CHAPTER VI

DISCUSSION

In this chapter, the 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 settings. Detailed discussion of individual topics are described below.

Geologic Setting

As indicated in Chapter 3 that both the Nam Cho and the Sop Prab - Ko Kha basalts lie sharply over the Triassic Lampang rock units, suggesting that these two suites are at least younger in ages than the Triassic. In fact field evidence also indicates that there are more than two localities where these basalts have flown over the Cenozoic gravel deposits (see Figs. 3.4 and 3.5). This further implies that the basalts from both areas, especially that of the Sop Prab-Ko Kha area, are quite young. However, it is not certainly known that the covered gravel beds are formed either in Tertiary or as young as in Quaternary.

From the above mentioned evidences along with the very recent geochronological result from the Ar/Ar dating approach (av. 2.5 Ma, Farrar and Langidg, per. comm., 1995), it is quite possible that these two basalts may have occurred during Late Pliocene, which is equivalent to the fifth episode of Cenozoic basaltic volcanism in Thailand proposed by Sutthirat et al. (1994).

In the median areas where extensive outpouring of basalts is dominated, then exists a N-S trending mojor 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 scenario 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.

During Early Tertiary the other collision event (Shang-Thai / Western Burma) had reactivated the hibernated active zone to live and result in development of fractures and faults to last 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 rocks in the study area. It is inferred, from field evidence, that both basaltic suites may have occurred as subaerial volcanism rather than subaqueous one.

Gem-Bearing and -Barren Basalts

Several workers (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 for these two basaltic areas. 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 rocks (northern and southern areas) have not formed from the cogenetic magmas. If based solely upon the gem occurrences, the Nam Cho basalt is regarded more gem-related, whereas the Sop Prab - Ko Kha is not likely. However, gems found in some pits within the Sop Prab - Ko Kha area, probably suggesting that thin veneer layer of the Nam Cho basalt had once existed on top of the Sop Prab-Ko Kha basalt and was later completely eroded away, or parts of high aluminous sediments of Tertiary or Quaternary ages have been metamorphosed thermally by the Sop Prab-Ko Kha basalt to obtain high temperature product of corundum.

Field evidences have reveal that the lherzolite xenoliths are present abundantly in the Nam Cho basalt and being absent in the Sop Prab - Ko Kha basalt. Normative proportion of plagioclase [100An/(Ab+An)] versus normative of hypersthene or nepheline (see Fig. 6.1) shows very significant scheme for distinguishing the Nam Cho basalt from the Sop Prab - Ko Kha basalt. 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 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. The author's study well confirmed with those of Vichit et al. (1978) and Jungyusuk and Khositanont (1992) who both suggested that corundum-related basalts in Thailand always comprise dunite-peridotite xenoliths 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 those of the Sop Prab - Ko Kha are not.

