clinopyroxene in the heavier rare earths. Aluminous enstatite is chemically similar to pyrope-almandine garnet and, if similarly enriched in the heavier rare earths, in a liquid-orthopyroxene or clinopyroxene-orthopyroxene partition, could be a major factor in producing the light-element enriched rare earth pattern of alkali olivine basalts. A knowledge of orthopyroxene-liquid, clinopyroxene-liquid and phlogopite-liquid partition relationships at high pressures would probably show methods by which fractionation could yield liquid fractions with Rb/Sr, U/Th, U/Pb and Th/Pb ratios different from those in either the initial pyrolite source for the magma or the mantle material processed by the wall-rock reaction mechanism.

A corollary of the "wall-rock reaction" mechanism is that zones of pyrolite which are still potential sources for basaltic magma in major element chemistry, may acquire lower abundances and different element-ratios for the incompatible elements by being "processed" through an early magmatic cycle. The application of this to the origin of lherzolite nodules in basalts is discussed in the following section. Batches of magma or accumulates from magmas formed in early magmatic cycles may remain as segregated bodies within the mantle and develop isotopic ratios for Sr and Pb which are of local extent and very different from the ratios in subjacent pyrolite. Such bodies may be intersected by later ascending magmas, and, if their content of incompatible elements is extracted by wall-rock reaction, may modify the composition and isotopic ratios of the later magma batch.

To summarize, the fractional crystallization and slow ascent of an olivine tholeiitic magma at 35—70 km depth or the slow ascent of an alkali olivine basalt magma derived by direct partial melting at 35—70 km, would be accompanied by extensive and highly selective reaction with mantle wall-rock. This would cause overall enrichment in incompatible elements and selective fractionation amongst them. The process would also lead to heterogeneity in incompatible element distribution and ratios in the mantle, creating the necessary conditions for development of varied Pb-isotope ratios and, to a less marked degree, Sr^{87}/Sr^{86} ratios in different mantle regions.

It is important to note that enrichment in incompatible elements accompanies fractionation of an olivine tholeiite magma near its depth of segregation so that magmas enriched in incompatible elements at 35—70 km depth are of alkali olivine basalt type. Enrichment in incompatible elements while retaining tholeiitic affinities requires that an olivine tholeiite magma cools and fractionates at lower pressures i.e. along the trend towards high-Al_2O_3 tholeiites or towards quartz tholeiites. This aspect of wall-rock reaction is treated in more detail in the following section.

e) Wall-Rock Reaction at Lower Pressures

Under some conditions it is possible that an environment suitable for extensive wall-rock reaction may occur under lower pressure conditions, e.g. if magma segregation occurs at higher levels in the mantle or if continued magmatic activity causes wall-rock temperatures in the lower crust or top of the mantle to approach the magma temperature. There are important differences between the nature of the highly enriched "incompatible elements" in a process of wall-rock reaction at low pressure in comparison with wall-rock reaction at high pressure. At high

pressure, plagioclase is not a stable phase in the wall-rock mineralogy, and strontium behaves as an incompatible element since it does not readily enter either clinopyroxene or orthopyroxene. At low pressure, plagioclase is a major stable phase in the wall-rock mineralogy and as strontium substitutes for calcium in plagioclase, strontium will behave as a "compatible element" in fractionation or reaction processes. In addition, at sufficiently low pressure, plagioclase may be a liquidus or near-liquidus phase and as strontium is preferentially enriched in plagioclase (Wilkinson, 1959; Heier, 1962, p. 436), precipitation of this phase will prevent marked enrichment of strontium in a fractionating basaltic liquid at very low pressure.

Titanium may exhibit similar differences in behaviour at high and low pressure particularly if ilmenite or titanomagnetite have the character of relatively refractory phases at low pressure in intermediate or acidic compositions. Changes in redox potential between mantle and lower crust environments may also potentially alter the role of titanium.

The Jurassic tholeiites of Antarctica, South Africa and Tasmania are considered to be possible examples of magmas which have trace element contents determined in large part as a result of wall-rock reaction and fractionation processes occurring at low pressure, and in these particular continental examples, in a crustal rather than upper mantle environment. The Ferrar Dolerites (Antarctica) and Tasmanian dolerites are highly enriched in K, Rb, U, Th but are conversely low in Sr and Ti in comparison with olivine and quartz tholeiites from oceanic islands or oceanic ridges (Compston et al., 1966). In the Ferrar Dolerites there is strong K_2O enrichment accompanying increasing SiO_2 oversaturation in the sequence of magmas ranging from olivine tholeiite (0.38% K_2O, 50.40% SiO_2) to pigeonite quartz tholeiites (1.27—1.76% K_2O, 55.25—55.87% SiO_2) (Gunn, 1962, 1966). The initial Sr^{87}/Sr^{86} ratios for both Tasmanian and Antarctic tholeiites are consistently above 0.710, in contrast to the much lower values (0.702—0.704) found in alkali olivine basalts or tholeiites of oceanic areas.

It is suggested that the parental olivine tholeiite magmas for these intrusions began to crystallize at crustal levels giving rise to a spectrum of magma compositions for individual intrusions ranging from oversaturated, iron-rich pigeonite tholeiite to more magnesian olivine tholeiite (Gunn, 1962, 1966). The period of slow ascent of very large volumes of basic magma through the lower crust established conditions suitable for selective extraction of a low-melting fraction from the wallrock environment. The nature of this extraction process presents some difficulty if the average lower crust is of intermediate or acid composition, unless it is a partial melting process with migration of the liquid phase into the basaltic magma. The elements enriched in the basaltic magma are considered to be those least able to substitute in the major phases of the surrounding wallrock, i.e. in pyroxenes, plagioclase, quartz and possibly hornblende and ilmenite or titanomagnetite. The contaminating material would be anticipated to have high Sr^{87}/Sr^{86} ratios and lead isotopic ratios consistent with geologically old crustal material. Heier et al. (1965), Compston et al. (1966) and Gast (1966) have discussed more fully the role of contamination processes by crustal material enriched in Sr^{87}/Sr^{86} in deriving the particular chemistry of the Tasmanian and Antarctic tholeiites. Compston et al. (1966) present arguments favouring a highly selective contamina-