

pyroxene crystallizing increases rapidly over a small temperature interval. A run at 1,410° C, only 30–40° C below the liquidus, contains common garnet and is very near the solidus.

The crystallization interval in the picrite at 22.5 kb is also small. Clinopyroxene appears to be the liquidus phase at 1,450° C and there is only minor glass present at 1,430° C. In the picrite composition, garnet and olivine appear at similar temperatures and there is also a small amount of a brownish high R.I. phase. The determination of the solidus is particularly difficult in this composition due to outgrowths of quench clinopyroxene on the abundant primary clinopyroxene crystals.

#### *g) Crystallization at 27 kb*

In all three basaltic compositions, garnet is the liquidus phase at 27 kb and is joined by clinopyroxene at about 10° C below the liquidus. In the picrite composition garnet, clinopyroxene and orthopyroxene all appear together in the near-liquidus run at 1,500° C. Orthopyroxene disappears at lower temperature (between 1,480° C and 1,500° C) and minor amounts of either spinel<sub>ss</sub> or ilmenite<sub>ss</sub> occur. The run at 1,480° C is very near the solidus and a run at 1,430° C is below the solidus. The latter run does not contain detectable olivine but olivine is a minor but definite phase at 27 kb, 1,200° C. The melting interval of the picrite at 30 kb is an extremely small one of about 40° C — the melting interval of similar compositions at atmospheric pressure is about 375° C (1,425° C to 1,050° C, cf. TILLEY, YODER and SCHAIRER, 1965).

In the olivine tholeiite composition the liquidus is at about 1,500° C and the solidus at 1,430° C. Garnet is probably the liquidus phase although the presence of quench clinopyroxene in the 1,490° C run makes the absence of primary clinopyroxene difficult to establish. The presence of euhedral garnet in clear glass in parts of the olivine basalt runs (at 1,450° C and 1,460° C) and in the alkali olivine basalt run at 1,430° C demonstrates that garnet is the liquidus phase in these compositions (Fig. 2D). The quench clinopyroxene forms feathery and turbid aggregates and, in some cases, quite large anhedral crystals which are distinguishable as quench rather than primary crystals only by their patchy occurrence, the presence of characteristic lines of small inclusions and the absence of a change in refractive index at edges against feathery, definite quench material. Garnet and clinopyroxene are the only phases observed in the crystallization sequence. The solidus of the alkali olivine basalt at 30 kb is about 1,350° C giving a melting interval for this composition of about 90° C. The solidus of the olivine basalt was not determined.

#### *h) Stability of Orthopyroxene as a Liquidus Phase in the 9–18 kb Pressure Interval*

YODER (1964) found enstatite as a liquidus phase in the forsterite-albite system at 9 kb but interpreted the enstatite as metastable, proxying for olivine. Extending this interpretation, TILLEY and YODER (1964) suggested, as a possible interpretation of GREEN and RINGWOOD's (1964) results, that orthopyroxene appearing as a liquidus phase from basaltic liquids at moderate pressure might also be metastable, crystallizing in place of clinopyroxene. Arguments against this interpretation may be developed from the observed readiness of clinopyroxene to nucleate, even during quenching; from the experimental runs in which both orthopyroxene and clinopyroxene occur as co-existing phases and from the restriction of orthopyroxene as a liquidus phase to a definite pressure interval. To demonstrate the stability of orthopyroxene, rather than either garnet or clinopyroxene, as the liquidus phase at 13.5 kb in the olivine tholeiite composition, the glass was run for 4 hrs at 27 kb, 1,100° C. This yielded an assemblage of fine-grained clinopyroxene and common, larger subhedra or euhedra of garnet. The garnet + clinopyroxene assemblage was then re-run for 1 hr at 1,380° C, 13.5 kb yielding an assemblage of euhedral orthopyroxene, uncommon relict garnet and glass + minor quench clinopyroxene. The relict garnet shows clear evidence of partial solution and is not a stable phase under these conditions. The opx + liquid

assemblage obtained from an eclogite (ga + cpx) starting material is the same as that obtained under the same run conditions using glass starting material. The runs carried out in the olivine tholeiite for only 5 mins. at 13.5 kb demonstrate that clinopyroxene, rather than orthopyroxene, may crystallize metastably in very short runs but these runs also show that at temperatures of 1,400° C, run lengths of about 5 minutes may be sufficient to allow nucleation and moderate growth of stable liquidus phases. These observations effectively refute TILLEY and YODER's (1964) suggestion that the orthopyroxene reported in our earlier runs was a product of metastable crystallization.

*i) Microprobe Analyses of Crystals in Partial Melting Runs*

Microprobe analyses of olivine, pyroxenes and garnets are listed in Tables 8—12. The analysis of clinopyroxene was only practical in runs in which this phase grew as large well-formed crystals, i.e. near-liquidus runs. The determination by direct analysis of only three elements (Fe, Ca and Al) means that the contents of Ti and Na are unknown — these constituents are unlikely to be of significance in either olivine or orthopyroxene but the clinopyroxene may have appreciable Ti (0.5—2% TiO<sub>2</sub>) and low Na (0.5% Na<sub>2</sub>O) contents if comparison is made with early-formed clinopyroxenes of natural basalts. This is further substantiated by later microprobe analyses in this laboratory of clinopyroxenes in other basaltic compositions by T. H. GREEN and R. F. BULTITUDE (unpublished data). These analyses include direct determination of Na, Ti contents of the clinopyroxenes.

*j) Olivine Analyses (Table 8)*

The olivines in all compositions show an extremely low Al<sub>2</sub>O<sub>3</sub> content and a low but measurable CaO content of 0.3%. This compares closely with the 0.4% CaO in olivine from Kilauean tholeiites reported in a preliminary study by MURATA, BASTRON and BRANNOCK (1965). Liquidus olivines have consistently higher Mg/Mg + Fe molecular ratios than olivines formed below the liquidus and the correlation of nominal temperature with Mg/Mg + Fe ratios for a given composition gives an independent check on the reliability of relative temperature intervals between runs. On this basis the olivine (100 Mg/Mg + Fe = 92.2) at 4.5 kb, 1,350° C in the olivine tholeiite is closer to the liquidus than the olivine (100 Mg/Mg + Fe = 90.8) at 10 kb, 1,350° C. The partition of magnesium and iron between liquidus olivine and liquid composition has previously been discussed and an empirical mean partition coefficient of 1.33 has been derived for the relationship between basaltic liquid and liquidus olivine or orthopyroxene of composition range 92 > 100 Mg/Mg + Fe > 82. This empirical partition coefficient is defined by the ratio

$$\left( \frac{100 \text{ Mg}}{\text{Mg} + \text{Fe}} \right)_{\text{Crystal}} / \left( \frac{100 \text{ Mg}}{\text{Mg} + \text{Fe}^{++}} \right)_{\text{Liquid}} = K_{O, L}.$$

In each run, ten separate olivine crystals were analyzed and the analysis of each crystal is the mean of 3 to 10 separate spot analyses 2 to 3 microns apart. The analysis given in Table 8 is the mean of the ten separate crystal analyses. It was observed that some olivine crystals showed slight zoning with more iron rich cores than rims. Also it was observed that crystals located close to the platinum