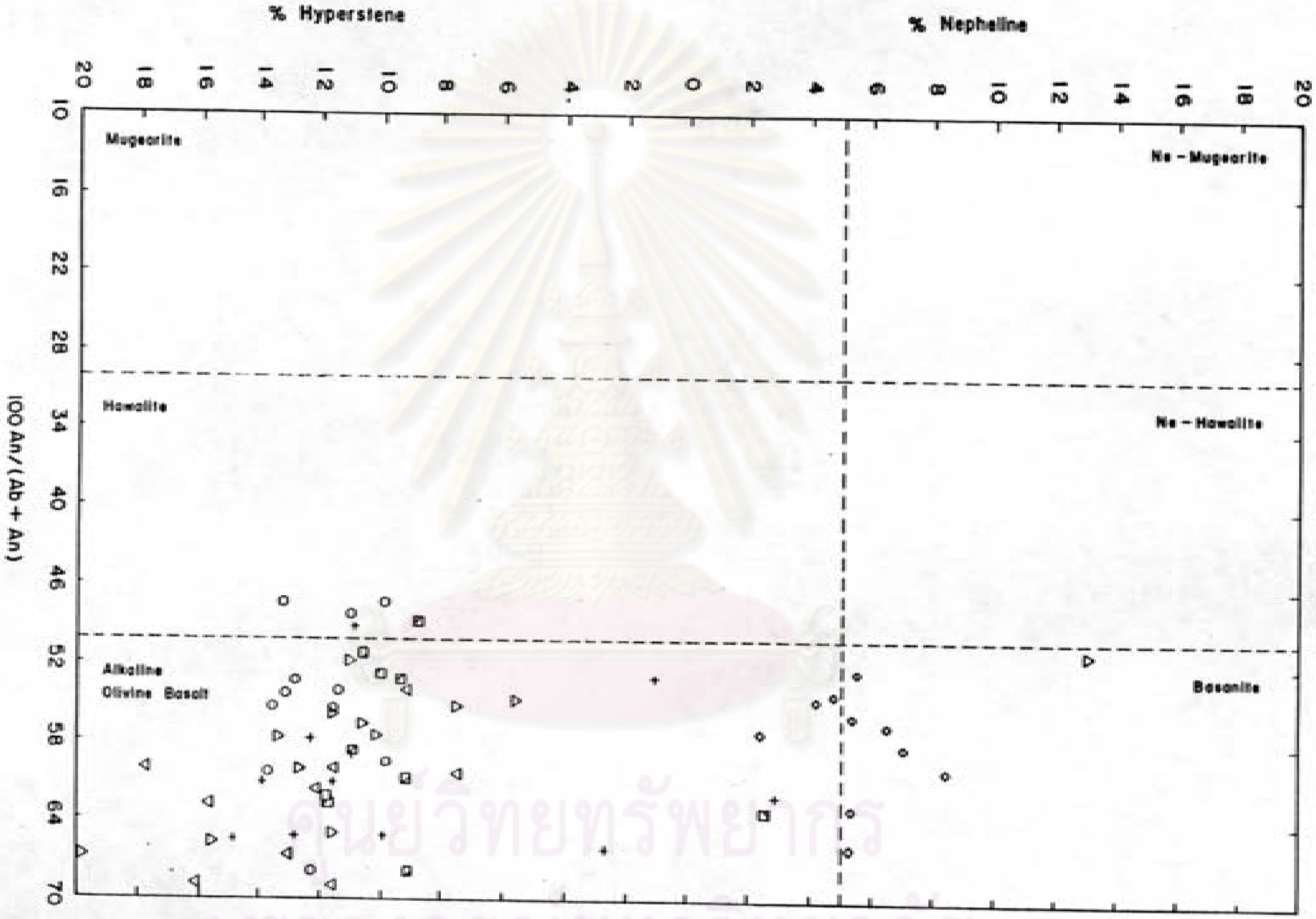


Fig.6.1. Plot of normative hyperstene or nepheline against normative plagioclase composition for the Nam Cho and the Sop Prab-Ko Kha basalts (fields from Barr and Macdonald, 1981).

Petrogenetic Model

Most flows of the Sop Prab - Ko Kha basalt bear general similarity in their mineralogy and texture, which are considerably different from those of the Nam Cho basalt. Petrographic evidences imply that both basalts are of alkaline affinity, but however, the Nam Cho is stronger alkalic. These include the presence of fine-grained, olivine phenocrysts, the rarity or absence of orthopyroxene, the less appearance of plagioclase phenocrysts, the common intergranular to subophitic texture, the abundance of Ca-rich clinopyroxene in groundmass.

Geochemical results also strongly support that the Nam Cho and the Sop Prab - Ko Kha basalts 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 (Fig. 5.8) indicates that these two basalts are clustered in the high Al basalt field. Several trace-element bivariate plots such as Ti versus Zr, and variation triangular multielement diagram as Ti-Zr-Y, indicate that basalts of these two areas are identified as within-plate basalts (see details in next section : 6.3). Field evidence suggests that subaerial volcanism is more likely, implying that these basalts are of continental volcanic type, not oceanic volcanic affinity.

Since 1950s, the idea of partial melting of the upper mantle materials and give rise to basaltic magmas has been universally accepted. The upper mantle is referred to be inhomogeneity in composition. It varies im its mineral assemblages according with depth or pressure and it varies in its chemical composition, especially those of trace element, according to the geotectonic environments. Basaltic rocks may have been formed from the primary magma or from derivative magma. Furthermore, its composition varies in wide range starting from strongly undersaturated alkalic to oversaturated. It has been generally agreed that the highly alkali basalt is supposedly generated at higher depth in the upper mantle or by lower degree of partial melting (Green and Ringwood, 1967, Hess and Poldervaart, 1968, and Wilson, 1989). If this principle is brought about to apply in the study area it would clearly seen that the Nam Cho basalt, the stronger in alkalinity, would have generated at deeper depth in the upper mantle or by lower degree of partial melting from source materials than the Sop Prab -Ko Kha basalt would. Furthermore, abundances of peridotitic nodule especially spinel-lherzolite incorporated in the Nam Cho basalt would possibly indicate that basaltic magma was at depth not greater than 75 km or equivalent of 25 kb when the nodules were added.

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 (Fig. 6.2) after Jaques and Green (1980).

