

RAPID FALL OF THE K/T SULFURIC ACID AEROSOLS AND OCEANIC pH REDUCTION. Sohsuke Ohno¹ and Seiji Sugita¹, ¹Univ. of Tokyo, Dept. of Complexity Sci. and Eng. , oono@impact.k.u-tokyo.ac.jp

Introduction: Geologic evidence indicates that the K/T mass extinction occurred on 65 million years ago is caused by an asteroid or comet impact [e. g., 1]. However, the actual mechanism that caused the mass extinction is still very controversial. The impact-generated sulfuric oxides are thought to cause an environmental perturbation and it is one of the most plausible hypotheses of the K/T killing mechanism [e. g., 2, 3]. Laboratory experiments by Ohno et al. [4] suggest that the degassed sulfur have been dominated by SO₃, not SO₂, and that the sulfuric oxide should have quickly formed sulfuric acid aerosols.

The mechanism of the environmental perturbation due to the sulfuric acid aerosol depends strongly on its residence time. If the residence time was longer than several years, blockage of the sunlight would last several years, resulting in significant decrease in the oceanic temperature [e. g., 5, 6]. If the residence time was short, the sulfuric acid could also cause a mass extinction by strong sulfuric acid rain fall [e. g., 2, 7]. Injection of $\sim 10^{16}$ mol of sulfuric acid, which is an upper estimate for the K/T event, to the upper 100m of the world ocean would not lead to a significant change in oceanic pH if the timescale of the fall of sulfuric acid aerosol was slow enough to achieve dissolution equilibrium between the ocean and the atmosphere [8]. The residence time of sulfuric acid aerosols is estimated as 6-9 months [5] and several years [6], which is comparable or longer than the timescale to achieve equilibrium.

However, previous theoretical models for aerosol fall out [5, 6] underestimate the fall out rate significantly because they calculate coagulation and sedimentation of the sulfuric acid aerosols assuming that only sulfuric acid aerosols exist in the atmosphere. The mass of silicate dust particles in the atmosphere immediately after the K/T impact is estimated to be much larger than the mass of the sulfuric acid aerosols, $\sim 10^{14}$ kg [e. g., 9]. Thus, in this study, we carried out a theoretical model calculation of coagulation and sedimentation of atmospheric aerosols when sulfuric acid aerosols coexist with silicate condensate particles in order to estimate accurately the residence time of the K/T sulfuric acid aerosols under more realistic conditions.

Theoretical model: In our model, the time evolution of the distributions of the sulfuric acid and the silicate condensate particles were calculated in order to

estimate the residence time of sulfuric acid in the atmosphere. The key mechanism is sweep out of sulfuric acid aerosols by silicate condensate particles. Large-sized silicate particles (~ 100 μm in diameter) fall down much more quickly than the sulfuric acid aerosols (~ 1 μm in diameter), because their terminal falling velocity, determined by the Stokes' law, is much larger. Thus, the silicate condensate particles sweep out the small sulfuric acid aerosol particles. This would promote particle growth, accelerating the fall out speed.

We consider ballistic reentering of silicate and sulfuric acid particles from an impact vapor cloud and solve a time-dependant one-dimensional differential equation of the size and vertical distribution of the particles in the atmosphere. The distribution of the initial velocity of the released particles from the impact vapor cloud is given by the model of the velocity distribution of impact vapor in a hemispherically expanding impact vapor cloud [10]. Then we calculate the time of flight of the ballistically flying particles using the formula given by [11]. The normalized mass flux of reentering sulfuric acid and silicate condensate at the upper boundary of the atmosphere are shown in Fig. 1. The reentered particles are decelerated by the friction with the atmosphere. We assume that the velocity of falling particles is decelerated to the terminal velocity at 130 km in altitude for the sulfuric acid aerosol particles ($D = 1$ μm) and at 90 km for the silicate condensate particles ($D = 100$ μm). Then we solve the time-evolution of the distributions of the sulfuric acid and the silicate condensate particles in the atmosphere considering coagulation and sedimentation of two aerosol species.

Results of the model calculation: Fig. 2 shows the result of the model calculation. The mass of the sulfuric acid aerosol particles that have not coagulated with the silicate condensates decreases within a few hours or even shorter time, although the total mass of sulfuric acid in the atmosphere increases until 10 hours after the impact. This is because that the sweep out of sulfuric acid aerosols by silicate condensates occurs within a few hours. The residence time of the sulfuric acid coagulated with the silicate condensates is shorter than one day. Then sulfuric acid falls down to the ground with a very short timescale. Approximately 50 % of the total mass load falls down to the ground within one day, and approximately 70 % falls down within two days.

