

**Global Methane Production by Iron Meteorites Impacts on Early Earth.** Y. Sekine<sup>1</sup>, S. Sugita<sup>1</sup>, T. Kadono<sup>2</sup>, and T. Matsui<sup>3</sup>, <sup>1</sup>Dept. of Earth and Planetary Sci., Univ. of Tokyo, Bunkyo, Tokyo 113-0033, Japan, <sup>2</sup>Institute for Frontier Research on Earth Evolution, Yokosuka, Kanagawa 237-0061, Japan, <sup>3</sup>Dept. of Complexity Sci. and Engineering, Univ. of Tokyo, Bunkyo, Tokyo 113-0033, Japan

**1. Introduction:** Impacts of planetisimals on early Earth have been considered to affect the origin and evolution of life and atmosphere (1). We suggest an importance of organic synthesis due to catalytic reaction like Fischer-Tropsch catalysis over the hot iron condensates. When condensed particles, formed in an expanding impact vapor plume, reenter into the atmosphere, those would be heated by the drag of atmosphere (2) and form a stagnant layer. In such a high temperature condensate layer, catalytic reaction like Fischer-Tropsch catalysis over the hot iron condensates may proceed rapidly.

**2. Atmospheric Heating:** In a hypervelocity impact, most of the impactor and a part of the target are vaporized, and form a vapor plume. We used the density and velocity distribution model by Zel'dovich and Razier (3) for the vapor plume. In this study, we assume an impactor as an iron meteorite (diameter=10km, impact velocity=15km/s). According to the model, the density distribution is given by

$$\rho(r) = \frac{A}{R^3} \left(1 - \frac{r^2}{R^2}\right)^\alpha \quad (1)$$

where  $R$  is the plume radius. The constant  $A$  and integer  $\alpha$  are determined by mass and energy conversions. We assume the ratio of its specific heats to be 9/7. The total mass of resulting vapor cloud is estimated by using the results of numerical simulation of iron impact into anorthosite target (4). The velocity increases linearly from its center (0km/s) to the outer-edge (22.0km/s). The outer-edge velocity is estimated by using the planar impact approximation (5).

The condensation of some gas species in a vapor cloud occurs during an early stage of expansion and the subsequent flight of the condensates is given by a ballistic flight. Then, we calculate the mass, energy deposition, and flight time of the condensates as a function of distance from the impact site. We consider two cases: 10- $\mu$ m and 100- $\mu$ m sized condensates. The condensates with diameter of 100 $\mu$ m and 10 $\mu$ m effectively stop at a height where the pressure is 1, and 0.1Pa, respectively (2). The temperature of upper atmosphere increases owing to the friction between the condensates and the atmosphere. Therefore, we can assume

that the atmosphere is composed of two layers, that is, the upper heated condensate-stagnant layer (hereafter we call this the hot condensate layer) and the lower atmosphere. The condensate sinks slowly in the condensate layer. The sinking speed  $w$  is given by

$$w = \frac{2\rho_p r^2 g}{9\eta} \left[ 1 + \left(\frac{\lambda}{r_c}\right) \left( A + B \exp \left\{ -\frac{Cr}{\lambda} \right\} \right) \right] \quad (2)$$

where  $r_c$  and  $\rho_p$  are the radius and density of the particle,  $g$  is the acceleration of gravity,  $\eta$  is the viscosity of the gas and  $\lambda$  is the mean free path length (6). We use  $\eta$  at 273K, that is  $1.73 \times 10^{-5}$ kg/m/s. For  $\lambda$  we use the mean free path length at each corresponding pressure level of the present atmosphere. The values of empirical constants,  $A$ ,  $B$ , and  $C$  are given by Kasten (6).

We calculated the temperature of the condensate layer by using the following energy balance equation

$$\frac{\partial e}{\partial t} = m_{\text{con}}(t) C_{\text{vcon}} \frac{\partial T(t)}{\partial t} + \frac{\partial m_{\text{con}}(t)}{\partial t} [C_{\text{vcon}}(T(t)-T_0) + f_m Q_m + f_v Q_v] \quad (3)$$

$$+ m_{\text{at}} C_{\text{vat}} \frac{\partial T}{\partial t} + \frac{\partial m_{\text{at}}}{\partial t} C_{\text{vat}}(T(t)-T_0) + 2\sigma T(t)^4$$

where  $m_{\text{con}}$  and  $m_{\text{at}}$  are the masses of the condensates and the gas in the condensate layer,  $e$  is the kinetic energy given to the condensate layer,  $C_{\text{vcon}}$  (=1.2J/g/K) and  $C_{\text{vat}}$  (=1.0J/g/K) are the heat capacities of the condensates and atmosphere,  $Q_m$  (=4.0 $\times 10^3$ J/g) and  $Q_v$  (=8.0 $\times 10^3$ J/g) are the latent heats of melting and vaporization,  $f_m$  is the fraction of molten reentering condensate,  $f_v$  is that of vaporized one,  $\sigma$  is Stefan-Boltzmann constant and  $T$  is the temperature of the condensate layer (2).

