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Chemical reactions in the Fe_2SiO_4-D_2 system with a variable deuterium content at 7.5 GPa

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Abstract

Hydrogen-induced decomposition of fayalite (Fe_2SiO_4) at high pressure is of considerable interest for a better understanding of the chemical processes occurring in the cores and mantles of icy satellites. At pressures up to 10 GPa and temperatures 250–300 °C (typical of the cores and mantles of Jupiter's and Saturn's satellites), a variable amount of hydrogen can react with fayalite contained in their rocks. Volatile compounds that can form via these reactions are usually identified by mass spectroscopy. In our experiments, we used compressed deuterium gas instead of hydrogen to ensure that the volatiles analyzed by mass spectroscopy could only result from the decomposition of fayalite. To study the effect of the amount of deuterium present in the system, the fayalite (Fa) samples were deuterated at $P = 7.5$ GPa and $T = 280$ °C with the preset molar ratios D_2/Fa = 1, 1.5, 2.2, and 5 in the reaction cell. The deuterated samples were further quenched to the liquid N_2 temperature and, after releasing the pressure, removed from the reaction cell and studied by quadrupole mass-spectroscopy, X-ray diffraction, and Raman spectroscopy. Our results showed that the high-pressure deuteration invariably led to the chemical decomposition of fayalite. The solid products of the reaction varied from a mixture of ferrosilite ($FeSiO_3$) and iron at D_2/Fa = 1 to a mixture of silica and iron at D_2/Fa = 2.2. The decomposition occurred via breaking the Fe-O bonds and was always accompanied by the formation of water. Applying the observed reactions to the natural conditions of, e.g., the center of Titan or Ganymede, one may infer that fayalite can be dissolved in the hydrogen fluid or replaced by iron, ferrosilite, or silica depending on the molar ratio H_2/Fa.

Keywords: Fayalite, hydrogen, ferrosilite, high pressure, decomposition reaction, silica, iron