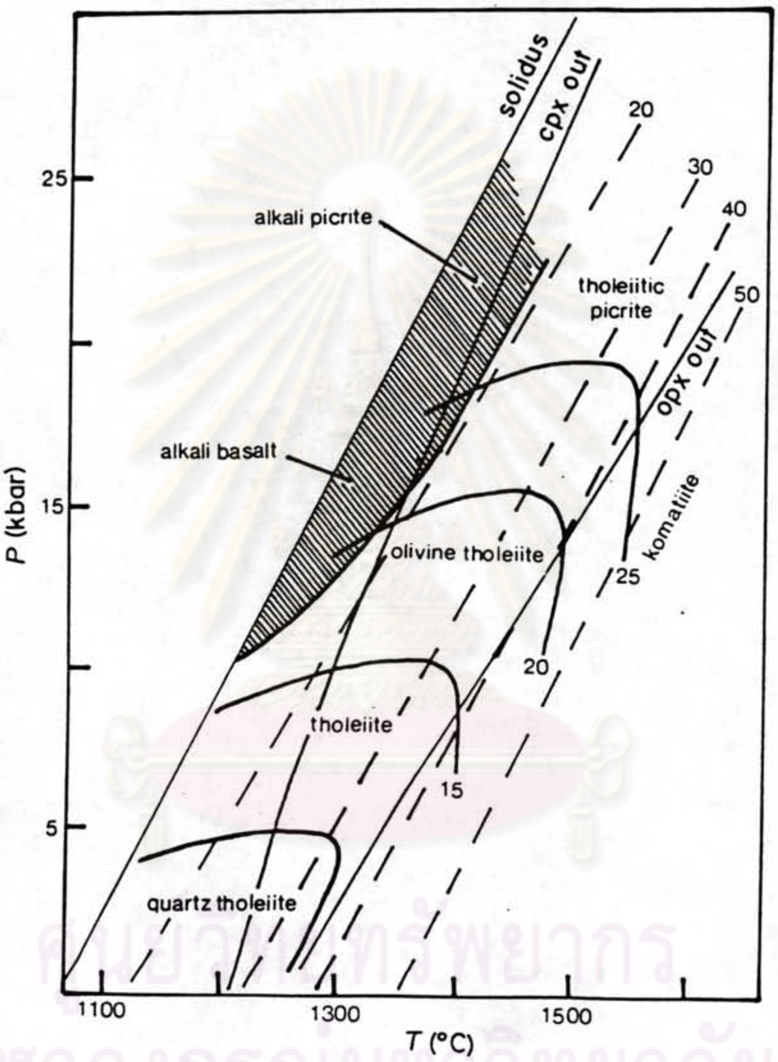


Fig.6.2. Experimentally determined partial melting characteristic of an enriched lherzolite source (after Jaques and Green, 1980).

Rare earth element (see Figs. 5.11 to 5.16) informations favour that basalts of both areas have been evolved from similar process. However, when compared to the standard diagram (see Rollinson, 1993) in Fig. 6.3, it is observed that both basaltic rocks experience small degree of partial melting, which, in this case, fits fairly well with the 2 to 5 % trend.

Tectonic Settings

As stated above both the Nam Cho and the Sop Prab - Ko Kha basalts 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 Pliocene.

Actually it is clearly 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 by 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 suites. These diagrams are collectively called "tectonomagmatic discrimination diagrams".

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

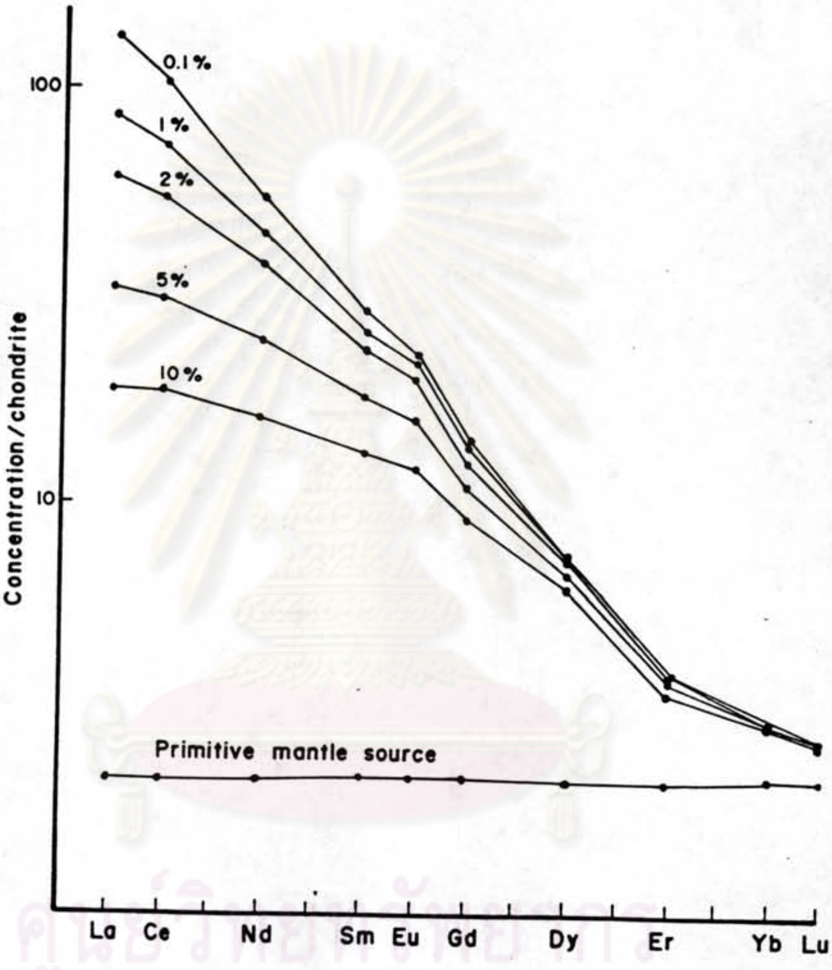


Fig.6.3. Chondrite normalized patterns from calculating model of ranging in degree of partial melting (Rollinson, 1993).

1) The diagram which utilize relatively immobile trace and minor elements. These diagrams are shown in Figs. 6.4 and 6.5. The ternary plots of Ti/100-Zr-Y*3 (Fig. 6.5) and Nb*2-Zr/4-Y (Fig. 6.4) both depict that the Sop Prab - Ko Kha (and Nam Cho) basaltic rocks are fallen in the within-plate basalt. It is also clear that with the expectation of some Nam Cho values, they definitely represent within-plate alkalic rather than within-plate tholeiite ;

2) The diagram which uses major and minor elements as discriminant parameter. Fig. 6.6 shows the values of TiO_2-MgO-P_2O_5*10(Mullen, 1983) for the basalts of the Nam Cho and the Sop Prab - Ko Kha areas, suggesting that all are assigned to be oceanic island alkalic ; and

3) The diagram which utilizes immobile trace elements (Fig. 6.7) shows log Ti versus log Zr plots (Pearce and Cann, 1973) of the Nam Cho and the Sop Prab - Ko Kha rocks, suggesting that these 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. Fig.6.8 depicts Zr/Y versus Zr values of the Nam Cho and the Sop Prab - Ko Kha basalts fallen within the within-plate basalts. According to Pearce (1982) the Ti/Y-Nb/Y diagram (shown in Fig. 6.9) successfully separates 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 Prab - Ko Kha rocks are plotted in the field of the within-plate basalts field, and with rather alkalic subfield.

