

THE STABILITY FIELDS OF ALUMINOUS PYROXENE PERIDOTITE AND GARNET PERIDOTITE AND THEIR RELEVANCE IN UPPER MANTLE STRUCTURE

D. H. GREEN and A. E. RINGWOOD

Department of Geophysics and Geochemistry, Australian National University

Received 21 September 1967

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

(1) spinel + orthopyroxene \rightleftharpoons olivine + garnet

(2) aluminous pyroxene \rightleftharpoons garnet + pyroxene (lower alumina).

The role of spinel in the lower pressure assemblages is sensitively dependent on temperature and bulk composition. For the pyrolite composition preferred for the upper mantle, spinel is absent above 1300°C and the first appearance of garnet at pressures of 24 kb (1300°C) to 31 kb (1500°C) is due to reaction (2). In this composition garnet does not appear on the pyrolite solidus nor in its melting interval at pressures below 31.5 kb.

At temperatures less than 1300°C, garnet appears at 21 kb (1100°C) to 24 kb (1300°C) and develops by reaction (1) at the expense of spinel. The amount of garnet formed by this reaction is dependent on the alumina content of the pyroxenes and throughout the temperature range 1100-1500°C the amount of garnet present increases markedly with increasing pressure within the garnet peridotite field. Microprobe analyses of orthopyroxenes demonstrate that this is matched by decreasing Al_2O_3 content of the pyroxenes and allow preliminary estimation of P, T -dependent curves of constant Al_2O_3 content for orthopyroxene in garnet peridotite assemblages.

The experimental data are applied to estimate density and seismic velocity variations along oceanic and continental geothermal gradients in a pyrolite upper mantle. It is emphasized that seismic velocity distributions are sensitively affected by variations in geothermal gradient and by mantle chemical composition, e.g. by variation from pyrolite to residual, refractory, dunite-peridotite. It is suggested that seismic velocity (V_s) variation in an oceanic upper mantle of pyrolite composition may be characterized by two low-velocity channels:

- (1) a narrow, but sharply defined low-velocity zone at 60-70 km depth caused by mineralogical zoning in the upper mantle;
- (2) a broader low velocity zone at 120-150 km depth defined primarily by the critical gradient for V_s in the upper mantle but accentuated by mineralogical variations in pyrolite.

1. INTRODUCTION

In previous papers we have advanced arguments for specific model compositions for the peridotite upper mantle [1-4] and have used the term "pyrolite" for these deduced mantle compositions. On theoretical grounds and on the evidence of natural rocks approaching the pyrolite composition, it has been demonstrated that pyrolite may crystallize in four different mineral assemblages within the P, T conditions of the upper mantle. These mineral assemblages are as follows [2-4]:

- a. Olivine + amphibole \pm enstatite ("ampholite")
- b. Olivine + pyroxenes + plagioclase ("plagioclase pyrolite")

- c. Olivine + aluminous pyroxenes \pm spinel ("pyroxene pyrolite")
- d. Olivine + pyroxenes + garnet ("garnet pyrolite").

The stability relationships of these assemblages in model pyrolite composition have been experimentally investigated in our laboratory and the present letter explores the implications of this study on mineralogical and seismic velocity variations in the upper mantle.

2. EXPERIMENTAL METHOD

The ultramafic compositions used in the investigation are listed in table 1.

Table 1
Chemical compositions and CIPW norms of model pyrolite compositions used in experimental runs.

| | Pyrolite I [2] | Pyrolite II | Pyrolite III [3] |
|--|----------------|-------------|------------------|
| SiO ₂ | 43.20 | 43.95 | 45.20 |
| TiO ₂ | 0.58 | 0.57 | 0.71 |
| Al ₂ O ₃ | 4.01 | 3.88 | 3.54 |
| Cr ₂ O ₃ | 0.42 | 0.41 | 0.43 |
| Fe ₂ O ₃ | 0.35 | 0.75 | 0.48 |
| FeO | 7.88 | 7.50 | 8.04 |
| MnO | 0.13 | 0.13 | 0.14 |
| NiO | 0.39 | 0.39 | 0.20 |
| MgO | 39.54 | 39.00 | 37.48 |
| CaO | 2.67 | 2.60 | 3.08 |
| Na ₂ O | 0.61 | 0.60 | 0.57 |
| K ₂ O | 0.22 | 0.22 | 0.13 |
| 100 Mg Mg + Fe ⁺⁺ atomic ratio | 89.9 | 90.3 | 89.2 |
| CIPW Norm | | | |
| Or | 1.1 | 1.1 | 0.8 |
| Ab | 5.2 | 5.2 | 5.0 |
| An | 7.5 | 7.3 | 6.6 |
| Di | 4.6 | 4.3 | 6.8 |
| Hy | 3.8 | 9.4 | 15.8 |
| Ol | 75.6 | 69.8 | 62.5 |
| Ilm | 1.1 | 1.1 | 1.3 |
| Mt | 0.5 | 1.2 | 0.7 |
| Chr. | 0.6 | 0.6 | 0.6 |

Pyrolite I and pyrolite III refer to the model compositions calculated by Green and Ringwood [2] and Ringwood [3], respectively. They differ principally in their MgO/SiO₂ ratios and thus in pyroxene/(Al,Cr)₂O₃ and pyroxene/olivine ratios. Pyrolite II is a composition intermediate between the two in which the enstatite/olivine ratio of Pyrolite I was increased without appreciable change in the R₂O₃ content. The experimental compositions were prepared from AR grade chemicals, carefully ground and reacted together under high temperature reducing conditions and then analyzed for FeO and Fe₂O₃ contents. The initial mixes were extremely finegrained (≤ 1 micron) and consisted of olivine, clinopyroxene, orthopyroxene and plagioclase. To facilitate identification of minor phases and of the presence or absence of small degrees of partial melting, compositions were prepared which are equivalent to the pyrolite compositions of table 1 after extraction of 50% olivine [Mg_{91.5}Fe_{8.0}Ni_{0.4}Mn_{0.1}] from pyrolites I

and II and after extraction of 40% olivine [Mg_{91.6}Fe_{8.1}Ni_{0.2}Mn_{0.1}] from pyrolite III. In all experiments conducted with these modified pyrolite compositions, excess olivine was present as a stable phase. Hence the above procedure did not affect in any way the equilibrium relationships which are discussed below.

Crystallization of the experimental compositions was carried out using a single-stage, piston-cylinder apparatus [5,6] and a pressure correction of -10% was applied to the nominal pressure for all runs [7]. Samples were run in both platinum capsules and in graphite capsules. In seeking to determine the solidus for the pyrolite composition it was found that the graphite capsules, while preventing Fe-loss from the sample to capsule walls, gave poorly reproducible results and indicated anomalously low temperatures for the beginning of melting. Using the dry furnace assemblies with talc + boron nitride pressure media [6,8] welded platinum capsules gave satisfactory results for the