal texture may be also formed in opaque crystal, possibly indicating ilmenite form.

The accessory minerals include apatite, zeolite, and calcite. Apatite is always less abundant (average about 2%), with small size (much less than 0.01 mm). It is found only in few samples. Apatite is always assembled in plagioclase, and always forms short prismatic crystals. Zeolite occurs as secondary mineral with radiate form. It can be rarely found in vugs. It is presented subhedral short prismatic form with less abundance (about 3%). Calcite is rarely found as secondary mineral, that forms along cracks. It always shows anhedral crystals with less abundance (about 3%).

Glass contains averagely about 10 to 15% of total volume. It always occurs as intersertal texture and is frequently devitrified to form secondary minerals.

4.2.3. The Third Basaltic Flow

The third basaltic flow is lying over the second flow. The thickness of the third flow is about 4 to 5 m. It is still characterized by fine-grained, porphyritic, olivine basalt (Figure 4.19), and somewhat partially similar to those of the second flow. Vesicles (about 1 to 5 mm long) also appear in the upper part. They often develop parting (0.1-0.3 m thick) in the thin lower part. Soil, a weathering product of basalt during a short quiescent period is present on top of this flow. Microscopically, this basalt typically occurs as hypocrystalline, with aphanitic granularity. It is invariably characterized by trachytic and porphyritic textures (Figure 4.20 and Figure 4.21). Intersertal, interstitial,

Figure 4.19 A specimen of the third flow of the Sop Prap-Ko Kha basalt showing vesicular, porphyritic, fine-grained, olivine basalt.

4.20 a

4.20 b

Figure 4.20 Photomicrographs show large olivine (Ol) phenocryst surrounded by plagioclase (P), pyroxene, opaque, and glass (G), and comprising trachytic, intersertal, interstitial textures (4.20a: uncross nicols, 4.20b: cross nicols).

and subophitic textures are quite common in this basalt. Skeletal texture of opaque and olivine crystals are also diagnostic. Mineral constituents generally include 25 to 35 % plagioclase, 10 to 15 % pyroxene, 10 to 20 % olivine, 5 to 15 % opaques, 5 to 10 % accessories, and 25 to 30 % glass.

Plagioclase (Figures 4.21, 4.22) always occurs as subhedral lath or microlite forms. Its grain size averages from 0.02 x 0.3 mm to 0.1 x 0.6 mm . Plagioclase relatively forms Carlsbad-albite twin in more abundant than albite twin. The composition is optically classified in range from andesine (An_{33}-An_{49}) to labradorite (An_{51}-An_{66}). Plagioclase laths often interlock between grains, showing intersertal or interstitial textures. Plagioclase microlite often exhibits trachytic texture, an indicative of flow lava.

Pyroxene is frequently found as groundmass, whose average grain size ranges from 0.01 to 0.3 mm. It always occurs as anhedral to subhedral crystals (Figures 4.21, 4.22). It is rarely found as phenocryst. It mainly comprises clinopyroxene (frequently augite). It often forms short prismatic crystals, whose cracks and one-direction cleavages frequently occur.

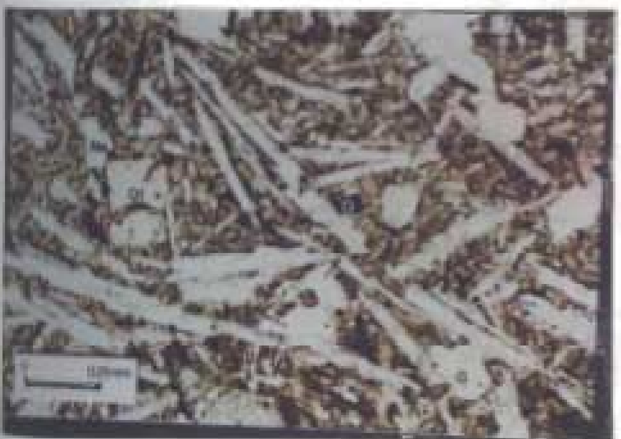
Olivine is mostly present as anhedral, subhedral, and euhedral crystals. Olivine phenocryst (Figures 4.20, 4.21) certainly occurs more abundant than olivine of groundmass. Phenocryst is about 0.1 to 1 mm in size, whereas groundmass ranges from 0.01 to 0.08 mm. Skeletal texture often develops in this basalt. Olivine mainly forms cracks with moderately weathering (or deuteric alteration). It is optically present as biaxial negative with high 2V angle (closely 90°).

4.21 a

4.21 b

Figure 4.21 Olivine (Ol) phenocrysts surrounded by pyroxene (Py), plagioclase (P) microlite, glass (G), and opaque, forming mainly interstitial, intersertal, and trachytic textures (4.21a: uncross nicols, 4.21b: cross nicols).

4.22 a



4.22 b

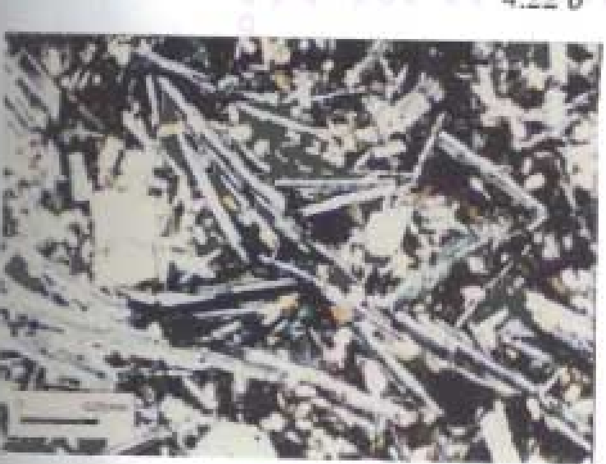


Figure 4.22 Interstitial of subhedral olivine (Ol), opaque (O), and pyroxene between laths of plagioclase (P), and glass (G) form intersertal texture, with moderate subophitic texture (4.22a: uncross nicols, 4.22b: cross nicols).

Opaque minerals (Figure 4.22) always show anhedral to subhedral habits. They are often accompanied in groundmass, and associated with pyroxene and glass. Average grain size of opaques is 0.01 to 0.05 mm. Skeletal texture (significant outlines of ilmenite ?) also occur in opaque minerals

Accessories largely include calcite and apatite. Calcite is typically a secondary mineral that may be found as amygdules in some samples. Calcite constitutes 5 to 10% of the total volume, that always occurs as anhedral crystal nearby plagioclase, weathered pyroxene, and broken olivine. The calcite is often present in spaces and vugs. Apatite is frequently present as subhedral, short to stubby prismatic forms. It comprises about 1%, with small grain size (much smaller than 0.01 mm).

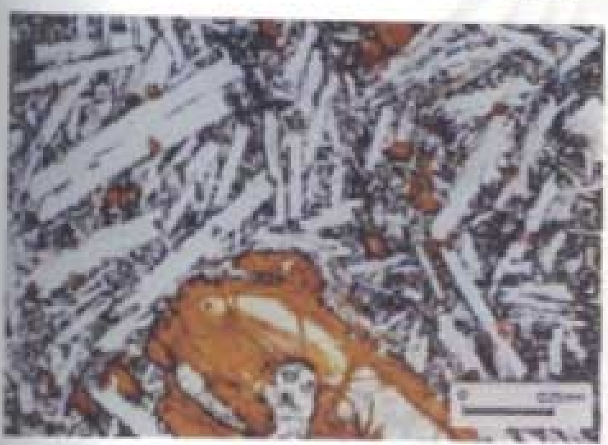
Glass ranges from 25 to 30 % content. Devitrification is always present in glassy groundmass, that also occurs as vugs and intersertally in voids.

4.2.4. The Fourth Basaltic Flow

The fourth basaltic flow is about 2 to 3 m thick and is overlying almost parallel to the third flow. The fourth flow generally contains vesicular olivine basalt in the upper, and massive olivine basalt in the lower part. Columnar jointing is frequently encountered in this flow, however jointing is obscured due to moderate weathering. Basalt is normally characterized by pale grey to dark grey, fine-grained to aphanitic, porphyritic rock (Figure 4.23). Microscopically, this basalt mainly appears as hypocrystalline, with aphanitic granularity. Intersertal, interstitial, and porphyritic textures (Figures 4.24, 4.25, and 4.26) are commonly present. Subophitic and trachytic textures are also widely distributed. Glass is more common in the upper flow than in the lower flow. Basalt is

Figure 4.23 A specimen of the fourth flow of the Sop Prap-Ko Kha basalt showing vesicular, fine-grained, microporphyritic, olivine basalt.

4.24 a



4.24 b

Figure 4.24 Photomicrographs show engulf texture of olivine (Ol) phenocryst surrounded by plagioclase (P) laths, and interstitial of pyroxene (Py) and iddingsite (I),with intersertal texture (4.24a: uncross nicols, 4.24b: cross nicols).

composed of 25 to 35 % plagioclase, 10 to 15 % pyroxene, 10 to 15 % olivine, 10 to 15 % opaque minerals, 5 to 15 % accessories, and 20 to 35 % glass.

Plagioclase (Figures 4.24, 4.25, and 4.26) always occurs as tiny microlite in groundmass and subhedral lath forms as phenocrysts. Average grain size of plagioclase is approximately 0.01 mm wide and 0.2 mm long in the groundmass. Phenocrystic plagioclase ranges in length from 0.3 to 0.5 mm and in width from 0.05 to 0.1 mm. Both Carlsbad-albite and albite twins are encountered, the former being more abundant. Petrographic evidence suggests that plagioclase ranges from andesine (An_{36}-An_{45}) to labradorite (An_{50}-An_{70}).

Pyroxene is always present in groundmass (Figures 4.24, 4.25). Average grain size ranges from smaller than 0.01 to 0.05 mm. It is frequently pale green to greenish brown. It generally occurs as anhedral to subhedral crystals with plagioclase, pyroxene often forms interstitial in spaces between plagioclase laths. It also partially enclose plagioclase, becoming subophitic texture. Cracks are generally formed, whereas one-direction cleavage is also common. Pyroxene is commonly characterized by clinopyroxene (mostly augite).

Olivine commonly forms as phenocrysts (Figures 4.24, 4.26) and in groundmass. Phenocrysts of olivine range from 0.1 to larger than 1 mm, and olivine in the groundmass averages about 0.01 to 0.06 mm in size . Olivine always occurs as subhedral to euhedral crystals. Cracks are frequently developed, and they are filled with secondary mineral as serpentine. Reaction along rims are also common. Skeletal texture may be present in some sections. The optical investigation is rather difficulty due to moderate weathering . However, it also shows high 2V angle of biaxial negative.

4.25 a

4.25 b

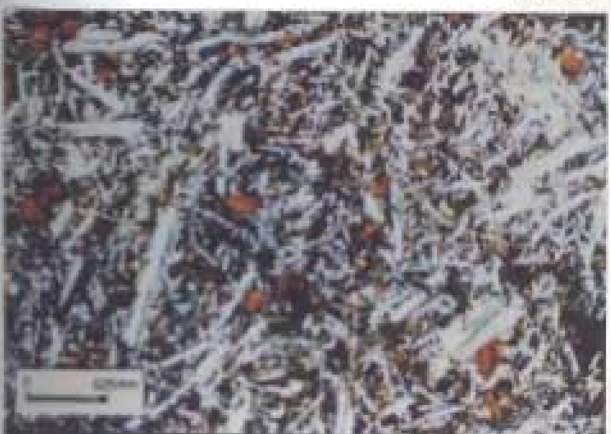


Figure 4.25 **Subhedral plagioclase (P) forming lath and microlite forms, pyroxene (Py), opaque (O), and iddingsite (I), with intersertal, interstitial, and microporphyritic textures (4.25 a: uncross nicols, 4.25b: cross nicols).**

4.26 a

4.26 b

Figure 4.26 **Anhedral olivine (Ol), and iddingsite (I) phenocrysts, with lath of plagioclase (P), opaque (O), and small pyroxene forming interstitial, subophitic, and intersertal textures (4.26a: uncross nicols, 4.26b: cross nicols).**

Opaque minerals are smaller than 0.01 to 0.05 mm in size. They frequently form anhedral to subhedral crystals and are associated with pyroxene in the groundmass (Figures 4.25, 4.26). The euhedral crystal is rarely found. Skeletal texture possibly signifies ilmenite habit. Opaques sometimes form square or rounded shapes.

Accessories include apatite, zeolite, and calcite. Apatite is rarely found in this basaltic flow, and contains less than 2 % of total volume. It occurs as subhedral, short prismatic, with very fine-grained size. Apatite always inserts in grains of plagioclase and glass. The other uncommon secondary minerals, zeolite, iddingsite and calcite, can be found in less abundance in few samples.

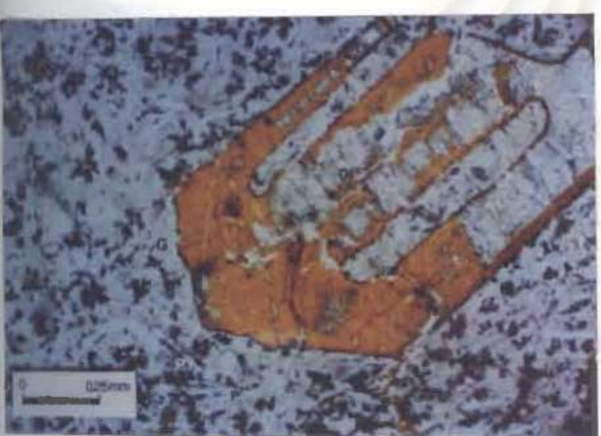
Glass ranges from 20 to 35 % of total volume. Vesicular and vug-filled textures are also dominant in this basaltic flow. Glass always occurs in voids of plagioclase, formming intersertal texture. Devitrification is also recongnized in the upper part of the flow.

4.2.5. The Fifth Basaltic Flow

This basaltic flow is the uppermost unit of the Sop Prap-Ko Kha basalt. It is about 6 to 7 m thick at road cut section between kms 568 to 569 on the Highway number 1, immediately in the volcanic crater vicinity. The vesicular basalt (Figure 4.27) with high weathering and parting are diagnostic features. Microscopically, this basalt mainly shows porphyritic and intersertal textures. Subophitic, trachytic, and amygdaloidal textures are subordinate. It is frequently characterized by hypocrystalline with aphanitic granularity.

Figure 4.27 A specimen of the fifth flow of the Sop Prap-Ko Kha basalt showing fine-grained, porphyritic olivine basalt.

4.28 a



4.28 b

Figure 4.28 Photomicrographs show large olivine phenocryst in aphanitic groundmass of pyroxene (Py), plagioclase (P), and glass (G), and forming trachytic, intersertal, and interstitial textures (4.28a: uncross nicols, 4.28b: cross nicols).

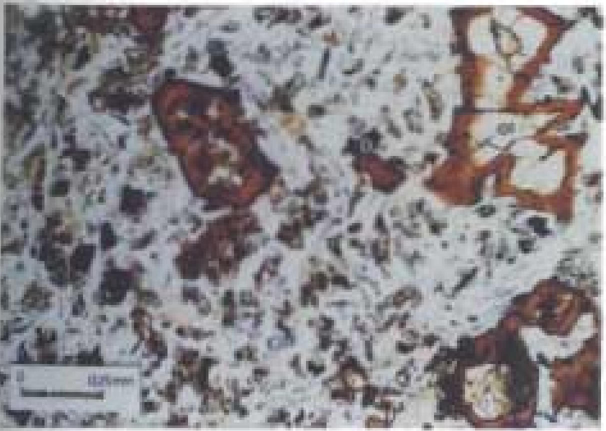
Amygdules of calcite (Figure 4.30) and zeolite filled in vugs, vesicles, and other spaces. Interstitial texture (Figures 4.29, 4.30) is often present by pyroxene that occurs in space between plagioclase laths. Mineral constitnent includes includes 25 to 35% plagioclase, 15 to 20% pyroxene, 10 to 15% olivine, 10 to 15% opaque minerals, 5 to 10% accessories, and 25 to 35 % glassy materials.

Plagioclase (Figures 4.29, 4.30) commonly occurs as microlite crystals, though lath form is moderately present. It also forms subhedral crystals, with average grain size of about 0.05 mm wide and 0.2 mm long. Twinning of plagioclase include Carlsbad-albite and albite twins, both of which have nearly the same amount. Plagioclase is petrographically determined to be ranging from andesine (An_{30}-An_{49}) to labradorite (An_{50}-An_{60}).

Pyroxene also occurs as anhedral to subhedral short prismatic form and is often associated in groundmass (Figures 4.29, 4.30). Its size averages from smaller than 0.01 to 0.06 mm. Pyroxene is often pale green with high relief. Pyroxene, predominantly clinopyroxene (with augitic composition), frequently shows cracks rather than cleavages (often one-direction). It always forms cluster, associated with opaque minerals. And it may be interstitial in spaces between plagioclase laths.

Olivine frequently appears subhedral crystal, though it is rarely present as anhedral and euhedral crystals. Olivine phenocryst (Figures 4.28, 4.29, and 4.30) is as large as 1 mm, whereas olivine in groundmass ranges from smaller than 0.01 to 0.05 mm. Olivine often occurs as phenocryst in this basalt. Olivine frequently shows skeletal texture. It is frequently weathered, and most of olivine crystals show irregular cracks. Optically olivine is biaxial negative, with high 2V angle.

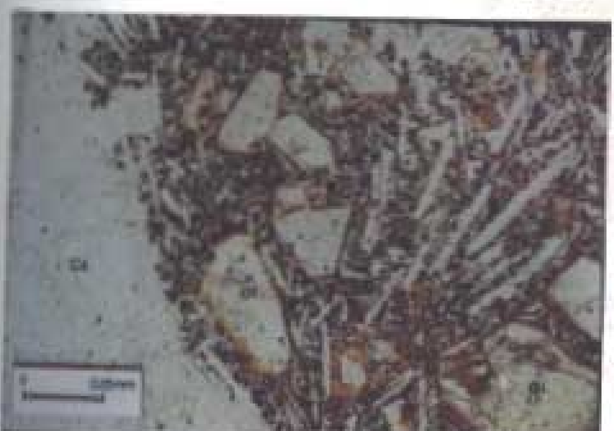
4.29 a



4.29 b

Figure 4.29 Phenocrysts of olivine (Ol) and iddingsite (I) surrounded by plagioclase (P) microlite, opaque (O) and pyroxene, showing intersertal, interstitial, and porphyritic textures (4.29a: uncross nicols, 4.29b: cross nicols).

4.30 a



4.30 b

Figure 4.30 Subhedral olivine (Ol) phenocrysts and laths of plagioclase (P) surrounded by pyroxene, opaque, and glass (G) forming trachytic, intersertal, interstitial, and porphyritic textures, with calcite (Ca) occurring in fracture of basalt (4.30a: uncross nicols, 4.30b: cross nicols).

Opaque (Figure 4.29) minerals always occur as anhedral to subhedral crystals, some mutually associated with pyroxene. Grain size of opaque averages from less than 0.01 to 0.05 mm. It is mainly present as square and rounded forms, suggesting the occurrence of pyrite. Opaque mineral sometimes shows skeletal texture, implying the ilmenite crystal.

Accessories include apatite, and calcite (Figure 4.30). Apatite is present as subhedral to euhedral short prismatic forms and usually associated with plagioclase. It invariably shows very small size (much less than 0.01 mm), and occurs in small amount (less than 3 %). Calcite, the other secondary minerals, is also found in this basalt. It occurs as anhedral crystals in vugs (Figure 4.30) of few samples.

Glass is mainly present in this basaltic flow, ranging from 25 to 35 % of total volume. It also shows intersertal texture, and may be devitrified as dirt.

CHAPTER V

GEOCHEMISTRY

5.1 Introduction

A total of 65 basalt samples, including 10 samples from the north basaltic terrane and 55 samples from the south basaltic terrane, were chemically analysed for their major and some trace elements. Among 65 samples, 30 selected samples comprising 5 samples from the northern basaltic terrane and 25 samples from the southern basaltic terrane, were determined for some rare earth elements. The major and trace elements were mainly analysed by X-ray fluorescence (XRF) method, whereas rare earth elements were analysed by neutron activation analysis (NAA) technique. Almost analytical methods are descriptively concluded in the Appendices. The major element oxides of these basalt samples were computed for CIPW normative values using "NEWPET" computer software program created by Geological Survey of Canada (Table 5.2). Rare earth element analyses of 6 duplicate basalt samples were cross checked by NAA technique of Chemex Labs Ltd., Canada.

5.2 Major Element Data

The major elements of the basalt samples analyzed (Table 5.1), included SiO_2, Al_2O_3, Fe_2O_3, FeO, CaO, MgO, Na_2O, K_2O, TiO_2, MnO, and P_2O_5. Detailed of individual oxides are presented below.

In addition results from both Nam Cho and Sop Prap - Ko Kha basalts are compared with those (Table 5.4) of the well-documented continental basalts, such as Deccan Flood Basalts (Cox and Hawkesworth, 1985) in India and Kenya Naivasha Rift Basalts (Davies

Table 5.1 Major element analyses (in percent) of 65 basalt samples for the Nam Cho and the Sop Prap-Ko Kha basalts.

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	H_2O	LOI	TOTAL	$Mg^{\#}$
S-2	49.22	16.53	5.90	3.05	7.77	5.99	2.88	1.36	1.93	0.12	0.70	0.78	2.38	95.45	77.78
S-4	48.22	17.39	6.07	1.96	7.63	4.90	2.25	1.98	2.01	0.13	0.85	0.61	5.11	93.39	81.67
S-8	49.00	17.78	4.92	3.19	7.48	4.22	2.79	2.71	2.12	0.13	0.86	0.74	2.95	95.20	70.22
S-11	49.48	17.80	5.32	2.78	7.36	4.54	3.26	1.37	2.14	0.12	0.88	0.66	3.53	95.05	74.43
S-13	49.32	17.69	4.72	3.26	7.27	4.63	3.50	1.24	2.11	0.12	0.85	0.48	3.45	95.01	71.68
S1-1	49.24	17.03	3.95	4.67	7.67	5.42	2.57	2.98	2.05	0.21	0.74	0.45	1.92	96.53	67.41
S1-7	48.63	16.45	6.76	3.36	8.41	5.11	2.12	2.48	1.99	0.18	0.62	0.35	2.40	96.11	73.05
S1-10	47.15	16.07	3.83	5.32	9.23	6.87	1.97	2.19	2.01	0.15	0.64	0.52	2.98	95.43	69.71
S1-13-2	46.18	16.08	3.33	6.31	8.48	7.76	2.40	1.83	2.06	0.17	0.70	0.56	2.88	95.30	68.67
S1-14	46.37	15.93	6.00	4.35	8.97	6.19	2.19	1.44	2.08	0.14	0.70	1.22	3.29	94.36	71.72
S7-2	48.25	17.60	4.78	3.64	7.85	4.32	2.49	1.91	2.11	0.13	0.83	0.80	4.25	93.91	67.90
S7-3-1	47.62	16.59	5.77	3.00	8.67	4.94	1.69	2.56	2.05	0.14	0.71	0.82	4.50	93.74	74.59
S7-5	46.08	15.82	3.51	5.52	9.61	6.85	1.58	2.10	1.94	0.14	0.61	0.61	4.44	93.76	69.27
S8-2	48.23	16.59	5.75	4.18	8.38	5.80	2.68	1.44	2.10	0.14	0.71	0.58	2.42	96.00	71.21
S8-5	46.89	15.99	6.34	3.73	8.75	5.54	2.49	0.62	2.14	0.17	0.78	1.32	3.95	93.44	72.58
S 18-2-1	49.17	18.13	5.88	2.44	7.34	4.52	3.09	1.53	2.11	0.12	0.91	1.08	3.31	95.24	76.75
S 18-3	48.72	17.83	5.79	2.54	7.47	5.01	2.06	3.35	2.11	0.12	0.85	0.67	2.91	95.85	77.85
S 18-5-2	47.75	17.44	3.08	4.58	8.17	5.75	2.10	3.66	2.01	0.12	0.85	0.46	3.55	95.51	69.11
S 18-7	47.85	16.70	4.96	4.41	8.69	5.73	2.39	2.80	2.00	0.14	0.67	0.55	2.31	96.34	69.84
S 18-11	47.62	16.60	2.92	6.25	8.14	7.20	2.38	2.30	1.95	0.15	0.69	0.72	2.47	96.20	67.25
S 19-1	48.40	17.45	5.00	3.24	7.66	5.16	1.74	2.90	2.00	0.13	0.80	0.96	4.12	94.48	73.95
S 19-3	49.46	17.95	4.88	3.25	7.39	4.65	3.22	1.94	2.00	0.12	0.87	0.92	2.82	95.73	71.83
S 19-5	47.44	16.90	4.80	3.47	8.55	5.98	2.20	2.02	1.96	0.13	0.77	1.05	3.98	94.22	75.44
S 19-7	48.64	16.76	5.55	3.96	8.27	5.70	1.85	2.73	1.94	0.14	0.67	0.88	2.26	96.21	71.95
S 19-9	47.14	16.09	2.86	6.42	8.47	7.08	1.72	2.83	1.93	0.15	0.63	0.57	3.72	95.32	66.28

Table 5.1 (cont.)

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	H_2O	LOI	TOTAL	$Mg^{\#}$
S 21-1	49.43	17.96	3.33	4.78	7.44	4.28	2.95	1.52	2.07	0.13	0.90	1.24	3.42	94.39	61.48
S 21-4-2	49.42	17.05	7.03	2.20	7.92	4.89	2.56	1.38	2.05	0.14	0.80	1.28	2.98	95.44	79.85
S 21-6	47.22	16.38	3.91	5.40	8.33	6.92	2.22	2.08	1.97	0.14	0.66	0.80	3.44	95.23	69.55
S 21-8	47.28	15.95	3.49	6.14	8.35	7.10	1.67	2.49	1.97	0.15	0.66	0.82	3.43	95.25	67.33
S 21-10	46.93	15.98	2.30	6.00	10.21	6.58	1.79	2.39	1.96	0.17	0.63	0.47	3.96	94.94	66.15
S 24-1	48.58	17.57	3.97	4.19	7.54	5.06	2.44	1.81	1.99	0.13	0.84	0.92	4.13	94.12	68.28
S 24-2	49.42	17.97	5.88	2.67	7.48	4.25	3.17	1.56	2.07	0.13	0.86	0.85	3.07	95.46	73.94
S 24-4	47.68	16.76	2.73	5.75	8.44	6.58	2.17	2.75	2.01	0.13	0.73	0.79	2.74	95.73	67.10
S 24-6	47.30	15.92	2.79	6.43	8.49	6.98	2.07	2.54	1.92	0.14	0.63	0.68	3.42	95.21	65.93
S 24-7	47.70	16.18	2.80	6.65	8.57	7.02	2.05	2.50	1.93	0.15	0.63	0.68	2.81	96.18	65.30
S 29-1	49.42	17.86	5.51	2.85	7.43	4.89	3.56	1.51	2.05	0.11	0.84	0.87	2.65	96.03	75.36
S 29-3	49.81	17.24	7.67	1.65	8.18	4.73	3.42	1.32	1.98	0.13	0.72	0.58	1.99	96.85	83.63
S 29-5	48.37	17.19	6.48	2.29	7.85	5.15	1.64	2.90	2.03	0.14	0.78	0.76	3.95	94.82	80.03
S 29-10	47.22	16.36	2.59	6.61	8.19	6.65	2.36	2.20	2.02	0.14	0.66	0.67	3.29	95.26	64.20
S 29-11	48.12	16.56	2.65	6.51	8.74	6.91	2.65	2.68	1.97	0.15	0.70	0.38	1.33	97.64	65.42
S2-2	46.60	16.29	5.92	4.19	8.54	5.92	2.69	1.29	2.16	0.15	0.79	1.47	2.95	94.54	71.58
S13-1	46.83	17.27	2.80	3.26	11.13	4.44	2.44	3.09	2.10	0.09	0.76	0.66	3.00	94.21	70.82
S6-2	45.72	15.80	6.79	2.72	9.10	7.65	1.63	2.69	2.05	0.16	0.66	0.60	3.31	94.97	83.37
S14-7	46.37	15.79	4.17	5.45	8.61	7.15	1.68	2.73	2.02	0.14	0.63	0.68	3.50	94.74	70.04
S12-6	45.81	16.22	2.23	7.16	8.73	7.40	2.42	2.99	2.13	0.16	0.65	0.55	2.32	95.90	64.81
S20-2	48.79	17.35	3.91	4.29	7.43	5.42	3.54	1.43	2.11	0.13	0.82	1.07	2.62	95.22	69.25
S14-1	46.45	16.84	5.03	2.88	8.05	5.40	1.47	2.87	1.99	0.13	0.79	1.09	5.82	91.90	76.97
S22-4-1	46.45	15.96	3.57	5.40	8.52	7.03	1.54	2.88	1.99	0.14	0.65	0.76	3.71	94.13	69.88
S25-4	46.81	15.95	2.72	6.71	8.25	6.90	2.15	2.47	1.99	0.14	0.59	0.61	3.46	94.68	64.70

Table 5.1 (cont.)

