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Preface

Diffusion and partitioning in planetary interiors

1. Introduction

This special issue gives an overview of recent progress in the related fields of element partitioning and diffusion at high pressures and temperatures. Geochemical models of large-scale differentiation processes in planetary interiors, such as core formation and partial melting in magma oceans or beneath mid-ocean ridges, require accurate data on how major and trace elements distribute themselves between the relevant phases (including solid and molten silicates, oxides and metal alloys) at high pressures and temperatures. Major and trace element diffusion data are important for evaluating whether chemical equilibrium is likely to be achieved during these differentiation processes, and to quantify the extent of chemical interaction that can be expected over time. Diffusion rates are also fundamentally linked to several important physical properties of minerals and liquids, including rheology, and thus contribute to our understanding of dynamical processes such as convection in planetary interiors.

Two conferences held in the 1970s (the Conference on Geochemical Transport and Kinetics, held in June 1973, and the International Conference on Experimental Trace Element Geochemistry (‘Sedona Conference’), held in September 1977), can be seen as the starting point for geochemical research on diffusion and trace element partitioning in phases relevant to planetary interiors. Since then, novel experimental and analytical techniques have allowed experimental measurements of diffusion and partitioning at increasing elevated pressure and temperature conditions, of increasingly direct relevance to processes taking place in the interiors of planets.

This special issue brings together 11 contributions spanning the pressure range from 1.5 to 24 GPa, the latter equivalent to the top of the lower mantle on Earth, and close to the Martian core–mantle boundary. We hope that the bringing together of papers on diffusion and partitioning will lead to increased collaboration between researchers in these two fields and lead to new, more stringent constraints on large-scale geochemical differentiation processes at elevated pressures and temperatures.

2. Brief summary of contributions

Béjina et al. review models for the variation of diffusion rates with pressure, and discuss currently available data sets on diffusion in minerals at elevated pressures. They show the immense progress that has been made in experimental and analytical techniques, particularly during the past 5 years, but also highlight discrepancies that exist between different measurements of diffusion at high pressure. As a further illustration of recent advances, Holzapfel et al. present new measurements of the pressure and temperature dependence of Fe–Mg inter-diffusion in $(Mg_xFe_{1-x})O$ ferropericlase, an important phase in Earth’s lower mantle, as a function of iron content. They show an emerging consensus on the effect of pressure on cation diffusion rates in this phase, and use their data to constrain the extent of chemical interaction between Earth’s core and lower mantle since the time of core formation. Koga et al. use recently obtained data for carbon diffusion in diamond, in conjunction with nitrogen diffusion data, to model the decay of isotopic heterogeneities in diamond as a function of residence time and temperature in the Earth’s mantle. The paper illustrates the application of diffusion data to the subject of chronometry, and is an example of the type of knowledge that will become accessible with the

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advent of trace element and isotope analytical techniques with higher spatial resolution. The contribution of Reid et al. provides good evidence for a direct link between rheological properties and diffusion at elevated pressures and temperatures. Reid et al. present in situ viscosity measurements of silicate liquid as a function of pressure, and show that liquid viscosities compare favourably with viscosity estimates derived from oxygen self-diffusion measurements in these liquids at the same conditions. Dobson presents electrical conductivity measurements in sodium-bearing Mg-silicate perovskite, the main phase of the Earth's lower mantle, at very high pressures and temperatures. He finds that the electrical conductivity in this phase is controlled by diffusion of oxygen vacancies at low temperatures—another illustration of the link between physical properties and diffusion—with a possible transition to intrinsic electronic conduction at high temperatures. Finally, Watson et al. provide diffusion rates for some highly siderophile elements in solid iron–nickel alloys. These data are directly relevant for estimates of the cooling rates of meteorites and their parent bodies, and could also be relevant to the evolution of planets with solid metallic cores.

Fortenfant et al. provide new experimental data on the partitioning of highly siderophile elements between liquid metal and (Mg, Fe)O at pressures relevant to the differentiation of Earth's core and mantle. Data like these give tight constraints on early planetary accretion models. The Allan et al. paper reviews recent progress in the relatively new field of computer simulations of trace element partitioning. The tools described are likely to become more widely used in the near future, to study partitioning at extreme conditions not amenable to direct experimentation. As an illustration of the power of these tools, Corgne et al. provide a comparison between experimental and computational data on trace element partitioning between Ca- and Mg-silicate perovskites and silicate melts. Because of the very high pressures (exceeding 23 GPa) and temperatures (exceeding 2500 K) required, systematic experiments involving these phases are still very challenging, and insights from atomistic simulation will certainly aid in the interpretation of experimental results. McDade et al. discuss new experimental data on mineral-melt trace element partitioning during melting of upper mantle material, relevant to the formation of mid-ocean ridge basalt. The paper is an example of recent attempts to produce partition coefficients directly applicable to the modelling of complex petrological processes. Finally, Draper et al. present the most comprehensive collection of data on majorite-melt trace element partitioning to date. By using a starting composition similar to recent estimates of the Martian mantle they illustrate how mineral-melt trace element partitioning studies are becoming increasingly relevant to planetary science studies.

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