Two types of continental within-plate basalts are recognized continental flood basalts and continental rift basalts (see Wilson, 1989). The diagram of Pearce (1982)

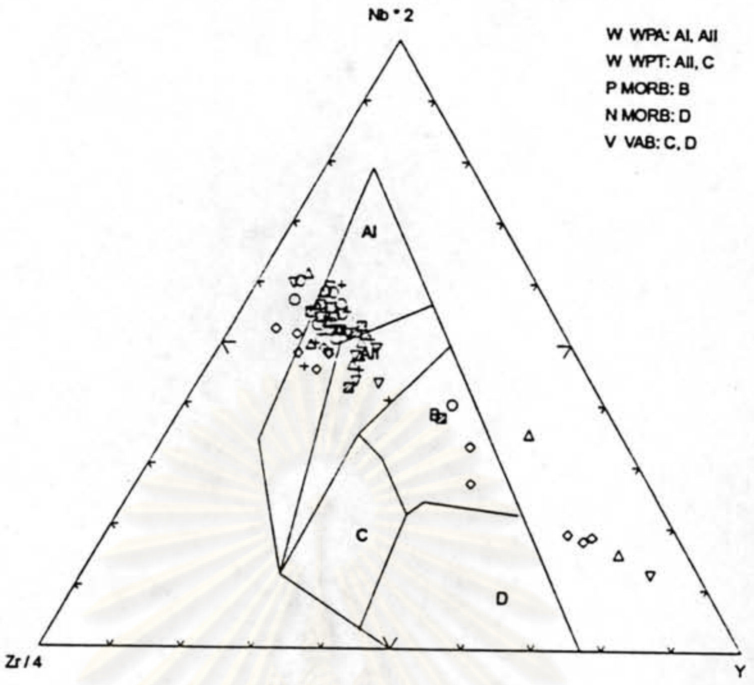


Fig.6.4. Ternary plot of Zr/4 - Nb*2 - Y of the Nam Cho and the Sop Prab-Ko Kha basalts (fields from Meschede, 1986) suggests that these basalt are mainly within plate alkaline and tholeiitic basalts.

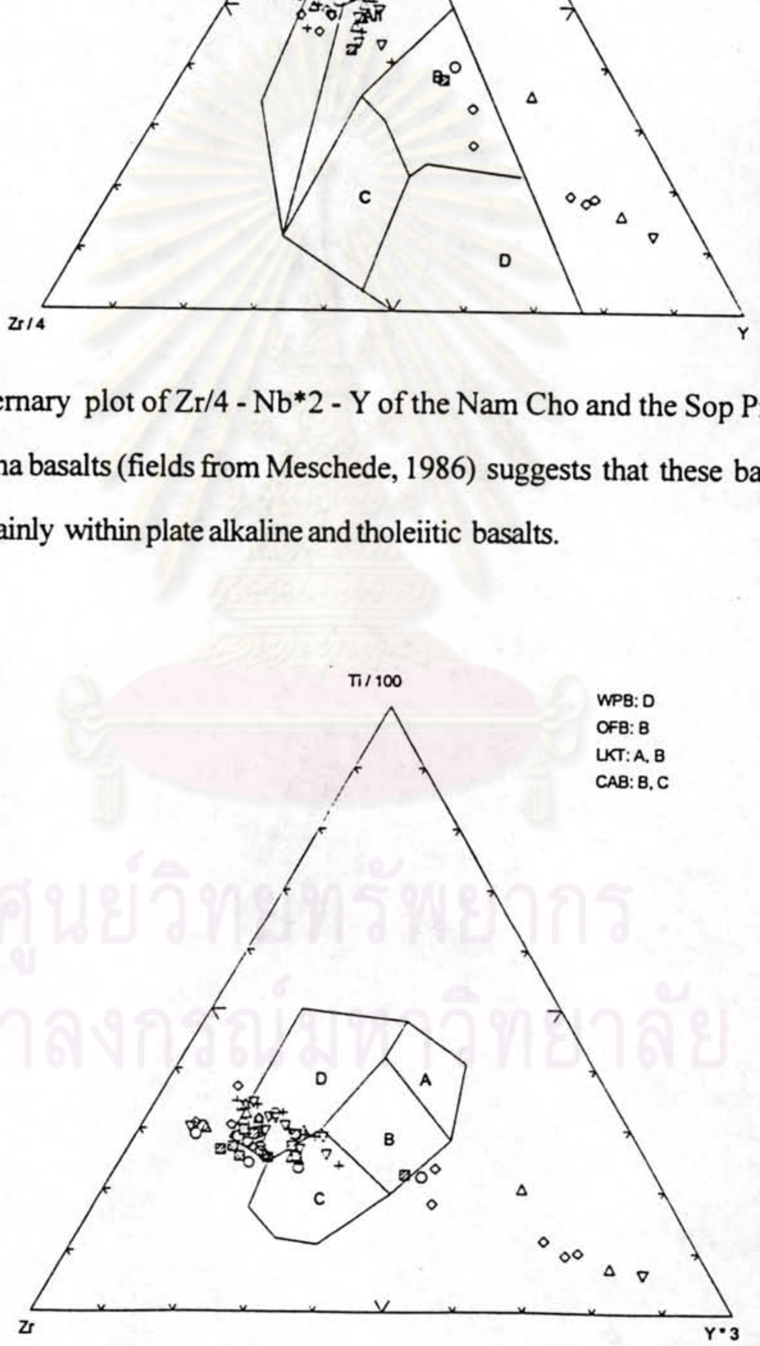


Fig.6.5. Zr - Ti/100 - Y*3 plot of basalts from the Nam Cho and the Sop Prab-Ko Kha areas (fields after Pearce and Cann, 1973).