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	H_2O	LOI	TOTAL	$Mg^{\#}$
S23-4-1	47.81	16.46	2.18	5.73	9.52	7.27	1.83	2.51	2.07	0.19	0.63	0.40	2.99	96.20	69.34
S28-1	48.98	17.84	5.16	2.76	7.38	4.43	3.63	1.55	2.09	0.14	0.91	1.24	3.02	94.87	74.10
S25-2	48.92	17.36	6.23	2.70	7.81	4.94	2.67	3.23	2.10	0.13	0.76	0.64	1.68	96.85	76.53
S28-3	45.13	15.95	3.07	3.57	12.98	4.46	2.75	2.71	1.99	0.21	0.63	0.56	5.10	93.45	69.01
S28-4	46.97	16.22	2.97	6.25	8.34	6.70	2.18	2.38	1.98	0.14	0.64	0.74	3.34	94.77	65.64
S27-11	45.44	16.12	2.31	7.11	8.91	7.85	1.68	2.95	2.21	0.16	0.68	0.52	2.75	95.42	66.30
N-1	43.10	15.45	4.73	7.07	9.66	7.71	3.32	0.96	2.48	0.19	0.75	0.85	2.97	95.42	66.03
N-2	43.53	15.87	5.28	6.35	9.23	7.16	2.80	2.56	2.37	0.20	0.80	0.86	2.21	96.15	66.77
N-3	42.86	15.79	5.51	6.11	9.38	7.30	2.63	2.58	2.47	0.21	0.79	1.24	1.97	95.63	68.05
N-4	42.89	15.25	4.35	7.04	9.67	8.53	2.84	0.98	2.53	0.19	0.66	0.89	3.00	94.93	68.35
N-5	44.98	15.99	5.61	5.12	8.30	6.75	3.40	2.72	2.08	0.19	0.75	0.50	2.35	95.89	70.15
N-7	44.07	16.10	7.16	5.11	9.07	6.14	3.40	3.07	2.32	0.21	0.82	0.35	1.22	97.47	68.17
N-8	45.35	16.03	6.19	4.92	8.62	7.08	3.16	2.87	2.12	0.20	0.80	0.45	1.58	97.34	71.95
N-9	44.51	15.61	6.05	5.09	8.79	7.49	3.24	2.76	2.19	0.20	0.76	0.52	1.74	96.69	72.40
N-11	45.10	15.80	5.58	5.29	8.54	7.38	3.11	2.91	2.11	0.19	0.74	0.57	1.58	96.75	71.32
N-12	45.24	16.29	4.32	6.47	8.56	6.90	3.34	2.85	2.08	0.19	0.76	0.38	1.59	97.00	65.53

Table 5.2 CIPW norm of 65 basalt analyses for the Nam Cho and the Sop Prap-Ko Kha basalts.

NORMATIVE SAMPLE	Q	Z	Or	Ab	An	Ne	Di	Wo	Hy	Ol	Mt	Cm	Hm	Il	Ap	Total
S - 2	4.79	0.04	8.06	24.37	28.23	-	4.90	-	12.65	-	4.68	0.03	2.67	3.67	1.67	95.76
S - 4	6.27	0.05	11.74	19.04	31.62	-	1.24	-	11.63	-	0.95	0.02	5.41	3.82	2.04	93.83
S - 8	3.12	0.05	16.05	23.61	28.07	-	3.14	-	9.06	-	4.60	0.02	1.75	4.03	2.05	95.54
S - 11	5.25	0.05	8.13	27.58	29.98	-	1.15	-	10.78	-	3.19	0.02	3.12	4.06	2.10	95.42
S -13	4.35	0.04	7.36	29.61	28.98	-	1.65	-	10.77	-	3.96	0.02	1.99	4.58	2.03	95.34
S 1-1	0.77	0.04	17.65	21.74	26.20	-	6.10	-	12.96	-	5.73	0.03	-	3.89	1.77	96.89
S 1 - 7	4.86	0.04	14.67	17.94	28.12	-	7.96	-	9.05	-	5.68	0.03	2.84	3.78	1.48	96.45
S 1 - 10	0.11	0.04	12.95	16.67	28.63	-	11.00	-	15.50	-	5.55	0.03	-	3.82	1.53	95.83
S 1 - 13 - 2	-	0.04	10.83	20.31	27.77	-	8.22	-	9.93	8.08	4.38	0.03	-	3.91	1.67	95.61
S 1 -14	3.78	0.05	8.53	18.53	29.46	-	8.66	-	11.41	-	8.49	0.03	0.15	3.95	1.67	94.71
S 7-2	5.87	0.05	11.32	21.07	31.30	-	2.29	-	9.70	-	6.08	0.02	0.59	4.01	1.98	94.28
S 7-3-1	5.59	0.04	15.17	14.30	30.24	-	7.26	-	8.96	-	4.21	0.03	2.87	3.89	1.70	94.25
S 7-5	0.66	0.02	12.46	13.37	29.92	-	11.43	-	15.94	-	5.09	0.03	-	3.68	1.45	94.06
S 8-2	4.13	0.04	8.53	22.68	29.05	-	6.55	-	11.42	-	7.87	0.03	0.32	3.99	1.69	96.30
S 8-5	6.75	0.05	3.68	21.07	30.70	-	6.42	-	10.83	-	6.42	0.03	1.91	4.06	1.86	93.79
S 18-1	5.15	0.05	9.07	26.14	31.18	-	-	-	11.26	-	2.17	0.02	4.38	4.01	2.18	95.62
S 18-2	3.12	0.05	19.82	17.43	29.60	-	1.99	-	11.56	-	2.50	0.02	4.07	4.01	2.03	96.20
S 18-3	-	0.05	21.66	17.77	27.42	-	6.51	-	7.35	4.77	4.47	0.02	-	3.82	2.03	95.86
S 18-5-2	-	0.04	16.58	20.22	26.65	-	10.12	-	10.40	0.10	7.19	0.02	-	3.80	1.60	96.73
S 18-7	-	0.04	13.62	20.14	27.88	-	6.82	-	12.16	6.23	4.23	0.02	-	3.70	1.65	96.49
S 19-1	5.50	0.05	17.17	14.72	31.34	-	1.68	-	12.08	-	5.11	0.02	1.47	3.80	1.91	94.85
S 19-3	3.24	0.06	11.51	27.24	28.92	-	2.39	-	10.48	-	5.11	0.01	1.36	3.80	2.09	96.20
S 19-5	3.12	0.04	12.08	18.61	30.34	-	6.30	-	11.99	-	5.96	0.02	0.69	3.72	1.84	94.71
S 19-7	4.48	0.04	16.26	15.65	29.40	-	6.18	-	11.34	-	7.64	0.02	0.28	3.68	1.60	96.57

Table 5.2 (cont.)

NORMATIVE / SAMPLE	Q	Z	Or	Ab	An	Ne	Di	Wo	Hy	Ol	Mt	Cm	Hm	I l	Ap	Total
S 19-9	-	0.04	16.75	14.55	27.88	-	8.45	-	14.64	3.95	4.15	0.02	-	3.67	1.50	95.59
S 21-1	5.16	0.05	9.01	24.96	31.37	-	0.26	-	13.41	-	4.83	0.02	-	3.93	2.15	95.15
S 21-4-2	7.73	0.05	8.17	21.66	31.07	-	3.02	-	10.79	-	1.64	0.03	5.90	3.89	1.92	95.86
S 21-6	0.06	0.04	12.31	18.78	28.65	-	7.06	-	17.61	-	5.67	0.02	-	3.74	1.57	95.51
S 21-8	0.65	0.04	14.73	14.13	28.73	-	7.11	-	19.73	-	5.06	0.02	-	3.74	1.57	95.53
S 21-10	-	0.04	14.14	15.14	28.56	-	14.88	-	9.77	4.11	3.33	0.02	-	3.72	1.50	95.23
S 24-1	5.30	0.06	10.73	20.64	31.80	-	1.01	-	13.52	-	5.76	0.02	-	3.78	2.20	94.64
S 24-2	5.20	0.05	9.25	26.82	30.29	-	1.46	-	9.91	-	3.06	0.02	3.77	3.93	2.06	95.82
S 24-4	-	0.05	16.27	18.36	27.94	-	7.81	-	11.40	4.70	3.96	0.03	-	3.82	1.74	96.07
S 24-6	-	0.04	15.03	17.51	26.70	-	9.51	-	12.44	5.05	4.05	0.02	-	3.65	1.50	95.49
S 24-7	-	0.04	14.78	17.34	27.62	-	9.05	-	13.70	4.66	4.06	0.03	-	3.67	1.50	96.45
S 29-1	2.62	0.05	8.95	30.12	28.38	-	2.81	-	10.88	-	3.64	0.02	3.00	3.89	2.01	96.37
S 29-3	3.92	0.04	7.86	28.94	27.85	-	6.70	-	8.69	-	0.03	0.03	7.65	3.76	1.72	97.18
S 29-5	5.81	0.05	17.16	13.88	31.13	-	3.04	-	11.42	-	1.99	0.02	5.11	3.85	1.87	95.33
S 29-10	-	0.04	13.01	19.97	27.61	-	7.41	-	13.10	4.94	3.76	0.02	-	3.84	1.57	95.28
S 29-11	-	0.04	15.86	22.42	25.43	-	11.19	-	0.98	12.74	3.84	0.03	-	3.74	1.67	97.94
S 2-2	2.85	0.05	7.64	22.76	28.64	-	7.15	-	11.44	-	7.78	0.04	0.55	4.10	1.89	94.89
S 13-1	-	0.05	18.28	15.70	27.17	2.68	19.34	-	-	1.76	4.06	0.03	-	3.99	1.82	94.87
S 6-2	-	0.04	15.92	13.79	27.90	-	10.46	-	12.86	0.95	3.38	0.03	4.46	3.89	1.57	95.25
S 14-7	-	0.04	16.16	14.21	27.53	-	9.14	-	15.31	1.20	6.05	0.03	-	3.84	1.50	95.00
S 12-6	-	0.04	17.69	14.94	24.61	3.00	12.07	-	-	14.98	3.23	0.03	-	4.05	1.55	96.19
S 20-2	1.15	0.05	8.48	29.95	27.32	-	3.86	-	13.12	-	5.67	0.02	-	4.01	1.96	95.59
S 14-1	4.30	0.05	16.99	12.44	31.10	-	4.37	-	11.44	-	3.97	0.02	2.29	3.78	1.91	92.66
S 22-4-1	-	0.04	17.04	14.05	14.69	13.20	18.91	-	-	8.93	5.18	0.03	-	3.78	1.55	97.39

Table 5.2 (cont.)

NORMATIVE / SAMPLE	Q	Z	Or	Ab	An	Ne	Di	Wo	Hy	Ol	Mt	Cm	Hm	Il	Ap	Total
S 25-4	-	0.04	14.62	20.73	25.25	-	9.83	-	5.36	10.22	3.94	0.03	-	3.78	1.40	95.22
S 23-4-1	-	0.04	14.85	15.48	29.34	-	11.41	-	12.64	4.09	3.16	0.03	-	3.93	1.50	96.48
S 28-1	2.54	0.05	9.20	30.71	27.90	-	2.70	-	9.78	-	3.32	0.02	2.87	3.97	2.18	95.25
S 28-2	0.65	0.05	19.11	22.59	25.91	-	6.59	-	9.26	-	3.06	0.02	4.12	3.99	1.81	97.17
S 28-3	-	0.04	16.03	8.99	23.21	7.73	26.15	1.82	-	-	4.45	0.02	-	3.78	1.50	93.73
S 28-4	-	0.04	14.10	20.98	26.14	-	9.22	-	7.35	7.88	4.31	0.03	-	3.76	1.52	95.32
S 27-11	-	0.04	17.45	14.21	27.79	-	10.05	-	2.56	14.41	3.35	0.03	-	4.20	1.62	95.71
N -1	-	0.04	5.73	20.15	24.46	4.30	15.33	-	-	12.37	6.86	0.02	-	4.71	1.79	95.77
N -2	-	0.05	15.20	13.58	23.22	5.48	14.33	-	-	10.58	7.65	0.02	-	4.50	1.91	96.53
N -3	-	0.05	15.28	12.22	23.72	5.44	14.49	-	-	10.20	7.99	0.02	-	4.69	1.89	95.98
N -4	-	0.04	5.82	19.38	26.03	2.52	14.54	-	-	14.21	6.31	0.03	-	4.80	1.57	95.26
N - 5	-	0.05	16.11	18.36	20.39	5.64	12.98	-	-	8.80	8.13	0.03	-	3.95	1.79	96.23
N -7	-	0.05	18.19	12.99	19.65	8.55	16.11	-	-	5.55	10.38	0.02	-	4.41	1.96	97.85
N -8	-	0.05	17.04	17.70	21.11	4.89	13.36	-	-	8.62	8.97	0.03	-	4.03	1.91	97.75
N -9	-	0.05	16.34	15.20	19.94	6.62	15.13	-	-	8.98	8.77	0.03	-	4.16	1.81	97.03
N -11	-	0.05	17.23	16.16	20.60	5.50	13.80	-	-	9.84	8.09	0.04	-	4.01	1.77	97.10
N -12	-	0.04	16.92	15.01	21.07	7.18	13.65	-	-	11.43	6.26	0.03	-	3.95	1.81	97.36

and Macdonald, 1987), and some Thai basalts such as Phu Fai gabbroid (Sutthirat, 1992) and Khao Kradong basalts (Plathong, 1994), both from southern Khorat.

SiO_2: The average content of SiO_2 of the Nam Cho basalts is about 44.16% relatively less than that of the Sop Prap-Ko Kha basalts (47.8%). The SiO_2 content of the Sop Prap-Ko Kha basalts shows a progressive increase from lower to upper flows, as av 47.19 % of the first flow, av 47.48 % of the second flow, av 47.09 % of the third flow, av 48.50 % of the fourth flow, and av 48.73 % of the fifth flow. These two Thai basalts have the average contents of SiO_2 fallen within the average range of those of the Deccan and the Kenya basalts. However, the SiO_2 contents of these Lampang basalts are nearly the same as those of the Phu Fai and the Khao Kradong basalts.

Al_2O_3: The Nam Cho basalts also contain av Al_2O_3 content (15.82 %), which is relatively lower than those of flows of the Sop Prap-Ko Kha basalts (16.86%). They comprise an orderly increase of Al_2O_3 contents from the lower to the upper flows, as 16.34 %, 16.73%, 16.55 %, 17.26 %, 17.42 %, respectively. The average contents of the Nam Cho and the Sop Prap-Ko Kha basalts, however, are higher than those of the Deccan flood and Kenya rift basalts. These two basalts contain the average Al_2O_3 contents higher than Khao Kradong and Phu Fai basalts.

Fe_2O_3 and FeO: It is evidenced that the Fe_2O_3 and FeO contents of the Nam Cho basalt, comprising approximately 5.48 % of Fe_2O_3 and 5.43 % of FeO, respectively, are relatively higher than those (4.41% and 4.28%, respectively) of the Sop Prap-Ko Kha basalts. However, results of the latter do not show a progressive change among layers. It is likely that these two basalt localities show the total Fe_2O_3 content slightly lower than those of the Deccan and the Kenya basalts. The Nam Cho and the Sop Prap-Ko Kha basalts contain Fe_2O_3 (total) content slightly lower than those of Phu Fai and Khao Kradong basalts.

CaO : Ranges of CaO content are frequently from 7.5 % to 9.5 %, for both basaltic terranes. The Nam Cho basalt gives a mean CaO content of 8.98 %, while CaO content of the Sop Prap-Ko Kha basalt decrease gradually from the lowest to the uppermost flows, with the exception of the third flow, as 8.75 %, 8.31 %, 8.93 %, 8.19 %, 7.64 %, respectively. However, the CaO contents from these two basalts are far less than CaO contents of the Deccan and the Kenya basalts. However, the CaO contents of both Nam Cho and Sop Prap - Ko Kha basalts are frequently higher than Phu Fai and Khao Kradong basalts.

MgO : Average MgO content of the Nam Cho basalt is relatively higher than that of the Sop Prap-Ko Kha basalt. The latter decrease distinctively from the lower to the upper flows, and exception arises for the fourth flow. These two basalts contain the average MgO higher than Deccan basalt and lower than Kenya basalt. However, the MgO contents of these basalts are moderately higher than Phu Fai basalts and lower than Khao Kradong basalts.

Na_2O : The Nam Cho basalt contains 3.12 % of mean Na_2O higher than those of the Sop Prap-Ko Kha basalts, and slightly increase respectively from the lower to the upper flows, i.e., 2.21%, 2.25 %, 2.06 %, 2.46 %, and 2.87 %. The Nam Cho basalt contain Na_2O contents lower than Phu Fai basalts and higher than Khao Kradong, Deccan, and Kenya basalts. The Na_2O contents of the Sop Prap - Ko Kha basalt are nearly the same as those of Khao Kradong and lower than Phu Fai, Daccan, and Kenya basalts.

K_2O : K_2O contents of the Sop Prap-Ko Kha basalt do not exhibit a clear trend, since they seem to increase from the first to the third flows, and remarkably decreasing from the third to the fifth flows. These include from the first to the fifth as 2.22%, 2.27 %, 2.61 %, 2.34 %, and 1.8 %. The Nam Cho basalt contains about 2.43 % of mean K_2O content. These two basalts contain av. K_2O contents much higher than those of the Deccan and Kenya basalts, but are slightly higher than those of Phu Fai and Khao Kradong basalts.

TiO_2: The TiO_2 contents (ranging from 2.08 to 2.48 %)of the Nam Cho give an average amount of 2.28 %. They are higher than those of the Sop Prap-Ko Kha basalt. The Nam Cho means are nearly the same as the average content of the Sop Prap-Ko Kha. The contents of the southern basaltic terrane are from the first to the last flows as 2.05 %, 2.01 %, 2.00 %, 2.04 %, and 2.06 %, respectively. The two basalt fields, however show av. TiO_2 contents lower than that of the Deccan and the Khao Kradong, but slightly higher than those of the Kenya and the Phu Fai.

MnO: The ranges of MnO contents of each flow of the Sop Prap-Ko Kha basalts are relatively restricted. Their mean contents range from 0.13 to 0.16 %, while that of the Nam Cho basalts is slightly higher, i.e. 0.2 %. These contents are nearly the same as the comparable reference basalts.

P_2O_5: The P_2O_5 contents of both basaltic terranes do not exhibit a clear trend and seem to be restricted from 0.7 to 0.8 %. The Nam Cho basalt comprises 0.76% of mean P_2O_5 content, whereas the Sop Prap-Ko Kha basalt contains orderly from the bottom to the top flows, i.e., 0.69 %, 0.68 %, 0.72 %, 0.78 %, and 0.82% for each mean. These mentioned values are quite higher than those of the comparable reference basalts.

One of the oldest and most commonly used types of variation diagram in igneous petrology is the Harker diagram (Harker, 1909), in which the weight percent of a concerned oxide is plotted against wt% of SiO_2 (Figure 5.1). Several Harker diagrams show positive correlation with SiO_2; including Al_2O_3, Na_2O, Fe_2O_3 whereas some, however, show negative correlation - CaO, Fe_2O_3(t), FeO, TiO_2 and MgO, and few depict no correlation with SiO_2, including, K_2O, P_2O_5 and MnO. However, when a comparison is made for those of the Nam Cho and the Sop Prap-Ko Kha data, it is quite possible that some values (as FeO,

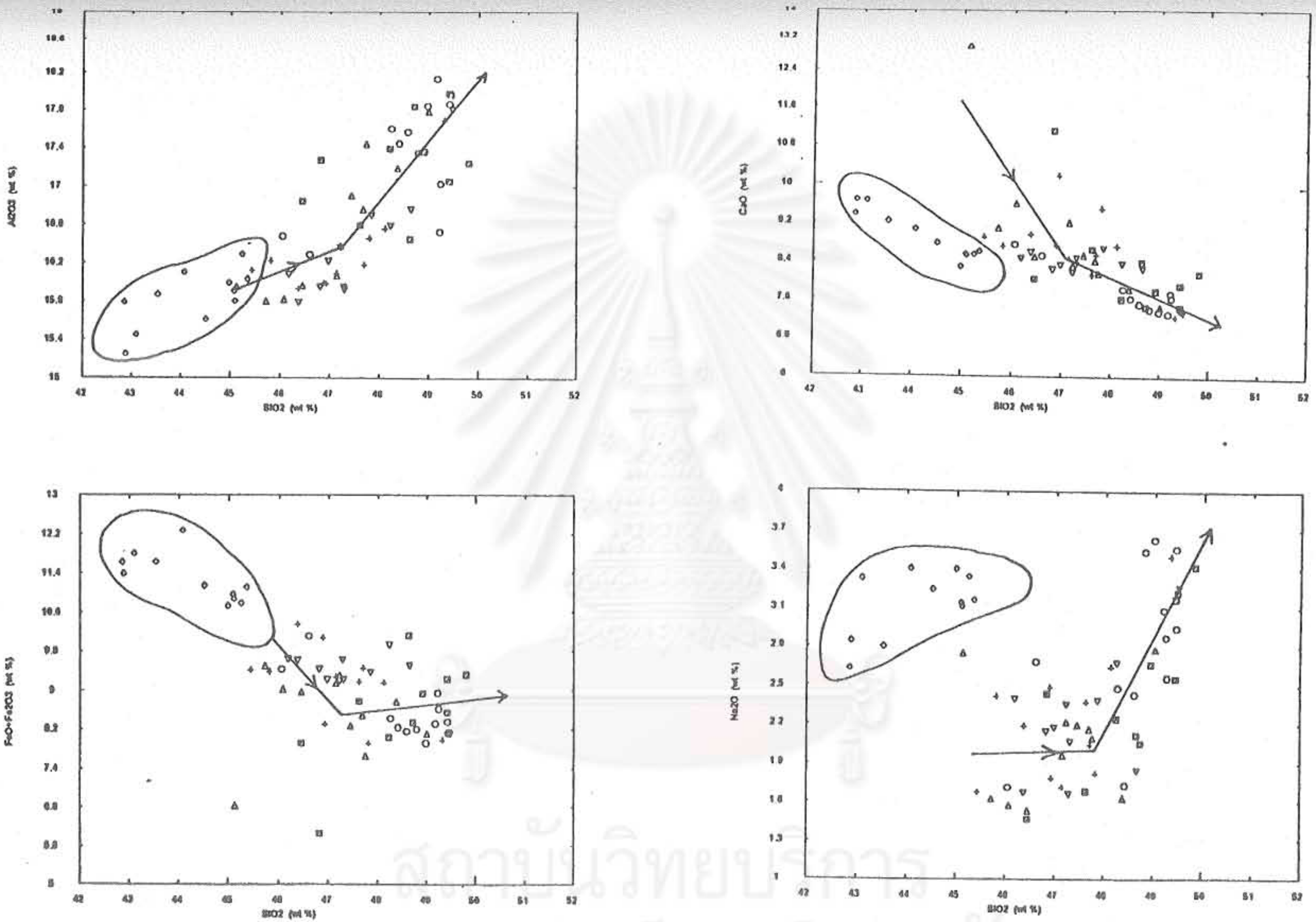
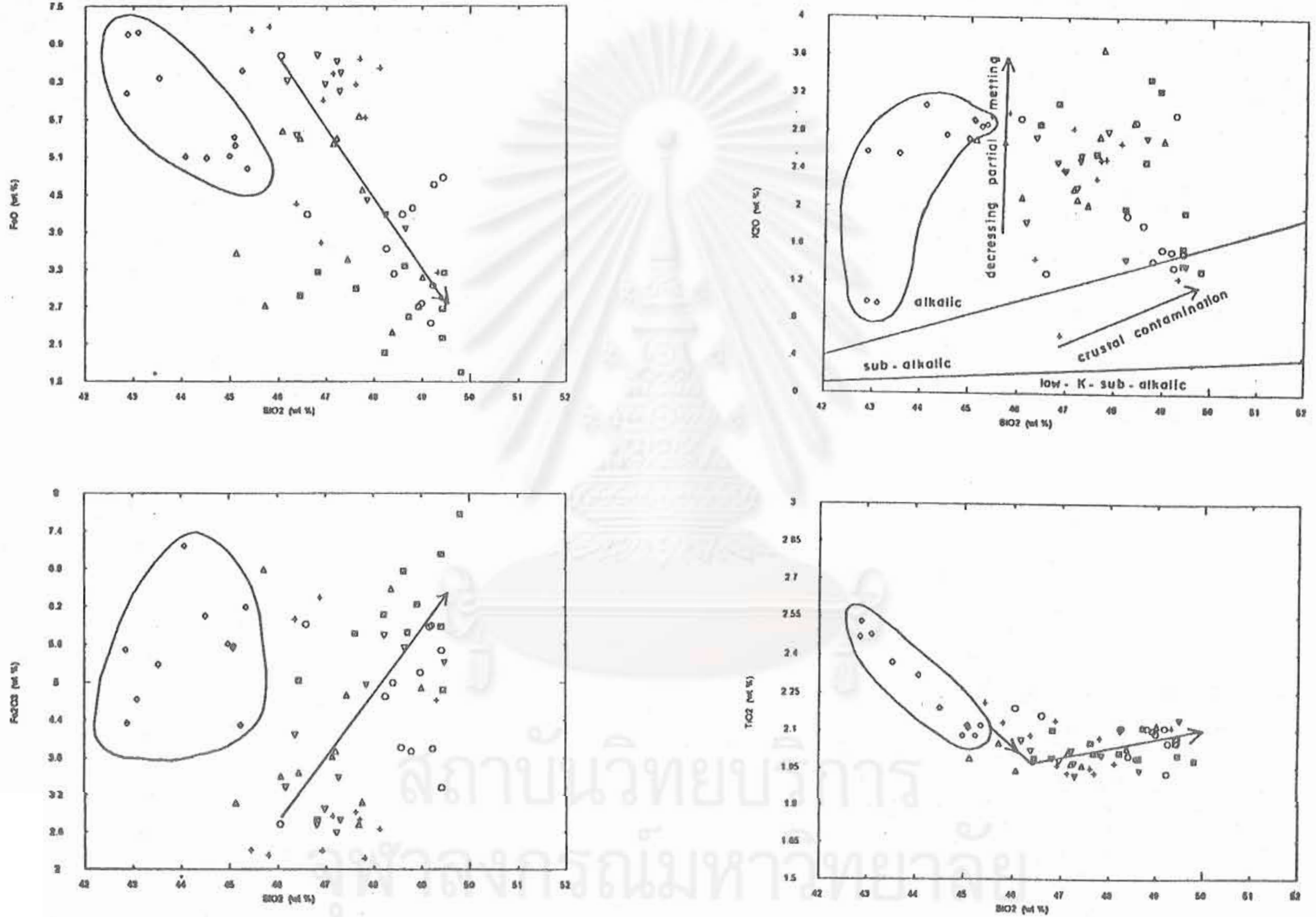
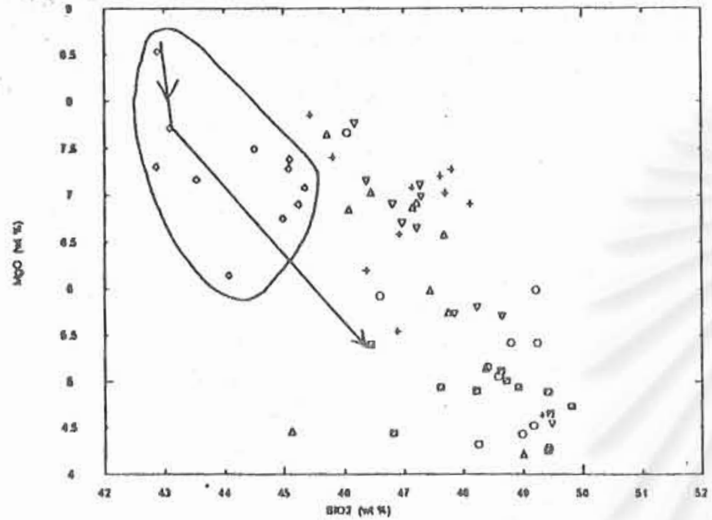
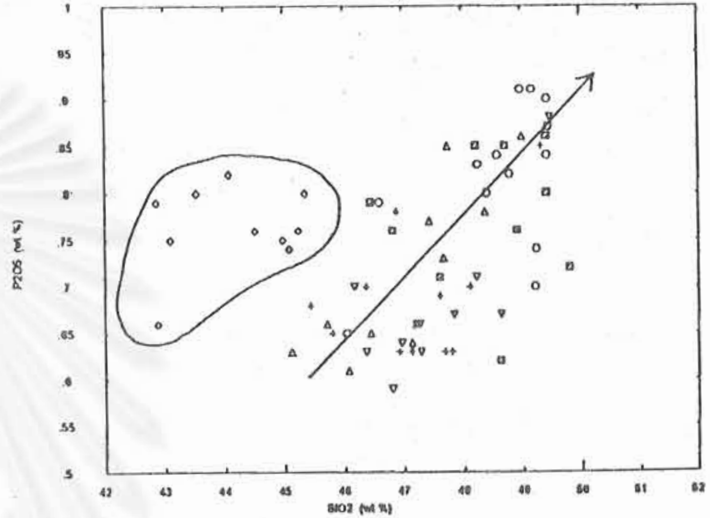


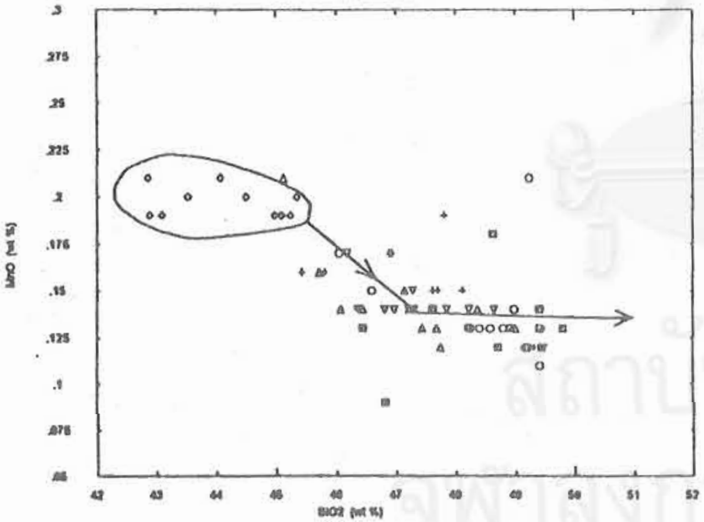
Figure 5.1 Harker variation diagrams of major oxides versus SiO_2 for basalts in the study area.

