Partitioning of Ni between olivine and an iron-rich basalt: Experiments, partition models, and planetary implications

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ABSTRACT

Trace element mineral-magma partitioning models are important in understanding processes by which basaltic magmas are generated. Partitioning models for nickel have been extrapolated from their original applicability for the Earth’s mantle to compositions appropriate for other planets, notably the Moon and Mars. Before partitioning models can be extrapolated to explain nickel concentrations in planetary basaltic compositions, these models need to be verified thermodynamically and experimentally using planetary basaltic compositions. Experiments conducted in this study on the Martian Gusev Adirondack-class basalt, Humphrey, with 1 wt% nickel in the magma have shown that Ni affects its liquidus phase relations. By stabilizing olivine to higher temperatures, Ni increases the liquidus temperature. These experiments have shown that the Hart and Davis (1978) model based on iron-free systems cannot be extrapolated to planetary, iron-rich, basaltic systems. This work verifies the independence of the Jones (1984, 1995) and Beattie et al. (1991) models from temperature and pressure effects and suggests extrapolation to planetary compositions is justified but needs further verification. Furthermore, these experiments support the Longhi and Walker (2006) hypothesis that at high temperature nickel may be incompatible.

Keywords: Phase equilibria, experimental petrology, lunar and planetary studies, igneous petrology, meteorite, high-pressure studies, high-temperature studies, major and minor elements

INTRODUCTION

The divalent transition-metal cations Fe, Mn, Co, and Ni, as well as Mg, are prominent constituents of the mafic minerals in terrestrial magma systems (e.g., Beattie et al. 1991; Hart and Davis 1978; Jones 1984, 1995) to calculate the appropriate $D_{\text{Ni}}^{\text{Mg}}$ for a bottom-up crystallization sequence of a lunar magma ocean (e.g., Elkins-Tanton et al. 2002; Warren 1985); for pressures and temperatures relevant to the lunar magma ocean, they calculated $D_{\text{Ni}}^{\text{Mg}} < 1$. Furthermore, they confirmed that the Jones-Beattie model can be extrapolated to high temperatures using experiments on a peridotite composition. These experiments produced Co incompatibility but did not attain sufficiently low $D_{\text{Mg}}$ to produce nickel incompatibility. This sort of decoupling of Ni from Mg in basalt genesis would have profound implications for interpreting Ni abundances in planetary basalts, particularly where there is evidence of extreme fractionation.

On the other hand, Papke et al. (1999) and Karner et al. (2003) inferred that Ni was strongly compatible, $D_{\text{Ni}}^{\text{Mg}} >> 1$, throughout all lunar basalt petrogenesis. They based their conclusion on olivine compositions in a wide range of lunar materials.