CHAPTER 5

PETROGENESIS

5.1 Primary Magma vs Derivative Magma

It is generally accepted that most basaltic magmas are generated by variable degrees of partial melting of mantle peridotites at different depths. These peridotites are constituted mainly by olivine, orthopyroxene and clinopyroxene, i.e. lherzolite, with minor other aluminous phases, e.g. plagioclase, spinel or garnet. The magmas equilibrated with the peridotite mineralogies, known as primary magma, may ascend rapidly to the earth's surface or undergo fractional crystallization at depths, giving rise to derivative magmas. The primary compositions of these magmas may be modified by wall-rock assimilation/contamination or magma mixing during uprising. Consequently, it is crucial to thoroughly consider whether the Mae Tha basaltic magmas, particularly the most primitive ones, are primary or derivative.

Criteria commonly utilized for recognition of primary basaltic magma that formed by partial melting of normal peridotite mantle include mg# and abundances of compatible elements in aphyric lavas and glassy rocks, and phenocryst assemblages in phyric lavas. The most important equilibrium constant pertinent to the process of partial melting of the upper mantle is the distribution coefficient expressed as molecular ratio of FeO/MgO in olivine to FeO/MgO in liquid (herein K_D^{OL-LIQ}). Many experimental studies show that the value for K_D^{OL-LIQ} is 0.30 ± 0.03 (e.g. Roeder and Emslie, 1970; Grove *et al.*, 1973). This value is independent on temperature but slightly increases with pressure. Assuming the $K_D^{OL-LIQ} = 0.33$ and the mg# of olivines in peridotitic assemblages = 0.86 - 0.90 corresponding to those in the undepleted upper mantle (Ringwood, 1966; Nicholls, 1967; Carter 1970), the values for mg# in the liquid equilibrated with olivines in the mantle have been calculated to be in a range of 0.60 - 0.70 (Irving and Green, 1976). In similar manner, Frey *et al.* (1978) proposed that primary basaltic magmas that are slightly modified by extensive crystal fractionation and/or crustal contamination should have high mg# (0.68 - 0.75) and high contents of compatible elements, such as Ni and Cr. As a consequence, Wilson (1989) summarized that the primary basaltic magmas derived from partial melting of upper mantle peridotites should have high values for mg# (≥ 0.70), Ni (> 400 - 500 ppm) and Cr (>1000 ppm), but low values for SiO_2 (<50 wt%). In case of phyric lavas, the primary basaltic magmas should contain olivine and orthopyroxene phenocrysts as indicated by experimental studies; clinopyroxene and other aluminous phases (plagioclase, garnet or spinel) may be present as additional phenocryst phases (Wilson, 1989; Hess, 1989).

Although the phenocryst phases in the rocks presented in this study were excluded during preparing samples for chemical analysis (see Section 3.1), the analyses do not represent the primary magma compositions since it is not easy to separate microphenocrysts and even some phenocrysts from the rocks. Keeping the porphyritic nature in mind and assuming that the analyses are analogous to magma compositions, the values for mg# (0.60 - 0.70), Ni (90 - 251 ppm) and Cr (128 - 329 ppm) of the Mae Tha alkalic lavas are too far below to be primary basaltic magma. In addition, as the REE patterns for Mae Tha basaltic lavas have chondrite-normalized La/Yb ratios of 11.47 - 12.86, garnet may occur as a residual phase in addition to olivine, orthopyroxene and clinopyroxene if the studied basaltic rocks represent primary liquids formed by partial melting of mantle lherzolite. The studied basaltic lavas, however, do not show such a phenocryst/microphenocryst assemblage, signifying that Mae Tha alkalic lavas cannot represent primary magmas but are derivative magmas.

5.2 Experimental Constraint

Judged from petrographic and geochemical characteristics (see Chapters 3 and 4), the Mae Tha basaltic lavas have experienced both fractional crystallization and crustal contamination, however, the former is the most predominant process. The order of crystallization of Mae Tha basaltic suite can be depicted as follows: olivine, chromian spinel, clinopyroxene and Fe-Ti oxide were the earliest phases to crystallize and then followed by plagioclase.