Figure 3.1 (cont.)









SYMBOL

◇ The Nam Cho Basaltic Suites
○ The Fifth Flow of Sop Prab - Ko Kha Basaltic Suites
▧ The Fourth Flow of Sop Prab - Ko Kha Basaltic Suites
△ The Third Flow of Sop Prab - Ko Kha Basaltic Suites
▽ The Second Flow of Sop Prab - Ko Kha Basaltic Suites
+ The First Flow of Sop Prab - Ko Kha Basaltic Suites

and K_2O) of these two basaltic terranes do not follow the same trend. In fact a few show subparallel liquid lines of descent (as Al_2O_3, MgO, and MnO), presumably suggesting the difference in the petrochemical evolution.

The most commonly used alternative to the Harker diagram is the MgO bivalent plot and is suggested for rocks containing highly variable contents of MgO values (Rollinson, 1993). The plots of MgO versus other oxide values are used herein because there exists an overlap range of Mg values for basalts from two terranes. These are shown in Figure 5.2. In general, the plots depict the results opposite to those of the SiO_2, since SiO_2 and MgO plots depict strongly negative correlation. In this study, the results gathered from these bivalent plots give the evolutionary trend similar to those of the SiO_2. Many plots including CaO, Al_2O_3, TiO_2, and P_2O_5 show inflection trends. Several diagrams including those of TiO_2, Fe_2O_3(total), MnO, and P_2O_5, show contrast in liquid lines of crystallization. These plots and diagrams perhaps suggest the difference in magmatic sources. Similar results can be made for the plots of solidification index [100MgO / ($MgO+FeO+Fe_2O_3+Na_2O+K_2O$)] versus oxides, as illustrated in Figure 5.3. Therefore, it is quite important to note herein that several different variation diagrams of bivalent plots indicate that the Nam Cho and the Sop Prap-Ko Kha basalts have not been evolved from the cogenetic magmatic sources. Classification of basalts using geochemical data variation diagrams with TiO_2 and MnO content (Figure 5.1) display strongly inflected and segmented trends, respectively, especially for those of the Sop Prap-Ko Kha basalt possibly providing powerful evidences for the different operation in crystal - liquid seperation during magmatic evolution. In general, inflections in trends are interpreted to mark the onset of crystallization of new mineral species. It is important to point out that also the variations of Al_2O_3, CaO, Fe_2O_3(total), Na_2O, TiO_2, and MnO versus SiO_2 for the Sop Prap-Ko Kha basaltic suites show strongly segmented trends at approximately 47-48 % SiO_2. Segmented linear correlation indicates the importance of different fractionation mineral assemblage in the magmatic evolution with points of inflection marking a new major crystallization

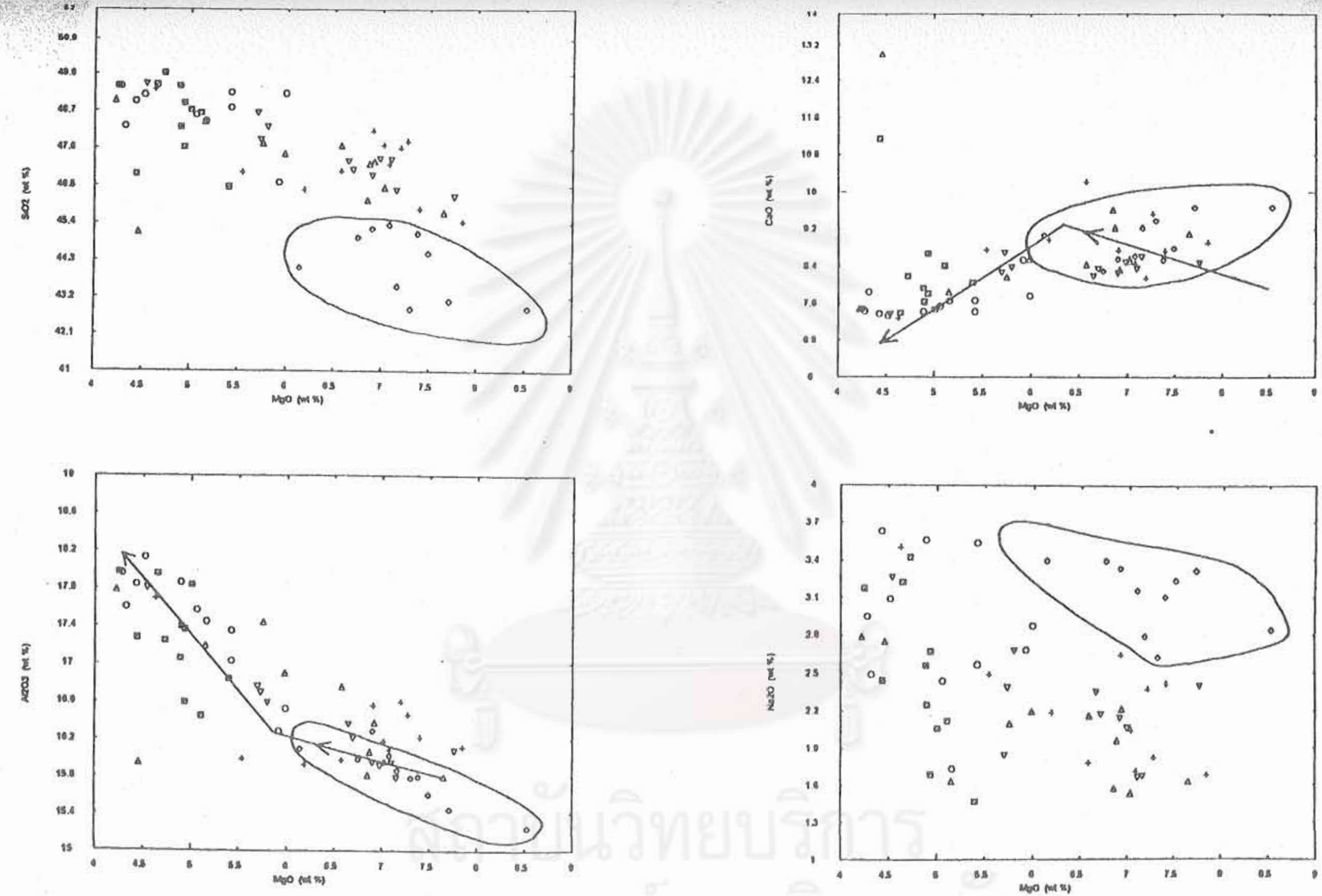
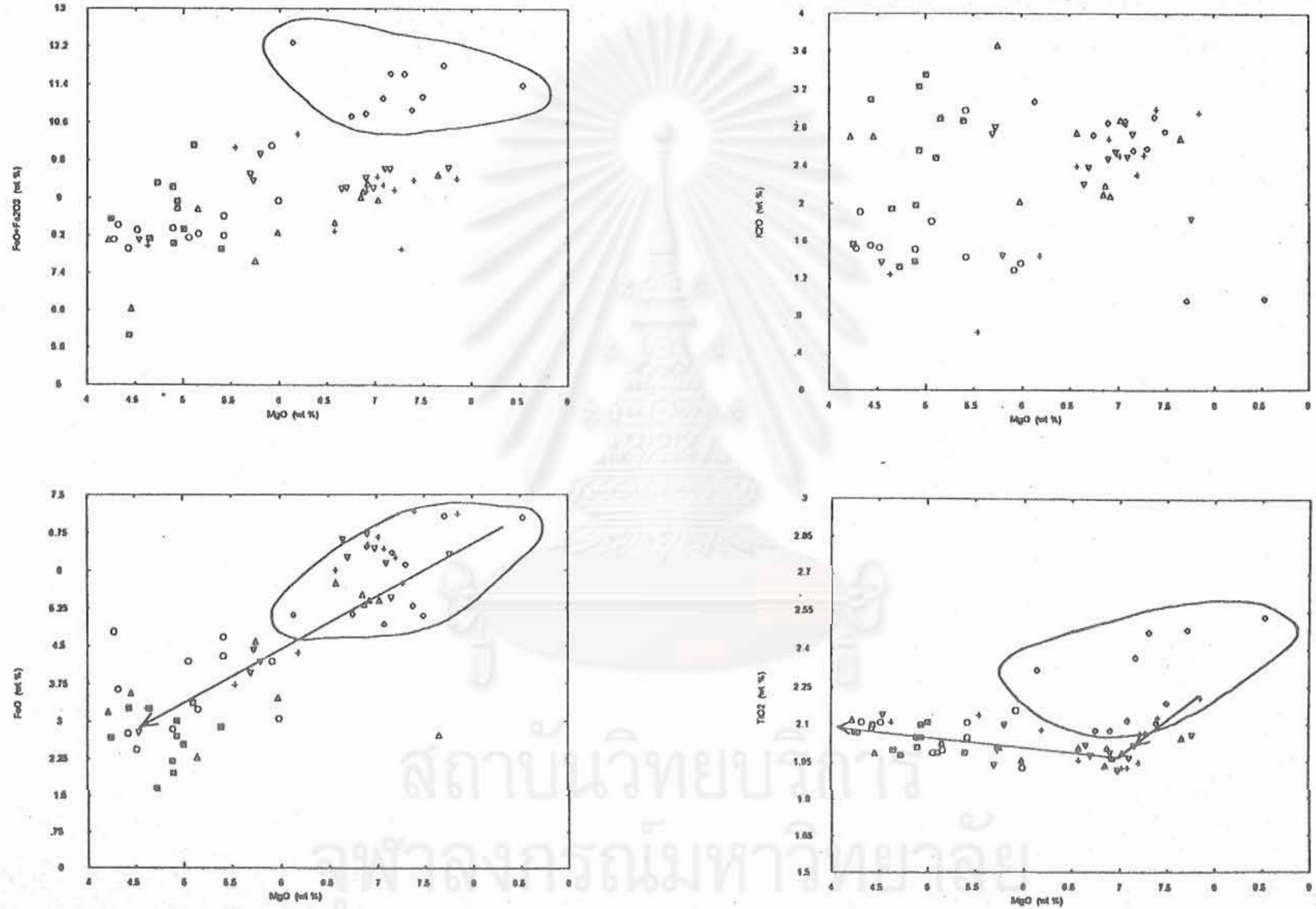
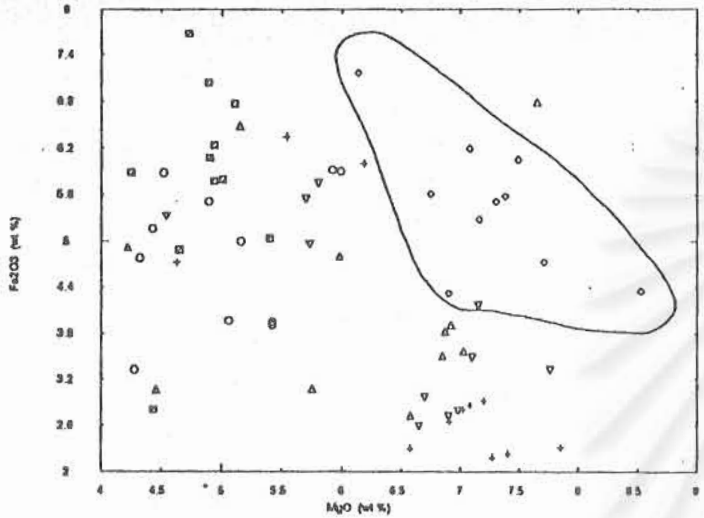
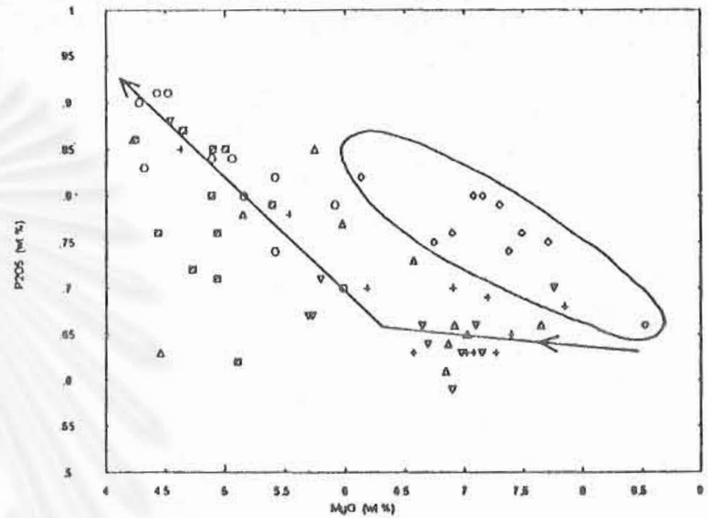


Figure 5.2 Variation diagrams plotting of MgO versus the other major oxides for the Nam Cho and the Sop Prap-Ko Kha basalts. Symbols same as Figure 5.1.

Figure 5.2 (cont.)




Fe2O3 (wt %)
MgO (wt %)


P2O5 (wt %)
MgO (wt %)

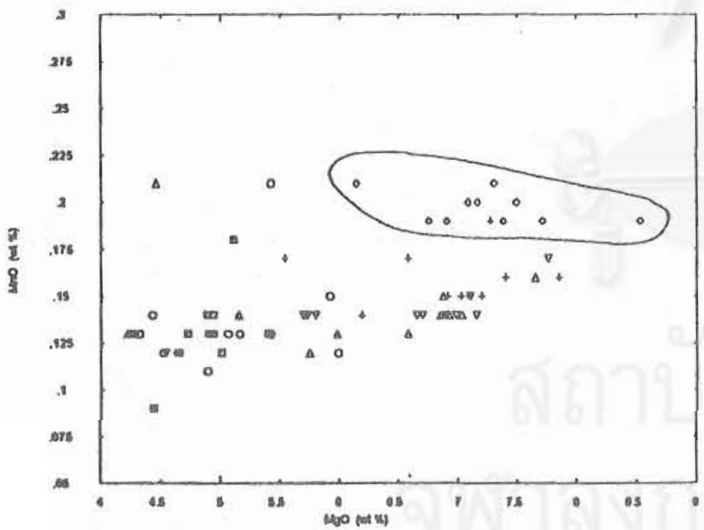

MnO (wt %)
MgO (wt %)

Figure 5.3 (cont.)

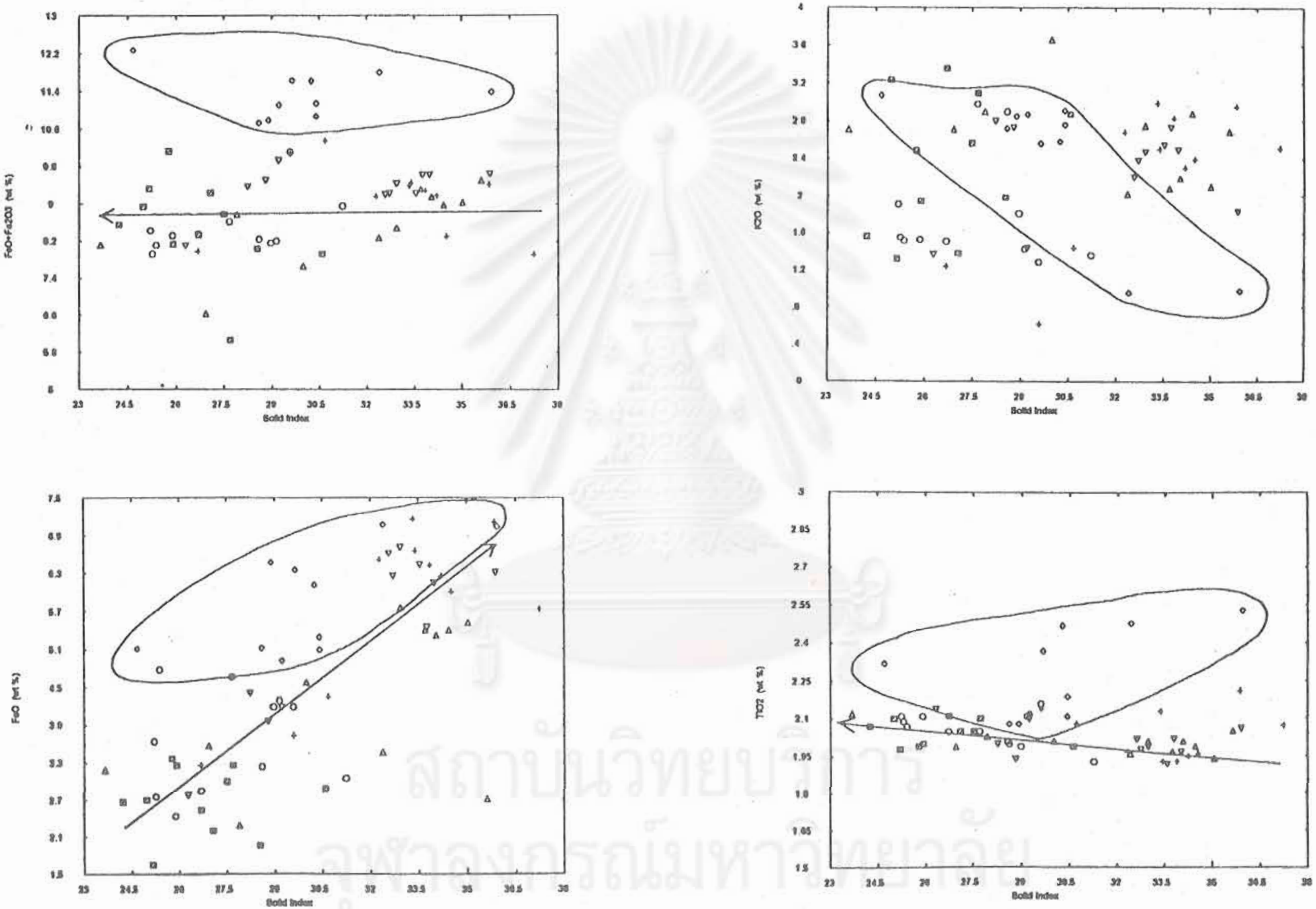
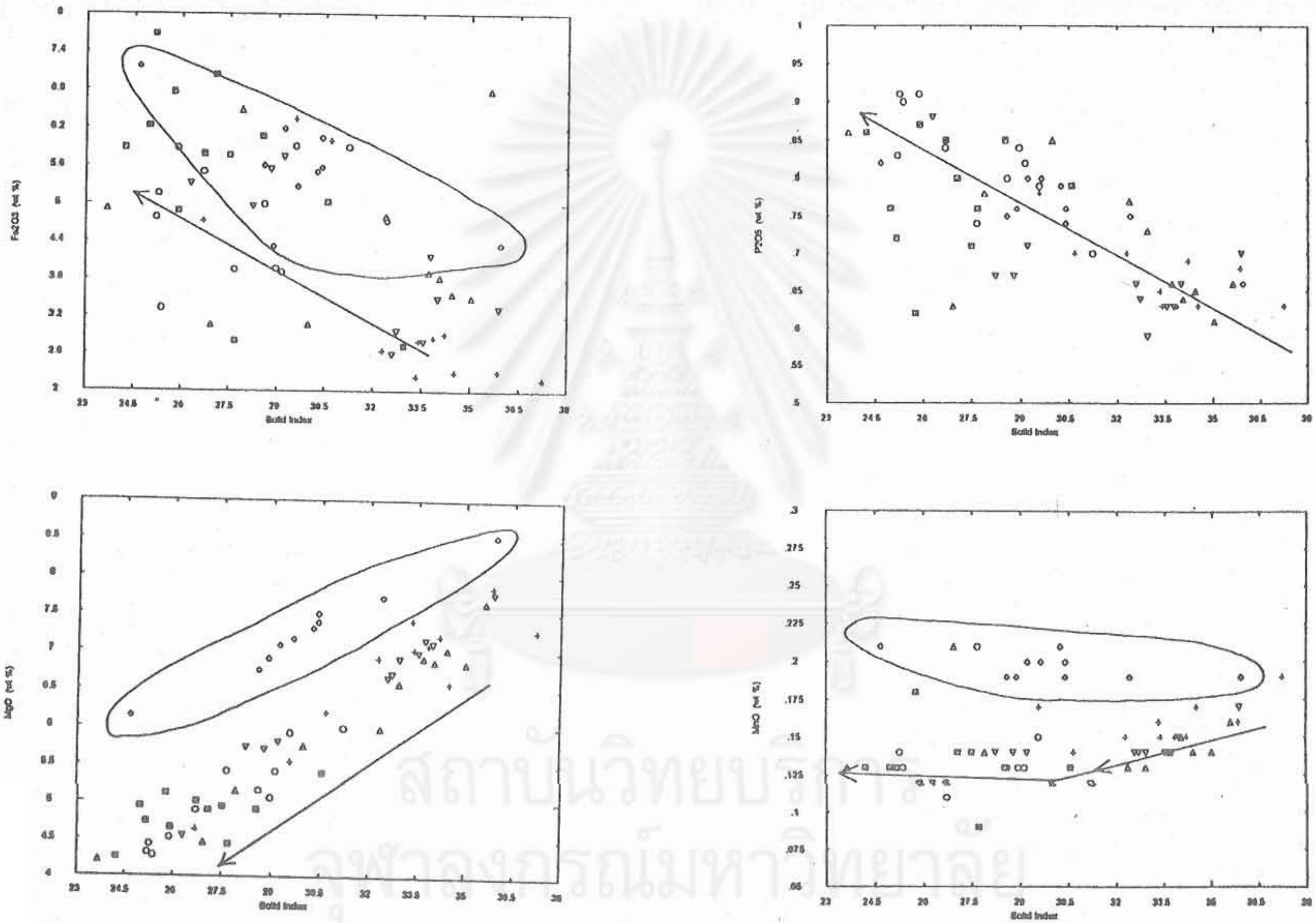


Figure 5.3 (cont.)



phase. This can be interpreted herein in terms of crystal fractionation dominated by olivine and plagioclase whereas clinopyroxene does not appear as a dominant phase. These evidences seem fit fairly well with petrographic evidences (see Chapter 4 for details). The total alkalis-silica (TAS) diagrams, one of the most useful classification schemes available for volcanic rocks (Cox et al., 1979), indicate that most of the values for the Sop Prap - Ko Kha volcanics are located in the basalt field, whereas those of the Nam Cho rocks are plotted in the basanite + tephrite field (Figure 5.4). Discrimination of rock series can also be done using TAS. In this case volcanic rocks may be subdivided into two major magma series - the alkaline and the subalkaline (originally termed tholeiite) series (Irvine and Baragar, 1971). It is clear that both basalt series are plotted on the alkalline side (Figure 5.5) close to the subalkaline - alkaline boundary. The same TAS plotting (after Middlemost, 1985) show that Nam Cho basalts are mainly named as basanite, and Sop Prap - Ko Kha basalts are commonly classed as alkaline olivine basalt (Figure 5.6).

Total alkali ($CaO+K_2O+Na_2O$) versus SiO_2 (Figure 5.7, Peacock, 1931) indicate the alkalic series for the Nam Cho and the Sop Prap - Ko Kha basalts. However, in term of a K_2O versus SiO_2 variation diagram (Figure 5.1), both basalts span the range from subordinate subalkalic to predominant alkalic.

A plot of the Alkali Index [A.I. = ($Na_2O + K_2O$) / 0.17 (SiO_2 - 43)] versus % Al_2O_3 clearly establishes the field of the high Al basalt (Figure 5.8). In addition, the marked scatter in variation diagram, such as the K_2O - SiO_2 plot, is interpreted to represent a natural consequence of polybaric crystal fractionation combined with source heterogeneity, variable degree of partial melting and crustal contamination (see also Cox, 1980). Quite more distinctive are the TiO_2 - SiO_2 and P_2O_5 - SiO_2 (or TiO_2-MgO and P_2O_5-MgO) plots which clearly differentiate between high TiO_2-P_2O_5 type for the Nam Cho basalt and low TiO_2-P_2O5 type for the Sop Prap - Ko Kha basalt. The wide range of TiO_2 (1.9 - 2.6 %) and P_2O_5 (0.6 -

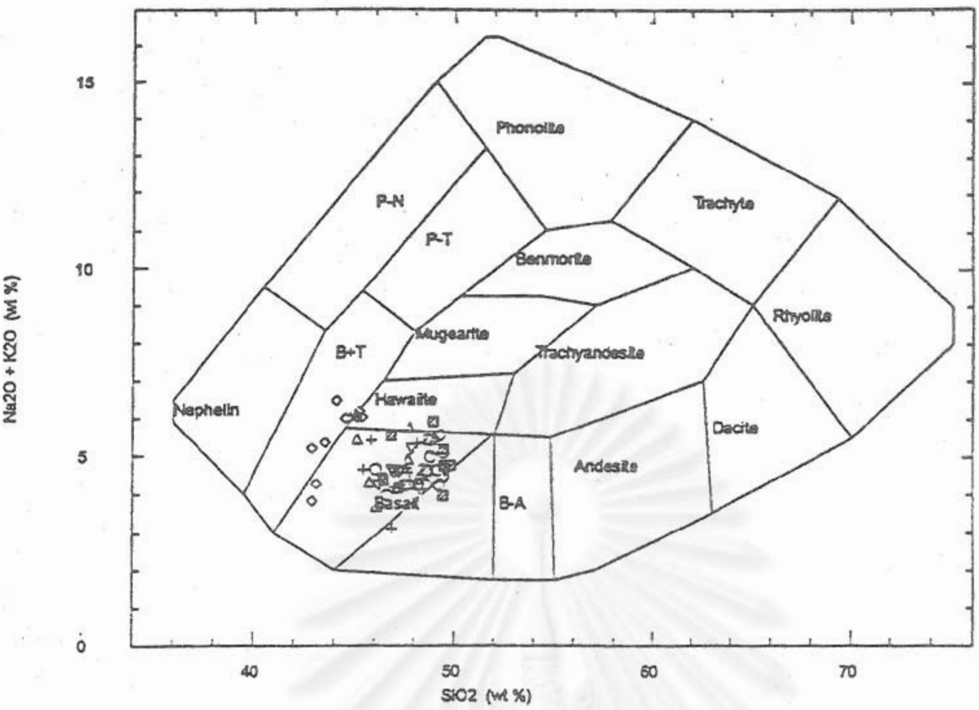


Figure 5.4 Plot of $Na_2O + K_2O$ against SiO_2 (fields from Cox et al., 1979). Symbols same as Figure 5.1.

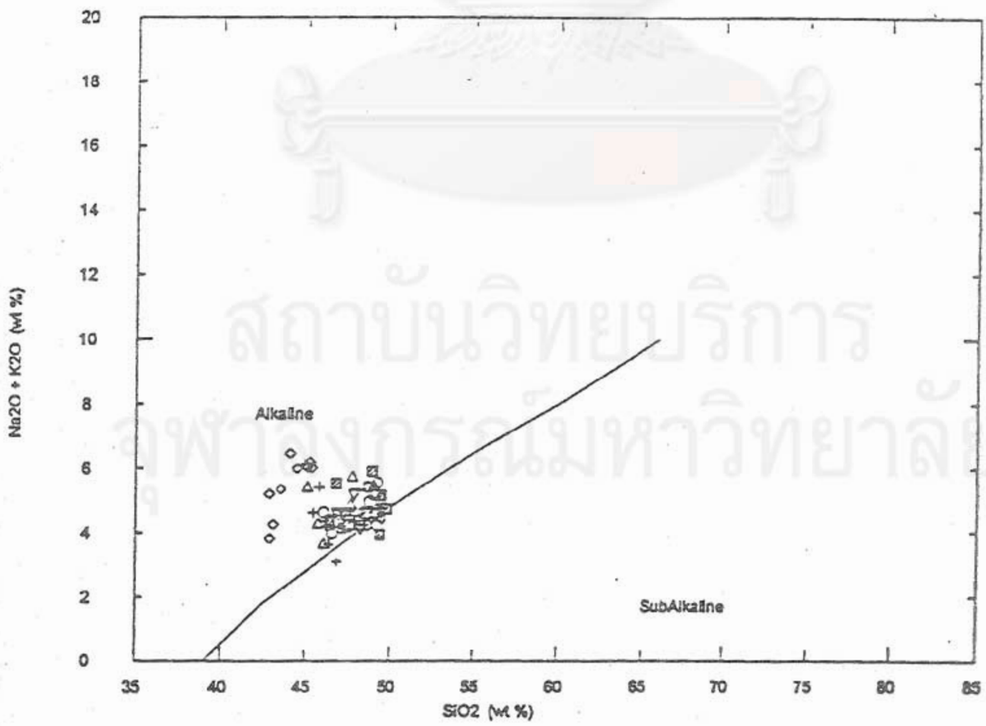


Figure 5.5 Total alkaline - SiO_2 plot (TAS) with line separating fields of alkaline and subalkaline magma series (Irvine and Baragar, 1971). Symbols same as Figure 5.1.