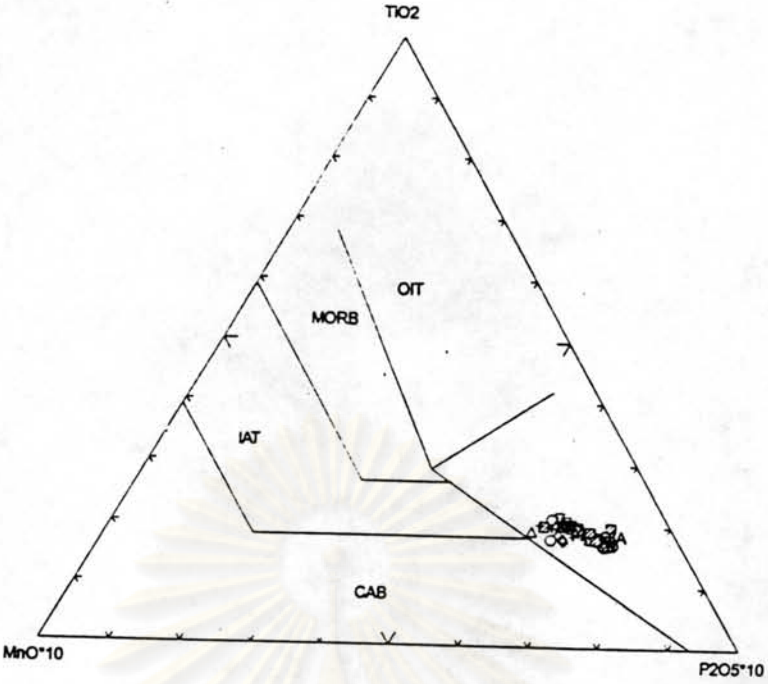


Fig.6.6. MnO*10 - TiO_2 - P_2O_5*10 variation diagram for the Nam Cho and the Sop Prab-Ko Kha basalts (fields after Mullen, 1983) show that these basalts are mainly plotted in ocean island alkaline field.

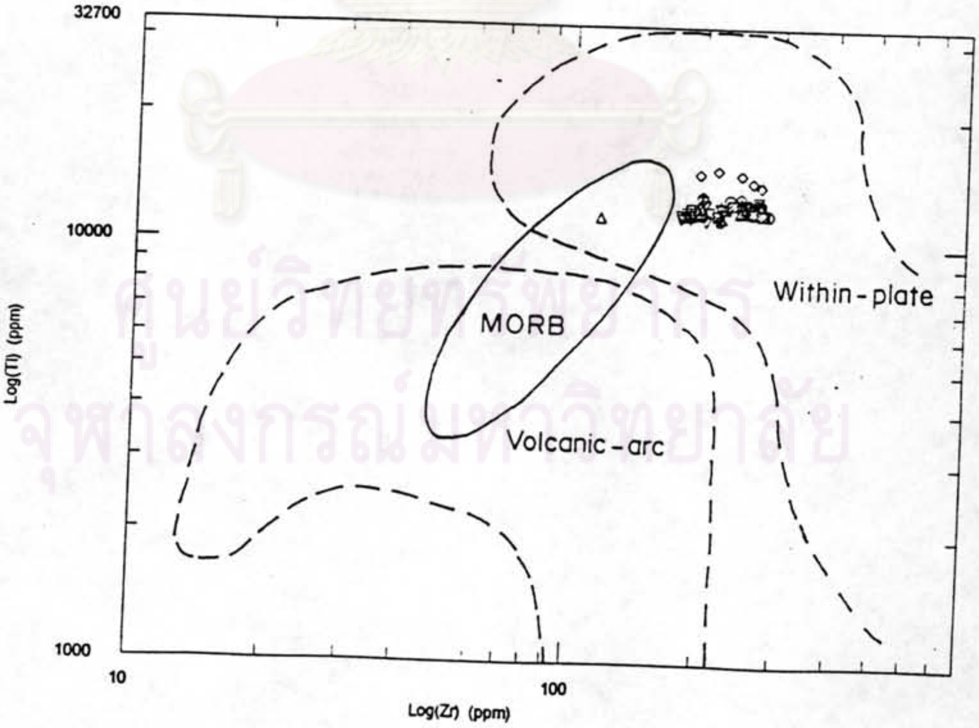


Fig.6.7. Variation diagram of log Ti versus log Zr for the Nam Cho and the Sop Prab-Ko Kha basalts (fields after Pearce and Cann, 1973).

