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 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 magma. 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 basaltic magma of Thoeng suite, particularly the most primitive one, is 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 in the range of 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 assembalges = 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 0.66-0.75 (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 partal melting of upper mantle peridotites should have high values for mg# ($\geq$ 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 sample preparation for chemical analyses presented in this study excluded phenocryst phases (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 porphyritic nature in mind and assuming that the analyses are analogous to magma compostions, the values for mg# (0.41-0.57), and compatible Ni (41-175 ppm) and Cr (38-282 ppm) contents of the transitional tholeiitic lavas from Thoeng suite are far below those for primary basaltic magma. As the REE patterns for Thoeng basaltic lavas have chondrite-normalized La/Yb ratios of 3.3-8.2, there should be garnet 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. These evidences signify that Thoeng transitional tholeiitic 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 Thoeng basaltic lavas have experienced both fractional crystallization and crustal contamination, however, the former is the most predominant process. The order of crystallization of Thoeng basaltic suite can be depicted as follows: olivine and plagioclase were the earliest phases to crystallize and then followed by clinopyroxene and Fe-Ti oxide in respect manner. The crystallization sequence is similar to those of mid-ocean ridge tholeiite (Schilling *et al.*, 1983), transitional tholeiitic lava of continental rift zone (Barberi *et al.*, 1975) and many tholeiitic suites of ocean-island affinities (Hughes, 1982).

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 constraint to discuss about petrogenesis. The sequence of crystallization discussed above is consistent with those from anhydrous experiments of mid-ocean ridge basalts (e.g. Kushiro, 1973; Bender *et al.*, 1978; Green *et al.*, 1979; Grove and Bryan, 1983; Fujii and Bougault, 1983), ocean-island basalts (e.g. Yoder and Tilley, 1962) and continental flood basalts (e.g. Thompson, 1972) at pressures less than 10 kb, i.e. low-pressure regime. Assuming that the mantle source beneath Thoeng basaltic suite is an unmodified mantle, it is postulated that the parental magma for Thoeng derivative magmas might have been transitional tholeiitic magma with higher normative olivine content. According to the anhydrous petrogenetic scheme of Jaques and Green (1980), this parental magma could be primary magma directly formed by partial melting of fertile pyrolite mantle in a pressure range of 10-15 kb , i.e. moderate-pressure regime, with degrees of partial melting less than 20%, or derivative magma resulted from removal of olivine from transitional picritic liquid (Fig. 42a). The olivine fractionation in the latter case is more likely to take place at the crust-mantle boundary because the picritic liquid has higher density than the lower crust. As the near-solidus transition between spinel peridotite and garnet peridotite is experimentally placed at a pressure range of about 25-27 kb (e.g. Ito and Kennedy, 1967; Green and Ringwood, 1967; Takahashi and Kushiro, 1983), the primary transitional tholeiitic magma is stuck

