CHAPTER II

REVIEWS OF LATE CENOZOIC BASALTS IN MAINLAND SOUTHEAST ASIA

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 the 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 and more extensive (Fig. 2.1). Basalts of similar age also occur 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.

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

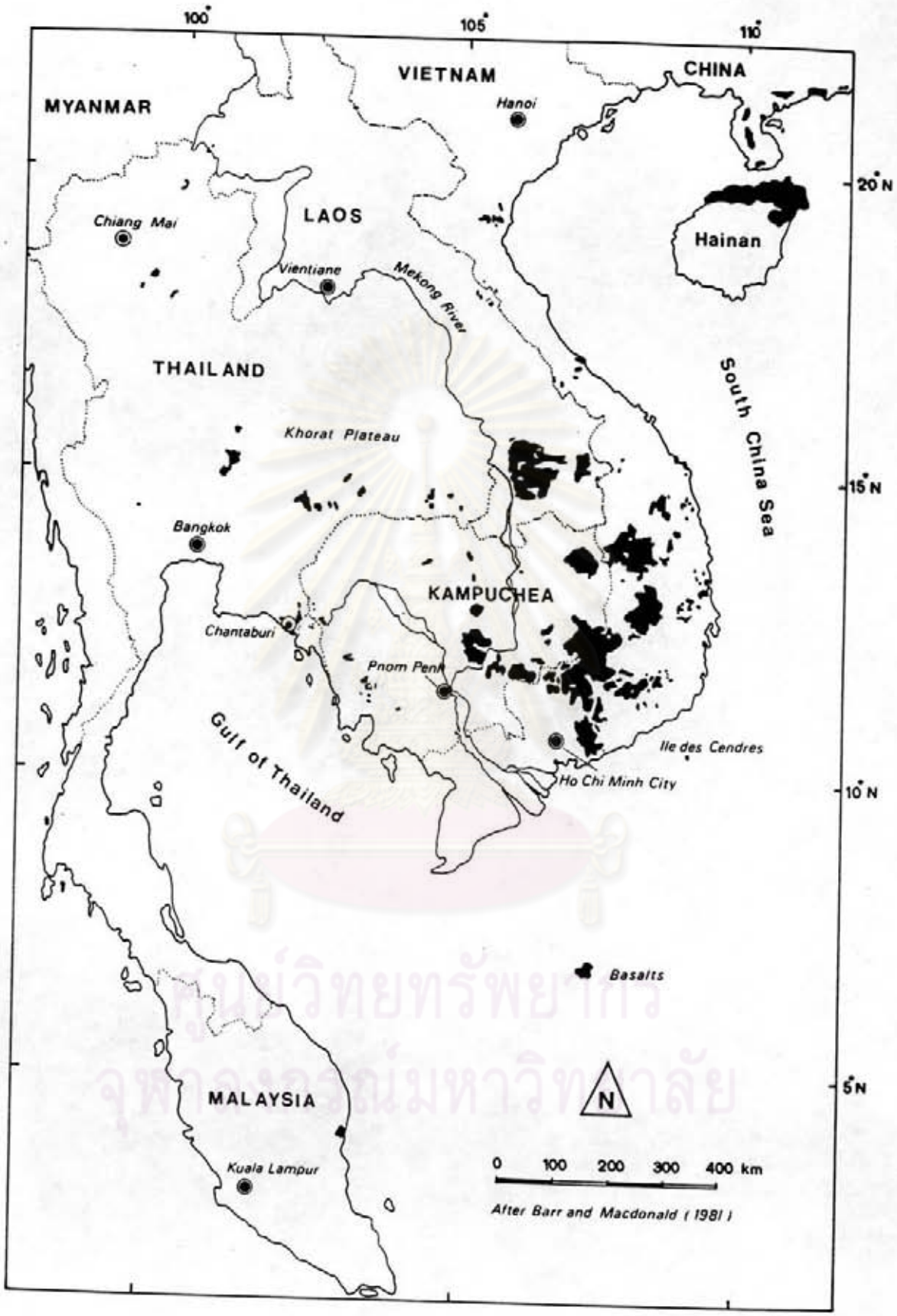

Fig.2.1. Map showing the distribution of Cenozoic basalts in parts of mainland Southeast Asia (after Barr and Macdonald, 1981).

age also occur in Malaysia and southern China (Fig. 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 will be presented in the next section.

Geology and Petrochemistry

A review paper was earlier performed by Barr and Macdonald (1981) regarding several aspects of Cenozoic basalts of Southeast Asia(Fig. 2.1). 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 into 10 areas (Fig. 2.1), based upon geographical locations as ; 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 Phloi area, Thailand, 8.) Khorat Plateau, Thailand, 9.) Northern Thailand, and 10.) Malaysian Peninsula. In addition, Cenozoic basalts of central Burma were also mentioned herein.

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 Fig. 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. 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.

3. Bolovens and Kasseng Plateaus

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 in nearby Kasseng Plateau (Hoffet,

1933a). Petrological data are not available for basalts of these plateaus. Zircons from the Bolovens Plateau were found to be geochemically similar to those from nearby Bokeo Plateau (Carbonnel et al., 1973). Age (1.36 ± 0.09 Ma) of basalts from this area is similar to that (1.29 ± 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.

