

The use of a classification based on the calculation of the CIPW norm enables objective grouping of analyzed basalts but it creates an artificial clarity of classification which is absent from the natural rocks. Apart from uncertainties introduced by the quality of chemical analyses and by post-magmatic or late magmatic changes in oxidation state, it is clear that the "critical plane of undersaturation" (Fig. 1) dividing olivine + nepheline normative basalts from olivine + hypersthene normative basalts is a finite zone of indeterminacy in basalt classification. Thus, POLDERVAART (1962, 1964) argued that a group of hypersthene-normative basalts were nevertheless petrographically and genetically related to the alkali olivine basaltic suite. These hypersthene-normative alkali olivine basalts characteristically have  $Ab - 2 En_{Hy} - 1.5 Fs_{Hy} > 0$ , while olivine tholeiites have values  $Ab - 2 En_{Hy} - 1.5 Fs_{Hy} < 0$  ( $Ab$ ,  $En_{Hy}$ ,  $Fs_{Hy}$  are the normative albite, enstatite in hypersthene, and ferrosilite in hypersthene, respectively). YODER and TILLEY (1962, p. 404) expressed similar uncertainty about the affinities of olivine basalts with low normative hypersthene contents. The data compiled by COOMBS (1963) and his definition of an "indicator ratio" to classify the basalt magma types are in good agreement with POLDERVAART's criteria for separation of the two suites. On the other hand, MACDONALD and KATSURA (1964) use a simple total alkalis ( $Na_2O + K_2O$  in weight per cent) vs silica plot to distinguish magmas of alkali olivine basalt type from the tholeiitic suite.

The test of any chemical method of classification is in comparison with the modal mineralogy, i.e. (a) the presence of phenocrystal and groundmass olivine in the alkali olivine basalt and absence of calcium-poor pyroxene; (b) the presence of calcium-poor pyroxene and partially resorbed or mantled phenocrystal olivine in the olivine tholeiites. However, such petrographic classification is frequently nondefinitive because of uncertainty in identification of groundmass and because of the presence of common glass within the rock. In general, these methods of basalt classification work equally well for rocks removed from the transition zone between alkali olivine basalts and olivine tholeiites but all are subjective and may be mutually inconsistent when applied to rocks within the transition zone. Nevertheless a fundamental point is that all the above attempts at classification recognise the existence of a continuous spectrum of basalt compositions between alkali olivine basalt magmas and olivine tholeiites.

#### *Previous Investigations*

The general question of possible fractionation trends of alkali olivine basalt and tholeiites at low pressure has been fully discussed by YODER and TILLEY (1962). These authors point out that the "critical plane of silica undersaturation"  $Cpx - Ol - Plag$  (Fig. 1) separating the alkali basalts from the olivine tholeiites represents a "thermal barrier" for fractionation at low pressures and that under normal low pressure conditions, fractionation trends in basaltic magmas move away from this plane on either side. The recognition of different basalt magma types and of a continuous spectrum of compositions between alkali basalts and tholeiites has accordingly posed a major problem in petrogenesis. One of the earliest hypotheses aimed at solving this problem involves the separation of hypersthene in place of olivine from olivine tholeiite magmas, leading to derivative

liquids of alkali basalt type (HOLMES and HARWOOD, 1932; POWERS, 1935, p. 65; LARSEN, 1940, p. 926; MACDONALD, 1949, p. 1576; and TILLEY, 1950, p. 45.).

An important step in the study of basalt fractionation was the initiation of detailed experimental work at high pressures on natural basalts (YODER and TILLEY, 1962; GREEN and RINGWOOD, 1964; TILLEY and YODER, 1964). YODER and TILLEY (1962, p. 507) appealed to the removal of garnet from a parental liquid at high pressures to produce an alkali basaltic liquid while, in contrast, removal of omphacite and effective enrichment of garnet in the liquid would produce tholeiite-type liquids. Calculations of the effects of extracting either garnet or omphacite from actual basaltic compositions as extruded at the surface show that the residual liquids do not possess typical basaltic compositions and do not follow the trend suggested (pages 153—156). Accordingly this hypothesis must be rejected in its simplest form. Nevertheless, YODER and TILLEY's results are important since they demonstrated a new control of fractionation in basalt magmas at high pressure and that the low pressure "thermal divide" between alkali basalts and their derivatives and olivine tholeiites and their derivatives was absent at high pressure.

GREEN and RINGWOOD (1964) demonstrated experimentally that orthopyroxene replaced olivine as the liquidus phase in an olivine-rich tholeiite at pressures from 13 to 18 kb. The orthopyroxene was shown to be rich in  $Al_2O_3$  and the extraction of aluminous orthopyroxene gave a very direct fractionation trend from olivine tholeiites to derivative alkali olivine basalt magmas. These experiments, although of a preliminary and reconnaissance nature, strongly supported earlier hypotheses on the role of hypersthene crystallization and demonstrated a fundamental change in the fractionation of olivine-rich basaltic magmas at modest pressures. The data provided a simple and very direct fractionation trend from olivine and hypersthene normative olivine tholeiites to olivine and nepheline normative alkali olivine basalt by separation of a single phase.

### Present Investigation

This paper presents the results of some 120 experimental runs over the period 1963—1966 investigating the melting relations of selected olivine-rich basaltic rocks. The study was aimed at extending and confirming the preliminary data on the role of aluminous orthopyroxene in basalt fractionation and obtaining further information on the possible direction of fractionation of basalts and effects of partial melting in the mantle at moderate to high pressures. Our approach to the problem has been to select an olivine tholeiite composition considered for petrographic reasons to be a possible "primitive" composition. The nature, compositions and proportions of phases which crystallize between the liquidus and solidus of the olivine tholeiite have been determined over a wide range of pressures. This information, together with knowledge of the original composition, allows the fractionation trends and compositions of residual liquids to be established for different load pressure conditions. Within a limited range of pressures (between 12 and 18 kb) it was found by these means that the residual liquid was fractionating directly *towards* the alkali olivine basalt field. Accordingly, a new basalt composition lying on the general path of fractionation of the olivine tholeiite, and intermediate in composition between the olivine tholeiite and a typical alkali olivine basalt was prepared. The composition of this basalt would be obtained by a