Atmospheric heating and the formation of Methane by large impacts

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The Earth has had experienced heavy bombardment of planetesimals at early stage of the Earth's evolution. This had important consequences for the origin and evolution of life and atmosphere. In hypervelocity impact, the impactor (asteroid) and a part of the target are vaporized and the vapor plume is formed. We model the expanding vapor plume as a hemispherical cloud with the velocity distribution that increases linearly from its center (0km/s) to outer edge. We use the Zeld'vich and Razier (1966) proposal as the density distribution of the vapor plume. We assume that the mass of vapor plume is given by the mass of the impactor and the mass of target region compressed more than 186GPa (the dunite begins vaporizing at 1bar after decompressed adiabatically from that pressure). The densities of impactor and target are the same and given by 3.0g/cm3. The vapor in the cloud condenses at early stage of expansion and the subsequent flight of the condensates is assumed to move ballistically. We determine the mass, the energy deposition and the flight time of the condensates from ballistic formulae as a function of distance from the impact site.

The reentering condensates stop effectively at the height corresponding to the atmospheric pressure of several to tens Pa by the drag of atmosphere. We assume that the atmosphere is composed of two layers, those are the heated upper atmosphere and the condensates layer (hereafter are called this Envelope layer) and the lower atmosphere. We determine the temperature of the Envelope layer and its time changes by solving the equation of energy balance. In the case of impact (diameter 10km, 20km and 25km) with 20km/s velocity, the results for the region of 24-30 angle from impact point are shown in Fig.1.

In the Envelope layer, the atmosphere will react on the iron metal (Fischer-Tropsch catalysis) supplied by asteroid, if the temperature increases to 400K-700K. The Fischer-Tropsch catalysis, in which CO and H2 are converted to hydrocarbon (mainly methane) over iron catalyst, follows 19 reaction steps (Table1) in the case of methane formation. We model the kinetics of this reaction following the gas-phase kinetic model. The rate-limiting step is assigned to be the hydrogenation step of the surface carbon and we determine the parameter of the reaction steps based on the experimental data (Krebs et al, 1979). Then, we solve a set of nine nonlinear ordinary differential equations describing the time evolution of the nine surface species for determining the methane formation rate.

In Fig.1, we show the numerical results for the case of impact (diameter 25km) with 20km/s velocity, at 24-30 angle from impact point. In this figure, the time evolution of methane formation rate and that of the cumulative methane production are shown. We assume that 5wt% of the mass of the impactor is deposit as a iron metal. The results show that the reaction time is more than 1day and the cumulative mass of methane formation is about tens gram per square meter. The formation rate of organic carbon of this process is much larger than that of UV or IDPs, although UV and IDPs has been considered as the influential organic carbon sources. Since the generation of life and its building materials needs the concentration of organic carbon, this process may be suggested to play a key role in the origin of life.

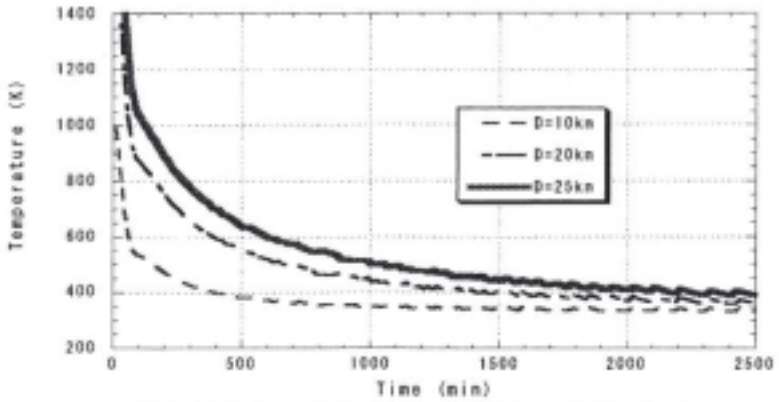

Fig. 1: Temperature time evolution of Envelope in the case of D=10, 20 and 25km impact

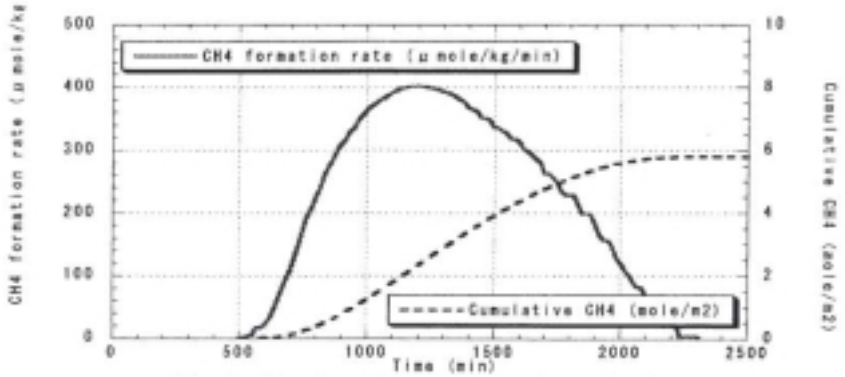

Fig. 2: The formation rate and cumulative production (mole) of CH4 (impactor diameter 25km, at the region 24-30° from impact point: pH2=0.5Pa, pCO=2Pa)

step	reaction		products
1.	$H_2(g) + 2f1$	→	$2H^*$
2.	$CO(g) + f2$	→	CO^*
3.	$2H^*$	→	$H_2(g) + 2f1$
4.	CO^*	→	$CO(g) + f2$
5.	$CO^* + f5$	→	$C^* + O^*$
6.	$C^* + O^*$	→	$CO(g) + f2 + f5$
7.	$C^* + H^*$	→	$CH^* + f1$
8.	$CH^* + H^*$	→	$CH_2^* + f1$
9.	$CH_2^* + H^*$	→	$CH_3^* + f1$
10.	$CH_3^* + H^*$	→	$CH_4(g) + f1 + f2$
11.	$O^* + H^*$	→	$OH^* + f1$
12.	$OH^* + H^*$	→	$H_2O(g) + f1 + f5$
13.	$OH^* + f1$	→	$O^* + H^*$
14.	$CH^* + f1$	→	$C^* + H^*$
15.	$CH_2^* + f1$	→	$CH^* + H^*$
16.	$CH_3^* + f1$	→	$CH_2^* + H^*$
17.	$CH_3^* + CH_3^*$	→	$C_2H_6(g) + 2f2$
18.	C^*	→	G^*
19.	G^*	→	C^*

Table 1:The steps involved in the reaction mechanism for the conversion of CO and H2 to CH4 over iron catalast. (The chemical species with * is absorbed to the surface. f1,f2,f5 are the free site of H,C,O and G represents the unreactive carbon)