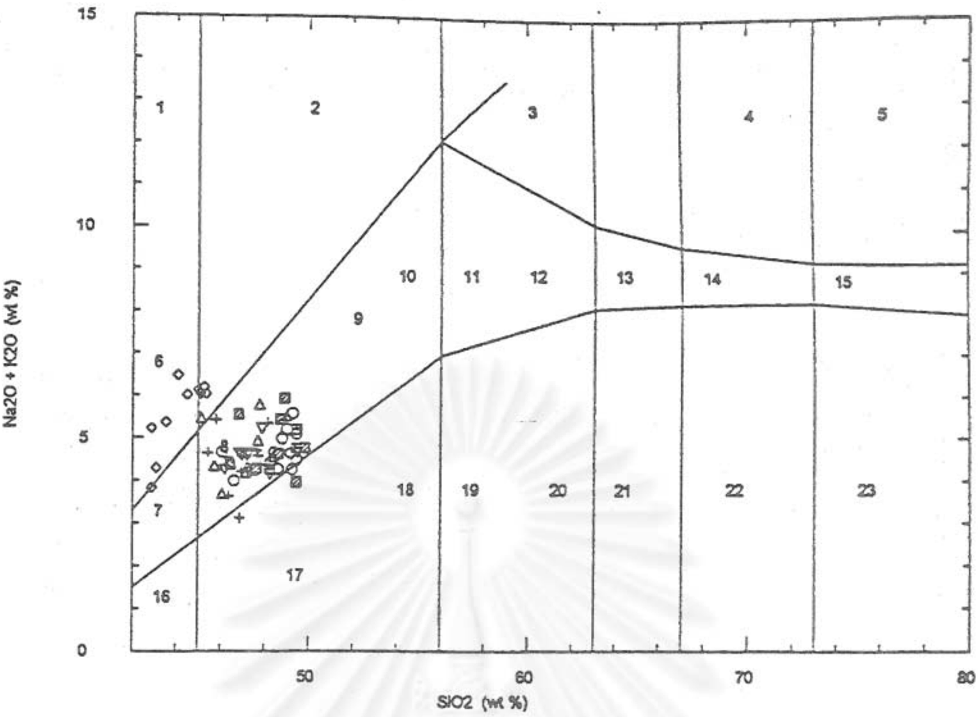


Figure 5.6 Chemical classification nomenclature using the total alkaline versus silica diagram (after Middlemost, 1985) shows basanite name of the Nam Cho basalt and alkaline olivine basalt of the Sop Prap-Ko Kha basalt. Symbols same as Figure 5.1.

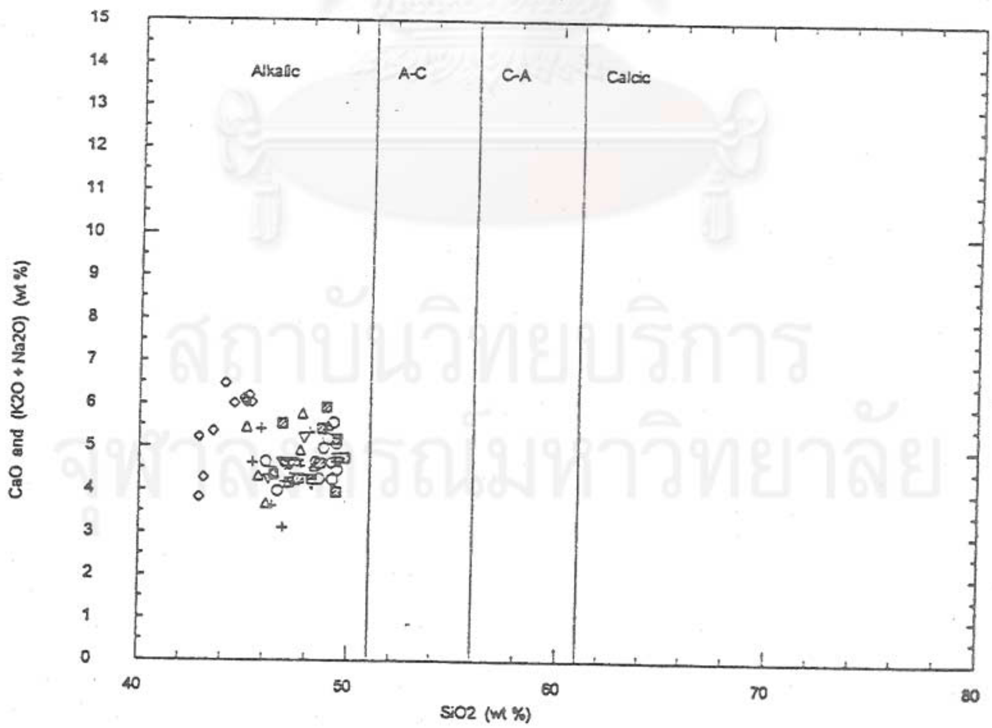


Figure 5.7 Plot of CaO and $K_2O + Na_2O$ versus SiO_2 (after Peacock, 1931) displays alkaline range of most sample plottings from the Nam Cho and the Sop Prap-Ko Kha basalts. Symbols same as Figure 5.1.

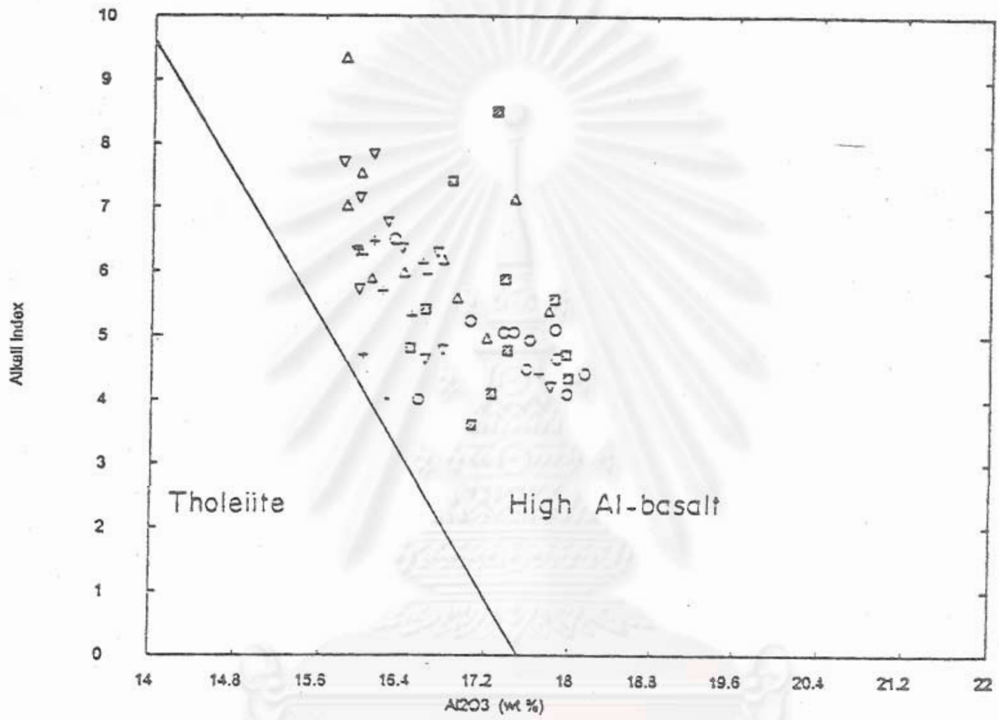


Figure 5.8 Plot of Alkali Index (A. I.) versus wt.% Al_2O_3 of the Nam Cho and the Sop Prap-Ko Kha basalts (fields from Middlemost, 1975). Symbols same as Figure 5.1.

0.95%) contents at constant SiO_2 and MgO must, therefore, reflect the partial melting of heterogeneous mantle source combined with some effect of crustal contamination. Similar situation was made earlier for Parana basalts in Brazil (see also Mantovani et al., 1985, Petrini, 1987). Therefore, this is an ample evidence to conclude at present that those two basaltic rock suites may have been evolved from similar petrogenetic fashion but from different mantle source.

5.3 Trace Element Data

Table 5.3 illustrates the trace-element values for the Nam Cho and the Sop Prap - Ko Kha basalts. Again these values are compared with those of Deccan, Kenya, Phu Fai, and Khao Kradong basalts and their equivalents. The detailed description of individual trace elements are given below.

Ba : Ba values of Sop Prap - Ko Kha and Nam Cho basalts range from 687 to 1,057 ppm and average about 813.56 ppm. These values are higher than those of Deccan and Kenya basalts and those of the Phu Fai and the Khao Kradong basalts.

Ce : Ranges of Ce contents are frequently from 29 to 46 ppm and average about 36.42 ppm, for those of both basaltic terranes. These values are higher than those of Kenya basalts, and higher than those of Phu Fai and Khao Kradong basalts of Thailand.

Co : Nam Cho and Sop Prap - Ko Kha basalts contain Co content ranging from 50 to 71 ppm. When compared with Phu Fai basalts, the Nam Cho and the Sop Prap - Ko Kha basalts show higher Co values than the Phu Fai rocks.

Cr : Cr values of Sop Prap - Ko Kha and Nam Cho basalts range from 108 to

Table 5.3 Trace element analyses (in ppm) of 65 basalt samples for the Nam Cho and the Sop Prap-Ko Kha basalts.

SAMPLE	Ba	Ce	Co	Cr	Nb	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
S-2	682	37	51	153	47	161	26	66	984	324	24	50	218
S-4	826	28	50	103	56	106	23	99	1902	347	22	51	260
S-8	878	47	42	91	61	107	35	82	1024	354	13	74	254
S-11	832	43	41	91	57	107	30	93	1303	370	10	68	266
S-13	838	46	65	89	58	99	29	90	986	345	24	43	219
S1-1	766	32	48	140	43	122	28	95	1327	350	82	43	187
S1-7	778	36	47	150	30	131	38	38	1243	351	31	80	198
S1-10	676	28	56	132	33	122	36	28	1862	343	17	69	197
S1-13-2	766	36	53	118	37	148	44	35	943	363	25	66	218
S1-14	903	44	48	149	41	140	23	40	1122	365	22	74	239
S7-2	804	27	46	86	50	95	40	73	1407	359	12	60	253
S7-3-1	681	25	39	156	38	113	10	95	2726	351	76	65	196
S7-5	617	22	44	130	39	114	11	114	1107	326	114	42	116
S8-2	698	30	48	151	42	117	46	37	910	371	28	76	202
S8-5	823	39	46	141	35	163	52	50	1113	369	21	71	243
S 18-2-1	966	48	50	84	61	75	5	79	1248	342	33	10	270
S 18-3	977	36	56	98	58	86	5	56	1072	337	41	67	249
S 18-5-2	905	36	54	83	52	90	5	79	1101	328	31	29	254
S 18-7	778	20	57	94	36	123	5	89	1639	338	37	17	221
S 18-11	731	20	59	104	40	97	5	72	848	335	21	63	218
S 19-1	782	28	60	78	58	95	5	76	1396	391	44	67	258
S 19-3	843	31	64	69	58	78	5	109	2171	390	26	52	275
S 19-5	695	24	47	100	44	87	48	373	2305	372	416	75	220
S 19-7	667	22	58	101	39	102	5	336	1352	382	513	28	178
S 19-9	666	41	52	115	33	100	5	52	852	371	32	61	187

Table 5.3 (cont.)

SAMPLE	Ba	Ce	Co	Cr	Nb	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
S 21-1	894	63	52	92	58	97	5	74	1193	358	21	57	245
S 21-4-2	773	34	59	132	49	90	5	45	1858	359	35	63	225
S 21-6	699	45	57	77	39	105	5	33	910	342	31	63	185
S 21-8	669	20	56	116	40	119	5	41	888	349	37	71	183
S 21-10	743	20	55	114	42	113	5	33	910	321	35	49	187
S 24-1	820	54	60	78	55	78	5	95	2602	361	30	65	281
S 24-2	835	49	59	92	55	76	5	81	1232	371	34	41	267
S 24-4	736	40	193	130	43	103	5	54	1057	354	38	38	242
S 24-6	641	34	56	97	36	107	5	35	957	338	43	63	203
S 24-7	636	24	57	121	36	122	5	23	781	346	51	51	215
S 29-1	870	46	51	108	61	99	5	66	1032	402	30	60	256
S 29-3	770	58	60	152	44	105	5	147	978	379	23	60	216
S 29-5	782	51	57	76	47	75	5	58	2672	402	41	57	243
S 29-10	735	38	52	103	39	114	5	31	780	377	33	74	206
S 29-11	795	45	57	117	40	107	5	41	902	343	28	71	192
S2-2	816	44	46	177	44	179	41	47	1082	356	20	67	230
S13-1	809	20	50	118	52	144	14	36	3871	355	24	73	234
S6-2	687	27	62	137	41	106	37	44	857	366	15	74	194
S14-7	640	20	46	120	38	101	25	67	755	352	22	77	192
S12-6	722	25	59	136	40	120	34	50	830	374	14	79	198
S20-2	875	38	39	99	62	86	31	81	1326	350	25	64	254
S14-1	836	47	54	96	54	78	7	59	4649	338	20	69	272
S22-4-1	630	19	47	138	40	85	27	43	760	327	20	79	196
S25-4	537	20	42	134	38	101	36	45	674	340	23	10	187
S23-4-1	728	20	61	131	43	122	39	39	780	360	24	81	183

Table 5.3 (cont.)

SAMPLE	Ba	Ce	Co	Cr	Nb	Ni	Pb	Rb	Sr	V	Y	Zn	Zr
S28-1	1003	36	52	99	60	72	40	106	1197	366	12	65	269
S25-2	773	31	52	111	47	65	39	52	1041	357	21	68	233
S28-3	685	21	54	113	43	83	39	42	880	341	15	73	185
S28-4	598	20	39	122	44	87	5	87	709	347	16	30	178
S27-11	752	20	57	155	40	88	49	49	825	374	19	79	199
N-1	1106	61	71	80	36	90	5	157	922	432	96	10	196
N-2	1132	43	72	94	39	65	5	190	1052	415	272	80	258
N-3	1111	39	56	100	36	45	34	86	962	444	25	90	243
N-4	1057	25	54	139	36	74	50	64	853	429	14	84	215
N-5	969	27	57	132	44	97	36	77	946	346	27	85	256
N-7	1099	56	165	84	36	88	5	112	1052	387	126	24	270
N-8	1087	63	66	148	42	110	5	198	951	368	325	49	264
N-9	1006	40	60	130	37	103	33	80	911	372	18	80	243
N-11	984	54	59	190	40	103	32	88	912	353	10	84	251
N-12	1020	49	53	151	41	111	5	186	970	363	308	58	219

125 ppm, averaging 116.24 ppm. These values are higher than those of Deccan and Phu Fai basalts, but lower than that of Khao Kradong basalts.

Nb : Nam Cho and Sop Prap - Ko Kha basalts contain Nb contents ranging from 38 to 54 ppm with an average of 44.57 ppm. These contents are relatively higher than those of Deccan and Kenya basalts, but lower than that of the Phu Fai rocks.

Ni : Ni contents of Nam Cho and Sop Prap - Ko Kha basalts are ranging from 88 to 115 ppm, averaging 102.72 ppm. In addition, when compared with reference basalts, these two basalts show higher Ni contents than the Deccan and Phu Fai basalts, but lower than those of Khao Kradong basalts.

Pb : Pb values of Sop Prap - Ko Kha and Nam Cho basalts range from 21 to 38 ppm and average about 32.52 ppm. When compared with other Thai basalts, these values are higher than those of Phu Fai and Khao Kradong basalts.

Rb : Rb contents of the Sop Prap - Ko Kha basalt are lower than those the of Nam Cho basalt. These contents range from 49 to 123 ppm and averaging 82.15 ppm. The values higher than those of Daccan, Kenya, Khao Kradong, and Phu Fai basalts.

Sr : Sop Prap - Ko Kha and Nam Cho basalts are compared of Sr contents ranging from 904 to 2,067 ppm and averaging 1,263.87 ppm. These contents are higher than those of Deccan, Kenya, Phu Fai and Khao Kradong basalts.

V : Nam Cho and Sop Prap - Ko Kha basalts contain V values ranging from 350 to 427 ppm, with averaging 367.77 ppm. These values are higher than those of Phu Fai and Khao Kradong basalts.

Y : Nam Cho and Sop Prap - Ko Kha basalts contain Y contents ranging from 21 to 122 ppm (averaging 57.62 ppm). The values are higher than those of Deccan and Kenya basalts. In addition, when compared with other Thai basalts, the Sop Prap - Ko Kha and the Nam Cho basalts show higher Y values than the Phu Fai rocks and lower than the Khao Kradong basalt.

Zn : Zn values of Nam Cho and Sop Prap - Ko Kha basalts range from 52 to 70 ppm and average about 62.07 ppm. These values are lower than those of Deccan, Phu Fai, and Khao Kradong basalts.

Zr : Range of Zr for the Sop Prap - Ko Kha is from 203 to 247 ppm. These values are lower than those of the Nam Cho. When compared with values of Deccan and Kenya basalts, the Sop Prap - Ko Kha and the Nam Cho basalts contain higher than the reference basalts. In addition the Sop Prap - Ko Kha and the Nam Cho basalts have Zr values higher than those of Phu Fai and Khao Kradong basalts.

Figure 5.9 depicts the variation of Nb versus Zr (in ppm) for the Sop Prap - Ko Kha and the Nam Cho basalts. Both suites display a remarkably constant Zr/Nb ratio of 5.03, suggesting that both eruptives may represent the products of fractional crystallization. Figure 5.10 shows the variation of Y/Nb versus Zr/Nb for these two basaltic suites. The Sop Prap - Ko Kha basaltic suite plot on an apparent mixing trend between an enriched component and a depleted MORB- (mid-oceanic ridge basalt) source component, but close to enriched side. This provides a strong evidence for the rock of asthenosphere or MORB - source mantle in

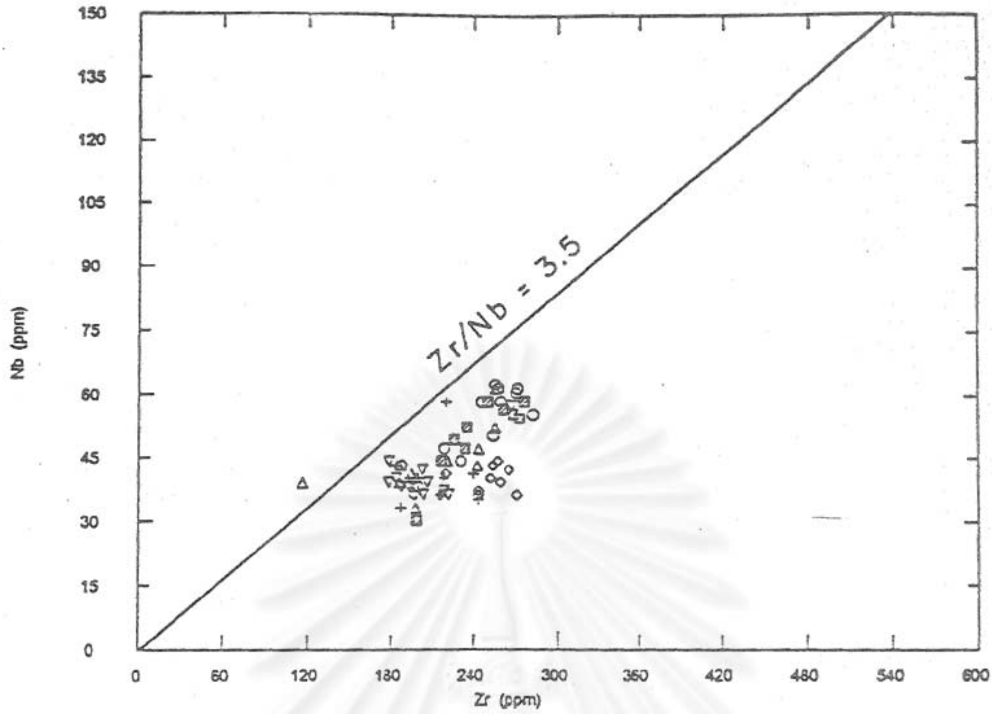


Figure 5.9 Variation of Nb versus Zr (ppm) for basalts from the study area. Symbols same as Figure 5.1.

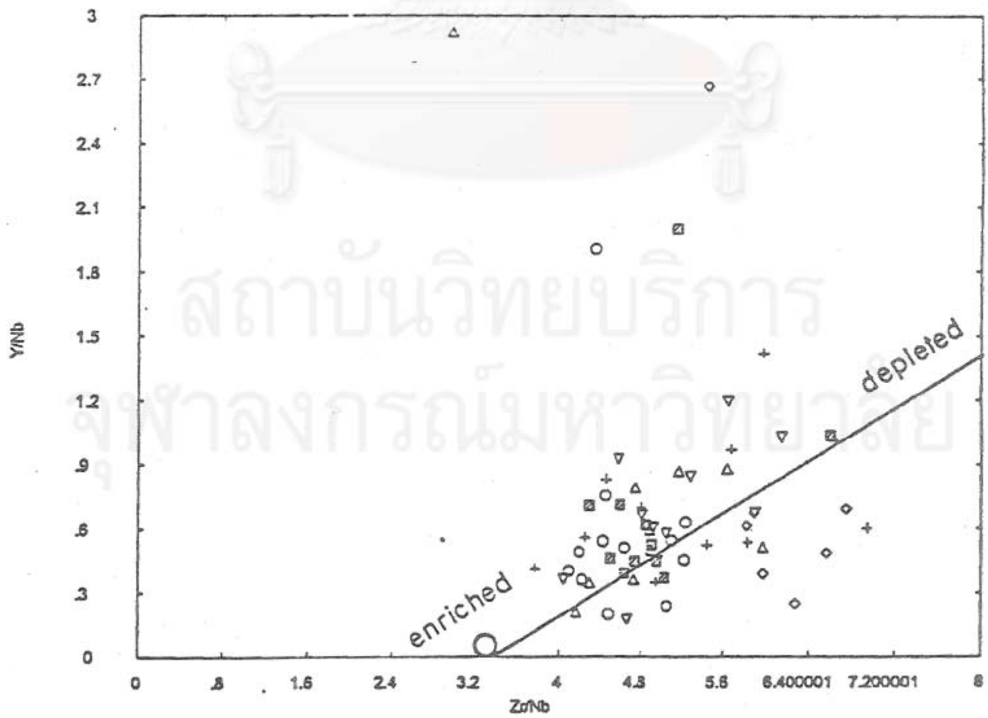


Figure 5.10 Variation of Y/Nb versus Zr/Nb for basalts from the study area and mixing trend line between an enriched MORB source component and a depleted MORB source component (Wilson, 1989). Symbols same as Figure 5.1.

Table 5.4 Major and trace element data for Deccan and Kenya continental basalts, compared to typical Phu Fai and Khao Kradong basalts in Thailand.

Elements	Deccan	Kenya	Phu Fai	Khao Kradong
SiO2	50.56	47.20	49.68	47.89
Al2O3	13.83	15.83	15.70	14.29
Fe2O3	13.79	1.60	2.16	4.52
FeO	-	9.61	7.34	6.35
CaO	9.62	12.27	7.29	8.04
MgO	5.12	7.34	5.51	7.20
Na2O	2.65	2.62	4.17	2.44
K2O	0.93	0.48	2.56	1.98
TiO2	2.57	1.95	2.14	2.89
MnO	0.17	0.20	0.12	0.14
P2O5	0.22	0.24	0.79	0.79
H2O	-	0.12	0.29	1.87
Ba	239.00	254.00	637.00	667.00
Ce	-	36.3.00	26.00	31.00
Co	-	-	34.00	-
Cr	44.00	-	< 20.00	155.00
Lu	202.00	-	34.00	59.00
Nb	15.9.00	23.00	-	56.00
Ni	44.00	-	27.00	175.00
Pb	-	-	8.00	< 5.00
Rb	15.00	9.00	22.00	45.00
Sr	219.00	382.00	1238.00	1029.00
V	-	-	154.00	341.00
Y	50.00	19.00	39.00	74.00
Zn	149.00	-	101.00	129.00
Zr	203.00	71.00	203.00	192.00

Data sources : Deccan from Wilson, 1989 (page 300); Kenya from Wilson, 1989 (page 348); Phu Fai from Sutthirat, 1992; and Khao Kradong from Platong, 1994.

the petrogenesis of these two suites in an actively extending rift segments. It is likely that the very high ratio of some of the Nam Cho basaltic suite may represent an original source characteristic, not produced predominantly by crustal contamination (see Dungan et al., 1986, Wilson, 1989). However, detailed Sr-Nd-Pb isotopic data are clearly required to confirm the involvement of contamination by crustal materials in the petrogenesis.

5.4 Rare Earth Element Data

The analyses of rare earth elements for selected 30 samples from Nam Cho and Sop Prap - Ko Kha basalts are presented in Table 5.5. These analyses comprise La, Ce, Nd, Sm, Eu, Tb, Dy, and Lu. The rare-earth elements (REE) are regarded as amongst the least soluble trace elements and are relatively immobile during low-grade metamorphism, weathering, and hydrothermal alteration (Rollinson, 1993). Because major elements of Thai Cenozoic basalts are usually mobilized by weathering process, then this investigation may become as a guide line for future studies. The REE analyses of each basaltic flow in both terranes are normalized to the primitive mantle source (chondrite) based on the work of Sun (1982). These chondrite normalized REE patterns are presented in Figures 5.11 to 5.16. Almost REE patterns of both basaltic flow layers of both terranes roughly show the similar trend (Figures 5.11 to 5.16). They frequently show steep slope that may indicate low degree of partial melting of the source rock. Heavy-REE abundances are only 5 times condritic for these two basaltic suites, suggesting the presence of residual garnet in the sources. These chondrite-normalized REE patterns of most basalts always display light-REE enrichment with very slightly depressed Eu anomalies, possibly indicating that plagioclase fractionation (negative anamally) is not as common as fractonation of olivine, pyroxene and possibly garnet (positive anomaly) (see also Wilson, 1989, and Rollinson, 1993).

Table 5.5 Rare earth element analyses (in ppm) of 30 selected basalt samples.