**3. CH<sub>4</sub> production by Fischer-Tropsch Catalysis:** Fischer-Tropsch catalysis, in which CO and H<sub>2</sub> are converted to methane and other hydrocarbons on the surface of metallic iron, was modeled following Kress and Tielens (7). They considered H\*, CO\*, C\*, CH\*, CH<sub>2</sub>\*, CH<sub>3</sub>\*, O\*, OH\* and graphitic carbon (G\*) as the surface intermediates and 19 reaction steps. We used the same value of the reaction kinetic parameters except the frequency factor of step 7 in Table 1 of their paper ( $2.0 \times 10^9$ /s in our reestimate). We determined the methane formation rate using this kinetic model. Next, we estimate the atmospheric composition of early Earth. We assume a mildly

reducing atmosphere ( $N_2$ ,  $H_2O$ ,  $CO_2$ , and  $CO$ ) and the partial pressures of each gas constituent are assumed to be 0.8 ( $N_2$ ), 0.1 ( $CO_2$ ) and 0.1 ( $CO$ ) bar, respectively (8). We also assume the lower and upper limits of the atmospheric  $H_2$  ratio as  $H_2/CO=0.03$  and 10, respectively (8, 9). Figure 1 shows the temporal variation of the methane formation rate and the temperature of the condensate layer for angular distance at  $84-90^\circ$  from the impact point. Figure 2 shows the methane formation rate as a function of the height of atmosphere. We show an estimate of the total methane production as a function of  $H_2/CO$  ratio in Fig. 3. Total methane production may reach to the order of  $\sim 10^{12-13}$  kg.

**4. Discussion:** Methane supplied to the upper atmosphere would be photodissociated and some of them are converted to HCN. HCN is a potentially important molecule for the origin of life. Zahnle (10) calculated the methane photodissociation and HCN formation in the Earth's early atmosphere. Assuming the constant conversion rate of methane to HCN (1–10%), the total production of HCN is estimated to be  $\sim 10^{10-12}$  kg. Those correspond to the HCN production in  $CO_2$ - $CO$  dominant atmosphere by UV radiation or electric discharge for several  $10^2$ - $10^5$  years. Since the formation of life building materials need the concentration of organic carbon, episodic supply of organic matter by Fischer-Tropsch catalytic reaction due to iron meteorite impacts may have played a key role in the origin of life.

**References:** (1) Chyba, C. F., and C. Sagan, *Nature*, 355, 125-132, 1992, (2) Zahnle, K. J., *Spec. Pap. Geol. Soc. Am.*, 247, 271-288, 1990, (3) Zel'dovich, Y. B., and Y. P. Raizer, *Physics of Shock Waves and High Temperature Hydrodynamic Phenomena*, San Diego, 1967, (4) O'Keefe, J. D., and T. J. Ahrens, *Proc. Lunar Sci. Conf. 8th*, 3357-3374, 1977, (5) Melosh, H. J., *Impact cratering*, New York, Oxford University Press, 1989, (6) Kasten, F., *J. Appl. Meteorol.*, 7, 944-947, 1968, (7) Kress, M. E., and A. G. G. M. Tielens, *Meteoritics & Planetary Science*, 36, 75-91, 2001, (8) Kasting, J. F., *Origins of Life and Evolution of the Biosphere*, 20, 199-231, 1990, (9) Hashimoto, G. L., and Y. Abe, *Proc. 28th ISAS Lunar and Planetary Symposium*, 126-129, 1995, (10) Zahnle, K. J., *J. Geophys. Res.*, 91, 2819-2834, 1986

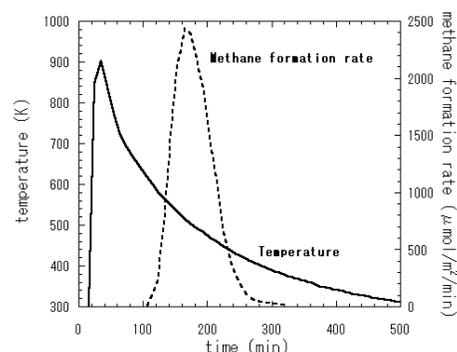


Fig. 1: Methane formation rate ( $\mu\text{mol}/\text{m}^2/\text{min}$ ) and temperature of the condensate layer as a function of time. The condensate diameter and the atmospheric  $H_2/CO$  ratio are  $100\mu\text{m}$  and 1, respectively.

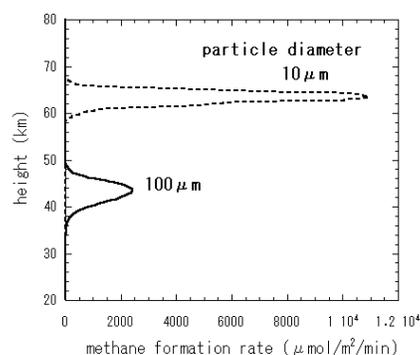


Fig. 2: Methane formation rate as a function of height of the atmosphere. The height is calculated for the today's atmospheric pressure. The atmospheric  $H_2/CO$  ratio assumed to be 1.

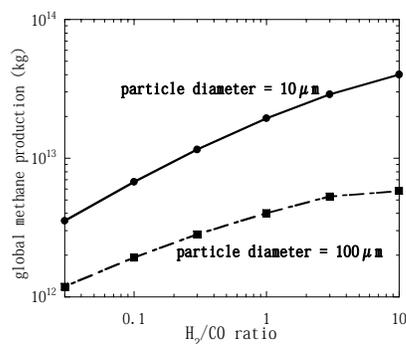


Fig. 3: Methane production as a function of  $H_2/CO$  ratio.