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Theoretical analysis of the atmospheric entry of sub-mm meteoroids of $Mg_xCa_{1-x}CO_3$ composition

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A B S T R A C T

Current models allow to reliably simulate mechanical and thermal phenomena associated with a micrometeor passage through the Earth's atmosphere. However, these models have rarely been applied to materials other than those most common in meteorites, such as silicates and metals. A particular case that deserves attention is the one of micrograins made of minerals, in particular carbonates, which have been associated, in meteorites, with organic molecules. Carbonates are known for their decomposition in vacuum at moderate temperatures, and they might contribute to the thermal protection of organic matter. In this work, a model with non isothermal atmosphere, power balance, evaporation, ablation, radiation losses and stoichiometry, is proposed. This paper includes the very first calculations for meteoroids with a mixed carbonate composition. Results show that the carbonate fraction of these objects always go to zero at high altitudes except for grazing entries, where the reached temperature is lower and some carbonate remains unreacted. For all entry conditions, peculiar temperature curves are obtained due to the decomposition process. Furthermore, a significant impact of decomposition cooling on the temperature peak is observed for some grazing entry cases. Although specific solutions used in these calculations can be improved, this work sets a definite model and a basis for future research on sub-mm grains of relatively volatile minerals entering the Earth's atmosphere.

1. Introduction

Micrometeors are submillimeter dust particles that represent the minor bodies majority population in the inner Solar System (Grün et al., 1985): they are among the most primitive materials in space, suggesting that they can provide keys to understand the chemistry of the early Solar System (Flynn et al., 2003). When micrometeors experience atmospheric entry, they are called micrometeoroids (MMs) and they undergo several modification (Genge et al., 1997); some of them survive the complex interactions with the atmosphere and are able to reach the Earth's surface. About $40 \pm 20 \times 10^6$ kg of MMs enters the Earth's atmosphere every year (although many of these grains are completely vaporized during the passage) (Love and Brownlee, 1993; Taylor et al., 1998; Zolensky et al., 2006), representing the dominant source of the annual interplanetary dust entering the Earth's atmosphere.

While entering the Earth's atmosphere, MMs experience several physical and chemical processes: collisions with atmospheric atoms, evaporation, ablation, temperature variation, decomposition. Various numerical models have been developed (Flynn, 1989; Love and Brownlee, 1991; Briani et al., 2013; Micca Longo and Longo, 2017) in order to simulate the different and various interactions between the MMs and the Earth's atmosphere.

The materials considered in previous studies are typical of retrieved MMs, i.e. mixed silicates. In this work, as in our previous studies (Bisceglia et al., 2017; Micca Longo and Longo, 2017), we are instead investigating much less common compositions, namely carbonates of alkaline-earth elements. The attention to this composition is supported by several considerations. Inorganic carbonates are often associated with organic matter (Flynn et al., 2000; Fonti et al., 2001; Pizzarello et al., 2006; Orofino et al., 2009; Blanco et al., 2013; 2014; D'Elia et al., 2017; Matrajt et al., 2012): the knowledge of their physical and chemical properties during the atmospheric entry may provide information about the

