

Table 13. *Hypothetical fraction of the olivine tholeiite at Atmospheric pressure*

Nature and estimated percentage of minerals	15% Olivine (Fo <sub>88</sub> )	18% Olivine (Fo <sub>88</sub> ) 12% Plagioclase (An <sub>80</sub> )	
<i>Composition of crystal extract</i>			
SiO <sub>2</sub>	40.0	43.1	
Al <sub>2</sub> O <sub>3</sub>	—	13.4	
FeO	14.3	8.7	
MgO	45.7	27.4	
CaO	—	6.4	
Na <sub>2</sub> O	—	1.0	
<i>Composition of residual liquid</i>			
	(Initial liquid)		
SiO <sub>2</sub>	46.95	48.1	48.6
TiO <sub>2</sub>	2.02	2.4	2.9
Al <sub>2</sub> O <sub>3</sub>	13.10	15.5	13.0
Fe <sub>2</sub> O <sub>3</sub>	1.02	1.2	1.4
FeO	10.07	9.3	10.7
MnO	0.15	0.2	0.2
MgO	14.55	9.0	9.1
CaO	10.16	12.0	11.8
Na <sub>2</sub> O	1.73	2.0	2.0
K <sub>2</sub> O	0.08	0.1	0.1
P <sub>2</sub> O <sub>5</sub>	0.21	0.2	0.3
<i>CIPW Norm</i>			
Or	0.67	0.7	0.8
Ab	14.7	16.8	16.7
An	27.6	33.0	26.4
Di	17.0	20.2	24.6
Hy	12.3	15.3	20.2
Ol	21.9	7.1	3.2
Ilm	3.8	4.6	5.5
Mt	1.4	1.8	2.0
Ap	0.5	0.5	0.6
100 Mg	72.1	63.3	60.3
Mg + Fe <sup>++</sup>			

appearance of plagioclase before clinopyroxene in our olivine-tholeiite composition and the relatively early appearance of plagioclase in relation to the Kilauea Iki fractionation (MURATA and RICHTER, 1965) are attributed to compositional differences. Thus the analyses that MACDONALD and KATSURA (1961, Table 1, analyses 2 and 3) used to estimate their parent magma do not fall on MURATA and RICHTER's (1966a, b) differentiation trend but are distinctly higher in Al<sub>2</sub>O<sub>3</sub> (cf. page 110 and footnote). The experimental and natural studies of low pressure fractionation are sufficient to form the conclusion that separation of olivine, plagioclase and clinopyroxene, in that order, from the chosen olivine tholeiite composition will result in derivative liquid compositions equivalent to Fe-enriched quartz tholeiites, with normal Al<sub>2</sub>O<sub>3</sub> contents. At these low pressure conditions,

derivative liquids from the olivine tholeiite composition will move out of the undersaturated olivine tholeiite field into the oversaturated quartz-tholeiite field (Fig. 1).

The results from the alkali olivine basalt composition are consistent with results from similar rocks studied experimentally by TILLEY, YODER and SCHAIRER (1963, 1964, 1965) and YODER and TILLEY (1962). The effect of olivine and calcic plagioclase separation would be to increase the normative nepheline content and also the  $\text{SiO}_2$  content. The relatively early appearance of plagioclase prevents any large increase in  $\text{Al}_2\text{O}_3$  content. The appearance of clinopyroxene amongst the phases crystallizing would result in either an increase or possibly slight decrease of normative nepheline content depending upon the composition of the particular pyroxene. In general terms, crystal fractionation at low pressures of compositions close to our alkali olivine basalt would yield liquids retaining normative nepheline but becoming richer in  $\text{SiO}_2$ , alkalis,  $\text{Al}_2\text{O}_3$  (in early fractionation stages) and  $\text{Fe}/\text{Fe} + \text{Mg}$  ratio. Some hawaiites and mugearites are probably natural examples of this low pressure fractionation trend (MUIR and TILLEY, 1961) although TILLEY, YODER and SCHAIRER (1965) have recently suggested that crystal flotation involving plagioclase enrichment with extraction of olivine and clinopyroxene may be involved in the genesis of hawaiite and mugearite.

Although the olivine basalt composition contains 1% of normative hypersthene, fractionation at low pressure may produce residual liquids closer to those derived from the alkali olivine basalt than from the olivine tholeiite. As in the other compositions, the crystallization sequence at atmospheric pressure is probably olivine-plagioclase-clinopyroxene. Separation of olivine and calcic plagioclase will result in a small increase in normative hypersthene content but the appearance of clinopyroxene may reverse this trend and even produce nepheline-normative liquids. This may occur if the clinopyroxene has sufficiently high (Mg, Fe)  $\text{SiO}_3$  solid solution and low  $\text{Al}_2\text{O}_3 + \text{Na}(\text{Al}, \text{Fe}^{+++}) \text{Si}_2\text{O}_6$  solid solution to yield a hypersthene normative composition. The olivine basalt and compositions derived from it in early stages of low pressure fractionation belong to the transitional group of rocks discussed by POLDERVAART (1964), which are hypersthene normative but show crystallization and fractionation sequences more typical of the alkali basalt suite. Although a nepheline normative liquid *may* be produced by low pressure fractionation from the olivine basalt composition it must be emphasized that this can only result after crystallization of large amounts of olivine, plagioclase, clinopyroxene and titanomagnetite — the residual liquid would in fact be trachytic and not basaltic.

#### *b) Fractionation at about 15—35 km Depth*

The experimental partial melting runs carried out at 9 kb provide the data on which the following discussion is based. The liquidus phase in all compositions studied is olivine but the second phase to crystallize is orthopyroxene in the olivine tholeiite, orthopyroxene + sub-calcic clinopyroxene in the olivine basalt and clinopyroxene in the alkali olivine basalt. This contrasts with the atmospheric pressure sequence of crystallization in which plagioclase is the second phase to crystallize. In addition to the late appearance of plagioclase at 9 kb, the experimental results suggest that the early crystallizing olivine may bear a reaction