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Quantifying the equilibration time of Fe, Cu and Zn concentrations and stable isotopes in metal-silicate partitioning experiments

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Abstract

Planetary differentiation studies have so far focussed on either elemental or isotopic distribution between silicate and metal. This study combines element partitioning behaviour and stable isotope fractionation through metal-silicate partitioning experiments that can be used to model planetary core formation. The first step in this ongoing project is to determine the time required for every experiment to achieve not only elemental equilibrium (<1 hour) but also isotopic equilibrium.

1. Introduction

Present geochemical models of planetary core formation tend to focus on either element abundances or stable isotope fractionation between mantle and core. The data obtained from these two techniques do not always yield the same conclusion. An example of this is the Si content of the Earth's core. Si isotopic data suggests that the core contains significant amounts of Si [6], whereas element partitioning data and seismological observations indicate that the Earth's core contains low amounts of Si [1]. In this study, we will combine element and stable isotope analyses in an attempt to solve this problem of inconsistent data.

Metal-silicate partitioning experiments can be used as a proxy for core formation and are needed to quantify the distribution of elements (and their isotopes) between metal (core) and silicate (mantle) [e.g. 3,4,7]. As the conditions and variables during the experiments can be controlled, systematic quantification of their influence on the elemental and isotopic partitioning behaviour is possible. The first step in this process of quantification is determining the time that is required to reach equilibrium conditions for both elements and their isotopes within the experiments.

2. Approach

Metal-silicate partitioning experiments are performed under high pressure-temperature conditions using an end-loaded piston-cylinder press. For the equilibration time series under conditions of 1GPa and 1823K, the time at these peak conditions ranged from 3 minutes up to 12 hours. A synthetic analogue of the lunar Apollo 15 Green Glass [2] was used for the silicate phase along with a Fe-metal containing 3wt% Cu, 2wt% Zn, 5wt% Ni and 1wt% Si for the metal phase. Half of the volume of experimental run products was used for elemental analyses, the other half for isotopic analyses. Elemental concentrations were obtained with an electron microprobe (EMPA) and laser ablation ICP-MS (LA-ICP-MS). The analyses for isotope fractionation require liquid chromatographic techniques before analyses with a multi-collector mass spectrometer (MC-ICP-MS) can be performed. These techniques include separating the metal and silicate phases using high-density liquids and column chemistry to isolate Fe, Cu and Zn for analyses. The results of the isotope analyses will be presented at this conference.

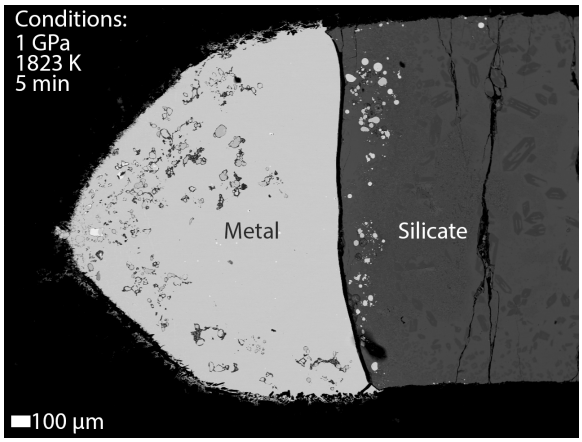

Figure 1: BSE image of an unequilibrated experiment.

3. Results

The run products typically show good segregation of the metallic phase and the quenched silicate melt. During short experiments with runtimes of up to an hour, the metal phase tends to be located in the bottom part of the capsule as it has a higher density than the silicate phase. Additionally, for the shortest experiments of 3 and 5 minutes, heterogeneous spots were found in the metal phase (Fig. 1), indicating the experiment was not in equilibrium. Results shown in Fig. 3 confirm this observation as the partitioning behaviour of Fe, Cu and Zn is significantly different from experiments that were running for more than half an hour. For long experiments spanning several hours the metal phase tends to stretch vertically throughout the sample, pushing the silicate phase to the sides of the capsule (Fig. 2), suggesting that some form of convection might have occurred.

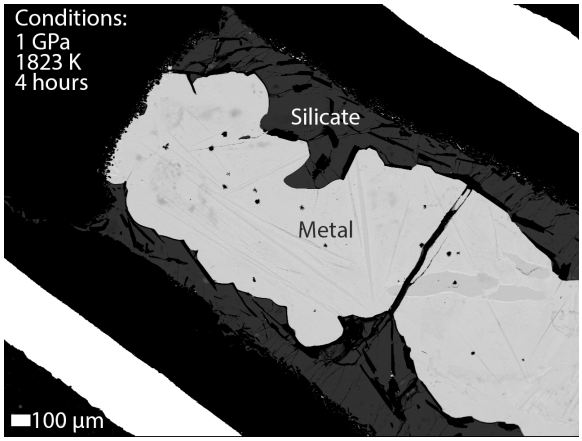

Figure 2: BSE image of an equilibrated experiment.

3.1 Element partitioning behaviour

Element analyses indicate that elemental equilibrium between the metal and silicate phases under the predetermined conditions is reached within one hour. Fig. 3 shows these equilibration times for several elements. The deviation in Log D values between equilibrated experiments is caused by slight internal deviations in the starting conditions and variables that are always expected in metal-silicate partitioning experiments. As isotope equilibration for Fe is known to take at least several hours [5], the overall equilibration time of the experiments will likely be longer than indicated based on the element partitioning behaviour.

4. Discussion & outlook

Although the data from this first part of the project cannot be directly applied to planetary core formation, it is an essential part of creating combined models of core formation based on element abundances and stable isotope fractionation. During planetary core formation it is assumed that some form of equilibrium is reached over millions of years. Therefore, it is important that our experiments reflect this process to avoid measuring unrealistic data that cannot be applied to core formation. Once the equilibration times for the experiments are determined, the next part of the project consists of systematically increasing the pressure and temperature during peak conditions as well as changing the compositions of our experiments to better reflect core formation of small planetary bodies that are formed under 'low' pressures (<5GPa) such as the Moon.

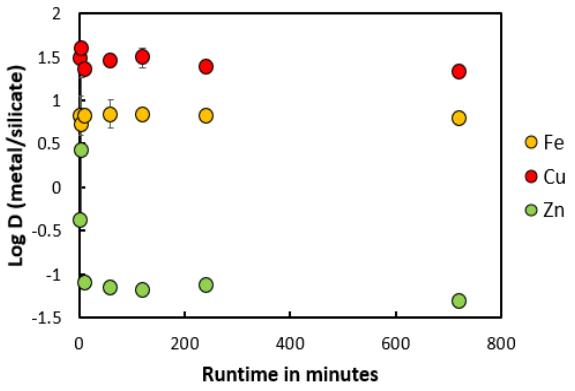

Figure 3: Partitioning behaviour of Fe, Cu, Zn (Log D) as a function of time at peak conditions

Acknowledgements

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