

in general alkali olivine basalts should have lower $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratios than olivine tholeiites of similar Al_2O_3 or SiO_2 content. This is the reverse of the observed situation cf. MACDONALD and KATSURA (1964, Table 9, p. 124) and the association of higher Al_2O_3 and lower SiO_2 contents with alkali olivine basalts relative to olivine tholeiites of similar 100 $\text{Mg}/\text{Mg} + \text{Fe}^{++}$ ratios, is consistent with fractionation control by aluminous orthopyroxene rather than garnet.

Discussion of the role of garnet in the basaltic compositions at 27–30 kb may be irrelevant if these particular compositions are appreciably divergent from the

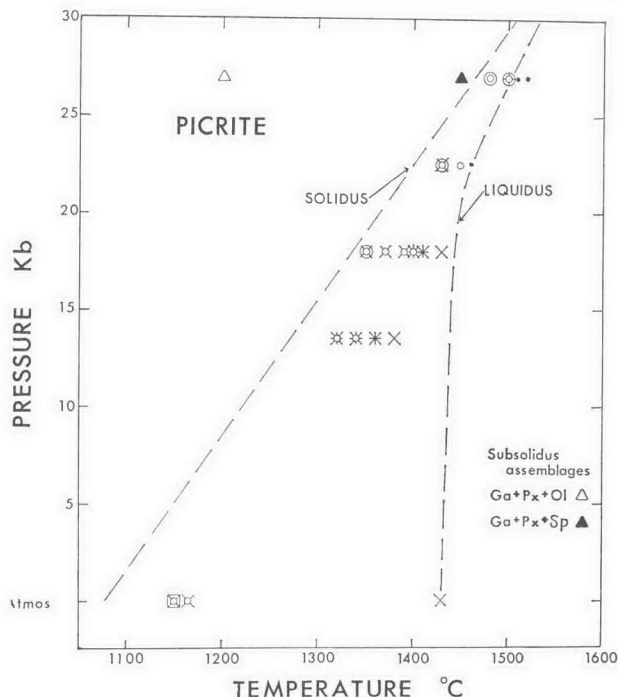


Fig. 7. Detail of melting and subsolidus experiments carried out on the picrite composition at high pressure. Solidus and liquidus positions are approximate only. Data at 1 Atmosphere is entirely interpreted from the literature (TILLEY, YODER and SCHAIRER, 1963, 1964, 1965). Symbols are the same as those of Figs. 4 and 6

composition of liquids which are partial melting derivatives of a mantle peridotite composition and thus in equilibrium with residual crystals of that peridotite. The presence of clinopyroxene and garnet on or very near the liquidus in these compositions suggests that at 27 kb these liquids could be in equilibrium with residual eclogite — rather than residual peridotite or dunite. Experimental work in progress in this laboratory has shown that garnet is unstable at 27 kb, 1,500°C in several peridotite compositions which are appropriate chemically for derivation of basaltic magmas leaving residual dunite or enstatite peridotite. Such compositions contain olivine + orthopyroxene + clinopyroxene ± spinel at the solidus at 27 kb and liquids derived from them by partial melting at this pressure may be expected to have one or more of these phases on the liquidus (cf. pages 160, 166, 167). It appears that the picrite composition may be closer to the composition of liquids

which may be derived from parental peridotite at 27 kb, particularly if in fact orthopyroxene is the liquidus phase at 27 kb, $1,500^{\circ}\text{C} < T < 1,510^{\circ}\text{C}$.

e) Summary of Fractionation Trends

The data and discussions of previous sections demonstrate that an olivine-rich tholeiite magma may fractionate to yield distinctive basaltic magma types at different pressures. These fractionation trends are depicted in Figs. 8–10.

(i) *Low Pressure or Shallow Crustal Fractionation (<15 km depth)*. Fractionation under these conditions is dominated by olivine as the liquidus phase with clinopyroxene and/or plagioclase appearing at lower temperatures. The field of olivine + liquid in compositions with 20–25% normative olivine may cover a wide temperature interval and, because of the Bowen reaction relationship, olivine remains the liquidus phase, in many compositions, into the quartz-normative tholeiite field. Thus, in the olivine tholeiites, olivine may show a reaction relationship with liquid, and fractionation of olivine-rich tholeiitic liquids (such as the olivine tholeiite) may yield quartz-normative residual liquids.

(ii) *Fractionation at about 15–35 km Depth*. Early stages of fractionation are dominated by olivine as at low pressure but the olivine is joined by orthopyroxene as the second phase in the olivine tholeiite composition and possibly the olivine basalt composition and by clinopyroxene in the alkali olivine basalt composition. Plagioclase only appears at temperatures very near the solidus. The crystallization of relatively large proportions of olivine and pyroxene(s) before the appearance of plagioclase contrasts with the crystallization sequence at low pressure and results in a marked increase in Al_2O_3 while retaining a relatively constant SiO_2 content at about 47–49% SiO_2 . In this load pressure or depth interval an olivine tholeiite will not fractionate to yield an oversaturated quartz-tholeiite but instead will fractionate to yield high- Al_2O_3 olivine tholeiites (5–10% normative olivine).

(iii) *Fractionation at about 35–70 km Depth*. In this depth interval, olivine does not appear as the liquidus phase except in the picrite composition. Fractionation is dominated by separation of aluminous orthopyroxene or orthopyroxene + sub-calcic augite. In either case magnesium-iron metasilicate is the major component removed with lesser but important amounts of alumina and calcium metasilicate. Extraction of these pyroxenes results in decrease in SiO_2 content, increase in $\text{Na}_2\text{O} + \text{K}_2\text{O}$ content and smaller percentage increases in Al_2O_3 and CaO contents. The fractionation trend yields olivine-rich, alkali basaltic magmas (i.e. nepheline normative) from parental olivine-rich tholeiitic magmas, and is in direct contrast to the shallow crustal fractionation trend of olivine tholeiites towards olivine-poor or quartz tholeiitic magmas.

(iv) *Fractionation at about 70–100 km Depth*. The appearance of garnet as the liquidus phase, without clinopyroxene, means that separation of garnet alone may occur over a very limited temperature interval and result in a fractionation trend producing higher $\text{SiO}_2 + \text{alkalis}$, lower Al_2O_3 , $\text{MgO} + \text{FeO}$ and approximately constant CaO in derivative liquids. The early appearance of clinopyroxene accompanying the garnet and the separation of garnet + clinopyroxene would change the fractionation trend, probably retaining an overall basaltic chemistry for the residual liquids but leading to increased FeO/MgO , increased K_2O , TiO_2 and possibly Na_2O , depending on the Na_2O content of the clinopyroxene.