Efficient methane production due to iron meteorite impacts during late-stage heavy bombardment

Seiji Sugita[1]; Peter Schultz[2]

[1] Dept. of Complexity Sci. & Eng., Univ. of Tokyo; [2] Dept. of Geol., Brown Univ.

Introduction

Methane is a very strong greenhouse effect gas and may have helped warming the early Earth and Mars atmospheres significantly. However, it is not known if there was a process that can supply methane at high rate enough to withstand the rapid destruction by UV-induced photochemistry. In this study, we propose a new methane-producing mechanism. More specifically, we consider impacts of iron meteorites into H_2O (e.g., ocean, polar cap, or permafrost) under a CO_2-dominated atmosphere, taking account of oxidation of meteoritic matter, atmospheric entrainment due to buoyancy uprise, and Fischer-Tropsh reaction on the surface of survived meteoritic metals.

Impact Vaporization and Condensation

When the thickness of target H_2O layer is much larger than the diameter of an impacting body, the vaporized water mass can be estimated with the Gamma model. A typical impact velocity of 10 km/s on Mars will result in vaporized water mass 1.9-2.7 times the iron impactor mass. This corresponds to 5.9-8.9 of molar ratio of H_2O/Fe in the resulting vapor cloud. Here, we consider near-vertical impacts and assume that both projectile vapor and target vapor are mixed well rapidly. If half of the impact energy (10MJ/kg) is partitioned to the internal energy of the vapor cloud, the mean vapor temperature is ~1800K before decompression. If the target contains 50% of silicate, the temperature will be about 2400K. As the vapor decompresses, the temperature will decrease, and solid and liquid phases will appear.

Buoyancy Uprise Process

After adiabatic decompression, entrainment of cold ambient air becomes the dominant cooling process of an impact vapor plume. The temperature T of the air-vapor mixture is given by a simple heat balance between hot vapor and entrained cold air. Calculation result shows that plume temperature goes through the catalytically active range when 1 to 10 times the vapor mass of air is entrained, depending on the post-decompression vapor temperature. This will require time comparable to the time needed for industrial catalyst to convert H_2 to CH_4 within a vapor cloud. Because vapor condensates expected in the vapor plumes considered in this study are small iron oxide grains coated with metallic nickel layer, it is very similar to industrially utilized catalysts. Thus the duration of catalytically active temperature condition is likely to be long enough to convert H_2 to CH_4.

Then near-equilibrium concentration of CH_4 can be catalytically produced in an uprising vapor cloud. Equilibrium calculation result indicates that methane yield reaches higher than 1/3 the stoichiometric maximum within the catalytically active temperature range (400-600K) when vapor mixing ratio is larger than 10%. Such high vapor mixing ratios at catalytically active temperatures is achieved when post-decompression vapor temperature is lower than about 2000K. Because the Gamma-model calculation indicates that mean pre-decompression vapor temperature for iron meteorites at 10 km/s is 1800-2400K, this condition can be met by a large fraction of iron impactors.

Methane Yield

A 30 km of iron meteorite is required to produce 0.2% of CH_4 in a 2 bar of CO_2 atmosphere on paleo-Mars. This composition of atmosphere is estimated to warm Mars to temperatures above freezing. Although such a large impact is not expected to occur frequently, it must have occurred at least several times during the heavy bombardment period. Then, a warm climate may occur episodically and last for several hundred of years of time (i.e., the photochemical lifetime of methane). Such episodic occurrence of warm climate is consistent with the geologic record of Mars.