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PREFACE

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Preface for article collection “geophysical properties and transport processes in the deep crust and mantle”

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1 Preface

This special volume (SPEPS, Special call for excellent papers on hot topics) is comprised of papers that were for the most part presented at Session S-IT18 during JPGU 2022 held in Makuhari, Chiba Prefecture, Japan, from May 22 to May 27, 2022. The papers in this SPEPS volume, which reflects the original JPGU session in May 2022, address properties and processes that govern the geochemistry and geophysics in the Earth’s interior. The contributions focus on mass and energy transport properties of fluids and magma because these materials are principal agents of mass and energy transport processes throughout the silicate Earth.

The transport processes are imaged globally and locally by geophysical observations such as seismic tomography and electrical conductivity profiles. The transport phenomena discussed in this volume include physical and chemical properties and processes of fluids and magmas as these affect near-surface seismicity and geochemistry in subduction zones as well as geophysical imaging and geochemical modeling of various scales from locally to globally derived from experimental and numerical results. Magma sources in the deep crust and mantle and transport to or near the surface are also imaged by geophysical tools.

The papers in book address those phenomena by reporting results of laboratory experiments, numerical modeling, and observations of natural phenomena using geophysical and geochemical approaches. These approaches include physical and chemical properties and process of fluids and magmas, from near-surface processes in subduction zones to properties and processes in the deep mantle. It also includes results of geophysical imaging at various scales from locally to globally.

A total of 8 papers are presented in this book. Three of these address geochemistry and geophysics of the Earth’s mantle and deep crust (Zhao and Genti, Harada and Tsujimori, and Akizawa and coworkers). The remaining 5 contributions include 2 that focus directly on the role of fluids in mantle processes (Ohtani and Ishii together with Ishii et al.) and 2 that are more general in nature with discussions of solubility and solution mechanisms of trace and minor elements in aqueous solution (Takahashi *and coworkers*, Mysen), and one paper that reports on modeling of phase relations (Gao et al.).

The papers that report on geochemical and geophysical observations of mantle properties and processes include a report on geophysical properties of subduction zone remnants in the deep mantle by *Genti and Zhao.* In this study, a global tomographic method resulted in high-resolution 3-D images of the mantle target areas beneath Asia, North America and the Arctic. The authors reported, in particular, on a stagnant slab below the 660 km between Canada and Greenland. The authors note that slabs such as the Izanagi and Farallon slabs below Northeast Asia and North America provide tomographic information that highlights the role of mantle dynamics such as heat transfer and convection in developing the regional tectonic features.

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Harada and Tsujimori described how abiotic synthesis of hydrocarbons, specifically methane (CH_4), can be formed in geological processes through serpentinization of olivine nodules in a carbonate (marble) matrix that supplies the carbon while ingress of H_2O provides hydrogen. The process is similar to reactions involving olivine and H_2O often suggested to take place in shallow subduction zones and accretion wedges. Following ingress and reaction with H_2O in the olivine to form hydrogen, the H_2 then reacts with CO_2 to form CH_4. This finding highlights that dolomitic marble can store abiotic methane in shallower crustal portions of orogenic belts. Such processes can also contribute to geothermal resources and may influence regional tectonics and climate, despite not being biologically produced.

Geochemical observations from mantle-derived nodules were reported by *Akizawa and coworkers* on microstructural textures from lherzolite nodules contained in nephelinite sampled at Cook Island. These lherzolites a comprised of fine-grained mineral aggregates that are rich in pyrope and include Cr-spinel grains together with pyroxenes and olivine. Reactions of aluminous spinel and pyroxenes yielded pyrope-rich garnet and olivine. It was suggested that following garnet formation, compression played a role in the decomposition of garnet into other fine-grained mineral aggregates. The authors propose that the oceanic mantle beneath these islands was once dragged down to a garnet-stable deep mantle region and later brought up through small-scale convection.

