Role of Hydrogen on the Rheological Properties of Silicate Minerals and Its Implications for Evolution of Terrestrial Planets

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Rheological properties of silicates have strong influence on the evolution of terrestrial planets. Recent progress in experimental and theoretical studies has made it possible to evaluate the influence of hydrogen on rheological properties of silicates on the quantitative basis.

Influence of water on rheological properties has been investigated on olivine and quartz and now we have a reasonably well-established microscopic model for the role of hydrogen on rheological properties. Although much less is investigated for deep mantle minerals, growing data set on defect-related properties in deep mantle minerals such as wadsleyite provide some hints as to the influence of hydrogen on rheology in these minerals.

Hydrogen is dissolved in these silicate minerals mainly as fully charge-compensated defects at cation sites (e.g., two protons at M-site). However, hydrogen is also dissolved as charged defects as seen by the experimental studies on electrical conductivity. These charged defects modify the concentration of defects at other sites such as Si- or O-site. Consequently diffusion coefficients of Si and O are modified by hydrogen dissolution. Hydrogen defects interact with dislocations and grain-boundaries. The motion of these 'extended' defects involves formation and migration of 'steps' (kinks or ledges), whose concentration is also dependent on water fugacity. Consequently, the rate of processes involving these extended defects (dislocations and grain-boundaries) is enhanced by water more than the processes involving point defect alone.

A combination of these microscopic models of rheological properties with thermal models of planets provides new insights into the evolution of planets. Some implications of these mineral physics observations on planetary evolution will be discussed including Earth-Venus contrast in tectonic style and the origin of plate tectonics on Earth.