Sample	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu
S-2	33.67	66.38	19.28	5.98	1.66	0.51	3.78	1.93	0.22
S-4	38.56	64.80	28.91	6.11	2.41	0.55	4.13	2.90	0.28
S-8	42.86	79.82	41.70	6.80	1.53	0.63	4.17	2.12	0.25
S-11	37.29	72.65	32.02	5.86	1.61	0.48	3.91	2.38	0.25
S-13	43.13	80.12	34.63	6.52	2.58	0.66	4.05	2.02	0.28
S1-1	31.80	64.68	24.79	6.09	1.65	0.82	3.22	2.14	0.33
S1-7	30.72	60.30	31.40	6.34	1.79	0.48	3.75	2.24	0.25
S21-4-2	33.84	70.86	28.56	6.40	1.52	0.83	4.98	2.51	0.34
S21-6	26.87	57.17	23.23	5.33	1.14	0.54	4.36	2.14	0.24
S21-8	29.35	60.68	18.86	5.38	1.12	0.62	4.49	2.70	0.25
S21-10	27.82	57.80	26.21	5.05	1.69	0.71	3.55	2.59	0.29
S1-10	31.22	53.34	30.43	5.97	2.26	0.43	4.63	2.31	0.18
S24-1	41.11	83.56	33.70	6.52	1.50	0.63	4.07	2.19	0.27
S24-2	37.15	64.00	39.19	5.99	1.53	0.67	4.52	2.16	0.25
S24-4	34.78	74.52	28.94	6.24	1.55	0.56	4.25	2.12	0.34
S24-6	27.31	54.77	21.80	5.21	1.14	0.56	4.68	2.26	0.20
S24-7	29.88	56.93	30.19	5.77	1.74	0.63	4.59	2.67	0.34
S29-3	33.75	66.57	22.38	6.21	1.20	0.42	4.37	2.11	0.24
S29-10	30.45	60.60	26.61	5.72	1.40	0.49	3.81	2.57	0.27
S29-11	28.42	44.03	25.32	5.71	1.29	0.58	4.01	2.45	0.21
S14-7	31.28	59.48	28.54	5.75	1.20	0.62	3.80	2.71	0.26
S12-6	29.20	56.80	28.16	5.89	1.84	0.63	4.40	1.86	0.25
S20-2	38.64	71.20	30.60	5.80	1.47	0.60	4.56	2.13	0.27
S28-1	39.35	60.08	28.58	6.04	1.66	0.42	4.36	2.89	0.27
S28-3	29.24	54.50	17.88	5.59	1.79	0.43	3.94	2.54	0.27
N-1	43.09	83.53	58.24	6.72	1.67	0.68	4.46	2.66	0.25
N-5	53.45	108.98	41.37	8.05	1.50	0.80	5.14	2.89	0.28
N-7	53.72	106.90	44.46	8.20	2.05	0.67	4.27	2.96	0.20
N-9	47.61	77.42	42.63	7.94	1.61	0.55	3.98	2.60	0.31
N-12	49.63	82.37	34.05	7.55	1.81	0.82	4.36	2.17	0.21

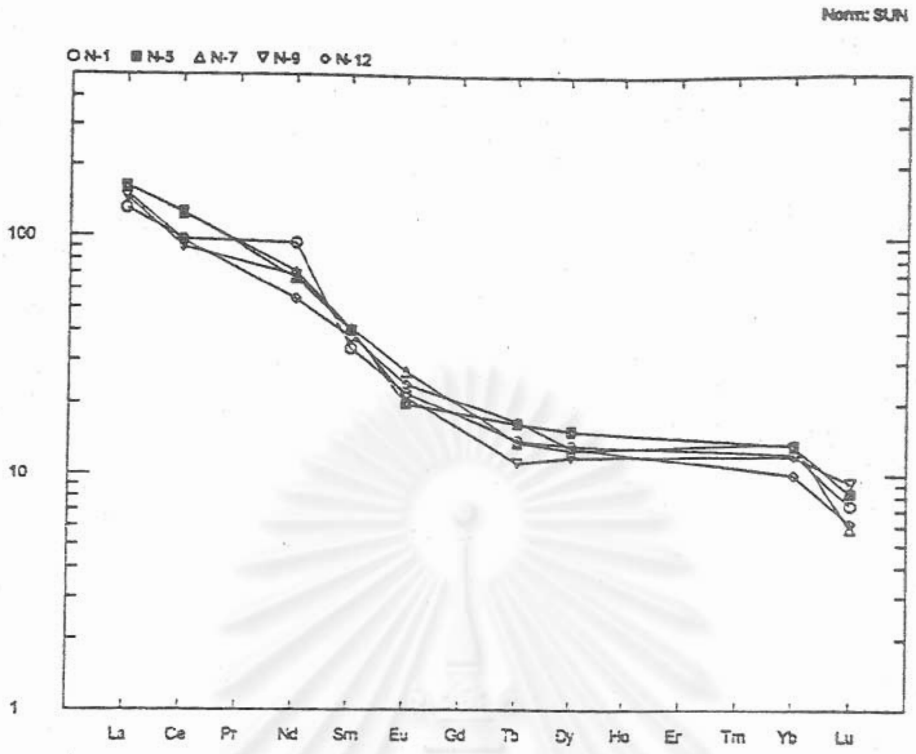


Figure 5.11 Chondrite normalized REE patterns of samples from the Nam Cho basalt.

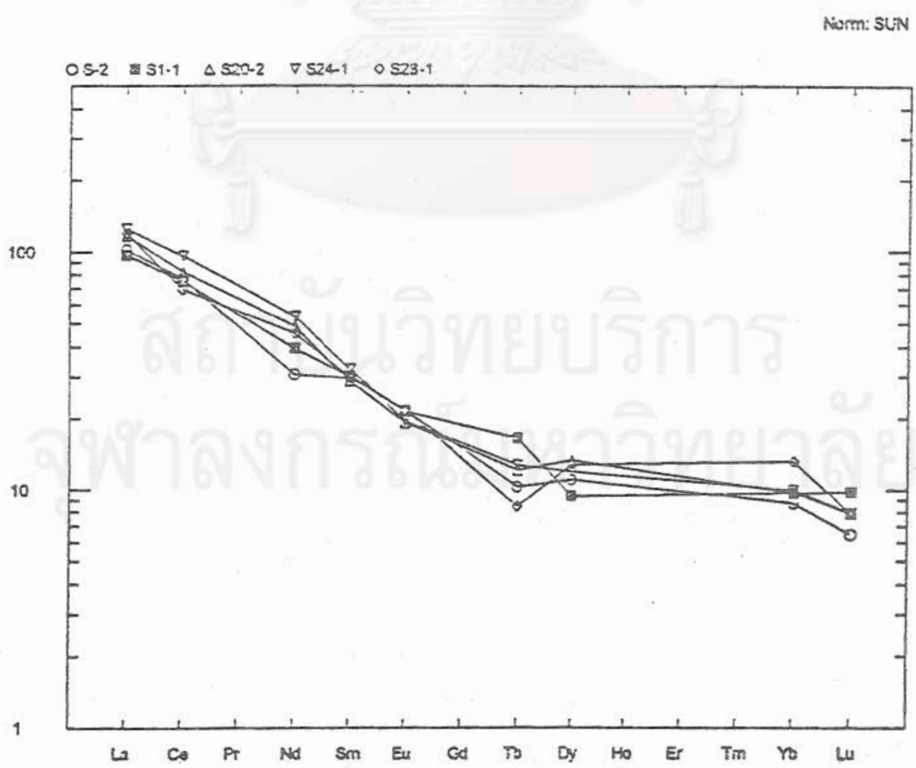


Figure 5.12 Chondrite normalized REE patterns of the fifth basaltic flow from the Sop Prap-Ko Kha area.

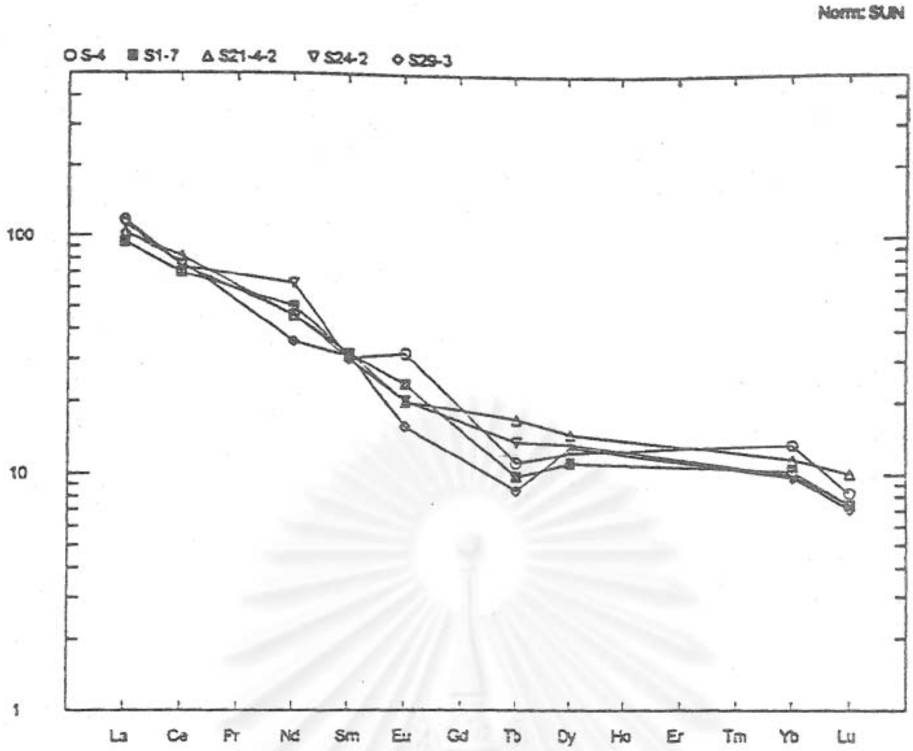


Figure 5.13 Chondrite normalized REE patterns of the fourth basaltic flow from the Sop Prap-Ko Kha area.

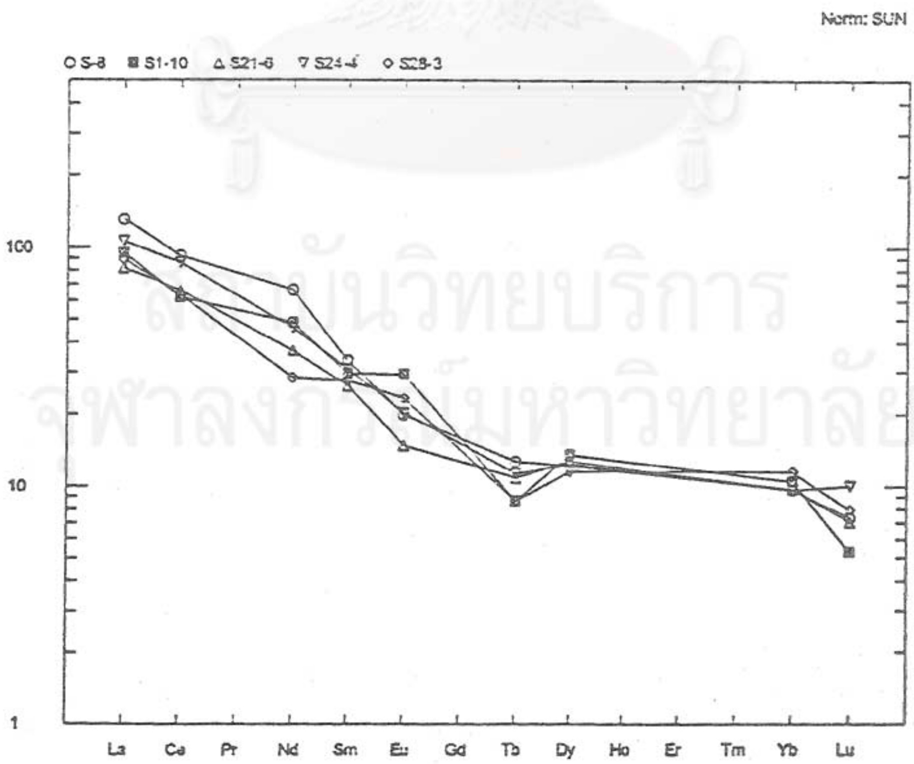


Figure 5.14 Chondrite normalized REE patterns of the third basaltic flow from the Sop Prap-KoKha area.

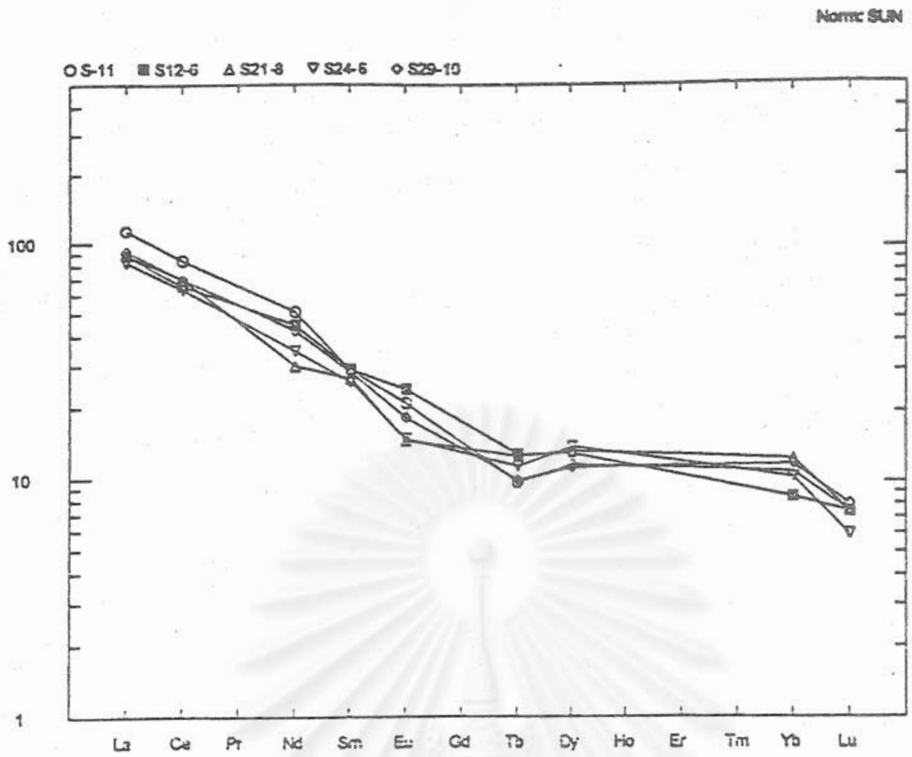


Figure 5.15 Chondrite normalized REE patterns of the second basaltic flow from the Sop Prap-Ko Kha area.

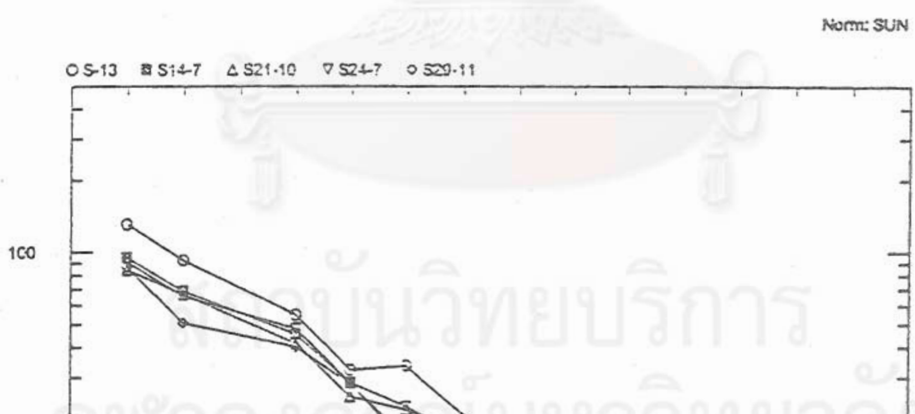


Figure 5.16 Chondrite normalized REE patterns of the first basaltic flow from the Sop Prap - Ko Kha area.

The package analyses (including rare earth elements) of 6 duplicate basalt samples, analysed by Chemex Labs Ltd. Canada, are illustrated in Table 5.6. These duplicate samples were representatively collected from the most flows of both basaltic areas. Their chondrite normalized REE patterns of some REE analyses are revealed in Figure 5.6. The general overviews of Chemex's chondrite normalized REE patterns also show decreasing from light REE to heavy REE. Although these analyses are relatively composed of always lower Nb, sometimes lower Gy, and frequently higher Tb or rarely lower Tb, than the previous analytical data. These different details lead to swing decrement of chondrite normalized REE patterns (light to heavy REE). Then the depressed Eu anormalies are not clearly expored in these pattern.

Table 5.6 Rare earth element analyses (in ppm) of 6 duplicate basalt samples, analysed by Chemex Lab Ltd. (Canada).

SAMPLE	Ce	Dy	Er	Eu	Gd	Ho	La	Lu
N-12	88	2	<20	1.5	<50	3	46	0.2
S-2	58	2	<20	1.5	<50	12	29	0.2
S-4	60	2	<20	2	<50	8	35	0.2
S-8	72	2	20	2.5	<50	12	38	0.2
S-11	56	2	<20	2	<50	4	37	0.2
S-13	66	2	<20	2	<50	6	36	0.3
	Nd	Pr	Sm	Tb	Th	Tm	U	Yb
N-12	5	10	6.2	2.5	7	3	1	2.1
S-2	5	10	5	0.5	5	<1	1	1.5
S-4	20	10	5.2	1.6	5	1	1	1.8
S-8	<5	10	5.6	1.1	6	3	<1	1.6
S-11	10	10	5.4	0.1	7	1	<1	1.5
S-13	10	110	5.3	2	5	3	<1	1.7

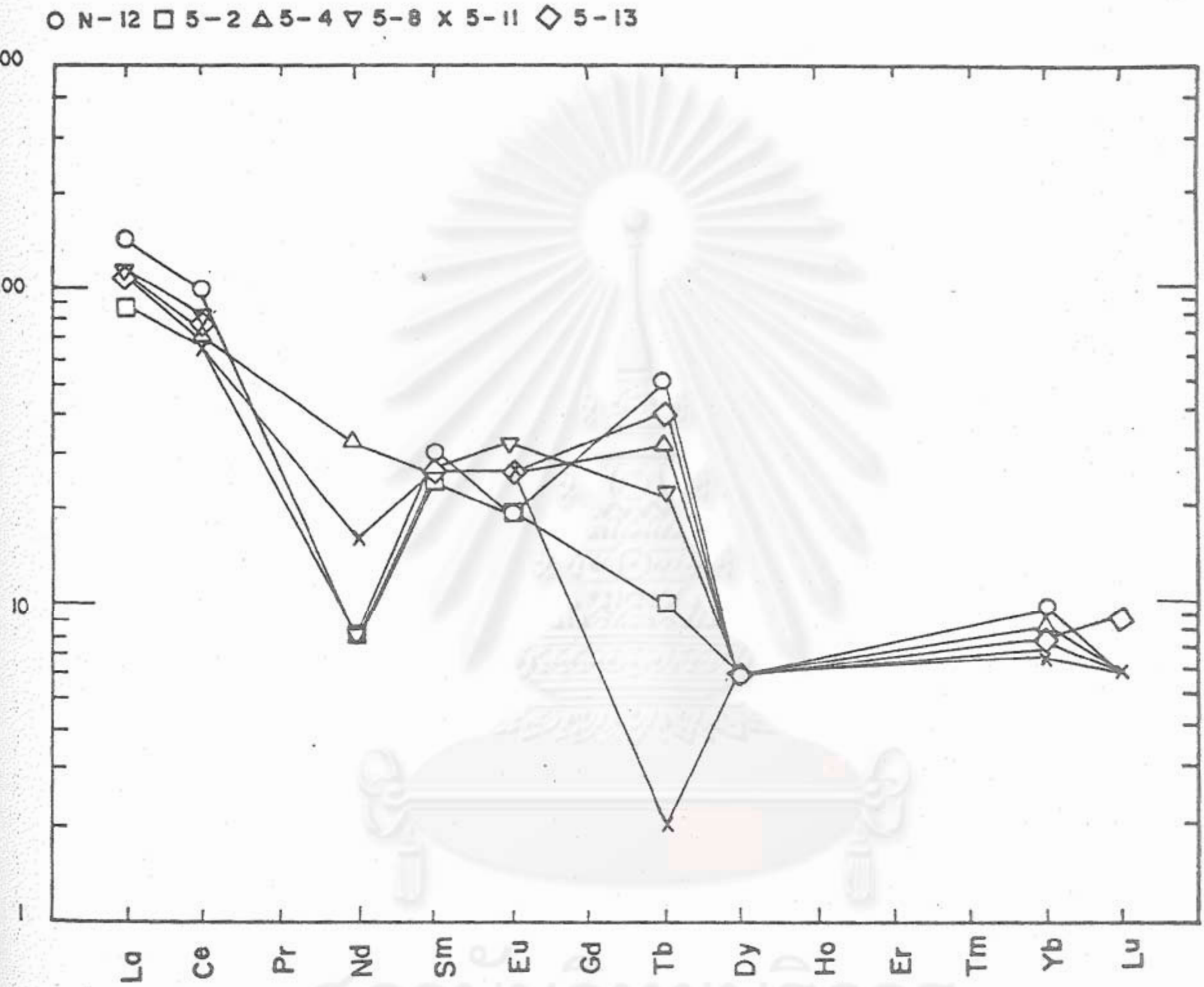


Figure 5.17 Chondrite normalized REE patterns of the duplicate basalt samples, those were analysed by Chemex Labs Ltd.

CHAPTER VI

GEOCHRONOLOGICAL DATA

6.1 Analytical Methods of Geochronology

Five samples of basalt samples (including 1 sample from Nam Cho area and 4 samples from Sop Prap - Ko Kha area) used for $^{40}Ar/^{39}Ar$ incremental step-wise heating analysis, were irrediated in the McMaster University (Hamilton, Qnt., Canada) reactor, which has been found suitable for this purpose by other workers (see Berger and York, 1979, Archibald et al., 1983). Samples were then loaded into an aluminum sample holder, designed to fit into the irrediation capsules used at the McMaster University. Samples were arranged in the canister coaxially, one wafer-like packet on top of another. The flux monitors were uniformly distributed in the can since the neutron flux was able to vary considerably over short distances in a nuclear reactor. The samples were irradiated for one hour and the canister receives high neutron flux. The sample package was allowed to cool to allow the decay of short-lived radioactive nucleides. After cooling, the samples were unloaded in a lead-lined box while wearing a high-efficiency particle respirator.

After irradiation, the samples were removed from the aluminum sample holder, and were analyzed at the Queen's University Geochronlab (Kingston, Ont., Canada). Laboratory procedures used in this study followed those outlined by Gerasimoff (1989) and Charusiri (1989). The samples were loaded into niobium-molybdenum crucibles and, following an 18 h bake-out, were incrementally heated in 1 h steps, with the temperature monitoring using an optical pyrometer. Argon gas was extracted and purified by conventional procedures. Corrections for Ca- and K- derived intefering isotopes were made, using correction factors determined by Bottomley and York (1976). The ages and uncertainties were calculated using equations given by Dalrymple et al. (1981).

The J values for flux monitors and the $^{40}Ar/^{39}Ar$ ages for the samples were calculated using expression given by Dalrymple and Lamphere (1971) and Dalrymple et al. (1981). The interpolated J values for the irradiated basalt samples ranged from 2.75×10^{-3} to 3.2×10^{-3} with an uncertainty of less than 0.5 %. The large difference among J values for a given irradiation indicated that the flux gradients were much greater than those reported by other workers using the McMaster reactor (see also Archibald et al., 1983) The quoted errors represent the analytical uncertainty at 2 σ level. These errors are valid for a comparison of the age of different steps for the same sample. The criteria used for determining plateau age were those of Fleck et al. (1977). The total gas age (t_g, or integrated age) represents a weighted average age based on the total amount of ^{39}Ar in each increment. The plateau age (t_p) is the mean of the apparent ages considered to be concordant, represented by a flat pattern on a plot of the $^{40}Ar/^{39}Ar$ dates for each step against the cumulative proportion of the released argon.

6.2 Geochronological Results

The 5 basaltic rock samples for $^{40}Ar/^{39}Ar$ geochronological analysis were selected from about 60 basalt samples investigated and collected by Sutthirat in 1995. The 5 basalt samples are composed of 1 sample (N-2) from Nam Cho basalt, and 4samples from Sop Prap-Ko Kha basalt, i.e., S-21-10 of the first flow, S-21-8 of the second flow, S-21-6 of the third flow, and S-29-3 of the fourth flow. The details of individual samples are present below.

N-2 : The whole-rock basalt is from Nam Cho basaltic area. The sample was heated in 4 steps from lower than 600 to 1,150°C (temperature of fusion). The age spectrum (Figure 6.1) reveals a fairly concordant release spectrum. The step 1 to 3, comprising approximately 92.5% of the total gas released, yield a good plateau age (t_p) of about 2.02 ± 0.16 Ma. However, the most 4 heating steps give the older intergrated or the total gas age (t_g) of about 2.07 ± 0.16 Ma, probably due mainly to contamination of atmospheric Ar in the last step.

The isochron plot for this sample (Figure 6.1) yields an intercept age (t_i) of 1.88 ± 1.73 Ma. The trapped $^{40}Ar/^{39}Ar$ component is equal to 320.42 ± 472.95. The corrected age of this sample is about 2.02 ± 0.16 Ma.

S-21-10 : This rock sample represents the first flow (lower) basaltic flow of the Sop Prap-Ko Kha area. It was collected at the road cut quarry between kms 568 to 569 on the highway number 1 (Figure 4.2). It was increasingly heated in 5 steps from 600 to higher than 1,190 °C. The age spectrum of this sample is illustrated in Figure 6.2. Although the first step (about 22.9% ^{39}Ar) shows relatively high apparent age, as a result of atmospheric contamination. The last four steps (about 77.1% ^{39}Ar) yield well-defined plateau age (t_p) of 2.41 ± 0.17 Ma. The total-gas (t_g), or integrated age, is calculated to be 2.72 ± 0.18 Ma.

The isochron plot for this sample (Figure 6.2) presents the younger intercept age (t_i) of 1.39 ± 4.01 Ma, with the trapped $^{40}Ar/^{39}Ar$ component of about 371.47 ± 1737.75. Thus, the geologic age for this sample is defined from the plateau age of ca. 2.41 ± 0.17 Ma.

S-21-8 : This rock specimen was collected from the second flow at the same location as S-21-10 in the Sop Prap-Ko Kha basaltic area. This sample was heated in 5 steps from 600 to 1,195 °C. The age spectrum shown in Figure 6.3 reveals a release spectrum complicated by an undulatory pattern, then the plateau age (t_p) cannot be defined from this

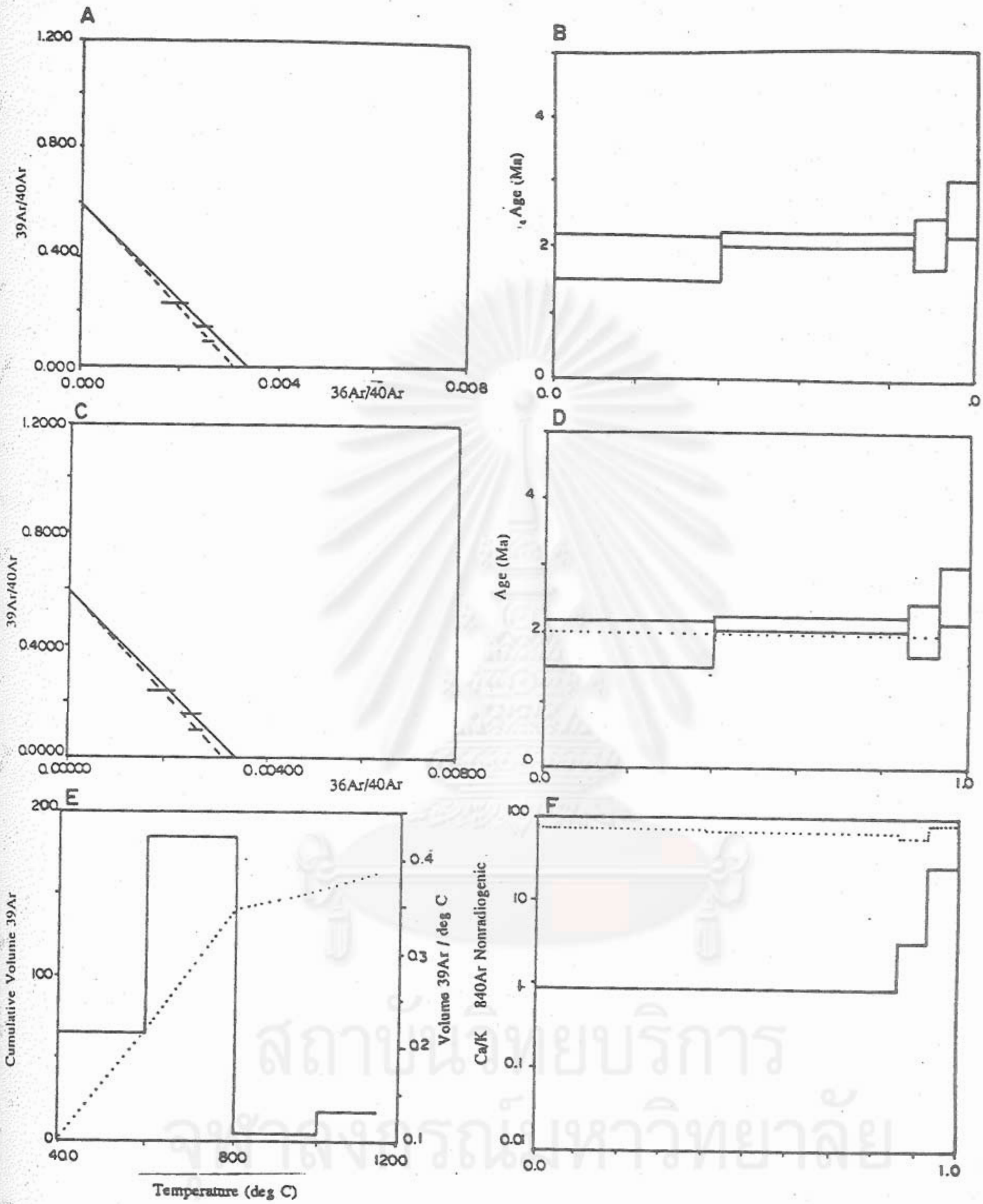


Figure 6.1 Plots of $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (A&C), Age (Ma) versus Fraction ^{39}Ar [B,and D with integrated age (dots)], and cumulative volume ^{39}Ar versus temperature (°c) (E) and Ca/K versus Fraction ^{39}Ar (F), for sample no. N-2, Nam Cho basalt.

