

Evaporation of icy planetesimals due to planetesimal bow shocks in a protoplanetary disk

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In a protoplanetary disk, planetesimals grow to planets by mutual collisions and accumulations. The gravitational interactions among the planetesimals increase eccentricities of the planetesimal orbits. When a relative velocity between the disk gas and planetesimal exceeds a sound velocity of the gas, a bow shock wave is produced on the leading side of the planetesimal.

It has been shown that heating by the planetesimal bow shocks in the nebular gas played a key role in formation of particles found in meteorites and interplanetary dust. For instance, the shock heating leads to formation of chondrules, millimeter-scale igneous silicate spheres in chondrites, by melting dust in the protoplanetary disk (e.g., Hood 1998; Weidenschilling et al. 1998; Ciesla et al. 2004; Miura and Nakamoto 2002). Furthermore, it is possible by a planetesimal bow shock to form various types of cosmic crystals, which are fine silicate crystals observed in chondritic meteorites and interplanetary dust particles (Miura et al. 2010).

So far, the attention has mainly been paid on thermal evolutions of dust particles in the shocked region in the previous studies. However, we note a possibility that the planetesimal bow shock leads to heating and evaporation of the planetesimal itself. A similar process is found in ablation of the planetesimals penetrating through the atmosphere of a protoplanet (e.g., Podolak et al. 1988; Pollack et al. 1986). Heating and resultant evaporation by the planetesimal bow shocks will suppress growth of planetesimals. Furthermore, cooling of the vapors thus produced will form small dust particles by re-condensation. Those dust clouds in the disk may be found in the infrared spectra of the protoplanetary disks.

In the present study, we focus on the planetesimal heating and evaporation by the planetesimal bow shocks. We evaluated the surface temperature and evaporation rate of the planetesimal using a simple model of planetesimal evaporation by the planetesimal bow shock. We applied the model of the planetesimal evaporation to the formation stage of protoplanets. Our results show that the icy planetesimals evaporate efficiently in the planetary oligarchic stage (Kokubo and Ida 2002), where strong shocks are generated by the gravitational perturbations from the protoplanets. The results suggest that the growth of a protoplanet is suppressed owing to the insufficient accretion of planetesimals onto the protoplanet. There may be an influence on the chemical composition in the asteroid region because the vicinity of asteroid belt (2-4 AU) corresponds to the region where the evaporation is effective.

References

- Ciesla, F. J., Hood, L. L., and Weidenschilling, S. J. 2004, *Meteorit. Planet. Sci.*, 39, 1809
Hood, L. L. 1998, *Meteorit. Planet. Sci.*, 33, 97
Kokubo, E., and Ida, S. 2002, *ApJ*, 581, 666
Miura H., Nakamoto T, and H. Susa, 2002, *Icarus* 160, 258
Miura, H., K. K. Tanaka, T. Yamamoto, T. Nakamoto, J. Yamada, K. Tsukamoto, and J. Nozawa, *ApJ.*, 2010, 719, 642
Pollack, J. B., Podolak, M., Bodenheimer, P., and Christofferson, B. 1986, *Icarus*, 67, 409
Podolak, M., Pollack, J., and Reynolds, R. T., 1988, *Icarus*, 73, 163
Weidenschilling, S. J., Marzari, F., Hood, L. L. 1998, *Science*, 279, 681

Keywords: protoplanetary disk, planetesimal, shock wave, evaporation

In-situ observation of DCPD crystal (010) surface dissolution during transformation into HAP in solution

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Biom mineralization is a biological process by which living organisms make use of organic matrix, such as peptides and proteins, to control the formation of functional minerals. The mineral brushite (DCPD) has been found under pathological conditions in kidney stones, some forms of arthritis, and caries. It has been proposed that brushite is a transient precursor for phase hydroxyapatite (HAP), which is the major inorganic component of bone and dental tissues. In recent years, the transformation mechanism from DCPD to HAP has attracted many attentions. The transformation from DCPD to HAP can be divided into two processes: dissolution of DCPD and precipitation of HAP. However, many researchers considered only the effect of interfacial energy on the transformation process from DCPD to HAP in solution and there were few literatures about kinetics of dissolution of DCPD. The purpose of this study is to reveal the details of fundamental process of the dissolution and the effects of bioorganic on the dissolution during transformation. For the purpose, we carried out in situ observations of dissolution of DCPD in solution by using the following microscopes. The phase shift interferometer (PSI) was used to measure the dissolution rate of DCPD crystal. Phase contrast microscope (PCM) and atomic force microscope (AFM) will be used to observe the change of crystal surface in atomic scale, e.g., the formation and growth of etch pit during dissolution process.

Firstly, we prepared the plate-like DCPD crystal around 2 mm in size by a simple precipitation method. The (010) surface of DCPD crystal during dissolution in solution has been in situ observed by PCM, PSI and AFM under different undersaturation, pH value, and concentration of Tris(hydroxymethyl)aminomethane. The reason why we chose Tris is that it is an organic compound and a primary amine, which can be widely used in biochemistry and molecular biology.