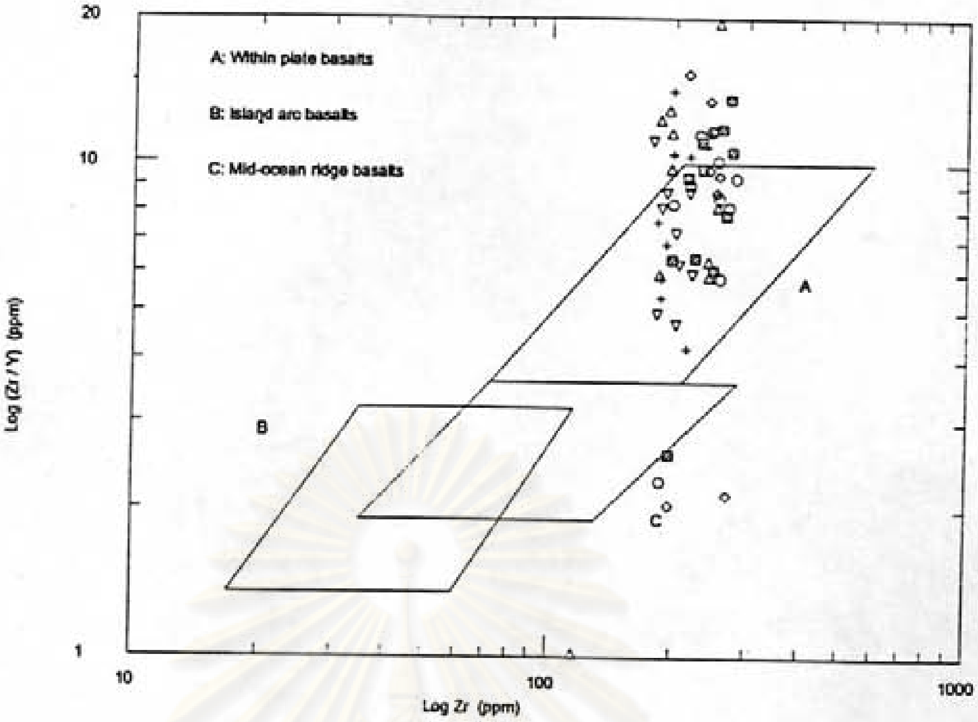


Fig.6.8. Plot of log (Zr/Y) against log Zr displays mainly within plate basalt of these sample plottings from the Nam Cho and the Sop Prab-Ko Kha basalts (fields after Pearce and Norry, 1979).

Fig.6.9. The log (Ti/Y) - log (Nb/Y) discrimination diagram for basalt plottings of the Nam Cho and the Sop Prab-Ko Kha areas (after 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 at several places do not plot in the within-plate tectonic setting.

Besides not only the SiO_2-K_2O plots of the Nam Cho and the Sop Prab - Ko Kha basalts indicate less crystal fractionation and less degree of partial melting, but also do the trace element ratios (Wilson, 1989) of Zr-Nb (Fig. 5.9) and Y/Nb-Zr/Nb (Fig. 5.10). Fig. 5.9 shows variation of Nb versus Zr (ppm) for basalts of the Sop Prab - Ko Kha and the Nam Cho, both basalts 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 regions.

Fig. 5.10 displays the variation of Y/Nb versus Zr/Nb for these two basaltic rocks. These basalts plot on an apparent mixing trend between an enriched component and a depleted MORB-source component, but populated and aligned closer to the enriched side. This provides a strong evidence for the role of asthenospheric or MORB-source mantle in the petrogenesis of these basaltic suite 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 of these petrogenesis of the Nam Cho and the Sop Prab -

Ko Kha basalts. The continental rift zone is defined herein as areas of localized lithospheric extension characterized by a central depression, uplifted flanks and a thinning of the underlying crust (after Wilson, 1989). High heat flow; 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.

According to Wilson (1989), two types of rifting are recognized based upon mechanism ; i.e., active rifting and passive rifting (Fig. 6.10), 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 upwelling plume is responsible for the initiation of a rift (active model), then the magma may be generated from oceanic island basalts (OIB) source mantle within the plume (Fig. 6.11) 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 basalts.

Therefore, it is quite essential to note that the first tectonic phenomenon was crustal downwarping, forming a protro-rift depression (as the formation of syncline for the studied area), implying that the lithospheric stretching (passive model) such is the prime fractor in the initial stage of rift development. As a consequence of stretching asthenospheric upwelling occurs, causing heating to the lithospheric plate, and crustal