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, 1969). Flows are largely covered by laterictic red earth. 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, 1969) 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). Chemical compositions of basalts range from tholeiitic to highly alkalic, they comprise tholeiites, hawaiites, mugearites, alkali olivine basalts, nepheline mugearites, nepheline hawaiites, and basanites.

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 basalt 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 ± 0.09 Ma. However, K/Ar age of 2.6 ± 0.2 Ma (Barr and Macdonald, 1981) from 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.

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 separate hills rising above the surrounding plain. Three of 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 ± 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 ± 0.13 Ma), O Chra (1.30 ± 0.17 Ma), and Phnum Ko Ngoap (1.43 ±0.10 and 1.42 ± 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 Chantaburi 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 ± 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 ± 0.02 Ma from the same area. Bignell and Snelling (1977) reported a K/Ar age of 8.5 ± 1.0 Ma for a basalt from Ko Kut island, south of Trat. Basalt from Tha Mai yielded a young K/Ar age of 0.44 ± 0.11 Ma. Whereas Sutthirat et al. (1994) reported a Ar/Ar age of 2.38 ± 0.16 Ma for basalt from Nong Bon, and 3.0 ± 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.

7. Bo Phloi area

Basalt at Bo Phloi 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 ± 0.17 Ma was reported by Barr and Macdonald (1981). Sutthirat et al. (1994) reported Ar/Ar age of 4.17±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.

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. Basalt from Khao Kradong, Burirum was reported to be 0.92 ± 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 ± 0.48 Ma (Barr and Macdonald, 1981). Basalt from Lam Narai was reported K/Ar age of 11.29 ± 0.64 Ma by Barr and Macdonald (1981), whereas Ar/Ar age of 18.1±0.7 Ma and 24.1±1.0 Ma were reported by Intasopa (1993). However Wichianburi basalts have yielded Ar/Ar ages of 8.82±0.09 Ma and 11.03±0.03 Ma (Sutthirat et al., 1994) and 9.08 ±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.

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 $\pm$ 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$\pm$0.3 and 0.6 $\pm$ 0.2 Ma are reported by Sasada et al. (1987) which are similar to the $^{40}Ar/^{39}Ar$ age of 0.59$\pm$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 Phloi 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.).

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.

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.

Gem - Bearing Basalts in Thailand

Distributions of late Cenozoic basalts are widespread in northern, eastern, and central Thailand (Fig. 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).