From in situ observation by PCM, we observed the triangle, quadrilateral, and trapezoidal etch pits on the (010) crystal surface under different conditions. We found that at the case of triangle etch pit, the step velocities, of [101], [-100] and [10-1] steps on the (010) surface are different in spite that the solution condition is the same. Especially, [-100] step has the fastest step velocity, which is opposite to the former report. It was also found that the step velocities increased evidently when two or three etch pits merged. In addition, the experimental data demonstrated that the dissolution rate normal to the (010) face became slower after adding Tris in solution. Therefore, it is considered that the effect of impurity on the crystal surface during dissolution process is very important, which may further change the crystal habit. Finally, these findings are helpful for us to further understand the mechanism of biom mineralization.

Keywords: Biom mineralization, DCPD crystal, dissolution, in-situ observation, etch pit

Oxygen isotopic composition as a fundamental reference marker in water-material chemical interaction.

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To understand the basic processes in water-material chemical interactions in nature it is common to use oxygen isotopic ratio as a reference marker. For this SMOW has been conventionally employed as a standard, but its validity as a universal reference in a whole solar system is currently in hot debate [e.g.1,2]. We urge that any cosmochemical study on water-material interaction in the early solar system (the objective of this session), either theoretical or experimental, must in the first place consider this fundamental constraint.

The latest report of GENESIS project [3,4,5] gave a convincing isotopic composition of oxygen in bulk solar wind (SW) sample collected on a concentrator. However, correction for putative isotopic fractionation between SW and the Sun is still needed to conclude the solar oxygen isotopic composition. Although a model-dependent and somehow circular argument on the fractionation process was suggested in the GENESIS report [5], a definitive examination of the isotopic fractionation is urgent. Here, we studied noble gas isotopic fractionation, and on the basis of the latter result, we discuss oxygen isotopic fractionation between SW and the Sun. Our result does not support the solar oxygen isotopic composition concluded from the GENESIS mission.

Firstly, we show that the average noble gas isotopic composition in the early solar system is represented by Q-noble gas in primitive meteorites, one of two major noble gas components (Q and SW) widely occurring in the early solar system. Next, we show that SW-noble gas was mass-dependently fractionated from Q-noble gas with a fractionation factor inversely proportional to a square root of mass ratio of isotope, namely in proportional to $1/(m_i/m_j)^{1/2}$, where m_i and m_j stand for the mass of isotope i and j . We note that the characteristic fractionation factor is the typical of a Rayleigh distillation type fractionation. If the noble gas isotopic fractionation factor concluded in this work were applied to the Genesis SW oxygen data, the corrected oxygen isotopic composition becomes much closer to the terrestrial oxygen than to those suggested in the GENESIS report [5], and therefore is contrary to a widely held view [1, 5] that the solar oxygen isotopic ratio is the same as CAI oxygen, but differs from the terrestrial oxygen. Besides the mass-dependent isotopic fractionation identified in the case of noble gas, additional mass-independent fractionation (MIF) may also be present, which we speculate attributable to the dissociation of CO in the lower solar photosphere [6,7].

[1] Clayton, R.N., *Nature* **415**, 860-861 (2002). [2] Ozima M., Podosek F.A., Higuchi T., Q.-Z. Yin, and Yamada A., *ICARUS* **186**, 562-570, 2007. [3] Heber V. et al., *Geochimica et Cosmochimica Acta* **73**, 7414-7432 (2009). [4] Heber V. et al., *Meteoritics and Planetary Science* **46**, 493-512 (2011). [5] McKeegan K.D. et al., *Science* **332**, 1528-1532 (2011). [6] Asplund M., Grevesse N. & Sauval A. J. *Annu. Rev. Astron. Astrophys.* **47**, 484-522 (2009). [7] Chakraborty S. et al., *Science* **321**, 1328-1331 (2008).

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Condensation with dust/gas separation and chemical fractionation in a protoplanetary disk

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The inner edge of a protoplanetary disk is the region where all the solids are vaporized, where condensation/evaporation plays a critical role in chemical evolution of dynamic disk. We have investigated chemical evolution of dust and gas with a kinetic condensation model (Nagahara and Ozawa, 2008, 2009) and kinetic parameters determined by condensation/evaporation experiments by our group. The model is based on the Hertz-Knudsen equation and mass balance between solid and gas in a cooling gas. Free parameters are cooling time of the system, total pressure and gas/dust separation efficiency, which is tentatively expressed by the critical size of dust separation.

The results show that there are three regimes in terms of chemical fractionation; one is the regime where no chemical fractionation takes place due to very fine grain size of condensing dust, one where no chemical fractionation takes place due to very large dust size, and one where effective fractionation takes place depending on the cooling time scale and critical dust separation size. The cooling rate and critical size for dust separation can be regarded as the relative velocity of gas around the inner edge, thus the dynamics of gas.

We discuss the conditions to achieve chemical fractionation among chondrites.