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An experimental study on hydrogen production during the serpentinization of olivine at 350 degrees C and 50 MPa

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The serpentinization of abyssal peridotites by hydrothermal fluids is assumed as the most plausible candidate to inorganically produce hydrogen to support hydrothermal ecosystem. However, its reaction rates and mechanisms, especially for hydrogen and hydrocarbon production, are still ambiguous. Laboratory experiments of serpentinization process are therefore important to put constraints on its thermodynamic and mineralogical characteristics; such studies have profound implications for geology, petrology, (geo)microbiology, and the early evolution of terrestrial biosphere on Earth and other planets.

We developed two types of high-temperature hydrothermal apparatuses for serpentinization experiments; batch-type and flow-type. In addition, we developed methods for direct and precise analyses of gas components through gas-chromatography, including hydrogen that are produced during serpentinization experiments at elevated temperature and pressure.

As a start-up of the experimental system, we performed an experiment for serpentinization of olivine in Na-Mg-Cl aqueous solution (artificial seawater) using the batch-type system. Natural olivine separates were reacted with the fluid at 350 degrees C and 50 MPa for 357 hours. Fluid samples were periodically collected during the experiment, and analyzed for determining the concentrations of H_2, CO_2, CH_4, and other light hydrocarbons. Detection limits of H_2, CO_2, and CH_4 were 0.5, 0.2, and 0.1 micro mol/L, respectively.

Amount of H_2 formed during the experiment at 350 degrees C reached 3.59 mM/L after 282 hours. This value is significantly higher than that of a previous similar experiment at 400 degrees C (Allen and Seyfried, 2003). As an explanation of enhanced H_2 production in our 350 degrees C experiment, we suggest that our experimental condition (350 degrees C) is located in the stability field of brucite + serpentine in the Mg-endmember system, and therefore forsterite is expected to be metastable leading to the accelerated serpentinization , while previous experiment at 400 degrees C was within a stability field of forsterite.

Detailed microscopic observation, electron microprobe, and Raman spectroscopic analyses of the run products show that olivine grains were partially serpentinized, and brucite and magnetite were confirmed as products as well as serpentine mineral. The serpentine mineral was identified as chrysotile by Raman analysis. The serpentinization reaction is estimated to:

$5.7\ (Mg_{0.9}Fe_{0.1})_2SiO_4 + 8.21\ H_2O = 2.85\ (Mg_{0.94}Fe_{0.06})_2Si_3O_5(OH)_4 + 2.34(Mg_{0.95}Fe_{0.05})(OH)_2 + 0.17\ Fe_3O_4 + 0.17\ H_2$

A mass balance calculation among the observed H_2 concentration, olivine, chrysotile, brucite, and magnetite suggests that 7.4 wt% of olivine in the starting material was serpentinized during the 357h experiment.