near the suggested limit of fractionation towards nepheline-enrichment at 35—70 km. Some Hawaiian volcanoes have a much later period of eruption of olivine nephelinites and nephelinites but these seem unlikely to be derived by extreme fractionation at 35—70 km of the alkali olivine basalt series.

The Hawaiian volcanic province is one in which the observed proportions and sequence of magma types support an hypothesis of origin of alkali olivine basalt magma by crystal fractionation of olivine tholeiite at 35—70 km depth. Complete transition between the magma types occurs at the depth of fractionation but later, shallow level fractionation of most liquids has imposed the effects of the low pressure thermal divide between the nepheline-normative and hypersthene-normative rock series leading to a greater chemical separation of the magma series. Perhaps the most notable effect of low pressure fractionation is that the average composition of the tholeiitic series for the Hawaiian volcanoes is almost exactly saturated in silica with either minor olivine or quartz in the norm (MACDONALD and KATSURA, 1964). These liquids represent the effects of precipitation of some 20% (if olivine only precipitated) to 30% (olivine $\pm$ clinopyroxene $\pm$ plagioclase) of crystals at very shallow depths from the olivine-rich tholeiitic liqudis present at 35—70 km depth. Geophysical data showing the existence of high density and seismically fast material at shallow depths beneath the central regions of Hawaiian volcanoes (STRANGE, WOOLLARD and ROSE, 1965; FURUMOTO, THOMPSON and WOOLLARD, 1965) may be consistent with such olivine-rich, low pressure accumulative material.

*b) Oceanic Ridge Volcanism*

In recent years, papers by ENGEL and ENGEL and their co-workers have focussed attention on the distinctive chemical characteristics of basalts dredged from the ocean floor at depths around 3,000 metres and located along the mid-oceanic ridges (Mid-Atlantic Ridge, Indian Ocean ridges, and the East Pacific Rise). Earlier analytical work by WISEMAN (1940) and independent work by NICHOLLS, NAWALK and HAYS (1964) support the conclusions of ENGEL and ENGEL (1964a, b), ENGEL, FISHER and ENGEL (1965) and ENGEL, ENGEL and HAVENS (1965) that a characteristic magma is of olivine tholeiitic character with $SiO_2 = 49—50\%$, $Al_2O_3 = 15—17\%$, $Na_2O = 2.5—3.0\%$, $K_2O < 0.3\%$ and $100\ Mg/Mg + Fe^{++} \sim 65$. This composition is closely similar to the high-alumina, olivine tholeiite composition derived by fractionation of low-$Al_2O_3$, olivine-rich tholeiite at 9 kb (pages 142—148) and also interpreted as a direct product of magma segregation from mantle pyrolite at depths around 30 kms.

ENGEL and ENGEL (1964b) and ENGEL, ENGEL and HAVENS (1965) have argued that these high-alumina olivine tholeiites are the only "primary" basaltic magma generated by partial melting within the mantle and that other tholeiitic and alkali magmas are derived by processes of crystal differentiation and volatile transfer, mainly in volcanic conduits at depths less than 3 km. The possible directions of fractionation of high-alumina olivine tholeiites at various pressures are at present under study by Mr. T. H. GREEN and his data is unfavourable to any hypothesis of crystal fractionation at shallow depths leading to alkali olivine basalt compositions (T. H. GREEN, personal communication).

There is an alternative process consistent both with our results on high pressure fractionation and partial melting and with the observed features of chemistry and distribution of volcanics along the mid-oceanic ridges. The high-$Al_2O_3$ olivine tholeiites have chemical compositions appropriate for liquids segregated from a pyrolite composition at the comparatively shallow depth of about 30 kms. With about 25% melting and segregation of the magma from pyrolite at about 30 kms depth, high-$Al_2O_3$ olivine tholeiitic liquids could be produced leaving residual olivine + low-$Al_2O_3$ enstatite. Apart from the probable dropping of minor (0—10% approx.) olivine during ascent, the high-$Al_2O_3$ olivine tholeiites show little chemical change consequent on low pressure fractionation. These magmas thus approach the simplest model of partial melting with extraction of a rather constant proportion of magma from a given volume of pyrolite and transport of the magma through the oceanic crust with a minimum of chemical change by either fractionation or processes of wall-rock reaction. In comparison with other tholeiitic provinces it may be relevant that the environment of intrusion or extrusion of the oceanic tholeiites requires 3—5 km less vertical travel than the exposed Hawaiian tholeiites and there is no thin zone of near-surface material of low density to be penetrated.

The distinctive chemical compositions of the oceanic tholeiites seem to require particularly intense or active upward movement of mantle such that separation of magma and crystals does not occur until depths of about 30 km. If the proposed rapid mantle upwelling process in any part of the mid-oceanic ridge begins to wane in intensity it is probable that the zone of magma segregation will move to greater depths and also the frequent, fissure type of eruption will change towards a localized and central type of eruption. If this process occurs then there will be a gradual transition from high-alumina olivine tholeiite to low-alumina olivine tholeiite or to alkali olivine basalt.

*c) Other Provinces*

The Hawaiian alkali olivine basalts are interpreted as the product of crystal fractionation of olivine tholeiite magma. Other basaltic provinces of regional extent are characterized by alkali-type magmas ranging from alkali olivine basalt to nephelinites and excluding the tholeiitic suite entirely. KUNO (1960) has drawn attention to this feature in Japan and correlated the distribution of the alkali series with a region characterized by particularly deep melting of the mantle. The Tertiary volcanic provinces of Eastern Australia are almost entirely of the alkali olivine basalt + basanite + nephelinite type. In contrast Tertiary basalts of Western Australia and the Jurassic dolerites of Tasmania are tholeiitic. The Tasmanian tholeiitic province, as well as the much more widespread Jurassic Ferrar dolerites of Antarctica and Karroo dolerites of South Africa form distinctive magma provinces. Other examples could be cited supporting the observation that basaltic provinces of regional extent may be typified by alkali olivine basalt magmas alone or by tholeiitic magmas alone. Examples such as these are interpreted as direct partial melting products from the mantle, with relatively constant conditions of melting and magma segregation over the region. Extensive fractionation at low pressure within the crust appears to be a normal characteristic of the continental tholeiitic series.