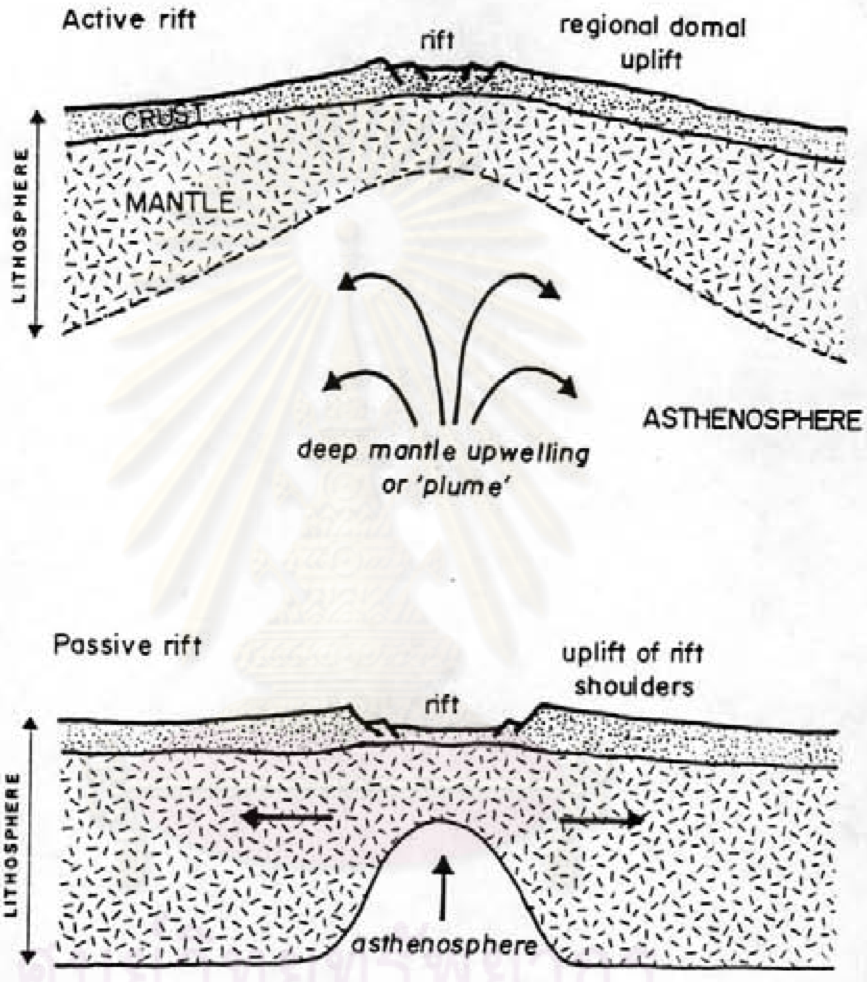
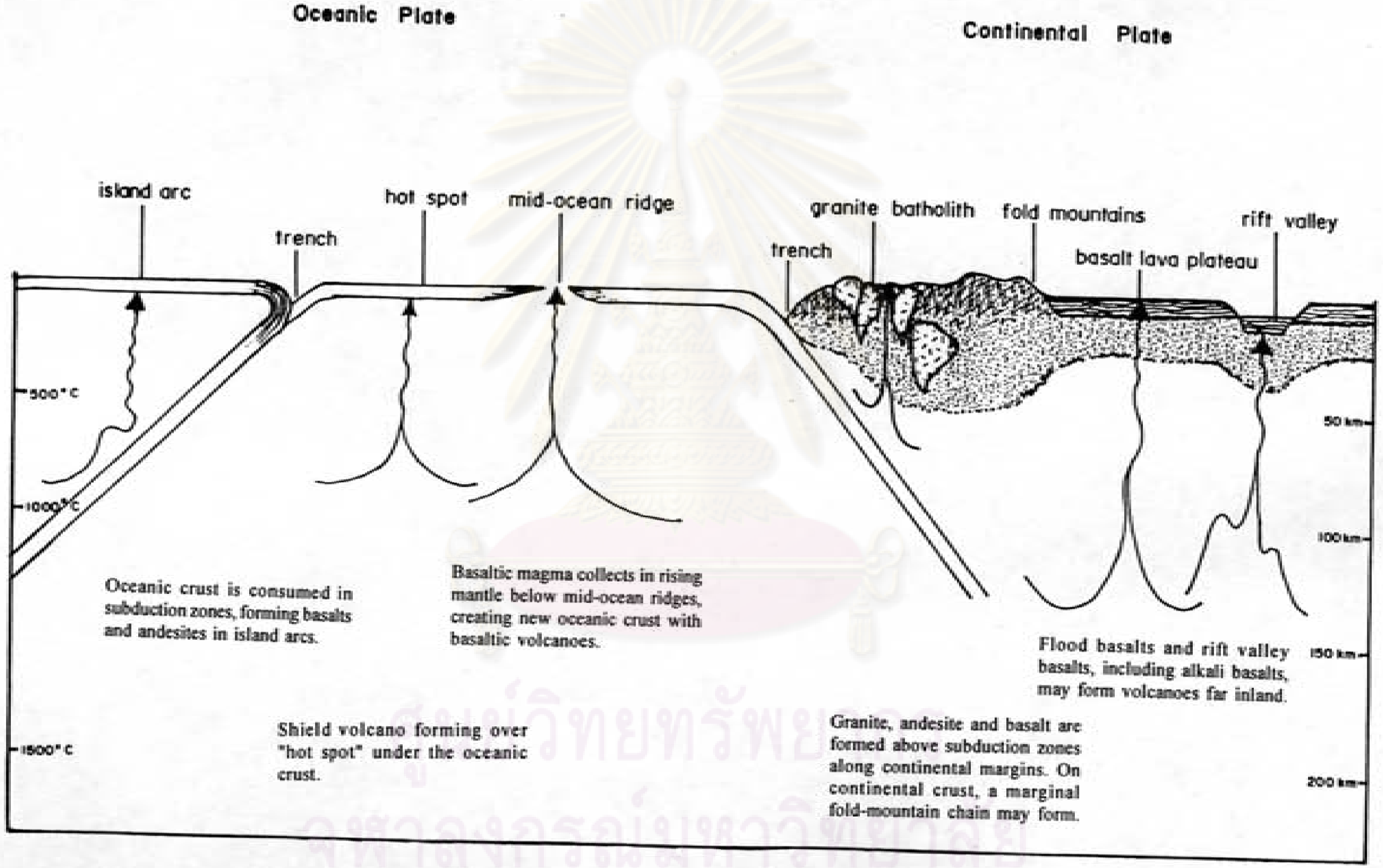


Fig.6.10. Active versus passive rifting models (after Keen, 1985).



Oceanic crust is consumed in subduction zones, forming basalts and andesites in island arcs.

Basaltic magma collects in rising mantle below mid-ocean ridges, creating new oceanic crust with basaltic volcanoes.

Flood basalts and rift valley basalts, including alkali basalts, may form volcanoes far inland.

Shield volcano forming over "hot spot" under the oceanic crust.

