Consideration of low pressure fractionation of basaltic magmas leads to a concept of two-fold division of magmas into nepheline-normative and hypersthene-normative types separated by a thermal divide (YODER and TILLEY, 1962). The study of fractionation at high pressure accentuates the transitional and continuous character of chemical variation in magma types but delimits three distinctive trends of fractionation characteristic of certain pressure intervals. These three trends require consideration in any petrogenetic classification of basaltic rocks.

The Generation of Basaltic Magmas

In the previous sections we have discussed the fractionation of basaltic magmas at various depths in the mantle and demonstrated mechanisms by which a "primitive" olivine-rich tholeiite magma may produce derivative liquids of alkali olivine basalt, high-alumina basalt or quartz tholeiite type. An important alternative hypothesis (e.g. KUNO, 1960; KUSHIRO and KUNO, 1963) maintains that the compositions of the principal basaltic magmas are determined by the depth in the mantle at which partial melting occurs rather than by subsequent fractionation processes. The data obtained from our experiments are used in the following sections to evaluate this hypothesis in detail.

An essential prerequisite to a discussion of the generation of basaltic magmas in the mantle is a consideration of the mineralogical and chemical constitution of the upper mantle. We will take up this subject in the next section, proceed then to the physical conditions of magma formation and finally investigate the chemical and mineralogical equilibria involved and their effect upon the composition of the resultant magma.

a) Chemistry and Mineralogy of Parental Mantle

It can be argued plausibly on general petrological and geochemical grounds that the chemical composition of the primary undifferentiated upper mantle should be somewhere between those of typical basalt and typical alpine peridotite. A chemical and petrological model for the upper mantle based upon this postulate has been developed by RINGWOOD (1962a, b; 1966a, b), GREEN and RINGWOOD (1963) and GREEN (1966a). In this model, the primary undifferentiated composition of the upper mantle is assumed equal to approximately 1 part of basalt to 3 parts of peridotite. This primary composition is called pyrolite (pyroxene-olivine rock). It is emphasized that the 3:1 proportion is not regarded as critical or unique, and substantial variations in this ratio are possible. Nevertheless an approximate 3:1 ratio is suggested by certain geochemical considerations and is convenient for the formulation of a specific model. The composition of pyrolite as derived by RINGWOOD (1966a) is given in Table 20.

An important property of compositions close to pyrolite is the ability to crystallize in four distinct mineralogical assemblages over the range of P, T conditions existing in the upper mantle. These are

1. Olivine + amphibole ± enstatite ± spinel (Ampholite);
2. Olivine + pyroxenes + plagioclase + chromite (Plagioclase pyrolite);
3. Olivine + aluminous pyroxenes ± spinel (Pyroxene pyrolite);
4. Olivine + pyroxenes + garnet (Garnet pyrolite).

The stability fields of these mineral assemblages for the model pyrolite composition given in Table 20 are currently under experimental investigation. A preliminary outline of the pyrolite stability fields was given by RINGWOOD, MACGREGOR and BOYD (1964), and RINGWOOD (1966b). Our latest experimental results require some modifications of the earlier boundaries of pyrolite stability fields but these are not of a fundamental nature. Much of the revision is caused by the necessity to introduce a pressure correction to earlier results because of nonuniform distribution of pressure in the furnace assemblies (GREEN et al., 1966). A provisional outline of stability fields for the pyrolite composition (Table 20) according to our latest experimental results is given in Fig. 11.

Table 20

Model composition of pyrolite (RINGWOOD, 1966a)

SiO_2	45.16
TiO_2	0.71
Al_2O_3	3.54
Fe_2O_3	0.46
FeO	8.04
MnO	0.14
MgO	37.47
CaO	3.08
Na_2O	0.57
K_2O	0.13
Cr_2O_3	0.43
NiO	0.20
P_2O_5	0.06

For the present purposes, it is important to observe that the boundary between the stability fields of pyroxene pyrolite and garnet pyrolite intersect the pyrolite solidus at a depth of 100 km. *Thus, the formation of magmas by fractional melting of pyrolite at depths smaller than 100 km would occur in the stability field of olivine + aluminous pyroxenes. Garnet would not play a significant role in the genesis of magmas by fractional melting at depths smaller than 100 km.* These considerations constitute a serious objection to the views of YODER and TILLEY (1962), O'HARA (1965) and others, that the principal basalt magma types are formed by direct partial melting of "garnet peridotite" in the upper mantle. In order to stabilise garnet at shallower depths in the mantle, a pyrolite composition possessing a much higher ratio of R_2O_3 $(Al_2O_3 + Cr_2O_3 + Fe_2O_3)$ to total pyroxene than appears reasonable would need to be assumed. Furthermore, a model invoking such a composition would encounter further difficulties because of the tendency for garnet to melt incongruently to aluminous enstatite at an early stage of fractional melting in ultramafic compositions, so that magmas produced at relatively low pressures (15—30 kb) are in equilibrium with residual olivine and aluminous pyroxene for a very wide range of possible mantle compositions.

b) Physical Processes of Magma Generation

The formation of a magma in the mantle requires the supply of a large amount of thermal energy, in excess of 100 cals per gram of magma, to a localised region. Physical processes, e.g. thermal conduction, radioactive heat generation, mass transfer, which might be responsible for the supply of this energy operate on a comparatively long time scale. In contrast, the time scale required for separation of crystals from liquid within the mantle directly by gravity or indirectly by deformational processes ultimately of gravitational origin, is probably smaller by orders of magnitude. Because of these conditions, the formation of magmas in the mantle will almost always be the result of *partial* melting rather than of complete melting. Where a substantial degree of partial melting occurred throughout a large volume, the magma will tend to segregate from residual crystals into a self-contained magma body which thereafter evolves