The results indicate that most of the sulfuric acid generated by the K/T impact would be swept out by the silicate condensates and fall down within a few days. The average residence time of a sulfuric acid aerosol in the atmosphere is estimated shorter than one day. The calculation results show that more than ~90% of the sulfuric acid aerosol particles would coagulate with the silicate condensates and fall down within 10 days. Such rapid fall of the sulfuric acid would lead to extremely intense global acid rain.

Oceanic acidification: The extremely short time-scale of the fall of the sulfuric acid may dramatically change the previous view on the role of the sulfuric acid on the K/T event. Previous studies [e. g., 5, 6] estimate the residence time of the sulfuric acid aerosol longer than 6 months. Such slow addition of the K/T sulfuric acid does not significantly change the pH in the global ocean surface layer [8]. The insensitivity of oceanic pH to the acid input occurs because carbonate buffer prevents a dramatic change in the pH in the marine surface water. Their estimate of the critical mass load that can drastically decrease the pH is $\sim 6 \times 10^{16}$ mol of sulfuric acid. This value is larger than most estimates of the K/T sulfuric acid [8]. However, the calculation results of the present study indicate that the sulfuric acid generated by the K/T impact would fall on the ground/ocean surface within a few days. This timescale is much shorter than the timescale of the gas exchange between the atmosphere and the oceanic upper layer. The carbonate buffer in the marine surface layer is significantly weakened when gas is not exchanged between the atmosphere and the oceanic upper layer. Thus, such fast addition of sulfuric acid would result in drastic decrease of the pH in most of the marine surface water even if the amount in the sulfuric acid is much smaller than the critical mass load estimated by [8]. The rapid fall of the sulfuric acid would result in drastic decrease of pH in the global ocean surface layer (see Fig. 3).

References: [1] Alvarez, L. W. et al. (1990) *Science*, 208, 1095-1108. [2] Brett, R. (1992) *GCA*, 56, 3603-3606. [3] Sigurdsson, H. et al. (1992) *EPSL*, 109, 543-559. [4] Ohno, S. et al. (2004) *EPSL*, 218, 347-361. [5] Pope, K. O. et al. (1994) *EPSL*, 128, 719-725. [6] Pierazzo, E. et al. (2003) *Astrobiology*, 3, 99-118. [7] Retallack, G. J. (1996) *GSA Today*, 6, 1-8. [8] D'Hondt, M. E. et al. (1994) *Geology*, 22, 983-986. [9] Pope, K. O. et al. (1997) *JGR*, 102, 21645-21664. [10] Zel'dovich, Y. B., and Y. P. Raizer (1967) *Academic*. [11] Ahrens, T. J. and J. D. O'Keefe (1978) *LPSC*, 9, 3787-3802.

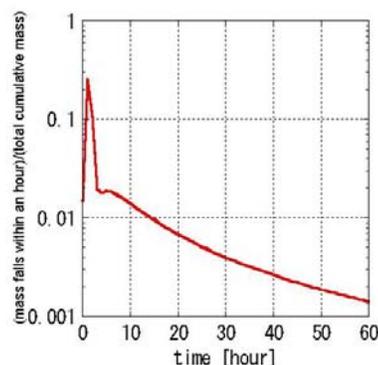


Fig. 1. The mass flux at the top of the atmosphere as a function of time.

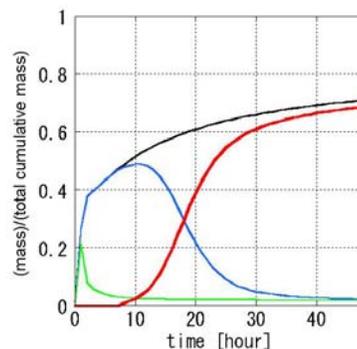


Fig. 2. The result of the model calculation. Black curve in the figure is the cumulative mass of the sulfuric acid aerosol particles that have reentered into the atmosphere. Green curve is the mass of the sulfuric acid aerosol particles that have not coagulated with the silicate condensates. Blue curve is the total mass of sulfuric acid in the atmosphere. Red curve is the mass of the sulfuric acid fallen down on the ground.

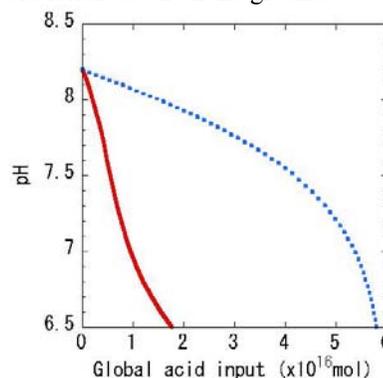


Fig. 3. Estimates of the pH in the oceanic surface layer as a function of the global acid input. Red solid curve is the pH when the gas exchange between the ocean and atmosphere does not occur. Blue dotted curve is the pH when equilibrium between the atmosphere and ocean is achieved. Red curve is much steeper than the blue curve.