

Metal Silicate Partitioning of Siderophile Elements and Core Formation in Planets. N. Rai^{1,2}, M.J. Walter² and C. J. Hawkesworth², ¹Department of Petrology, Faculty of Earth and Life Sciences, Vrije University, Amsterdam, Netherlands 1081 HV. nacrai@falw.vu.nl. ²Department of Earth Sciences, University of Bristol, UK, BS81RJ.

Introduction: Siderophile element signatures in Earth's mantle are a result of segregation of the iron rich core from the silicate mantle. Investigating the conditions and the extent of element partitioning into iron metal and silicate melt has very important implications for understanding the processes involved during the differentiation of planetary bodies into the mantle and core structures. In this experimental study, a systematic investigation of the partitioning behaviour of weakly siderophile elements (V and Si), nominally lithophile elements (Nb and Ta) and moderately siderophile and volatile elements (Ga and P) was done to investigate the effects pressure, temperature, silicate melt composition and oxygen fugacity on their metal-silicate partitioning. Metal silicate partition coefficients, D^M , where M is Ga, P, V, Nb, Ta and Si, are regressed against $1/T$, P/T , ΔIW , nbo/t (non-bridging oxygen/tetrahedral cation ratio, a silicate melt structural parameter) to derive equations of the following form: $\log D = \alpha + \beta(\Delta IW) + \delta(1/T) + \epsilon(P/T) + \chi(nbo/t)$. To account for the interaction of solutes in the iron alloy, the algorithm of [1], coded as program METAL [2] was used to calculate the solute activities in the solvent liquid iron.

It is investigated whether the silicate Earth's abundance of siderophile elements can be reconciled with single stage metal-silicate equilibrium at a unique set of P and T conditions. Using the results obtained from this study, the Wade and Wood, (2005) model of core formation in an early reducing magma ocean that deepened with time and in which conditions became progressively more oxidized is also tested.

Methods: Metal silicate partitioning experiments at different pressures were conducted

using Piston-cylinder and multi-anvil devices and graphite was the chosen sample container for all experiments. The silicate portions of all starting compositions used for this experimental study were prepared from a mixture of high purity oxide powders and carbonate (CaCO_3) and the bulk silicate compositions lie in the system $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$. The Fe rich metallic portion of the starting composition consisted of Iron metal powder and Fe_2O_3 which together constituted approximately 30% of the final weight. Having relatively large amount of Fe in the starting mixtures ensured that the final run products had metallic blebs large enough to be easily identified and analyzed on the EPMA. Variation in the Fe: Fe_2O_3 ratio and keeping the total Fe content approximately the same, served as means to create different oxidizing conditions. Similarly, varying the Fe:Si ratio in the starting mix provided a means to produce more reducing conditions, and also to examine the relative siderophile behaviour of Si. The mixtures for the two sets of experiments were then doped with very finely powdered crystalline GaP and approximately 1.5 wt.% each of V, Nb and Ta respectively. A total of nineteen and nine synthetic compositions were prepared for the V, Nb, Ta and Si bearing and Ga-P bearing metal-silicate partitioning experiments respectively. Although the metallic and silicate portions were initially mixed very intimately, upon melting the silicate and metal phases segregated to form one or more large metallic blebs which were surrounded by quenched silicate melt. In most of the experiments, both the metal and silicate displayed dendritic quench textures. So, for most analyses, a 20 μm defocused electron beam was used and on average between 10 and 30 analyses were undertaken for each phase in order to reproduce the bulk composi-

tion as accurately as possible. Analytical conditions were 20 KV accelerating voltage and 15 nA beam current, with acquisition times of 60-180 seconds for Ga, P, V, Nb and Ta, and 20 seconds for the other elements. The silicate phases were analysed using natural silicates and oxides as standards, and pure metals were used as standards for analysing the metallic phase.

Results: The new metal silicate partitioning data for V, Nb, Si, Ga and P obtained from this study when combined with data from literature provide additional constraints on estimates of conditions of core-mantle differentiation in Earth and are used to test the validity of the popular models of core formation. In trying to deduce a single set of P - T conditions for core formation in a deep magma ocean we obtained a solution set consisting of a wide range of P - T conditions ranging from 17 to 82 GPa and 2500 – 4500 K which shows that it is very unlikely to find one unique set of P - T conditions that can satisfy the observed mantle abundances of all elements. It is more likely that the ‘unique’ equilibration conditions may actually represent an average of a wide range of conditions generated during an extremely high powered and fast changing process. It is critically assessed whether V, Ga, P, Nb and Si are consistent with the model of core formation in a progressively oxidizing Earth [1]. Following the approach outlined in [1,3,4], a model is constructed here in which the Earth was grown in 1 per cent steps and the core segregated at the base of a magma ocean. The height of the magma ocean was assumed to increase in fixed proportion to the radius of the growing planet which was assumed to grow from 0 to 100 per cent without removal of any material. During the early stages of accretion, conditions were assumed to be more reducing (low Fe content of mantle) and approached the presently established FeO content in steps, the final step corresponding to the approximately 10 per cent of Earth

mass added during the giant collision of the proto Earth with a Mars sized impactor and leading to Moon formation [5]. Figure 1 shows that with some minimal adjustments to the obtained fit parameters, we find the progressively oxidizing model for Earth to be consistent with the mantle abundance of Ga, P, V, Nb and with the partitioning of 5.6% Si into the core.

References: [1] Wade J. et al. (2005) EPSL 236, 78-95. [2] Cottrell E. et al.(2009), EPSL 281 (3-4), 275-287. [3] Wood, B.J. (2008) Phil. Trans. R. Soc. A 366, 4339-4355 [4] Wood, B.J. et al. (2008) GCA, 72, 5, 1415-1426. [5] Halliday, A. N. (2004) Nature 427, 505-509.

Core Segregation at base of homogeneous progressively oxidizing magma ocean

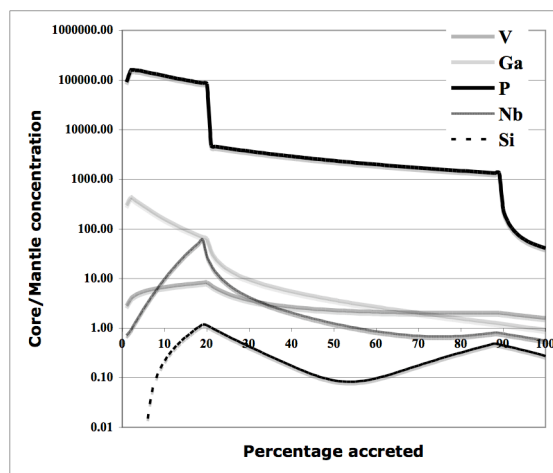


Figure 1. Calculated partitioning into the core for an Earth in which the oxidized Fe content of the mantle increases from 1 to 6.26 % in two steps at 20% and 89% of Earth accreted. The fit parameters for V were adjusted by less than 1 standard error to yield maximum partitioning into the core. Fit parameters for Nb, Si and P were also minimally adjusted within their uncertainties to yield D values consistent with observed mantle abundances.