Extensive melting and crystallization experiments on bulk compositions of wide spectra of both basalts and mantle peridotites have been conducted by many petrologists. The results of these experiments generally form part of important constraints to discuss about petrogenesis. Experimentation on both depleted and enriched lherzolite source compositions (Fig. 42) shows that tholeiitic basalt magmas can be produced by moderate degrees of partial melting (20-30%) of either source at pressures below 15-20 kb (50-70 km depth). At higher pressures picritic liquids are generated at the same degrees of partial melting. Alkalic basaltic magmas appear to be generated by smaller degrees of partial melting (< 20%) of enriched sources at pressures greater than 10 kb (35 km depth), while liquids akin to peridotitic komatiites can be generated by 40-50% partial melting of a fertile lherzolite, or 30-40% partial melting of a depleted lherzolite. Therefore, the primary magma for the Mae Tha basalts might have been produced by small degrees of partial melting of either a fertile mantle or a mantle intermediate between depleted and fertile mantles at pressures greater than 10 kb. As the Mae Tha basalts have compositions intermediate between trachybasaltic and potassic basanitic series, the pressure-temperature conditions for generating these basalts can be simply explained by the petrogenetic scheme of Green (1971) as illustrated in Figure 43. Although this scheme has been formerly used for discussing the origin of mid-ocean ridge basalts, the existence of alkalic basalts at pressures greater than 10 kb implies that the starting material used in experiments has fertile mantle or mixed fertile and depleted mantle compositions. Accordingly, the primary magma for Mae Tha basalts might have been originated by small degrees (approximately 5%) of partial melting of a fertile mantle or mixed fertile and depleted mantles with a small content of water under pressures slightly greater than 10 kb. The residual mantle mineralogies in this case should be olivine, orthopyroxene, clinopyroxene and amphibole. The presence of amphibole in the residual mantle can account for the potassic nature of the Mae Tha alkalic basalt suite (e.g. Oxburgh, 1964; Green, 1971). The primary magma for Mae Tha alkalic basalts might have undergone

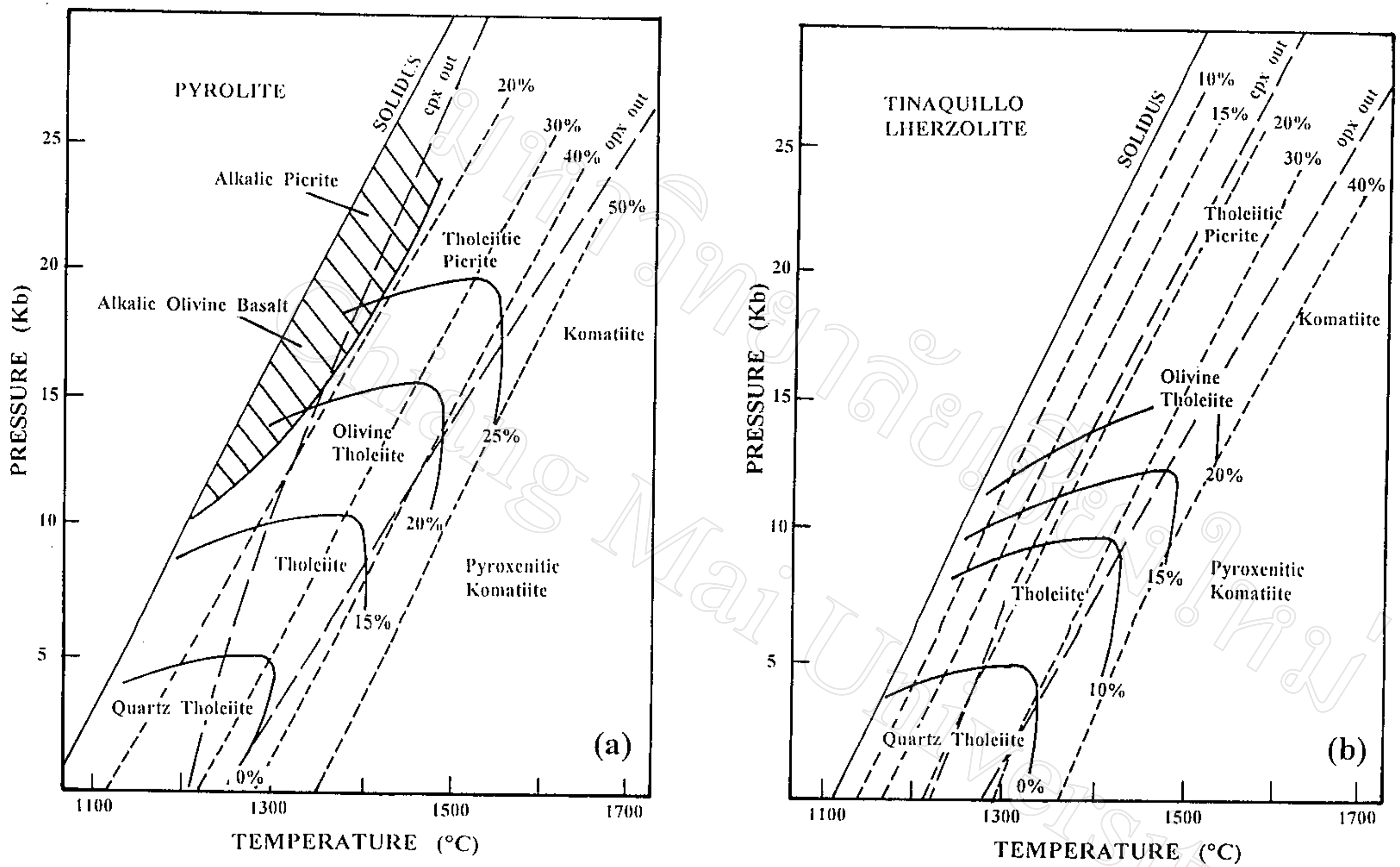

Figure 42 P-T diagrams for partial melting of (a) pyrolite (enriched mantle source) and (b) Tinaquillo lherzolite (depleted mantle source). The curved contours indicate the normative content of olivine in the melt. Long-dashed lines indicate disappearance of residual phases (cpx = clinopyroxene, opx = orthopyroxene). Short-dashed lines indicate percentage of partial melting. The ruled area represents the conditions necessary for the generation of alkalic basaltic magma (after Jaques and Green, 1980).

