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Hugoniot curve for forsterite under extreme conditions: O2 supply into the surface environment on the early Earth

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Recent dynamical model for impact flux to the Earth-Moon system based upon the chemical analyses of lunar samples and crater chronology suggests that impactors during the late heavy bombardment period are highly dynamically excited and their impact velocities to the Earth reach ~30 km/s. The amount of silicate vapor and its chemical composition, which are important factors to investigate the geological consequence after such hypervelocity impacts, have not been understood. This is because reliable Hugoniot curve for silicate materials higher than 200 GPa is not established due to technical difficulities, resulting in large uncertainty in the thermodyanamic path of isentropic release from shocked state. Although there is an EOS model, M-ANEOS, for silicate materials which is widely used for hydrocode calculations [e.g., Canup, 2012, Cuk & Stewart, 2012], the entropy gain for silica predicted by M-ANEOS is considerably smaller than that investigated by experiments. In this study, We carried out laser shock experiments at GEKKO XII-HIPER facility of Institute of Laser Engineering of Osaka University to obtain the Hugoniot curve for actual silicate material, forsterite, up to 1200 GPa on an entropy-pressure (S-P) plane. Shock temperatures and pressures during the propagation of laser-induced shock waves were measured simultaneously. Shock-induced entropy gain can be calculated using the obtained peak shock temperatures and pressures and thermodynamic relations. We found that the entropy gain for forsterite is much larger than the M-ANEOS prediction as well as silica. The amount of forsterite vapor after isentropic release can be calculated using the lever rule when the shock-heated forsterite is under thermal equilibrium during expansion. The amount of forsterite vapor is ~2 times than the M-ANEOS prediction. The redox state in impact-induced vapor clouds strongly depends on the degree of vaporization of silicates because the molar fraction of oxygen in silicate materials is higher than 0.5. Then, we conducted thermochemical calculation along with the isoentrope at ~30 km/s to calculate the molecular composition of released gas into the atmosphere after a meteoritic impact with CI-like chemical composition. We found that a large amount of molecular oxygen, which is not considered to be existed on prebiotic Earth, is likely to be released into the atmosphere. Hypervelocity impacts during the late heavy bombardment period might supply a large amount of oxygen into the surface environment. Such impact-induced oxygen might play important roles in a chemical evolution phase on the early Earth because oxidation reaction by molecular oxygen produced a large amount of free energy.

Keywords: Meteoritic impacts, Forsterite, Late heavy bombardment, Laser shock compression, Hugoniot curve, Surface environment on the early Earth