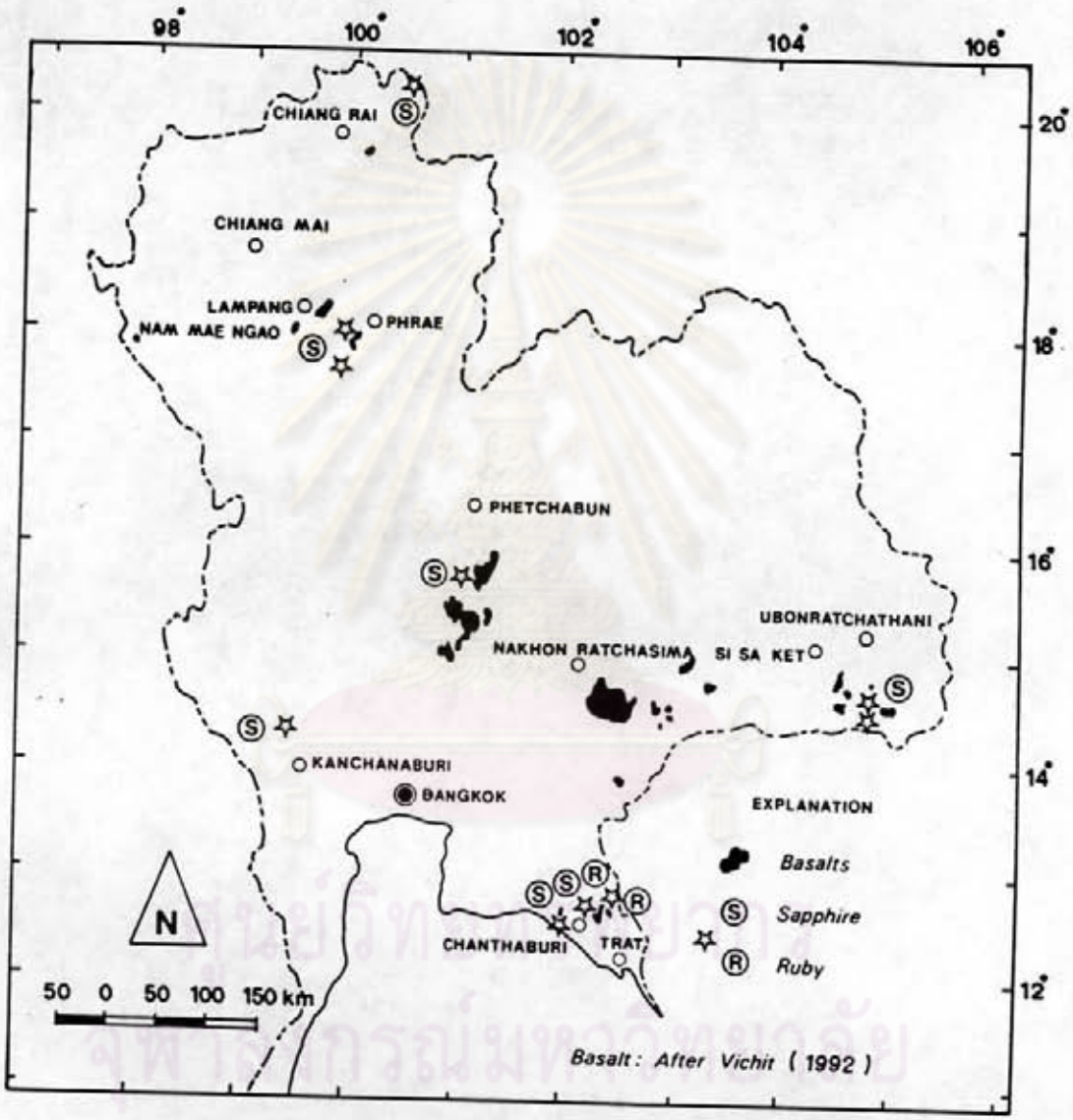

Fig.2.2. Map showing distribution of Cenozoic basalts and locations of ruby and sapphire deposits in Thailand (after Vichit, 1992).

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 Chantaburi-Trat area, Bo Ploi area, Phrae-Sukhothai area, Wichian Buri area, Ubon Ratchathani-Sri Sa Ket area, and Chiang Khong area. Distributions of basalts and corundum deposits in Thailand are presented in Fig. 2.2. The details of these basalts and gem deposits are described below.

1. Chantaburi - Trat area

Basalts of this area occur in Amphoe Klung, Amphoe Pong Nam Ron in Changwat Chantaburi, 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 $\pm$ 0.11 Ma for a basalt from KhaoPloi Waen area (Barr and Macdonald, 1981). The older age (3.0 $\pm$0.19 Ma) was reported for a basalt from Khao Wua using Ar/Ar dating method (Sutthirat et al., 1994) which is also in Khao Ploi Waen range. Fine-grained porphyritic hawaiite is suggested for basalts found in the northern part of this area at Ban Saphan Hin (Sirinawin, 1981) whereas the southern part is mainly occupied by gem-bearing basanite in Ban We Lu, Ban Ang Et and Ban I Ram (Jungyusuk and Sirinawin, 1983). The age of 2.57$\pm$ 0.2 Ma was obtained from a basalt sample from east of Chantaburi 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 ± 0.7 Ma was reported by Barr and Macdonald (1981) whereas $^{40}Ar/^{39}Ar$ age of 2.38 ± 0.16 Ma was determined by Sutthirat et al. (1994). Basalt from Ko Kut is as old as 8.5 ± 1.0 Ma and obtained from K/Ar method (Bingell and Snelling,1977).

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 Phloi, 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 ± 0.17 Ma (Barr and Macdonald, 1981), and $^{40}Ar/^{39}Ar$ age of 4.17±0.11 Ma is recently reported by Sutthirat et al. (1994). Aranyakanon (1988) suggests that the area of Bo Ploi 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.

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 $\pm$ 0.28 Ma (Barr and Macdonald, op. cit.).

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 dike crosscut this basaltic flow in many

locations. This basalt can be geochemically classified as alkali basalts, 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 ± 0.29 Ma (Intasopa, 1993), 8.82±0.09 Ma and 11.03 ± 0.03 Ma (Sutthirat et al., 1994).

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 characterized by dark grey rocks 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 ± 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).

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, 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 $\pm$ 0.12 Ma was obtained by K/Ar method (Barr and Macdonald, 1981). Gem-quality corundum has been mined only in Laos.

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 Ploi (Kanchanaburi)		3.14 ± 0.17[A]	4.17± 0.11[F]	
8. Khao Kradong (Burirum)		0.92 ± 0.3[A]		
9. Phu Fai		3.28 ± 0.48[A]		
10. E. Chantaburi	2.57 ± 0.2[C]			
11. Khao Ploi Waen (Chantaburi)		0.44 ± 0.11[A]		
12. Khao Wua (Chantaburi)			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)

1. Late Oligocene Episode (22 - 24 Ma)

The probable oldest Cenozoic basaltic rocks were in Lopburi area. The Ar/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 at 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 basalt of the Epoch were encountered.

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 by Intasopa (1993) using $^{40}Ar/^{39}Ar$ method, was Early Miocene (18-20 Ma). Again no gem-bearing volcanism has been reported yet.

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, basalt from the Phitsanulok basin was dated at 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).

4. Early Pliocene Episode (4 - 5.3 Ma)

This episode of basaltic volcanism took place during 5.3 to 4 Ma (Early Miocene). This event was evident from dated basalts at Chantaburi-Trat 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.

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 and Trat. 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.

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).