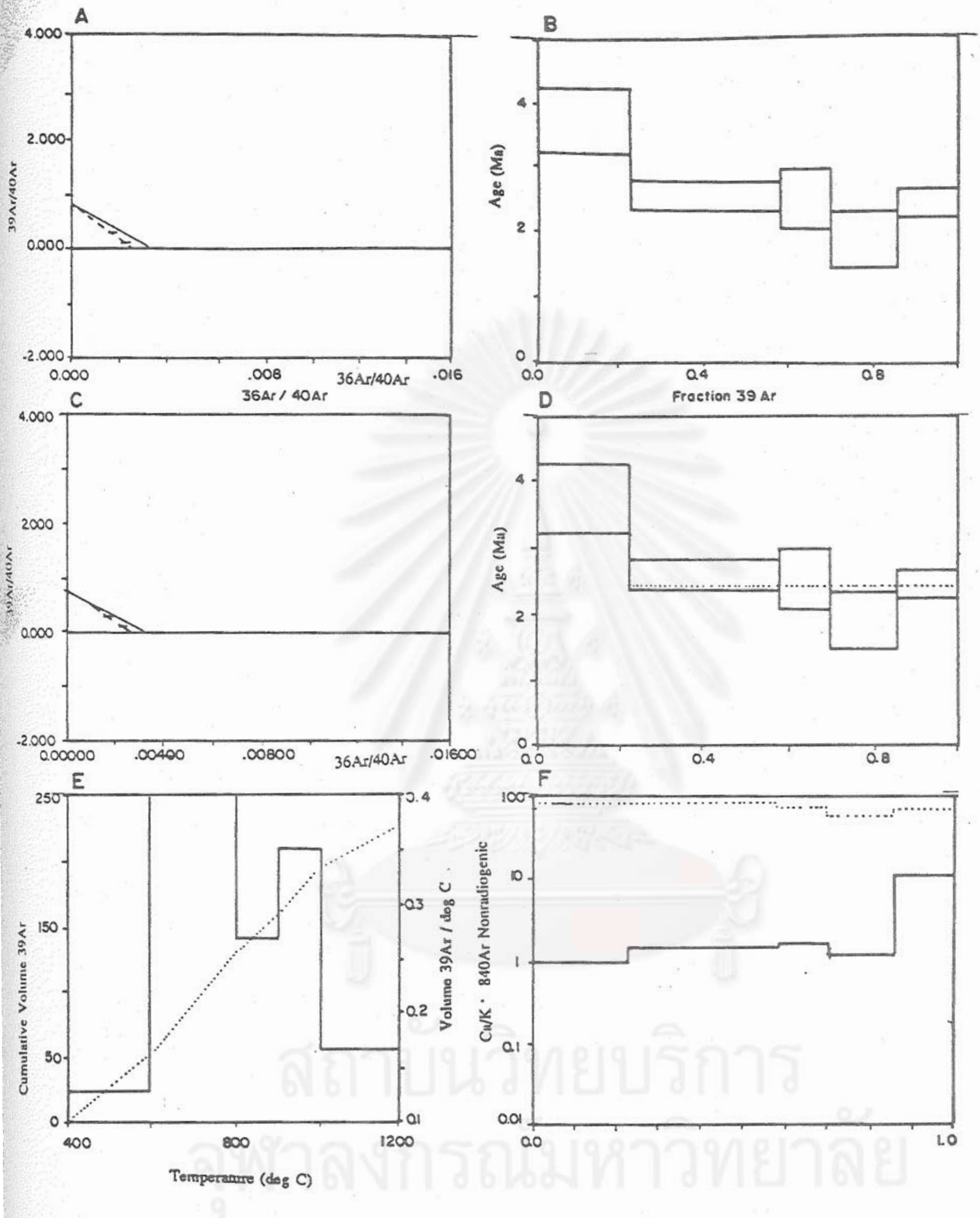


Figure 6.2 Plots of $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (A&C), Age (Ma) versus Fraction ^{39}Ar [B,and D with integrated age (dots)], and cumulative volume ^{39}Ar versus temperature (°c) (E) and Ca/K versus Fraction ^{39}Ar (F), for sample no. S-21-10, Sop Prap-Ko Kha basalt.

spectrum. The discordant age spectrum suggests inhomogeneous trapped argon. The total gas age (t_g) is 2.38 $\pm$ 0.17 Ma.

Figure 6.3 presents the isochorn plot for this sample, and yields an intercept age (t_i) of 2.83 $\pm$ 0.62 Ma. The trapped $^{40}Ar/^{39}Ar$ component is approximately 280.83 $\pm$ 108.81. The good geologic age of this sample is inferred to be the integrated age of ca. 2.38 $\pm$ 0.17 Ma.

S-21-6 : The whole-rock basalt sample of the third flow from the Sop Prap-Ko Kha area was similar location of samples S-21-10 and S-21-8. The sample was increasingly heated in 4 steps from 600 to higher than 1,190 °C. The age spectrum shown in Figure 6.4 represents a slightly discordant release spectrum. The step 3 and 4, containing approximately 75.4% of the total gas released, yield a plateau age (t_p) of 2.06 $\pm$ 0.31 Ma. However, the first two steps gave the higher apparent age of 11.03 $\pm$ 7.79 Ma (2.16% ^{39}Ar) and 3.05 $\pm$ 0.31 Ma (22.49% ^{39}Ar), respectively. This is interpreted to represent the date contaminated principally by atmospheric Ar. The total gas age for this sample is inferred to be 2.48 $\pm$ 0.33 Ma.

The sample does not present a linear-isochron array in the isotopic correlation plot (Figure 6.4). Then linear regression does not converge. Therefore, the geological age for this sample is represented by 85 % plateau age of ca. 2.36 $\pm$ 0.31 Ma.

S-29-3 : This rock specimen was sampled from the different location which is satuated at the central of Sop Prap-Ko Kha basalt. This sample was increasingly heated in 5 steps from 600 to 1,190 °C. Its the age spectrum is presented in Figure 6.5. The age spectrum is a slightly discordant release spectrum. It yields the total gas age (t_g) or integrated age of 2.46 $\pm$ 0.13 Ma.

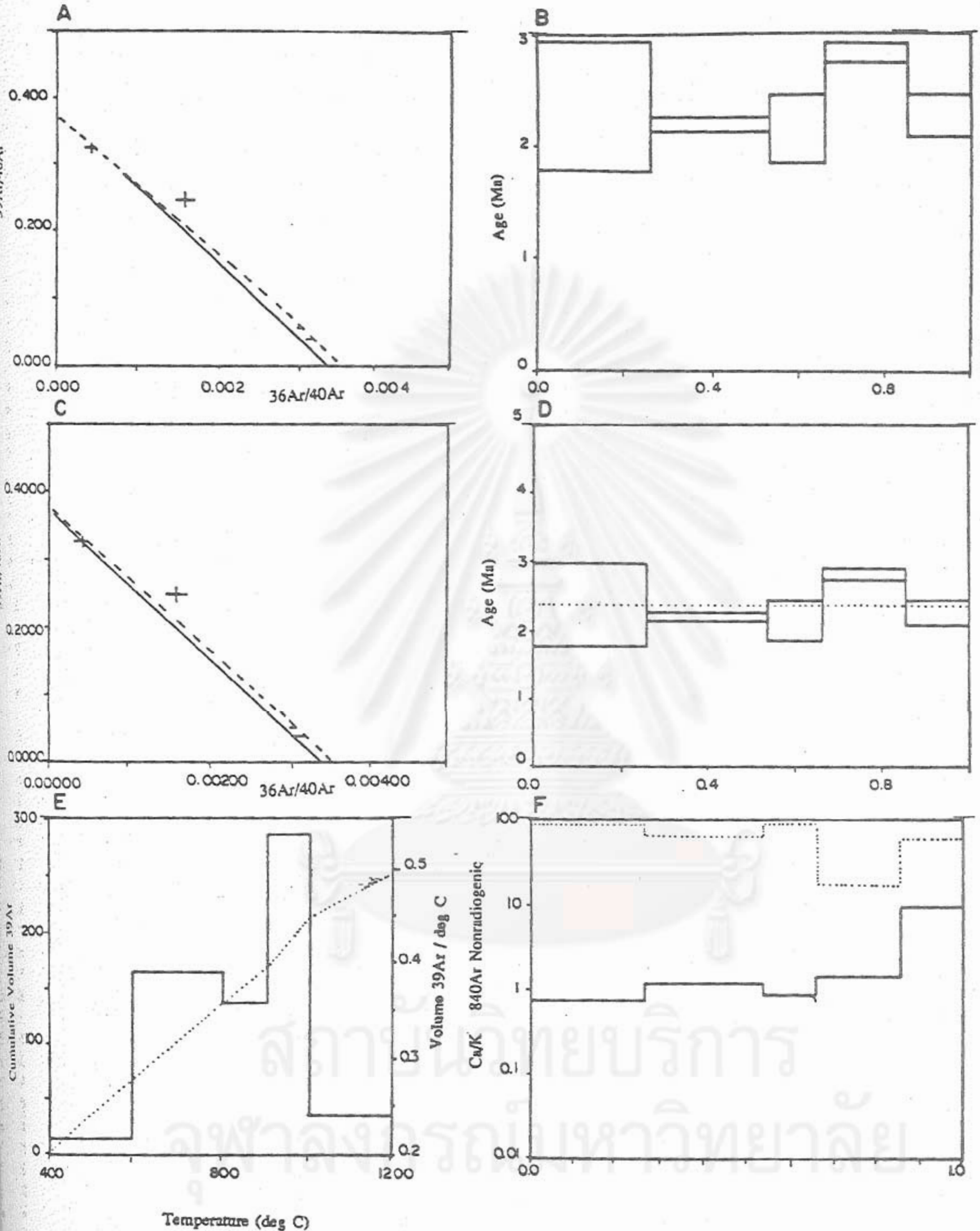


Figure 6.3 Plots of $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (A&C), Age (Ma) versus Fraction ^{39}Ar [B,and D with integrated age (dots)], and cumulative volume ^{39}Ar versus temperature (°c) (E) and Ca/K versus Fraction ^{39}Ar (F), for sample no. S-21-8, Sop Prap-Ko Kha basalt.

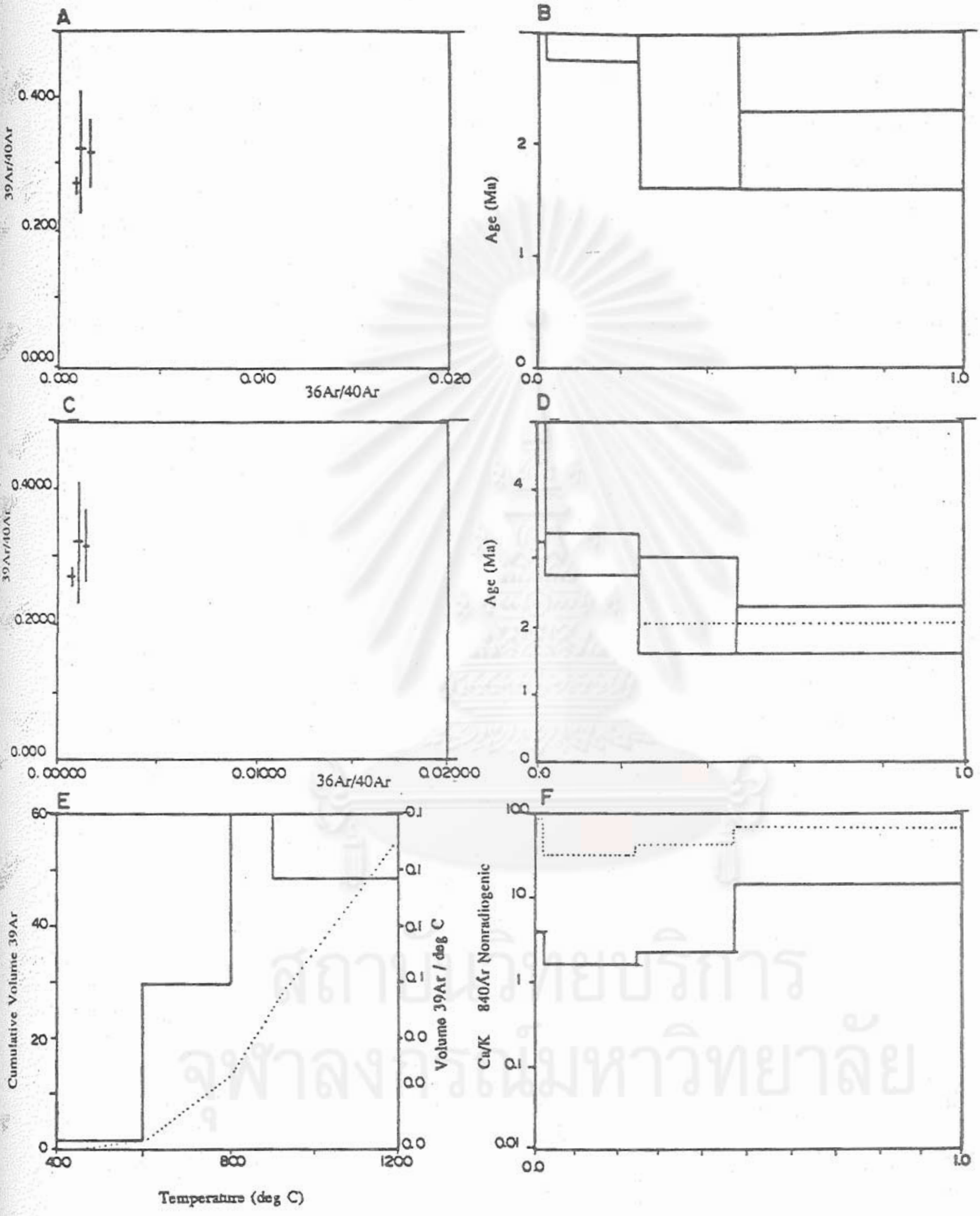


Figure 6.4 Plots of $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (A&C), Age (Ma) versus Fraction ^{39}Ar [B,and D with integrated age (dots)], and cumulative volume ^{39}Ar versus temperature (°c) (E) and Ca/K versus Fraction ^{39}Ar (F), for sample no. S-21-6, Sop Prap-Ko Kha basalt.

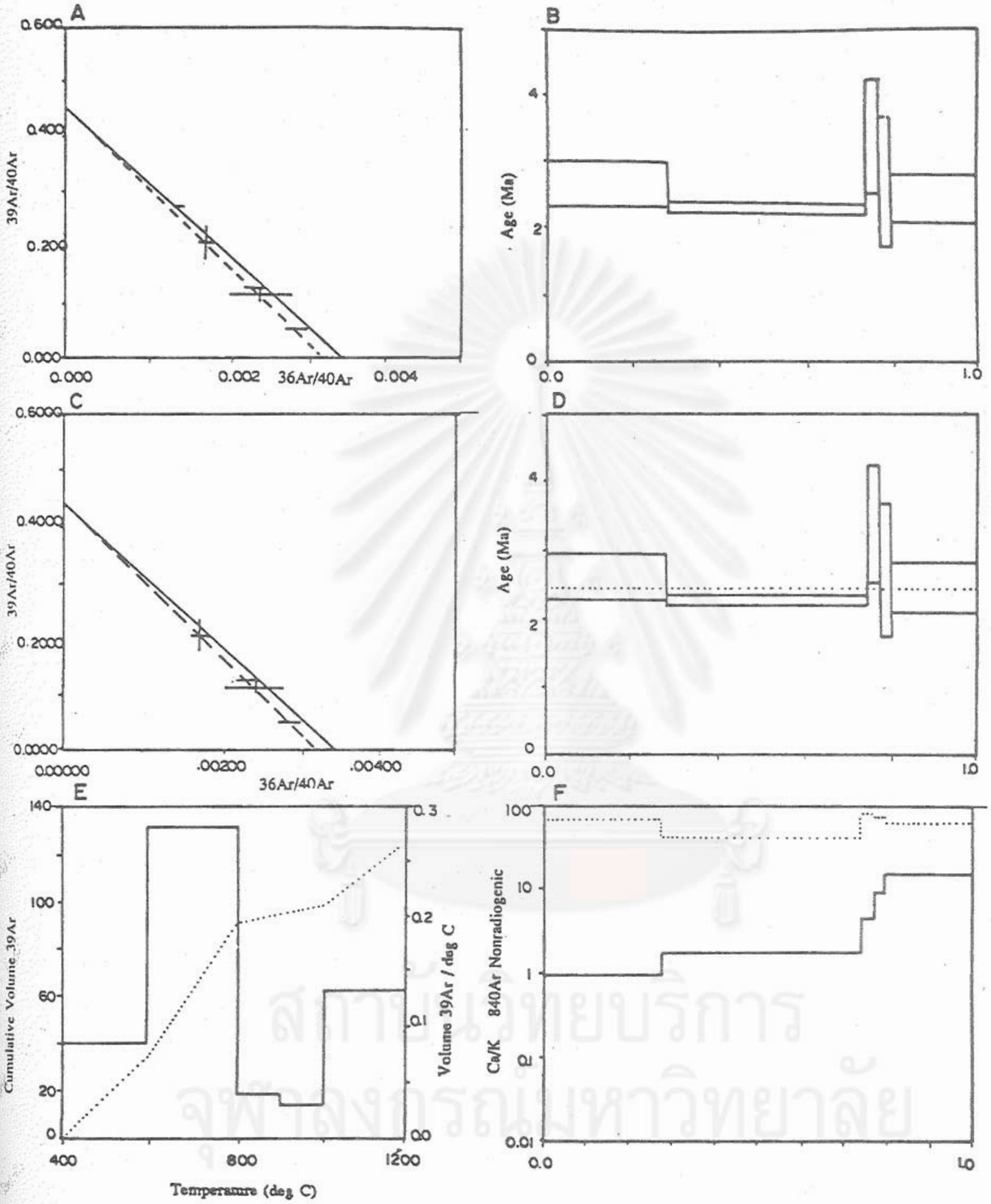


Figure 6.5 Plots of $^{39}Ar/^{40}Ar$ versus $^{36}Ar/^{40}Ar$ (A&C), Age (Ma) versus Fraction ^{39}Ar [B,and D with integrated age (dots)], and cumulative volume ^{39}Ar versus temperature (°c) (E) and Ca/K versus Fraction ^{39}Ar (F), for sample no. S-29-3, Sop Prap-Ko Kha basalt.

The isochron plot for this sample (Figure 6.5) defines two linear arrays, and yields an age of 2.31 ± 0.81 Ma. The trapped $^{40}Ar/^{39}Ar$ component is equal to 315.62 ± 179.65. The corrective age is nearly 90 % plateau age of ca. 2.30 ± 0.13 Ma.

The geochronological data indicate clearly than Nam Cho suite (ca. 2.02 Ma) is considered to be younger than the Sop Prap - Ko Kha suite (ca. younger than 2.30 to 2.41 Ma)..This current geochronological information places these two basaltic suites within the fifth volcanic eruption of Thailand during Cenozoic period (Sutthirat et al., 1994). This confirms that the age of eruption of gem - bearing basalt in Thailand is late Pliocene Epoch. Our result also indicates that the ages of both basaltic suites are dissimilar to those of the gem - barren Mae Tha basaltic suites of northern Lampang province as reported by Sasada et al. (1987; 0.8±0.3 Ma and 0.6±0.2 Ma), Barr and Macdonald (1981; 0.69 - 0.95 Ma), and Sutthirat et al.(1994; 0.5±0.05 Ma). The latter suites are, therefore, believed to have formed from different and shallower mantle region. These lines of evidences also point out that the upper mantle source region are heterogeneous beneath the Lampang area.

CHAPTER VII

DISCUSSION

In the section, the main focus is made on 4 important topics with respect to basaltic generation of the study area, including 1) geologic setting 2) gem-bearing and -barren basalts 3) petrogenetic model and 4) tectonic setting. Detailed discussions of individual topics are below.

7.1 Geologic Setting

As indicated in Chapter 3 that both Nam Cho and Sop Prap - Ko Kha basalts lie sharply over the Triassic-Lampang rock units, suggesting that these two suites are at least younger than Triassic. In fact the field evidence also indicates that these are more than two localities that these basalts flow over the Cenozoic gravel deposits (see Figures 3.4 and 3.5). This implies that the basaltic suites from both terranes, especially that of the Sop Prap-Ko Kha area, are quite young. However, it is not certainly known if the gravel beds are either Tertiary or as young as Quaternary. If the gravel bed (Figure 3.5) located at a higher attitude represents a terrace deposit, these two basaltic suites may have occurred during Late Tertiary. This phenomenon has not been proved yet.

From the above mentioned evidences together with the very recent geochronological result from the $^{40}Ar/^{39}Ar$ dating approach (see detailed in Chapter VI), it is quite possible that these two basalts may have occurred during Late Pleiocene, which is equivalent to the fifth episode of Cenozoic basaltic volcanism in Thailand as defined by Sutthirat et al. (1994).

In the median areas where extensive outpouring of basalts is dominated, there exists a N-trending major fracture almost parallel to the Mae Nam Wang River. This large-scale fracture may have been acted as a channel way for extrusion of these two volcanic suites. The age of fracture development is not ascertained. However, judging from the tectonic senario proposed recently by Charusiri et al. (1994), it is quite likely that the major fracture may have developed after Jurassic as a result of interaction between Shan Thai (or Chiang Rai / Lampang) and the Indochina microcontinents. Such a continental collision which perhaps occurred during Triassic - Jurassic may have triggered a large-scale deformation and caused the down-warping or synclinal structure of the study area. Several sets of fractures were created following the synclinal axial plane.

As a result, felsic intrusives may have taken place during this period. Sites of fracturings remain unchanged though time since the other collision event (Shang-Thai / Western Burma) during Early Tertiary provoke the resultant structure and reactivation of fractures and faults may have developed until Late Tertiary. This may have caused the extension fractures of the N-S trend during very Late Tertiary. This, in turn, gave rise to the generation of terrestial basaltic suites in the study area. It is inferred, from field evidence, that both basaltic suites may have occurred as subaerial volcanism rather than subaqueous form.

7.2 Gem-Bearing and -Barren Basalts

Several worker (Vichit et al., 1982, 1988, Barr and Macdonald, 1981, Jungyusuk and Khositanont, 1992) quoted from their extensive researches that gem (or corundum) -bearing and -barren basalts can be geochemically distinguished. An attempt has been made herein for these two basaltic terranes. As shown in Chapter 5 on geochemistry, separated and non-clustered trends of some major-oxides versus SiO_2, S.I., and MgO and several other variation diagrams, strongly advocate that these two basaltic suites (northern and southern areas) have not formed from the congenetic magmas, possibly reflecting the inhomogencity of subcrustal source origin. However, the parallelism of some trends surely points to the similar fashion on evolutionary crystallization process. If based solely upon the gem occurrences, Nam Cho basaltic suites, are regarded more gem-related, whereas Sop Prap - Ko Kha are not. However, gems do exist in some pits within the Sop Prap - Ko Kha basaltic terrane probably suggesting that some of the flows of the Sop Prap - Ko Kha are gem-bearing. In addition, it is not sure if the Nam Cho basalt magma which may represent the gem - related, is similar to the upper most flow of the southern region or not.

Petrographic evidences support that the lherzolite xenoliths of the Nam Cho basalt are far more abundant and larger in size than those of the Sop Prap - Ko Kha basalts. However, the quality of gems from both areas show that gems of the northern region are slightly better than those of the southern. This possibly implies the difference in ascending source materials. Normative percentages of plagioclase - 100An/(Ab+An) versus those of hypersthene or nepheline (see Figure 7.1) are very significant scheme for distinguishing the Nam Cho suite from the Sop Prap - Ko Kha suite. When compared to the other gem-bearing and gem-barren rocks from some selected areas in SE Asia (Barr and Macdonald, 1981), most of the gem-bearing basalts are located in the basanitoid (comprising Ne-mugearite, Ne-hawaiite, and basanite) fields where nepheline norm is the dominant phase, and the gem-barren basalts are located in the hawaiite (containing mugearite, hawaiite, and alkaline olivine basalt) fields where hypersthene norm is predominate. Our study is well conformed with those of Vichit et al. (1978) and Jungyusuk and Khositanont (1992) who suggested that corundum-related basalts in Thailand always comprise dunite peridotite xenolith and contain higher TiO_2 and lower SiO_2 contents. At this stage it is likely to conclude that almost all the Nam Cho basalts are gem-related but the Sop Prap - Ko Kha are not.

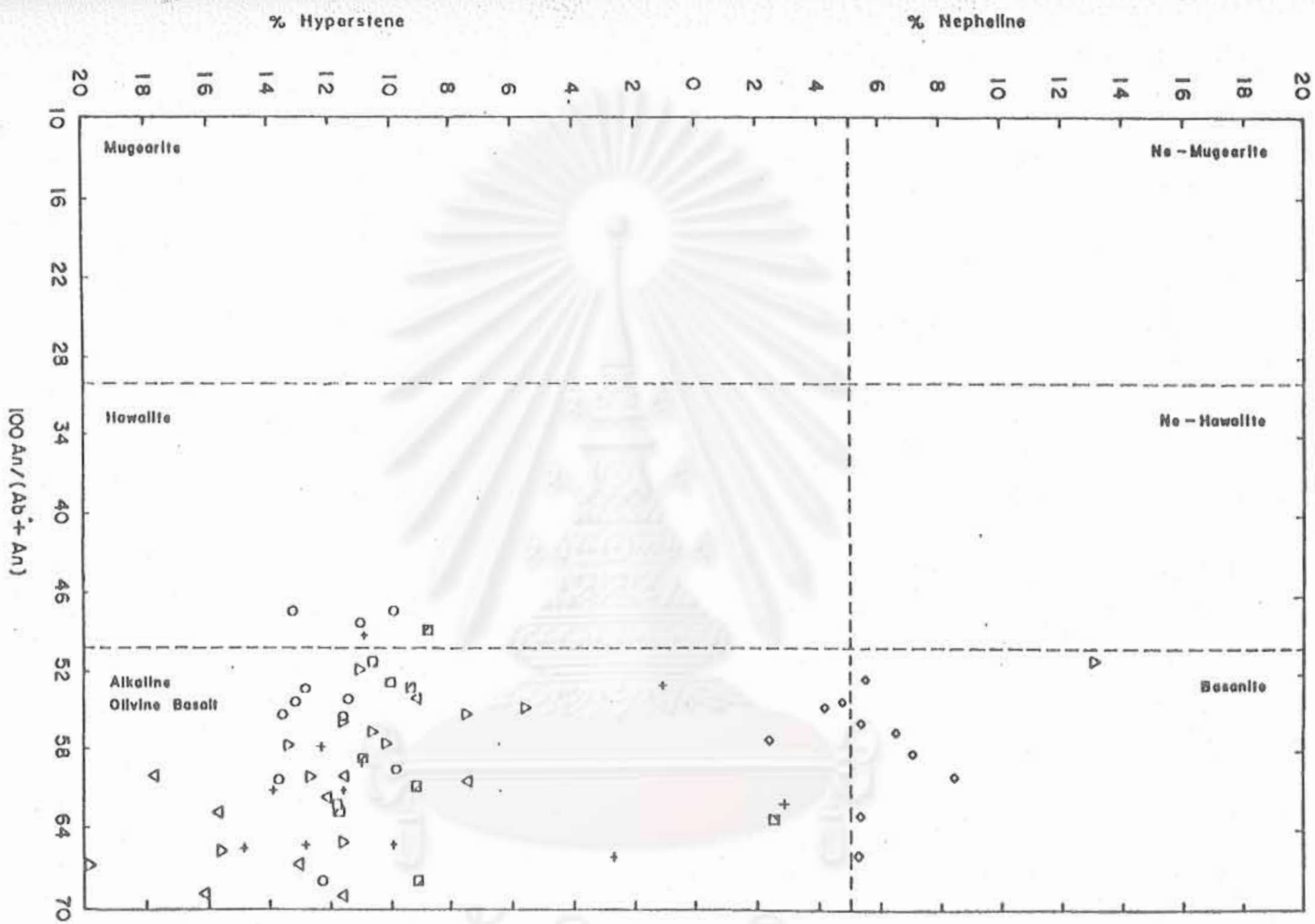


Figure 7.1 Plot of normative hyperstene or nepheline against normative plagioclase composition for the Nam Cho and the Sop Prap-Ko Kha basalts (fields from Barr and Macdonald, 1981).

7.3 Petrographic Model

As suggested in the earlier section (7.2), the basalts of Nam Cho and Sop Prap - Ko Kha terranes have several characteristics in common.

The most flows of the Sop Prap - Ko Kha basaltic suites bear similar mineralogy and texture, which are moderately difference from those of the Nam Cho basaltic suite. Petrographic evidences implies that both basaltic suites are of alkaline affinity. These include the presence of fine-sized, zoned olivine phenocrysts, the rarity of orthopyroxene, the less appearance of plagioclase phenocrysts, the common intergranular to subophitic texture, the abundance of Ca-rich clinopyroxene in groundmass, the abundance of ultramafic xenolith. Similar results were also deduced by Hughes (1982) and Wilson (1989).

Geochemical results also strongly support that the Nam Cho and the Sop Prap - Ko Kha basaltic suites are of alkalic composition based upon criteria proposed by Middlemost (1975) who used K_2O- and Na_2O - SiO_2 plots for differentiating alkaline from subalkalic (tholeiite) basaltic series. Additionally, a plot of Alkaline Index (A.I.) versus Al_2O_3 (Figure 5.8) indicates that these two basalt suites are clustered in the high Al basalt field. Several trace element bivariate plots such as Ti versus Zr, and variation triangular multielement diagrams as Ti-Zr-Y indicate that basalts of these two terrane are identified as within-plate basalts (see details in next section : 7.4). Field evidence suggests subaerial volcanism, implying that the basalts are of continental volcanic type, not oceanic volcanic affinity.