Ohtani and Ishii review the role of water in dynamics of the slabs. They report on experimental results aimed at characterization of H_2O distribution between hydrous phases and nominally anhydrous phases in the mantle. They found that H_2O always showed preference for the hydrous phases and nominally anhydrous minerals are nearly dry. The authors proposed that even wet slabs undergo transformations of dry olivine that may be responsible for deep-focus earthquakes. Hydrous minerals in the slabs release water as the slabs warms, producing locally hydrated mantle transition zone and dense water-bearing magmas at the base of the upper mantle. In short, the presence of water in hydrous minerals contained in subducting slab in subduction zones significantly influences slab behavior, earthquake dynamics, and the structure of the Earth's mantle.

Ishii and coworkers expand on the role H-bearing materials in the silicate mantle by reporting on experiments on partitioning of hydrogen between hydrous phase δ and stishovite under lower mantle temperature and pressure conditions. Hydrous phase δ (AlOOH) is considered the principal carrier of H_2O to the deep mantle. Both hydrogen and Al are partitioned into the phase δ relative to stishovite in 24–28 GPa and 1000°–1200 °C pressure and temperature ranges of the experiments. The authors also propose that the phase transition of stishovite coexisting with δ may contribute to the small-scale scatterers observed around 1900 km depth in the lower mantle.

Two papers report on the role of aqueous fluids as solvent of geochemically important minor and trace elements. They both observe that chemical interaction between nominally insoluble components (HFSE) other solutes can result in species in aqueous fluids, which are much more soluble in aqueous fluids than in pure H_2O. *Takahashi and coworkers* report on solubility of rutile (TiO_2) in aqueous Na-bearing solutions at high pressure and temperature to conditions resembling those of the uppermost upper mantle. The experiments were conducted *in-situ* in the hydrothermal diamond anvil cell to circumvent problems that arise when experimentally produced samples are quenched to ambient conditions prior to analysis. They report that rutile solubility in solutions that also contain NaF, Na_2CO_3, and Na_2SO_4 is much greater than the solubility in pure water. These results are in agreement with other experimental reports that indicate HFSE solubility in aqueous fluids can enhanced by orders of magnitude by formation of Na-bearing complexes in Na-bearing aqueous solutions. The experimental solubility data are used to document how complex formation in aqueous fluids in subduction zones can govern metasomatically altered regions of those tectonic settings.

Mysen reports on experiments aimed at problem areas somewhat similar to those on TiO_2 solubility by Takahashi. He addresses, however, the behavior of Re rather than Ti. In this study, it was observed that interaction of Re in solution with Na solutes enhances Re solubility by a factor of 10–15 compared with the solubility in pure water. Added SiO_2, on the other hand, reduced the solubility of Re. From the combined effect of Na_2O and SiO_2 solutes on Re solubility, the sodium's influence on Re solubility was more pronounced than that of SiO_2. It is suggested that interaction of Re with Na results in a Re species whose structure has Re is fourfold coordination with oxygen. In these structures, Na replaces H in portions of the structures where the oxygen forms bonding with Re. In summary, this study shows, as that of Takahashi on Ti solubility behavior, that fluid chemistry can be critical in determining the transport of high-field strength elements (HFSE) that are essentially insoluble in pure H_2O. These results lead to the conclusion that complex chemical interactions in fluids can significantly affect elemental mobility, making high-grade metamorphism, including that in subduction zones, more dynamic systems because of these interconnected geochemical processes.

Gao, Li, and Zhang describe results of thermodynamic modeling aimed at describing the phase relations in the SiO_2–H_2O system. This comparatively simple system remains a basis for understanding complex silicate-water systems in natural tectonic settings. In this study, the authors propose a thermodynamic model for SiO_2–H_2O fluid by modifying the traditional non-random two-liquid model with simplified polymerization reactions. On this basis, three-dimensional pressure-temperature-composition phase diagrams were constructed. The results of the modeling effort reported in this paper enhances our understanding of how silicate components interact with H_2O. The model provides a tool to predict and analyze mineral behavior in a range of terrestrial conditions.

In summary, this SPEPS volume contains snapshots of various geochemical and geophysical properties of Earth materials that are affected by aqueous fluids and magmatic liquids and, therefore, influence geophysical and geochemical processes in the Earth's interior. It is our hope that this information will serve as a guide to understand and aid in what observations, experiments, and modeling are best suited to characterize the role of fluids and magmas during formation and evolution of the Earth.

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