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MINERALOGY OF PERIDOTITIC COMPOSITIONS UNDER UPPER MANTLE CONDITIONS

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An experimental study of the stability fields at high pressure of plagioclase peridotite, aluminous pyroxene (±spinel) peridotite and garnet peridotite, has been carried out in compositions matching estimates of the average undifferentiated upper mantle (pyrolite). The appearance of garnet at high pressures results from either of two complex reactions:

a. spinel + pyroxene ⇌ olivine + garnet,
   (solid solutions)

b. aluminous pyroxene ⇌ garnet + pyroxene (lower Al_2O_3).
   (solid solution)

In the model pyrolite composition, garnet appears at 21 kb (1100 °C) to 24 kb (1300 °C) by reaction (a) but at temperatures above 1300 °C spinel is absent from the low pressure assemblage and garnet develops by reaction (b) at pressures of 24 kb (1300 °C) to 31 kb (1500 °C). Reactions (a) and (b) have very different *P*, *T* gradients. In the garnet peridotite field, the amount of garnet is inversely proportional to the alumina content of the pyroxenes. This is confirmed by microprobe analyses of orthopyroxene (ranging from 6.0 to 2.2% Al_2O_3, 0.7–0.9% Cr_2O_3) coexisting with garnet, olivine and clinopyroxene. Coexisting clinopyroxenes have higher R_2O_3 content and exhibit a variable, temperature dependent enstatite solid solution.

The experimental data are applied to estimate mineralogical, density and seismic velocity variations along oceanic and continental geothermal gradients in a pyrolite upper mantle. Although the mineralogical variation may produce a low velocity zone, the alternate explanation of incipient or minor partial melting is preferred. Experimental data on the maximum stability limit of amphibole in pyrolite (with 0.1–0.2% water) are presented showing that amphibole breaks down to olivine + pyroxenes + garnet + fluid phase at approximately 29 kb, 1000 °C. The instability of amphibole at depths >80–90 km is considered to result in a zone of incipient or minor melting in a pyrolite upper mantle with 0.1–0.2% water. The nature of the liquid in this zone is considered to be highly undersaturated olivine basanite or olivine nephelinite.

1. Introduction

The uppermost region of the Earth's mantle acts as the immediate source region for basaltic magmas and is the one part of the mantle "sampled" by magmatic or tectonic processes and, in certain circumstances, exposed for direct petrological and geochemical investigation. The properties of the upper mantle can also be rather closely defined by geophysical methods, particularly by seismological and gravity studies. The weight of geological and geophysical evidence on upper mantle composition favours an overall peridotitic composition and arguments against an alternative of eclogitic composition have previously been presented (RINGWOOD and GREEN, 1966; RINGWOOD, 1966a). In seeking to define an upper mantle composition more closely the petrologist must interpret the variety of basaltic magmas, of peridotitic xenoliths in magmas and vent breccias, high-temperature peridotites, and other peridotite occurrences in terms of parental mantle compositions, partial melting products, crystal residues and crystal accumulates. No unique synthesis of these data is possible at this stage but in previous papers we have used the term "pyrolite" for parental mantle capable of yielding basaltic magmas by partial melting and advanced arguments for specific pyrolite compositions (GREEN and RINGWOOD, 1963; RINGWOOD, 1966a). Other authors (ITO and KENNEDY, 1967; KUSHIRO and KUNO, 1963; KUSHIRO *et al.*, 1968; HESS, 1964; HARRIS *et al.*, 1967) have derived possible upper mantle compositions on other grounds or have selected specific samples of peridotite xenoliths. These compositions also have essential Al_2O_3, CaO and Na_2O and, like the pyrolite compositions, may crystallize in four different mineral assemblages within the *P*, *T* conditions of the upper mantle (minor accessory minerals such as ilmenite, apatite, phlogopite are omitted):

a. Olivine + amphibole ± enstatite ("ampholite"),