Green and Ringwood (1967) suggest that these compositions may be composed of 1:3 ratio of basalt: peridotite (pyrolite), while Yoder (1976) reported these would be contained by garnet periodotite. The primary magma was possibly derived by partial melting of source regions in the mantle. Then this primary magma may be evolved by crystal fractionation process in high pressure component to produce the derivative magma. Exception is that high-pressure component can produce the dervative magma. In addition magmas may have been interacted with rocks of the continental crust en route to the surface. Mg-Fe ratio is particularly useful as an index of crystal fractionation in mafic liquid (see Wilkinson, 1982), since it is regarded that Mg-Fe ratio changes markedly in the early stages of crystallization as a result of higher ratio of the liquidus ferromagnesian mineral than their host melts (Rollinson, 1993). The Fe-Mg ratio or the magnesium number (or $Mg^{\#}$) as it is usually called is herein expressed as $100(Mg^{2+}/Mg^{2+}+Fe^{2+})$ atomic fraction. The magnesium number ($Mg^{\#}$) shown in Table 5.1 of major element analyses of the Nam Cho and the Sop Prab-Ko Kha basalts are by and large range from 64 to 84. However, almost all of these magnesium number i.e., $Mg^{\#}$ are well over 66. The range of $Mg^{\#}$ of the Nam Cho basalt (65.5 - 72.4) is apparently more limited than those of the Sop Prab-Ko Kha basalt (61.5 - 83.6). Furthermore, the maximun - and the minimum - value of the magnesium number of the specimens collected for analyses from the Sop Prab-Ko Kha basalt is also higher and lower than the accordance values from the Nam Cho basalt. These results may attributed to the much lower in number of analysed specimen in the Nam Cho basalt. Nevertheless, it could possibly be concluded that these two basalts were supposedly formed from the primary magma originated by partial melting of the upper mantle source material (Green and Ringwood, 1967, Irving and Green, 1976) perhaps by small degree of partial melting for alkali basaltic magma from melting experiment (Figure 7.2) after Jaques and Green (1980). A spectrum of basaltic magma types can be divided into 3 broad groups, komatiite, picrite, and basalts (Wilson, 1989). Melting experiment shows that alkali basaltic magma appears to be generated by small degree of partial melting (Jaques and Green, 1980). This is taken into account the 2 to 5% partial melting behavior from REE information, it is inferred that the Nam Cho and the Sop Prap - Ko Kha suites may have occurred at ca. 15-20 kbar (equivalent to a depth of about 60 km) at a temperature range of 1,200-1,300°c and may have originated from the more primitive alkali picrite parental magma, with decreasing pressure and temperature.

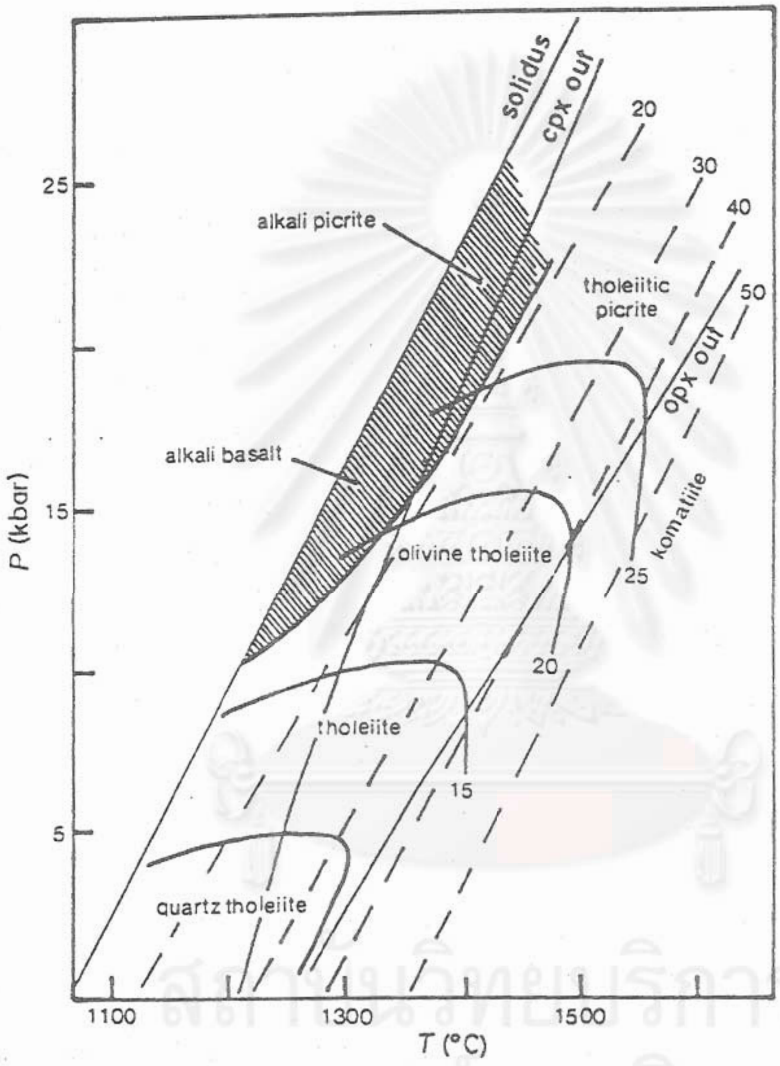


Figure 7.2 Experimentally determined partial melting characteristic of an enriched lherzolite source (after Jaques and Green, 1980).

When field boundaries of Meddlemost (1975) are applied for a plot of K_2O and SiO_2 and approximate trends of partial melting and crystal contamination. (and fractionation crystallization) of Mantovani et al. (1985) for Parana (Brazil) were used, then it is no surprising that the Nam Cho and the Sop Prap - Ko Kha basalts, though defined in separated field, follow the decreasing % partial melting trend (Figure5.1) with small amount of contamination.

Rare-earth element (see Figures 5.11 to 5.16) informations favour that basalts of both terranes have been evolved from similar process. However, when compared to the standard diagram (see Rollinson, 1993) in Figure 7.3, it is observed that both basaltic suites experience small degree of partial melting, which, in this case, fits fairly well with the 2 to 5 % trend.

7.4 Tectonic Setting

As stated above both Nam Cho and Sop Prap - Ko Kha basaltic suites are petrochemically regarded as alkalic, and the former being stronger than the latter. It is likely that they were formed in continental environment by subaerial volcanism during Late Pleiocene.

Though it is beyond the scope of this work to define tectonic setting without a fruitfully detailed information on geologic setting of the area concerned and its nearby regions. However, several workers (as Pearce and Cann, 1973, Shervais, 1982, Pearce, 1982, Rollinson, 1993) stated that tectonic settings or environments can be correlated with and determined using combined geochemical characteristics. Five tectonic environments are recognizable based upon these criteria, including oceanic ridge, volcanic arc, collisional setting, intraplate setting and passive continental margin. A large number of major / trace element discrimination diagrams are applicable to mafic volcanics for suggesting the paleotectonic environment of the volcanic

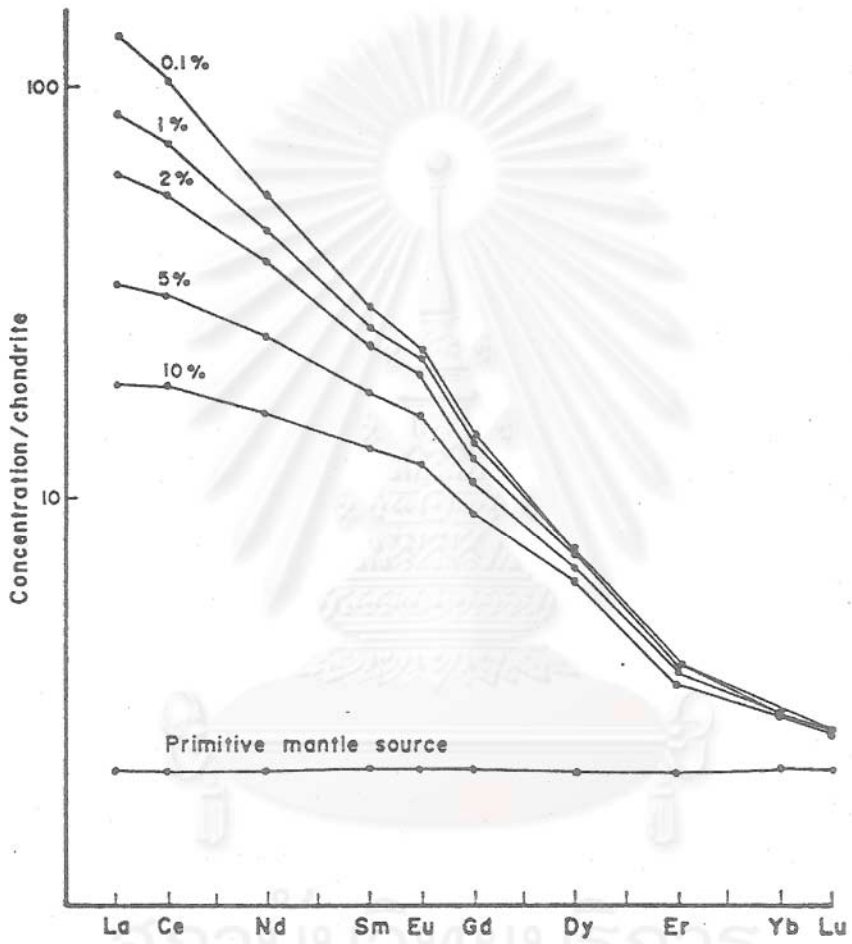


Figure 7.3 Chondrite normalized patterns from calculating model of ranging in degree of partial melting (Rollinson, 1993).

suites. These diagrams are collectively called "tectonomagmatic discrimination diagrams".

These types of such discriminant diagrams are used herein to suggest the possible tectonic setting of these two basaltic terranes. They include :

1) The diagram which utilize relatively immobile trace and minor elements. These diagram are shown in Figure 7.4 and 7.5. The ternary plots of Ti/100-Zr-Y*3 (Figure 7.5) and 2Nb-Zr/4-Y (Figure 7.4) both despict that the Sop Prap - Ko Kha (and Nam Cho) basaltic suites are fallen within the within-plate basalt. It is also clear that with the expection of some Nam Cho values, they represent within-plate alkalic rather than within-plate tholeiite ;

2) The diagram which uses major and minor elements as discriminant parameter. Figure 7.6 shows the values of TiO_2-MnO-P_2O_5 (Mullen, 1983) for the basalts of the Nam Cho and the Sop Prap - Ko Kha areas, suggesting that all are assigned to be oceanic island alkalic;

3) The diagram which utilizes immobile trace elements (Figure 7.7) shows Ti versus Zr plots (Pearce and Cann, 1973) of the Nam Cho and the Sop Prap - Ko Kha suites, suggesting that the basalts fit very well in the within-plate field. Pearce and Norry (1979) found that the ratio Zr/Y plotted against the fractionation index Zr proved an effective discriminant among basalts of contrast tectonic settings. Figure7.8 depicts Zr/Y versus Zr values of the Nam Cho and the Sop Prap - Ko Kha basalts fallen within the within-plate basalts. According to Pearce (1982) the Ti/Y-Nb/Y diagram (show in Figure 7.9) successfully seperates the within-plate basalt group from MORB (mid-oceanic ridge basalt) and volcanic arc basalts. It is clear that the Nam Cho and the Sop Prap - Ko Kha basaltic suites are plotted in the within-plate field, with rather alkalic subfield.

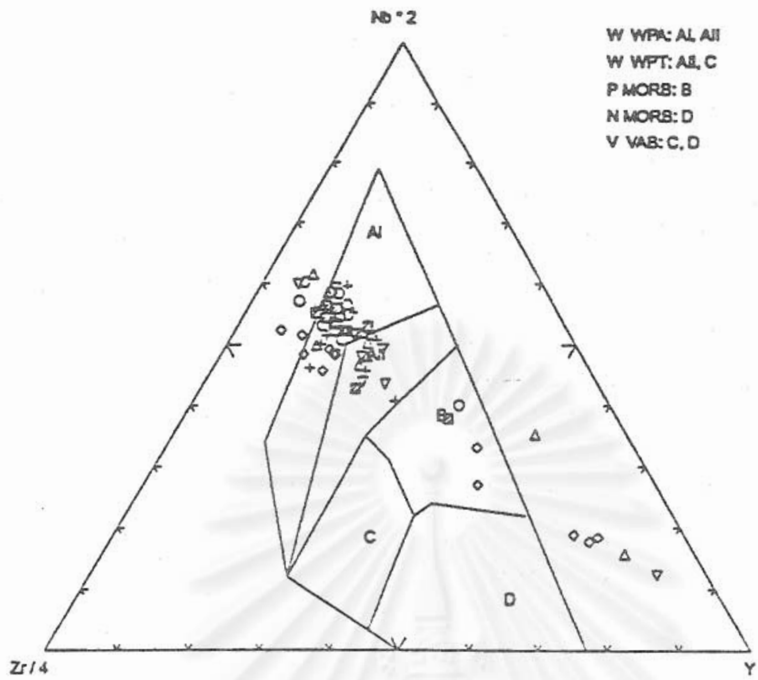


Figure 7.4 Ternary plot of Zr/4 - Nb*2 - Y of the Nam Cho and the Sop Prap-Ko Kha basalts (fields from Meschede, 1986) suggests that these basalts are mainly within plate alkaline and tholeiitic basalts. Symbols same as Figure 5.1.

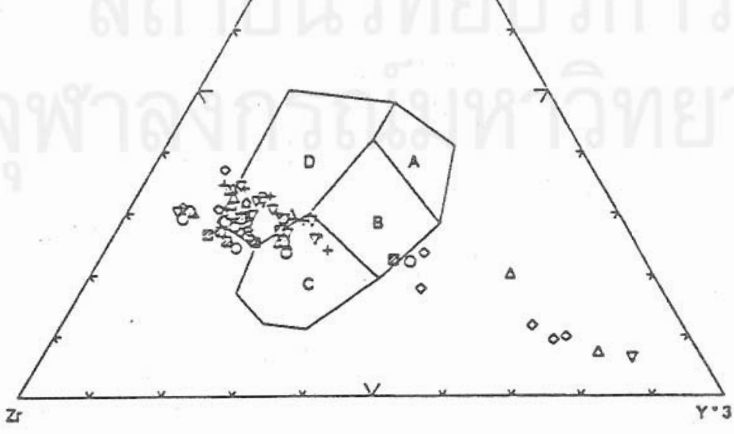


Figure 7.5 Zr - Ti/100 - Y*3 plot of basalts from the Nam Cho and the Sop Prap-Ko Kha areas (fields after Pearce and Cann, 1973). Symbols same as Figure 5.1.

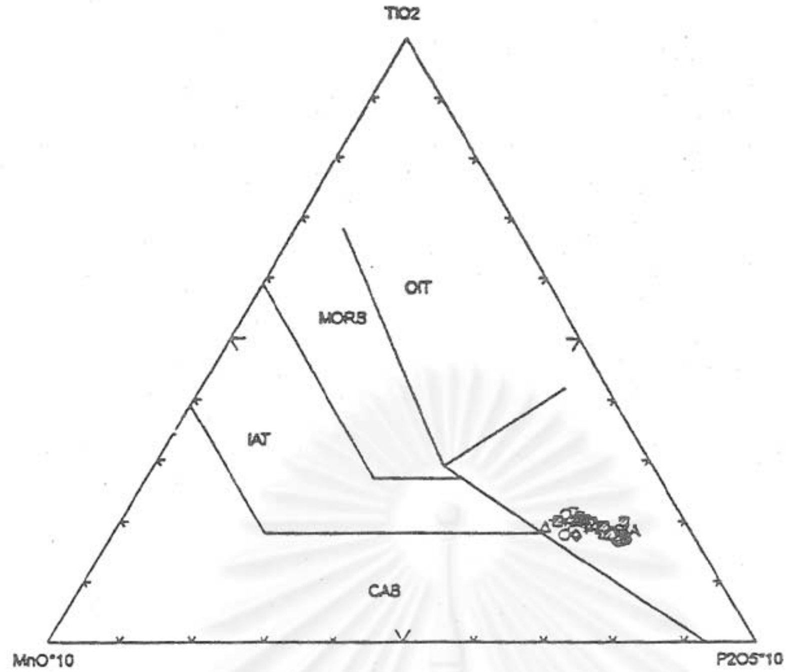


Figure 7.6 MnO*10 - TiO_2 - P_2O_5*10 variation diagram for the Nam Cho and the Sop Prap-Ko Kha basalts (fields after Mullen, 1983) show that these basalts are mainly plotted in ocean island alkaline field. Symbols same as Figure 5.1.

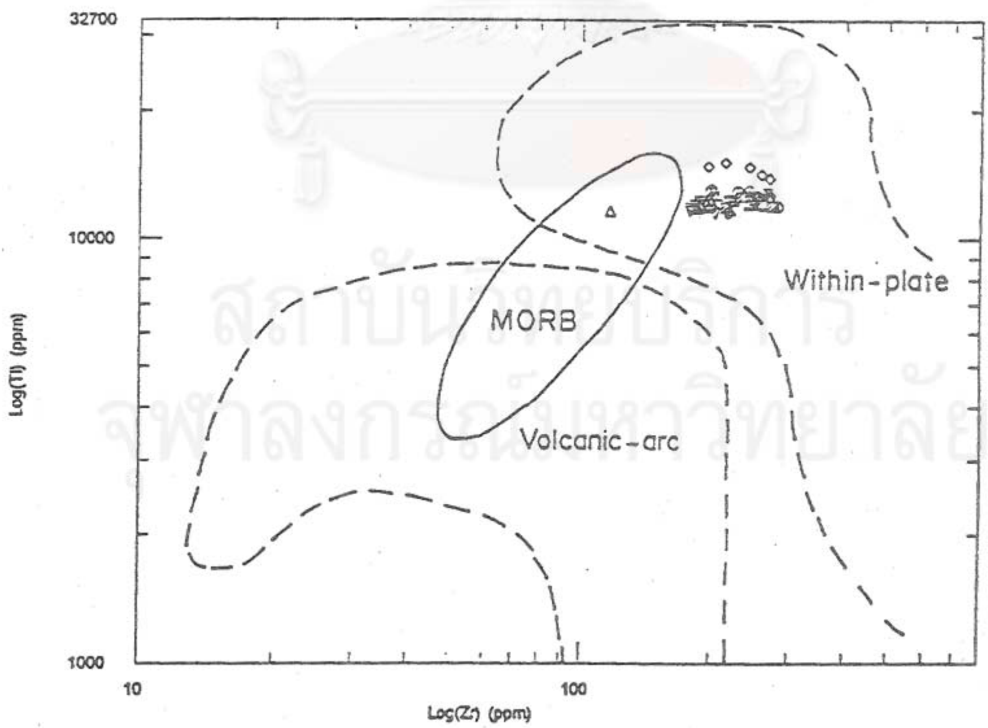


Figure 7.7 Variation diagram of log Ti versus log Zr for the Nam Cho and the Sop Prap-Ko Kha basalts (fields after Pearce and Cann, 1973). Symbols same as Figure 5.1.

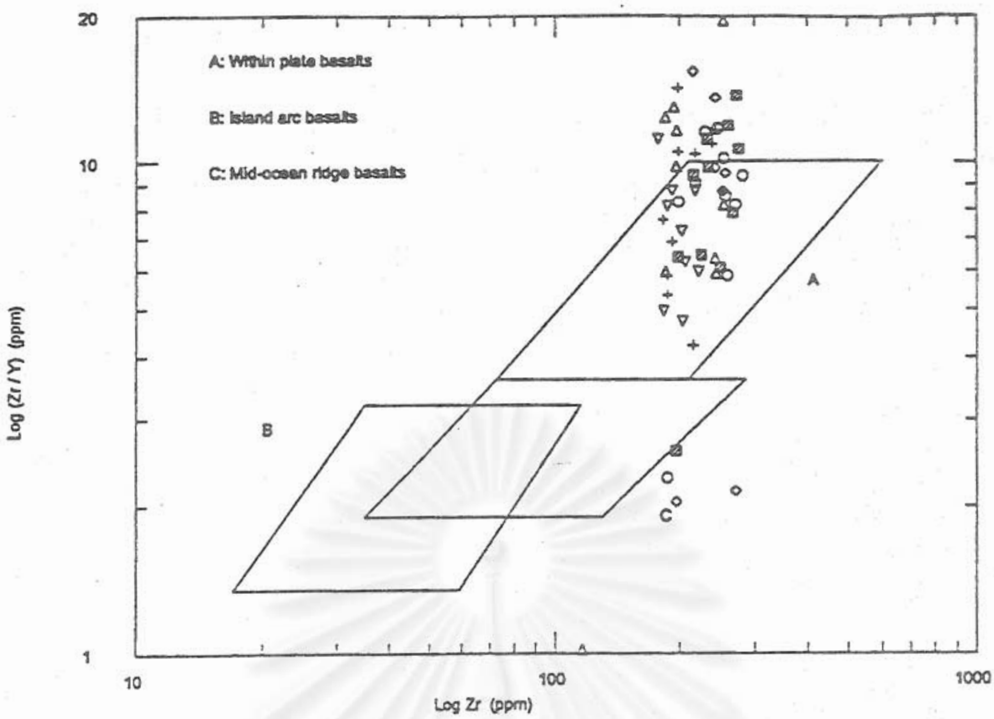


Figure 7.8 Plot of log (Zr/Y) against log Zr displays mainly within plate basalt of these sample plottings from the Nam Cho and the Sop Prap-Ko Kha basalts (fields after Pearce and Norry, 1979). Symbols same as Figure 5.1.

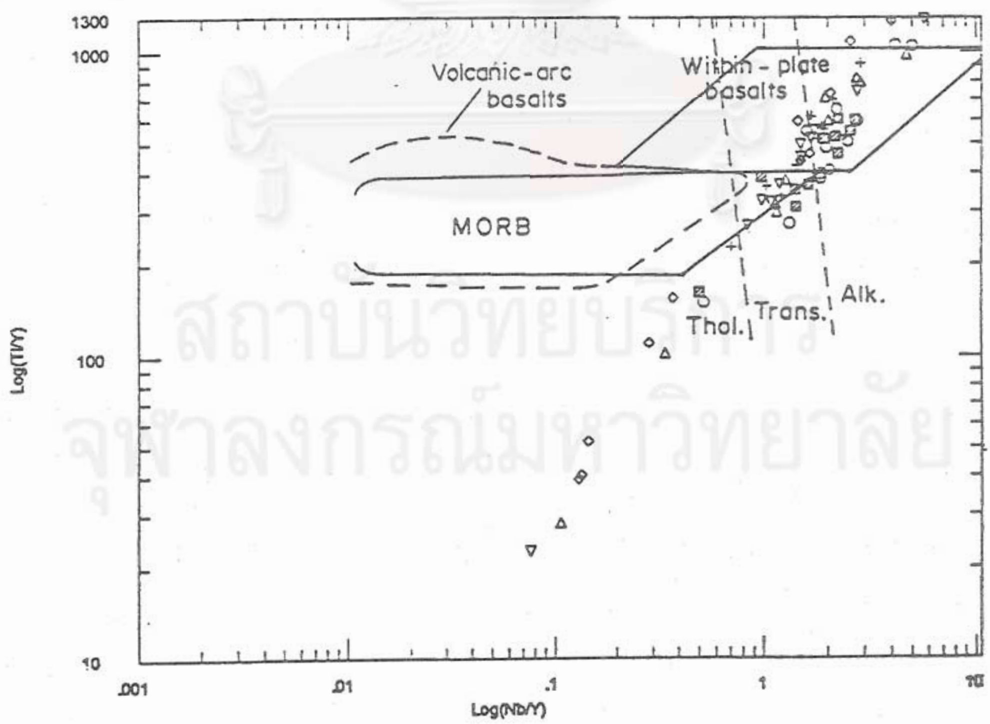


Figure 7.9 The log (Ti/Y) - log (Nb/Y) discrimination diagram for basalt plottings of the Nam Cho and the Sop Prap-Ko Kha areas (after Pearce, 1982). Symbols same as Figure 5.1.

Two types of continental within-plate basalts are recognized continental flood basalts and continental rift basalts (see Wilson, 1989). The diagram of Pearce (1982) for Ti/Y-Nb/Y plots are cryptic since most of the continental rift basalts are of alkalic affinity. In addition, according to Holm (1982) and Dancan (1987), continental flood basalts do not plot in the within-plate setting.

Besides not only the SiO_2-K_2O plots of the Nam Cho and the Sop Prap - Ko Kha suites indicate less crystal fractionation and less degree of partial melting, but also as the trace element ratio (Wilson, 1989) of Zr-Nb (Figure 5.9) and Y/Nb-Zr/Nb (Figure 5.10). Figure 7.10 shows variation of Nb versus Zr (ppm) for basalts of Sop Prap - Ko Kha and Nam Cho, both suites displaying a roughly constant Zr/Nb ratio of about 4.83 and 6.24, respectively, suggesting that both eruptives may represent products of fractional crystallization of the associated magma (see also Price et al., 1985). However, a slight difference in slope of both suites suggest that they could be petrogenetically derived from different mantle source region.

Figure 5.10 displays the variation of Y/Nb versus Zr/Nb for these two basaltic suites. These basalts plot on an apparent mixing trend between an enriched component and a depleted MORB-source component, but more populated and aligned closed to the enriched side. This provides an ample evidence for the role of asthenospheric or MORB-source mantle in the petrogenesis of these basaltic suites in an actively extending rift segments. It is quite plausible, as stated by Wilson (1989), that a quite high ratios of Zr/Nb and possibly Y/Nb are an original source characteristic, not produced by significant volume of crustal contamination, however detailed Sr-Nd-Pb isotopic information are clearly required to unravel the involvement of MORB-source mantle in their petrogenesis.

As mentioned above, several lines of evidences strongly advocate the continental rifting for the involvement if these petrogenesis of the Nam Cho and the Sop Prap - Ko Kha basaltic suites. The continental rift zones are defined herein as areas of localized lithospheric extension characterized by a central depression, uplifted flanks and a thinning of the underlying crust (see also Wilson, 1989). High heat flow and broad sources of regional uplift and magmatism are always associated with such tectonic structure. The occurrence of several hot springs (Charusiri et al., 1992) and the present-day high heat-flow (Thienprasert and Raksasakulwong, 1984) possibly support the continental rifting still existing at present-day time.

Most of the major well-studied rifts are frequently associated with volcanic products and this leads Barberi et al. (1982) to classify intra-continental plate into high-volcanicity and low-volcanicity types. The former is characterized by small volumes of eruptive products, low rates of crustal extension, discontinuous volcanic activity, and wide spectrum of basaltic magma compositions with little sialic differentiates. The latter is vise versa, and consist predominantly of mildly alkali basalts and bimodal distribution of mafic and felsic magma types. However, the absence of wide spectrum of magmatic basalts and the presence of mildly alkalic seems to supress the first possibility. Although the Cenozoic bimodal lavas are not present in the study area, regionally the vast volume of lavas and their volcanic products are found also in the region, as Lam Narai and Khok Samrong and Saraburi districts, giving rise to the association subalkaline rhyolite and weakly alkalic basalts for the confirmation to the high-volcanicity rift zone of the Nam Cho and the Sop Prap - Ko Kha suites.

According to Wilson (1989), two types of rifting are recognized based upon mechanism ; i.e., active rifting and passive rifting, the former caused by upwelling mantle splitting the continent along pre-weakened zones and the latter involving the mantle is forced to rise as the continents are pulled apart during lithospheric stretching. If deep-mantle up welling plume is responsible for the initiation of a rift (active model), then the magma may be generated from

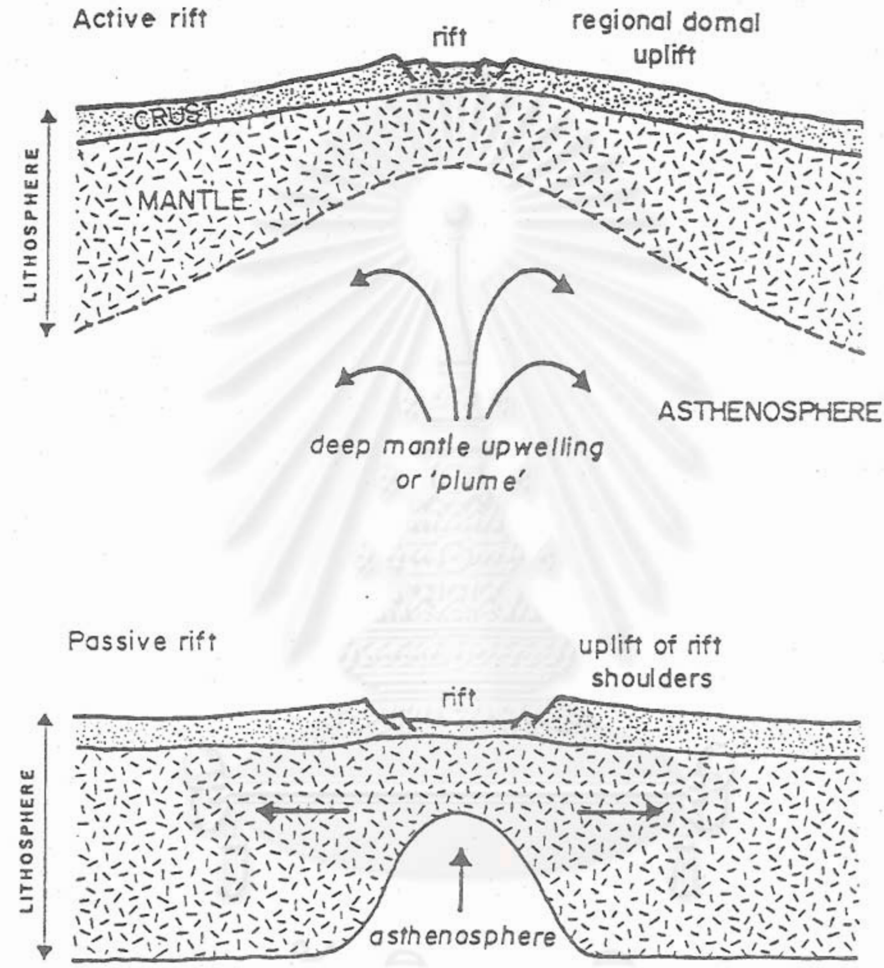


Figure 7.10 Active versus passive rifting models (after Keen, 1985).