Granite, andesite and basalt are formed above subduction zones along continental margins. On continental crust, a marginal fold-mountain chain may form.

Fig.6.12. Distribution of major mantle source components in relation to sites of continental and oceanic volcanism (after the Institute of Geological Sciences of England, 1974).

doming. Thus, it may be reliable, as similar to the recent studies (see Mohr, 1982 and Almond, 1986), that the rift evolved from a passive phase to an active phase. In summary, the simplistic model for the evolution of the basalts of the Nam Cho and the Sop Prab - Ko Kha areas are deciphered in Fig. 6.12.

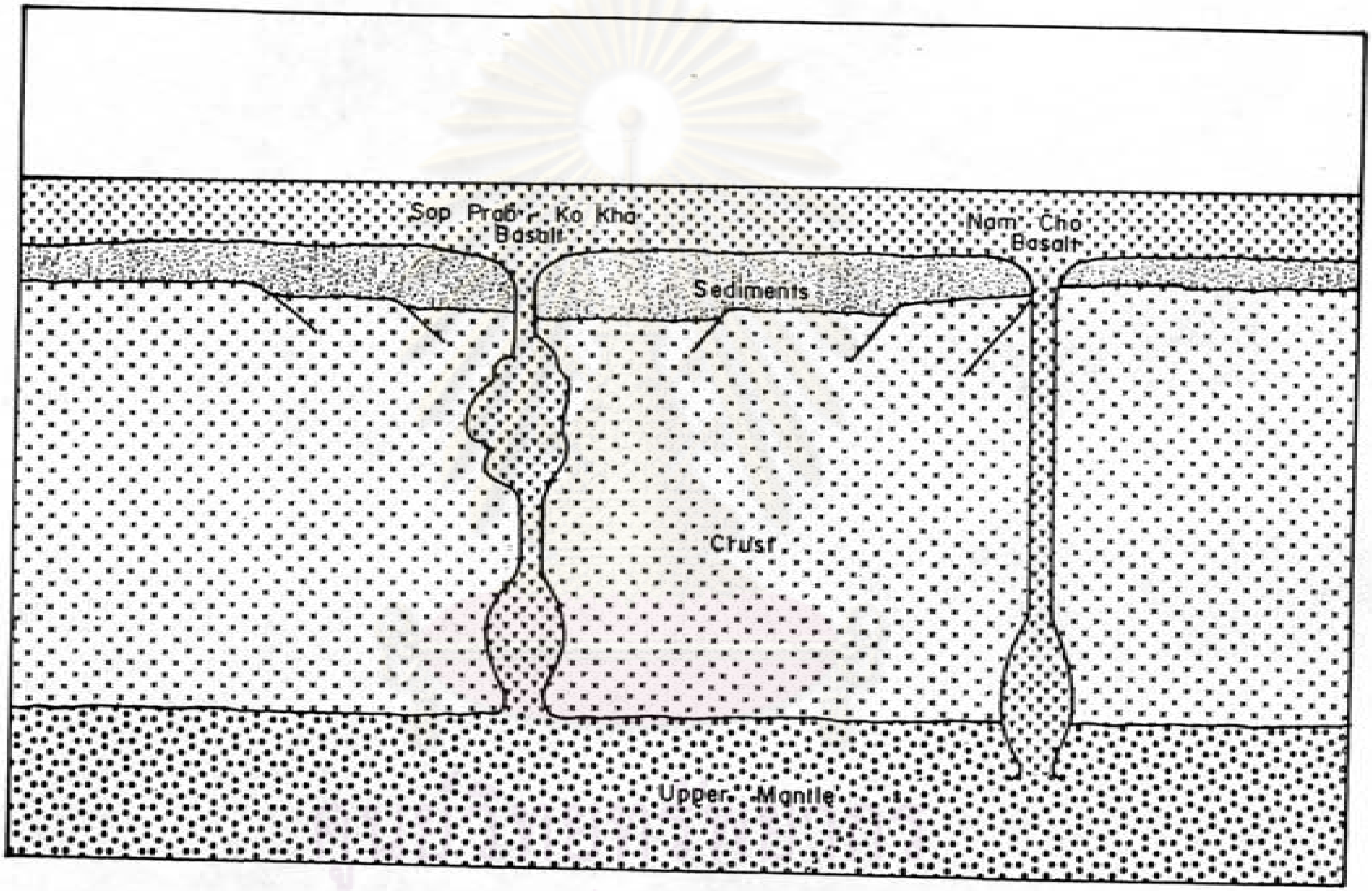


Fig.6.12. The simplified petrogenetic model of the Nam Cho basalt and the Sop Prab-Ko Kha basalt.

CHAPTER VII

CONCLUSION

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

2. Field and recent data on geochronological analysis indicate that these two basaltic rocks are quite young and the age is inferred to be ca. 2.0-2.8 Ma (Late Pliocene) equivalent to the fifth episode of Cenozoic volcanism in Thailand.

3. Petrologically, the Sop Prab - Ko Kha basalt which consists of five flow layers display similar mineralogy and texture but they are moderately different from the Nam Cho basalt. The Nam Cho basalt is always composed of spinel-lherzolite nodules and megacrysts (and large phenocrysts) of olivine and pyroxene.

4. Geochemically, the Nam Cho basalt is indicated to be gem-related rock, but the Sop Prab - Ko Kha basalt is classed as gem-barren rock.

5. The basalts of both areas were probably originated from primary magma, evolved by similar process of low degree of partial melting of upper mantle source region. However, the Nam Cho basalt was probably derived from the greater depth.

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

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