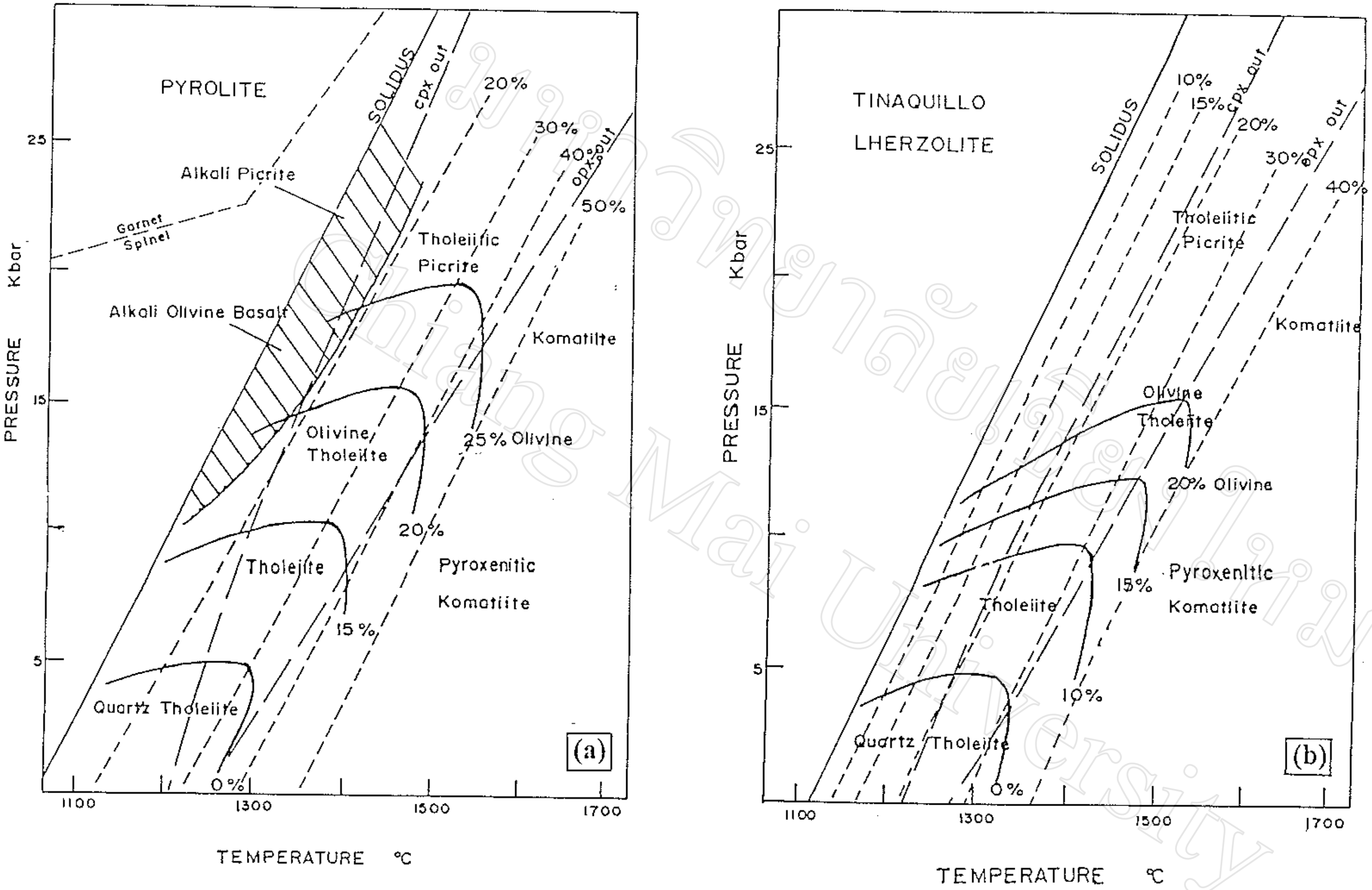

Figure 42 P-T diagrams for partial melting of (a) pyrolite (enriched mantle source) and (b) Tinaquilio lherzolite (depleted mantle source) The curved contours indicate the normative content of olivine in the melt. Long-dashed lines indicate disappearance of residual phases (cpx = clinopyroxene, opx = orthopyroxene). Short-dashed lines indicate percentage of partial melting. The shade area represents the conditions necessary for the generation of alkalic basaltic magmas. Garnet-spinel peridotite boundary is taken from Green and Ringwood (1970) (after Jaques and Green, 1980).

by the fact that garnet and clinopyroxene should be present in the residual peridotite. Consequently, the primary magma for Thoeng tholeiitic basalts was more likely to be transitional tholeiitic picritic liquid, derived from partial melting of the fertile mantle at pressures greater than 25 kb. The results of fertile mantle experiments (Fig. 42a), however, suggest that garnet and clinopyroxene could exist in the residual mantle if degrees of partial melting is less than 20% and the liquid should have alkalic picritic composition. The transitional tholeiitic picritic magma might be the primary magma if the source rock peridotite is intermediate between fertile and depleted peridotites (Figs. 42a and 42b). On the other hand, the parental magma for Thoeng basaltic suite might have resulted from mixing of tholeiitic picritic magma and alkalic picritic magma. The geochemical signatures of both within-plate and mid-ocean ridge affinities, therefore, support the diagnosis.