EXPERIMENTAL CONSTRAINTS ON THE EARLY DIFFERENTIATION OF THE EARTH'S MANTLE; T. Kato, I. Irifune, and A.E. Ringwood, Research School of Earth Sciences, Australian National University, Canberra, 2601.

The chemical composition of the upper mantle (pyrolite) which is parental to MORB's is characterized by near-chondritic relative abundances of many involatile lithophile elements, e.g. Mg, Ca, Al, Ti, Y, Sc, heavy and intermediate REE, Zr and Hf (1). On the other hand, the Si/Mg atomic ratio of upper mantle pyrolite (0.78) is significantly lower than the Cl chondritic ratio of 0.95. This latter characteristic has been interpreted as implying that the mantle has experienced melting and crystallization-differentiation, with the upper mantle thereby acquiring a smaller Si/Mg ratio than the lower mantle. Two principal scenarios have been advocated. According to e.g. (2), the narrow temperature interval between the solidus and liquidus of pyrolite near depths of 400 km implies that pyrolite itself represents a partial melt of more primitive chondritic mantle material. Since the liquidus phase for both pyrolite and chondritic compositions between 400-600 km is majorite garnet (3,4), it was accordingly suggested that the present upper mantle composition corresponds to that of a liquid what was once in equilibrium with liquidus and/or residual majorite at depths of 400-600 km. The second scenario (3) is based on the fact that MgSiO₃ perovskite would occur on the liquidus of chondritic model mantle compositions above 25 GPa (4). It maintains that melting and differentiation occurred at greater depths and involved MgSiO₃ perovskite as the principal phase crystallizing from the melt, and/or remaining in the refractory residuum e.g. (3,5).

We have tested these hypotheses by determining the partition coefficients for major and selected minor elements between majorite garnet and an ultramafic liquid, and between majorite garnet and MgSiO₃, and CaSiO₃, perovskites. The majorite/liquid partition coefficients were measured on a komatiite composition at 16 GPa, 2090°C, and the majorite-Mg perovskite-Ca perovskite partitions at 25 GPa, 1400°C, were obtained on a composition equivalent to pyrolite minus 60% olivine (1). The experiments were carried out in a MA-8 apparatus and the procedures are described elsewhere (6). Compositions of coexisting phases were determined by electronprobe microanalysis. Key results are summarized in the accompanying table.

It is readily shown that derivation of the pyrolite Si/Mg ratio from a chondritic parental composition would require fractionation of (or equilibration with) more than 50 percent of majorite or perovskite. Moreover Table 1 shows that Yb, Sc and Al are enriched in liquidus majorite relative to the melt by about a factor of 1.5-2, whereas Ca, Ti, Sm and La are depleted by at least a factor of about two. Thus extensive majorite fractionation would necessarily imprint non-chondritic Al/Ca, Al/Ti, Sc/Sm and Yb/Sm ratios on the residual liquid. Calculations based upon these data show that upper mantle pyrolite which possesses these elements approximately in chondritic relative abundances cannot have experienced prior separation of more than about 10% of majorite garnet. It is also seen from Table 1 that Sc and Ti are spectacularly enriched in an MgSiO₃ perovskite coexisting with majorite garnet, by factors of 4 and 20 respectively. These elements would be similarly concentrated in an MgSiO₃ perovskite phase on the liquidus of an ultrabasic melt. Fractionation of only a few percent of perovskite from a chondritic composition would cause the Sc/Al and Al/Ti ratios of the coexisting liquid to depart significantly from chondritic values. It follows that the present upper mantle cannot have experienced...
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any substantial fractionation involving either majorite or MgSiO₃ perovskite early in its history.

These results highlight the weaknesses of hypotheses which attribute the composition of the present upper mantle to extensive fractionation-differentiation controlled by majorite garnet or by MgSiO₃ perovskite. The hypothesis that the lower mantle is composed essentially of an MgSiO₃ perovskite phase, resulting from a large scale melting and differentiation process, is thus without foundation.

Table 1 also shows that heavy and light REE can be accommodated in CaSiO₃ perovskite in high concentrations and behave as compatible elements at depths below about 670 km. We predict on crystal chemical grounds that this will also apply to Sr, Pb, Nb and Ta, but not to U, Th, Zr, Hf, K, Rb and Cs which are likely to continue to display incompatible behavior. Experiments now in progress will shortly test these expectations. The results are likely to place strict constraints upon the locations of OIB source regions and on the extent to which the Earth was melted during its accretion.

REFERENCES

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<th>TABLE 1</th>
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<tr>
<td>16 GPa, 2090°C Komatiite composition</td>
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<tr>
<td><strong>Wt %</strong></td>
</tr>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>TiO₂</td>
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<tr>
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