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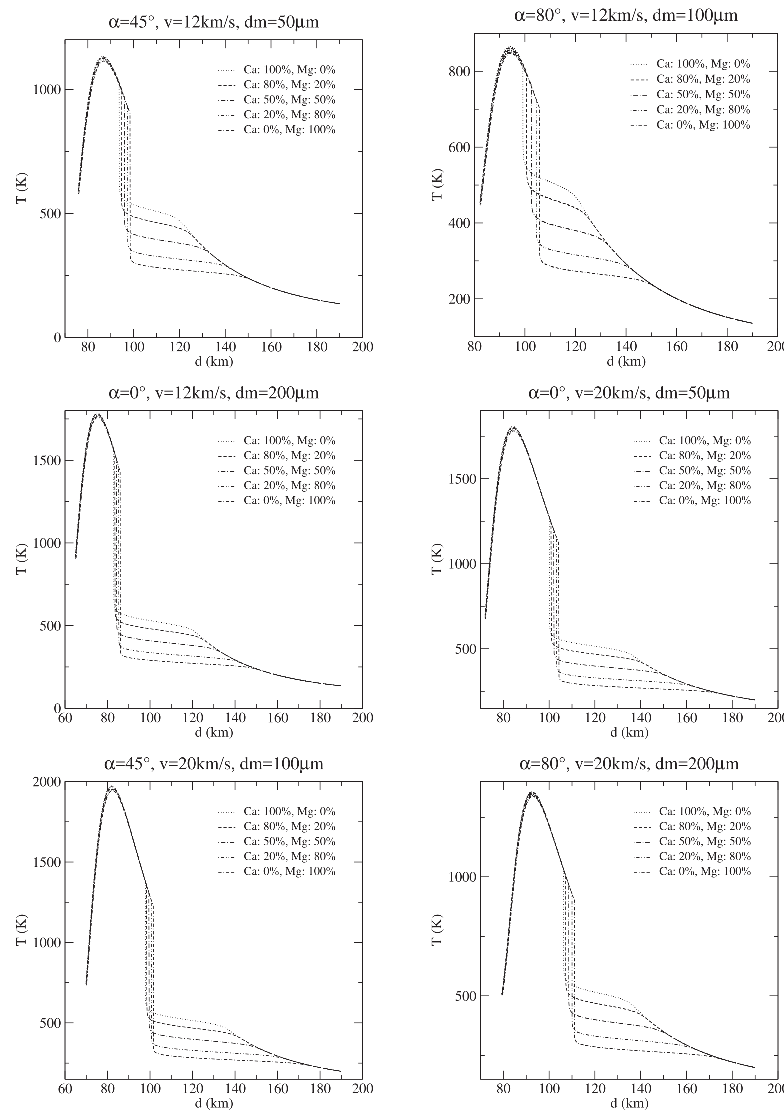

Fig. 1. Thermal curves, as a function of the quota *d*, for different entry scenarios (α is the entry angle, v is the entry speed and dm is the meteoroid diameter) of a $Mg_xCa_{1-x}CO_3$ MM.

chemical stability of organic matter in their parent bodies (comets, asteroids) and interplanetary dust. Carbonates of II group elements have been spectroscopically detected in cometary grains, in close association to complex organic molecules (Yabuta et al., 2014). $(Mg,Fe)CO_3$ is common among phyllosilicate-rich micrometeorites and CI chondrites (Noguchi et al., 2002). Carbonates (dolomite) have been reported in a micrometeorite from the CONCORDIA collection (Duprat et al., 2007). Ca-rich particles have been found within the spall zone of several craters, resembling calcium carbonate residue (Kearsley et al., 2007). $Mg/CaCO_3$ micrograins, with a linear dimension of $\approx 10-20\ \mu$m, have been reported inside EETA 79001 (Gooding et al., 1988): similar objects might have been released from mechanical fragmentation of a larger body and experienced entry as individual particles.

In our recent work (Micca Longo and Longo, 2017), the theoretical model focuses on the atmospheric entry of pure magnesite MMs. The model has been developed in close connection with the idea that carbonates, in particular magnesite, may be cooling materials, in the context of astrobiology and of the delivery of organic matter to biosphere from Space (Bisceglia et al., 2017). Actually, many works in the past (Anders, 1989; Maurette et al., 1990; 1995; Jenniskens et al., 2000; Maurette, 2006) suggested that micrometeorites might represent the major carrier of extraterrestrial C-rich compounds reaching the Earth's surface. So, the study of the physical and thermochemical behaviour of these materials, as main components of submillimeter grains during the atmospheric entry, becomes useful, but no such study is available in literature.

In this work, we generalize the atmospheric entry model of Micca Longo and Longo (2017) in order to account for a mixed composition, including calcium and magnesium cations. These compositions are not only of geochemical but also of astrobiological relevance, as they are close to the materials considered in the STONE artificial meteor experiment (Brack et al., 2002). Our entry model comes essentially from the one developed by Love and Brownlee (1991), extended to undertake the study of the materials proposed. The improvements include chemical decomposition, evaporation and consequent cooling. In the present extension to a solid mixture, we have included the stoichiometry of the material in its conversion from mixed carbonate to mixed oxide. Empirical relations are used to account for the energy transfer coefficient and the vapor pressure, which are connected to the chemical composition.

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