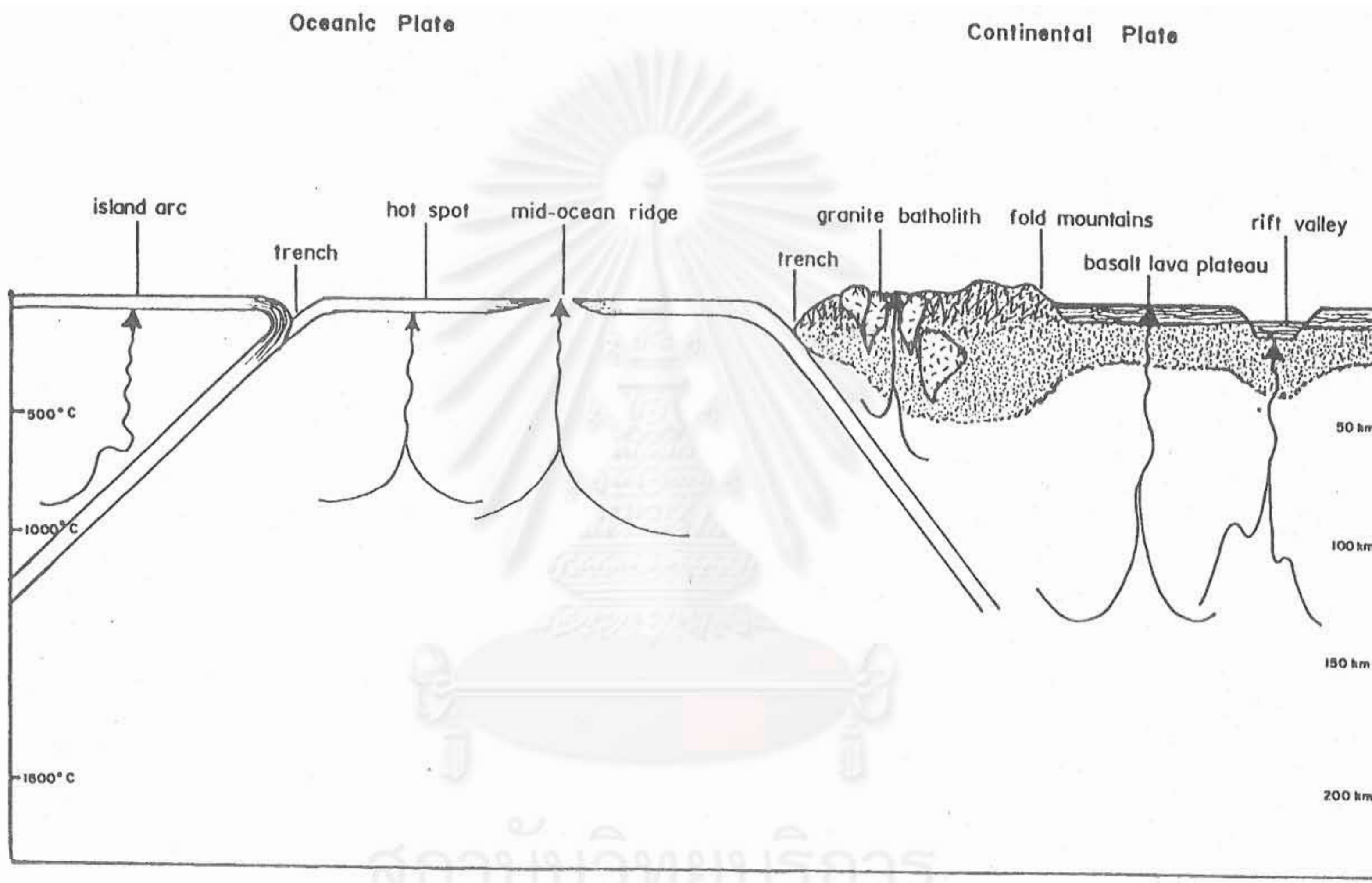


Figure 7.11 Distribution of major mantle source components in relation to sites of continental and oceanic volcanism (after the Institute of Geological Sciences of England, 1974).

oceanic island basalts (OIB) source mantle within the plume (Figure 7.11) and contain little contribution from the asthenosphere MORB source component. This is not the case for the studied basalts (as mentioned earlier). However, trace element data and alkaline nature indicate derivation from enriched mantle source (Bailey, 1983). This can be explained by the fact that beneath the continental rifts, the enriched source is simply the old subcontinental lithosphere, and that depleted MORB source asthenospheric mantle only becomes extensively involved in the "most actively" extending rift segments. The later situation is unlikely for the currently studied basaltic suites.

Therefore it is quite essential to note that the first tectonic phenomenon was crustal down warping, froming a proto-rift depression (as the formative of syncline for the studied area), implying that such the lithospheric stretching (passive model) is the prime factor in the initial stage of rift development. As a consequence of stretching asthenospheric upwelling occurs, causing heating to the lithospheric plate and crustal doming. Thus, it may be reliable, as similar to the recent studies (see Mohr, 1982 and Almond, 1986), that the rift may have evolved from a passive phase to an active phase. In summary, the simplistic model for the evolution of the basaltic suites of the Nam Cho and the Sop Prap - Ko Kha terranes are shown in Figure 7.12.

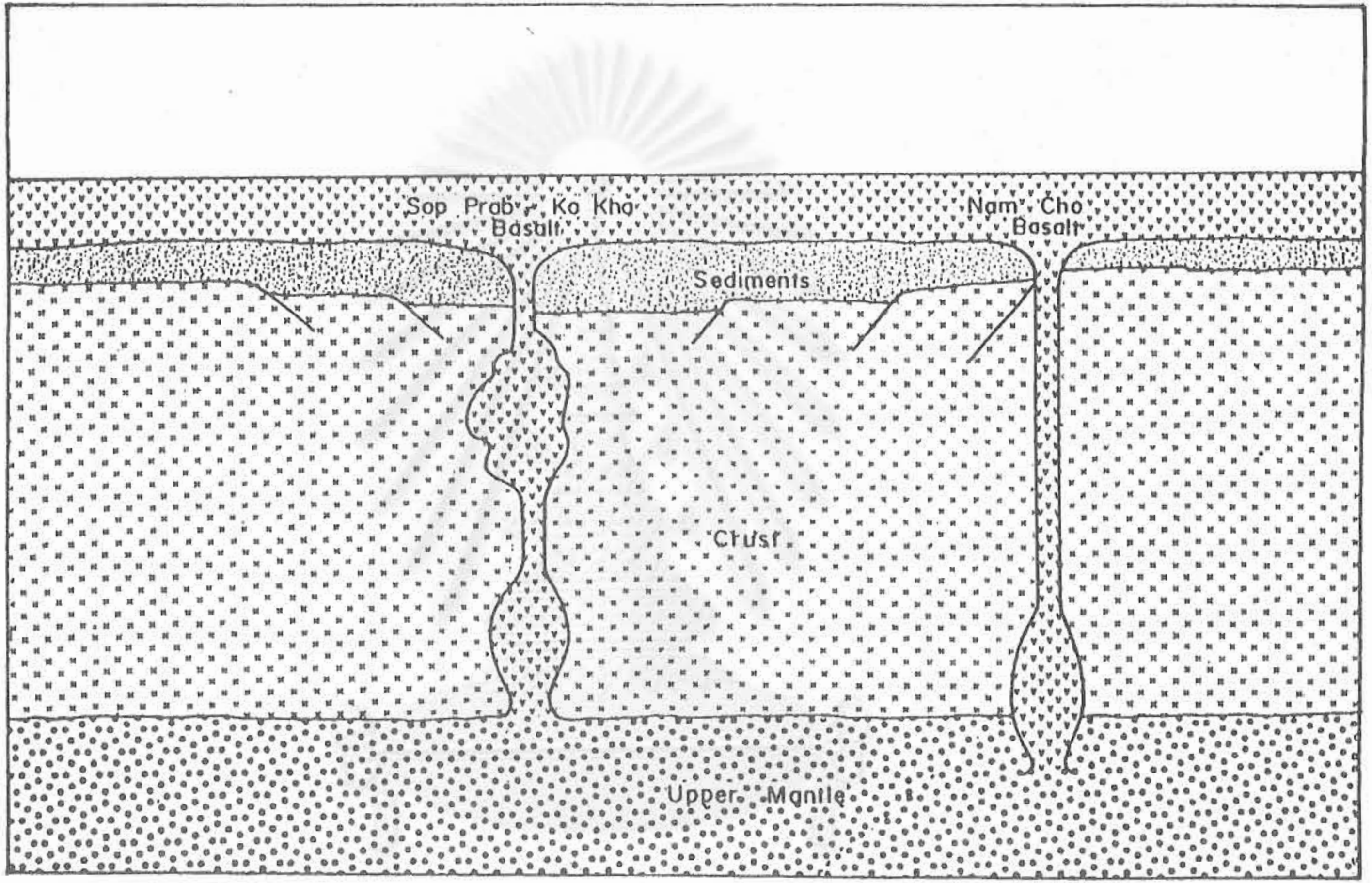


Figure 7.12 The simplified petrogenetic model of the Nam Cho basalt and the Sop Prap-Ko Kha basalt.

CHAPTER VIII

CONCLUSION

1. The Nam Cho basalts and the Sop Prap-Ko Kha basalts are classified as continental basalt related to extension rifting.The Nam Cho basalts are geochemically and petrologically classified as alkaline basalts, while the Sop Prap-Ko Kha basalts are mildly alkaline basalts.

2. The geochronological data indicate clearly than Nam Cho suite (ca. 2.02 Ma) is considered to be younger than the Sop Prap - Ko Kha suite (ca. younger than 2.30 to 2.41 Ma)..This current geochronological information places these two basaltic suites within the fifth volcanic eruption of Thailand during Cenozoic period (Sutthirat et al., 1994). This confirms that the age of eruption of gem - bearing basalt in Thailand is late Pliocene Epoch.

3. Petrologically, the Sop Prap - Ko Kha basalts which consists of five flow layers display similar mineralogy and texture but they are moderately different from the Nam Cho basalts. The Nam Cho basalts are always composed of spinel-lherzolite nodules and megacrysts (and large phenocrysts) of olivine and pyroxene with very fine-grained groundmass, equivalent to "Picritic basalt".

4. Geochemically, basalts of these two suites are frequently composed of major and trace elements. They are similar (or very slightly different from) to the Phu Fai gabbroid rocks and the Khao Kradong basalts from the southern region of Northeast Thailand. Although the Nam Cho basaltic suites are geochemically assigned as gem-related rocks, but the Sop Prap - Ko Kha basaltic suites are classed as gem-barren rocks.

5. The basalts of both terrane were probably originated from derivative magma, evolved by similar process with crystal fractionation, and limited crustal contamination processes, and low degree of partial melting of primary picritic-alkali basaltic magmas in the upper mantle source region. But their primary magmas are not similar, made from different or heterogeneous sources.

6. Sapphire occurrence and REE data indicate partial melting of primary magma at rather deep and high pressure (more than 20 kbar) and crystal fractionation of derivative magma, which sapphires may have been crystallized between this fractionation process.

7. However, information on gem exploration suggests that quantity and quality of these sapphire occurrences are not economical high.

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APPENDIX A

Analytical Techniques

Determination of Major Elements and Some Trace Elements

Most of major elements and some trace elements were determined by Mr. Somsak Sangsila, Mrs. Suchada Sripairojthikoon, Miss Sasithon Panthong, and Miss Piyanun Amnachsakullit, the staffs of Mineral Resources Analysis Division, DMR. X-ray fluorescence (XRF) technique was mainly used for analysing major elements and some trace elements, comprising SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, MnO, P_2O_5, Ba, Ce, Co, Cr, Nb, Ni, Pb, Rb, Sr, V, Y, Zn, and Zr. The main procedure is present as following :

1. Individual powdery samples were roasted at 105 °C about 3 hr and allow to cool to room temperature for longer than 24 hrs.

2. 1.3 gm of each sample and reference standard were roasted at 105 °C about 1 to 2 hrs for calculating H2O- content, that was determined by loss on weight.

3. These samples and standards were burned at about 950 to 1,050 °C about half hour for calculating the ignition loss, which was still determined by loss of weight.

4. About 6.5 gm of flux spectromelt "A12" (66:34 ratio of LiBO2 : Li2B4O7) and 0.05 gm of I2O5 were mixed into samples and standards. These mixers were fused at about 1,200 °C for 25 minutes.

5. The homogeneous pellets are prepared and always stored in the desiccator before X-ray fluorescence analysis.

6. X-ray spectrometer of Philips (model PW 1400) with Rh tube was used to analyse major elements and some trace elements by wave range dispersive method. The

analytical conditions of some elements were concluded in Table A1.

7. Most data were determined by the detector and relatively computerized by the computer system. Then final data are reported after these processings.

Determination of Rare Earth Elements (REE)

Neutron activation analysis (NAA) technique was used to determined some rare earth elements, containing La, Ce, Nd, Sm, Eu, Tb, Dy, Yb, and Lu. These rare earth elements were analyzed by Mr. Chanchai Asvavijnijkulchai, Physics Division, Office of Atomic Energy for Peace. The procedure of this analysis in an orderly sequence is shown below.

1. Weight app. 100 mg of a homogeneous powder of each sample, basalt standard of U. S. G. S. (BHVO-1), and geological material standard (SOIL-7) were weighed and put into new small polyethylene vials.

2. These vials were packed, and were composed of 2 samples with 1 standard (SOIL-7) , or 2 basalt standard (BHVO-1) with 1 standard (SOIL-7). The standard vial was always inserted between 2 samples and 2 basalts standard. The packages of basalt standard were prepared for accuracy testing.

3. About 3 packages were put into a clean polyethylene rabbit. The samples and standard in rabbits were activated together at the suitable epithermal neutron flux in a covered tube. The times for activation of each elements are concluded in Table A2.

4. The samples and standard were determined element by element by the detector system, that commonly comprises detector, preamplifier, amplifier, multichannel analyzer, printer, plotter, etc. The details of detection are concluded in Table A2.

5. Most corrected data would be computerized by the p.c. computer. Then final data would be present after these processing.

APPENDIX B

List of Analytical Samples

Sop Prap-Ko Kha Basalts

Sample number	Grid reference	Remark
S-2	406947	the fifth flow
S-4	406947	the fourTh. flow
S-8	406947	the third flow
S-11	406947	the second flow
S-13	406947	the first flow
S1-1	387942	the fifth flow
S1-7	387942	the fourth flow
S1-10	386937	the third flow
S1-13-2	385935	the second flow
S1-14	385935	the first flow
S7-2	398941	the fifth flow
S7-3-1	398941	the fourth flow
S7-5	394938	the third flow
S8-2	393937	the second flow
S8-5	393937	the first flow
S18-2-1	411946	the fifth flow

Sample number	Grid reference	Remark
S18-3	410945	the fourth flow
S18-5-2	414946	the third flow
S18-7	419946	the second flow
S18-11	423945	the first flow
S19-1	408948	the fifth flow
S19-3	408948	the fourth flow
S19-5	410950	the third flow
S19-7	411952	the second flow
S19-9	415956	the first flow
S21-1	405949	the fifth flow
S21-4-2	406952	the fourth flow
S21-6	409956	the third flow
S21-8	410957	the second flow
S21-10	412959	the first flow
S24-1	402950	the fifth flow
S24-2	401951	the fourth flow
S24-4	399953	the third flow
S24-6	397956	the second flow
S24-7	396958	the first flow
S29-1	410941	the fifth flow
S29-3	412940	the fourth flow
S29-5	415940	the third flow
S29-10	422942	the second flow
S29-11	424942	the first flow

Sample number	Grid reference	Remark
S2-2	383938	the fifth flow
S13-1	375920	the fourth flow
S6-2	360916	the third flow
S14-7	404925	the second flow
S12-6	376927	the first flow
S20-2	392947	the fifth flow
S14-1	402937	the fourth flow
S22-4-1	395950	the third flow
S25-4	396961	the second flow
S23-4-1	393961	the first flow
S28-1	419931	the fifth flow
S25-1	402958	the fourth flow
S28-3	422936	the third flow
S28-4	424938	the second flow
S27-11	385901	the first flow

Nam Cho Basalts

Sample number	Grid reference	Remark
N-1	477035	
N-2	477034	
N-3	477034	
N-5	477033	
N-6	476031	
N-7	475031	
N-8	474031	
N-9	474030	
N-10	474030	
N-11	473030	
N-12	472030	

APPENDIX C

XRD Patterns of Mineral Occurrences from Pittings, Megacrysts and Ultramafic Nodules of Basalts from the Nam Cho Area and the Sop Prap-Ko Kha Area

Fig. C

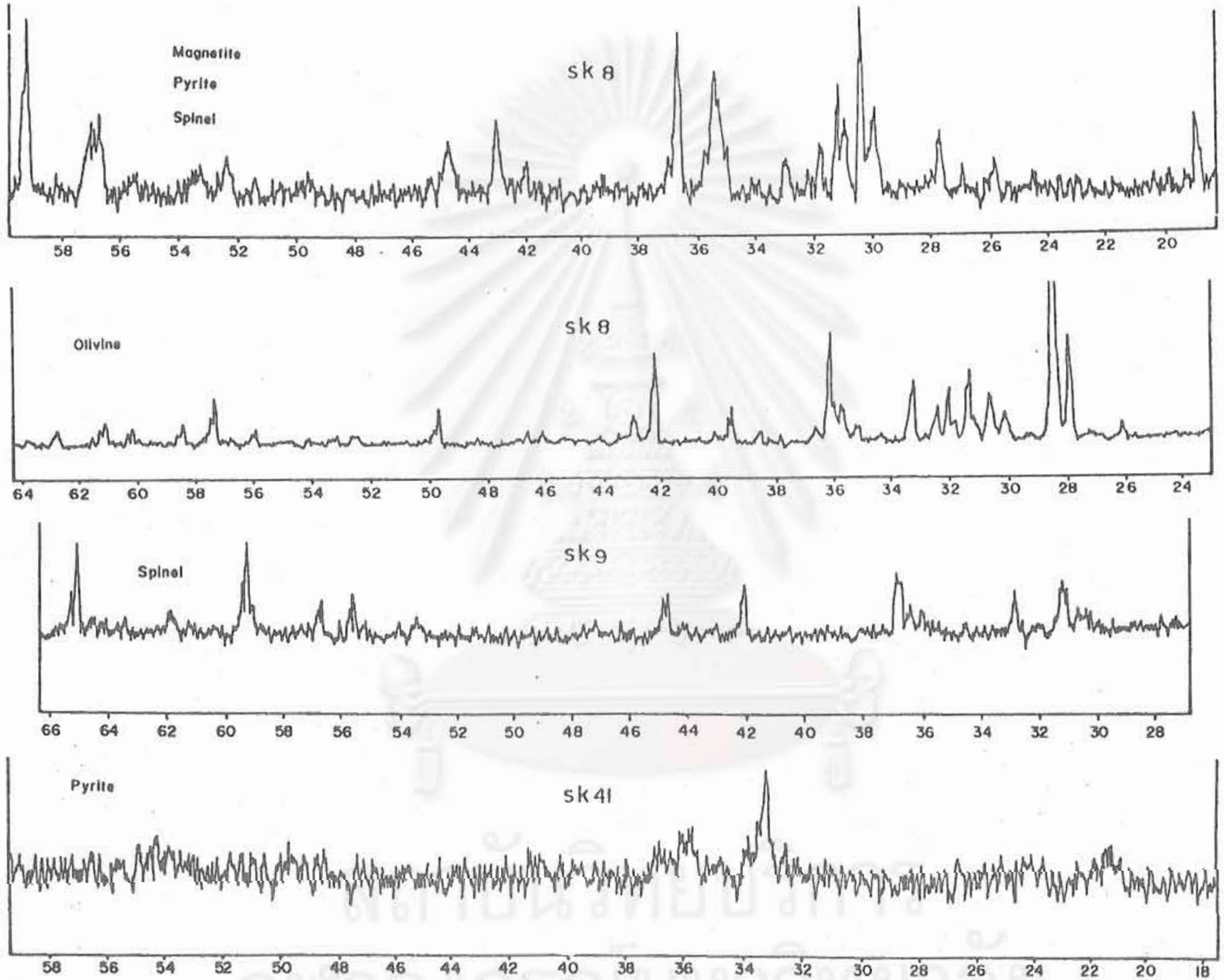
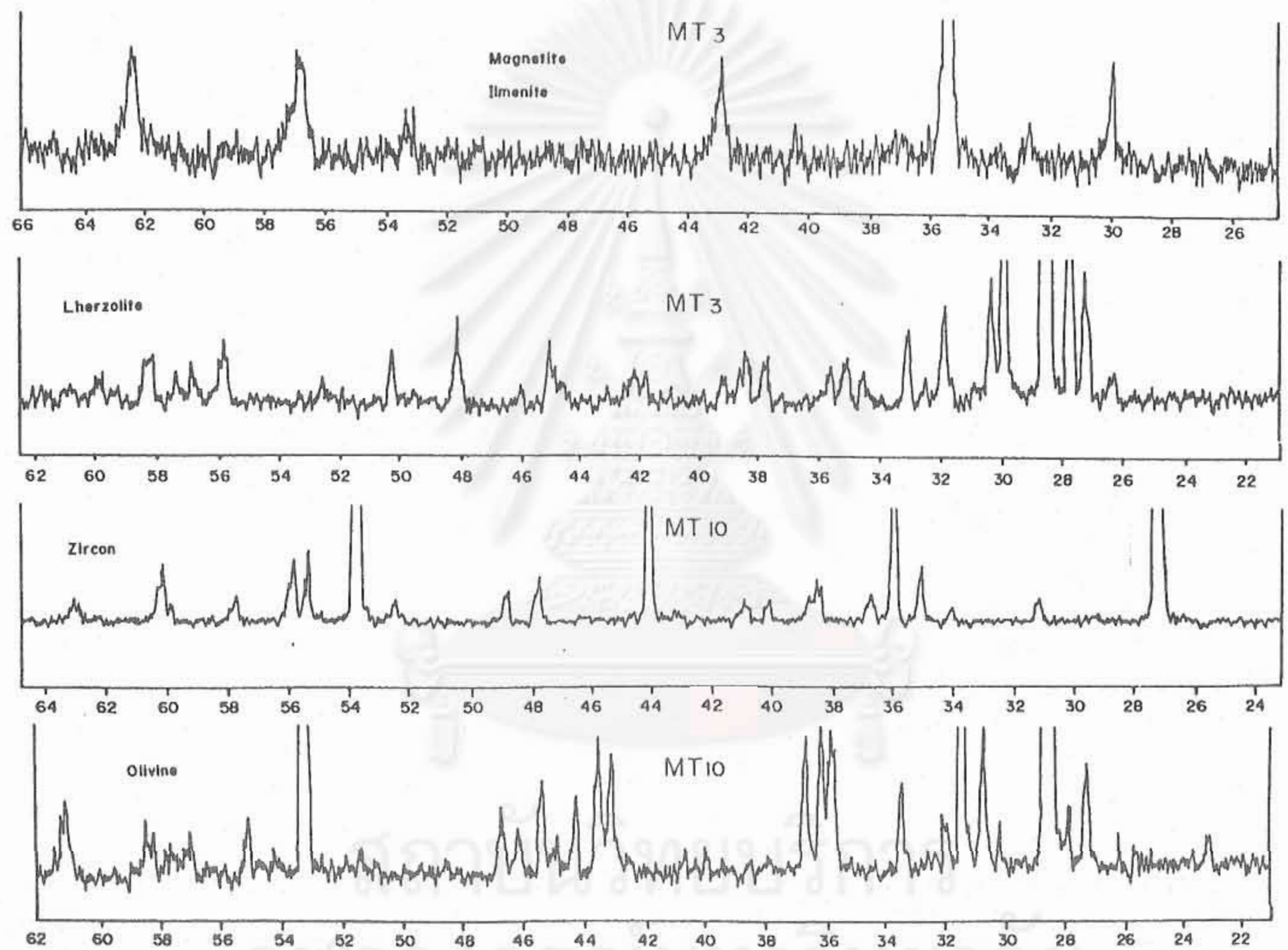
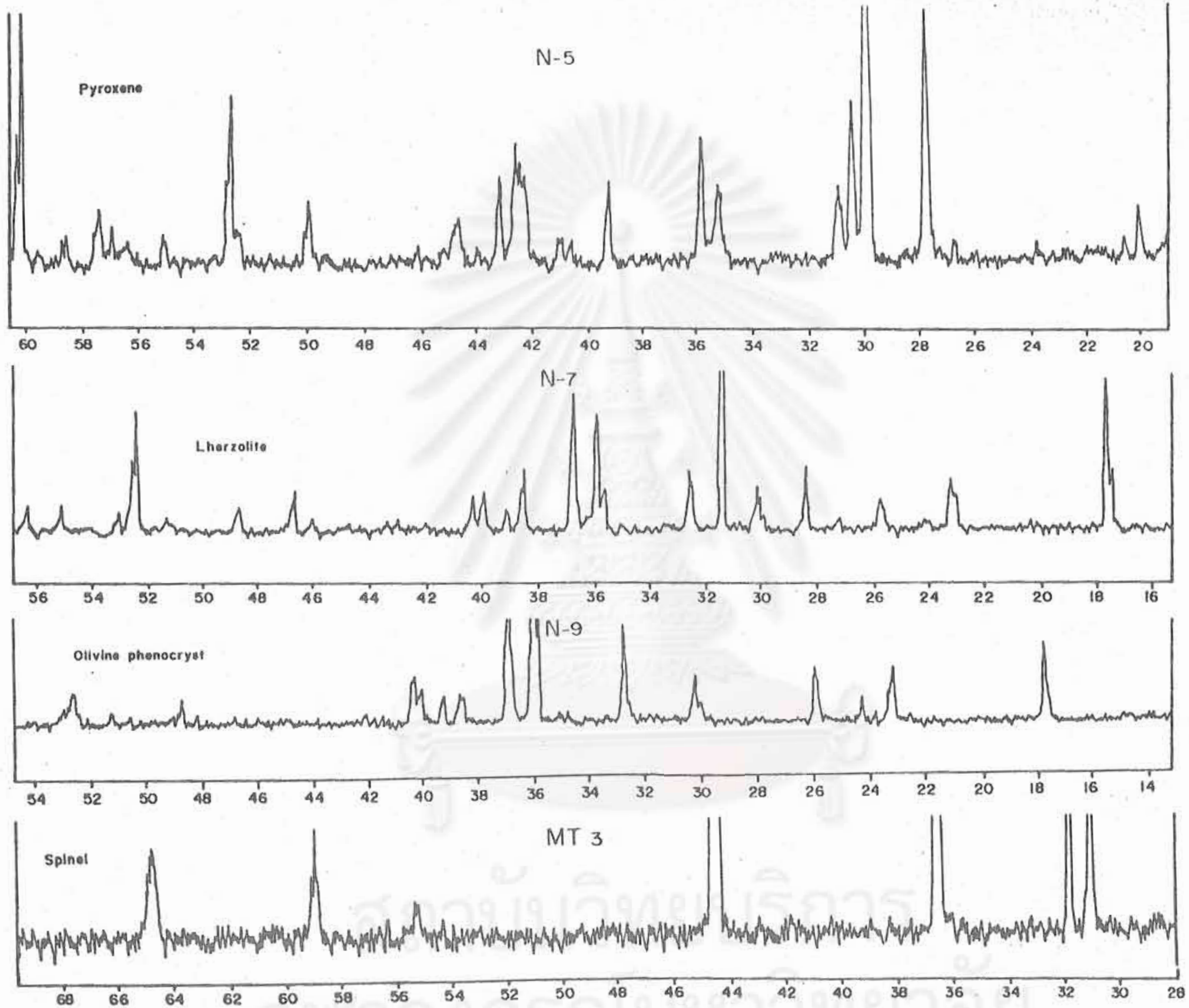

Magnetite
Pyrite
Spinel
sk 8
58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20
Olivine
sk 8
64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24
Spinel
sk 9
66 64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28
Pyrite
sk 41
58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18

Fig. C (cont.)


MT 3
Magnetite
Ilmenite
66 64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26
Lherzolite
MT 3
62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22
Zircon
MT 10
64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24
Olivine
MT 10
62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22


N-5
Pyroxene
60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20
N-7
Lherzolite
56 54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16
N-9
Olivine phenocryst
54 52 50 48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14
MT 3
Spinel
68 66 64 62 60 58 56 54 52 50 48 46 44 42 40 38 36 34 32 30 28