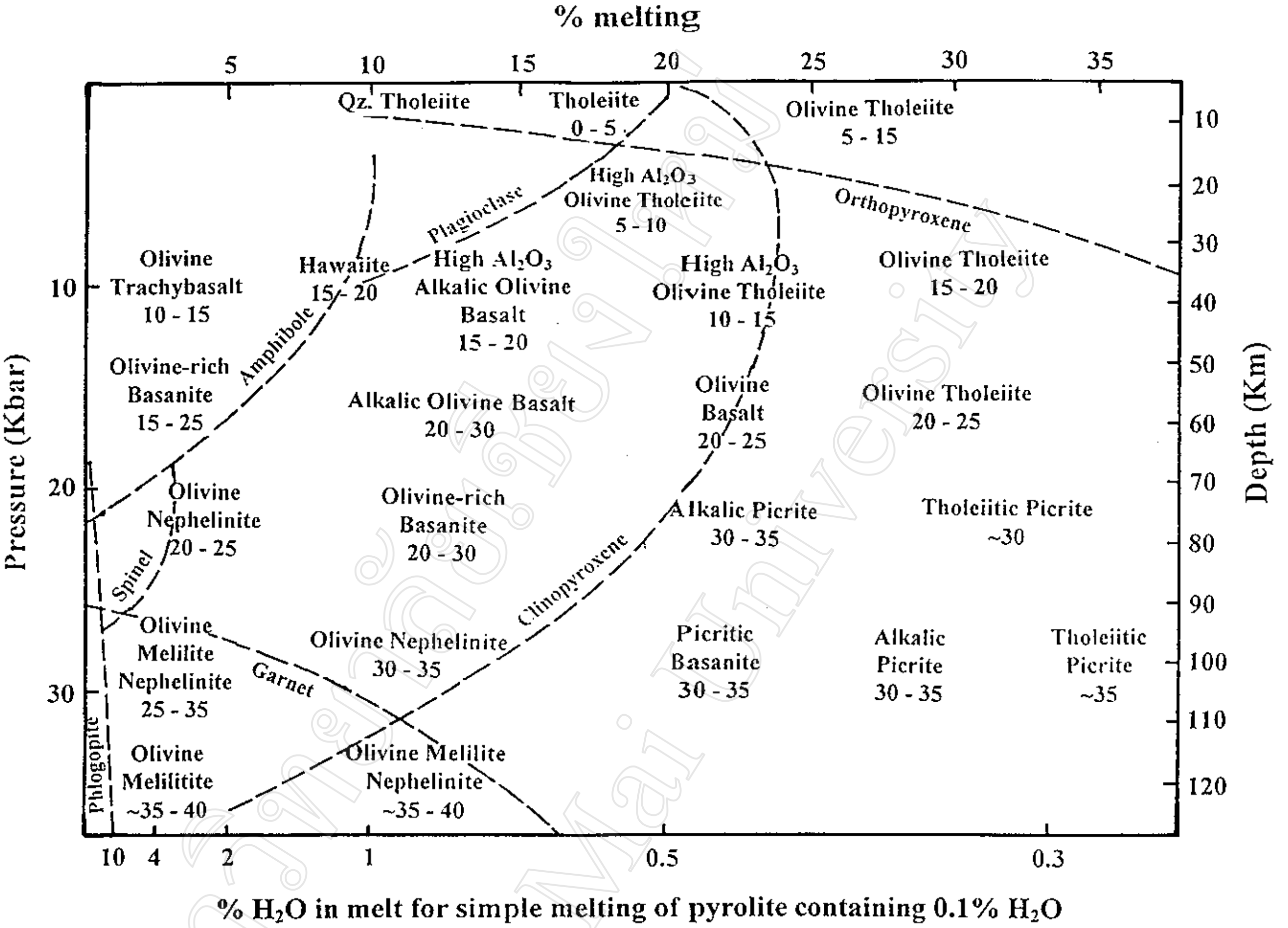

Figure 43 A petrogenetic grid for mantle-derived basalt magmas. Various basalt magma types are assigned to a % melt, pressure grid in which they are regarded as partial melting products of a pyrolite composition containing 0.1 % H_2O. The numbers placed with each basalt type refer to the normative olivine content of this liquid at its depth of origin. The dashed boundaries marked with a mineral name show that this mineral will occur among the residual phases remaining after extraction of magma types to the left of the boundary. Olivine is present in equilibrium, i.e. is a residual phase in the pyrolite composition, for all the magma types of this figure (after Green, 1971).

fractionation under a low-pressure regime to produce derivative liquids with chemical compositions corresponding to the Mae Tha alkalic basalts as the crystallization sequence for the Mae Tha basalts is very similar to those from anhydrous experiments of ocean-island picrobasalt at pressure 5 kb, i.e. 17-18 km depth (Fisk *et al.*, 1988).