Numerical simulation of I-type spherule formation; T. Yada, M. Sekiya, T. Nakamura and N. Takaoka Department of Earth and Planetary Sciences, Faculty of Science, Kyushu university 33, Hakozaki, Fukuoka 812-81, Japan.

Numerical simulations for atmospheric entry of spherules are performed to calculate the time dependence of velocity, altitude, spherules' radii and temperature. They indicate that the strong apparent gravitational acceleration due to atmospheric drag results in exposure of metallic cores to the air during melting and oxidation of spherules. Two major types of internal structures of Fe-Ni spherules are explained by this model.

Introduction

Spherical particles of 20-1000 μm size are found in deep sea sediments, polar ice and sedimental rocks. They have long been studied since 1883 (Murray and Renard, 1883), identified as extraterrestrial material from existence of wüstitite (Marvin and Einaudi, 1967), enrichments of Ni, Co (Smales et al., 1958) and Ir (Millard and Finkelman, 1970) and/or presence of the cosmogenic isotopes, such as $^{53}$Mn (Nishiizumi, 1983), $^{26}$Al and $^{10}$Be (Raisbeck et al., 1986). These spherules are categorized into iron (I), stony (S) and glassy (G) types from chemical composition (e.g., Blanchard et al., 1980; Brownlee, 1985). I-type spherules are composed of Fe-Ni oxide and metal. We separated spherules form deep-sea sediments dredged from 5800 m depth offshore Hawaii (9°30'N, 174°17'W). From the EPMA observation both of previous works and ours (Yada et al., 1995), two types of internal texture are observed in I-type spherules including Ni. The first one shows a Ni-free Fe-oxide mantle and a Fe-Ni metallic core, and the second one shows a Fe-Ni oxide having exsolution structures without core.

Brownlee et al. (1984) have given a model that IDPs melt by heat of atmospheric entry to form silicate melt and metallic melt. Then, individual spherules separate into a silicate melt sphere and a metallic one because of their density difference. In the metallic sphere, Fe is oxidized to form high Ni metallic core at first, followed by oxidation of Ni, and finally Pt group nuggets are left because the resistivity against oxidation increases in the order of Fe, Ni and Pt group. Bi et al (1993) reported that Ni-rich metallic cores were separated from Ni-free Fe-oxide mantle to form Ni-Fe metallic spherules whose Ni contents range from 27 to 100 wt% and Fe-oxide spherules without Ni.

Numerical simulation

Numerical simulations were performed about atmospheric entry of I-type spherule's precursor. We start calculations from 200 km in altitude. It is assumed that kinetic energy of air molecules colliding with spherules is all exchanged to heat and that iron evaporation from spherules has no influence to their movement because of isotropic evaporation of iron atoms. We calculate for time dependence of velocity, altitude, spherule's radius and temperature using the Runge-Kutta method. For data on air density at given altitude, we use the U. S. Standard Atmosphere (1976). Vapor pressure and latent heat of iron is from Kubaschewski et al (1967). The results of simulation indicate that 1) heating time is longer for higher entry angle from the local vertical, 2) spherules' size decreases mainly over 1900 °C, 3) both high speed and low angle entry cause the large apparent gravitational acceleration and 4) the apparent gravitational acceleration acting on spherules is maximum at almost final stage of evaporation.
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Discussion

According to our numerical simulation, spherules lose their mass in a few seconds during the atmospheric entry, as previously reported by Love and Brownlee (1991). Most of spherules lost 90 to 99% of original mass and oxidation products before the intense evaporation should be passed away from spherules. At almost final stage of evaporation, the apparent gravitational acceleration that spherules experience becomes maximum and then gradually decreases. Iron oxides would envelop Fe-Ni metal because of their difference in surface tension. In a metallurgical experiment under the terrestrial gravity, Fe-oxide melt with free surface is distributed on one side of Fe metal sphere because of difference in their densities, and the oxidation of iron from Fe-metal surface exposed to the external gas continued (Sun and Pehlke, 1994). In the case of spherules entering atmosphere, the apparent gravitational acceleration acting on spherules is typically around a thousand times as strong as the terrestrial gravitational acceleration. Thus, some part of the surface of metal core might always be exposed to the air and oxidation reaction proceeds therefrom, by which off-centered distribution of spherule's core can be explained. As mentioned above, the resistivity against oxidation increases in the order of Fe and Ni. Thus, iron is oxidized until it is extinguished from the core, or until an oxide mantle envelops the metallic core because of decrease of the apparent gravitational acceleration. Consequently, a high Ni metallic core is formed. If the core was exposed until iron is entirely excluded, Ni would be oxidized and finally the core would be extinguished to form a Fe-Ni oxide spherule. Herzog et al. (1994) showed that as the bulk Ni concentration of spherules decreases, the mass fractionation of Ni isotopes due to evaporation becomes intense. This observation is consistent with the model of an exposed core because nickel stays in the metal phase longer than iron and metallic Ni experiences more intense evaporation than iron oxides resulting from the difference in their vapor pressure.

References