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RESEARCH

Impacts of Cometary Meteoroids Bearing Biological Entities onto Surfaces in the Stratosphere

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We discuss the mechanics of cometary meteoroids of various sizes, carrying biological entities, impacting carbon SEM stubs. Meteoroids of radii less than 30μm (either of ice, organics or siliceous material) fall at slow enough speed so as not to cause damage to the enclosed biological structures, or to cause detectable indentations or cratering of the impacted surfaces.

1. Introduction

In a series of publications Wainwright et al (2013a, b) have reported the recovery of biological entities on EM stubs exposed for 17 minutes to stratospheric air at 23–27km. These entities were presumably embedded in larger icy or siliceous cometary meteoroids that encountered the Earth at typical relative speeds of ~40km/s. The meteoroids that do not end as meteors at heights of ~80km will reach the stratosphere at lower speeds, being slowed by the viscous drag of the atmosphere. Although homogeneous particles of either silicates or water-ice may become heated in the mesosphere during initial deceleration (Coulson and Wickramasinghe, 2003), low-density porous (fluffly) aggregates of 30–300μm radius will have sufficiently low thermal conductivities to remain cool at temperatures below 500K. When the particles fall to heights of 27km their terminal speeds are determined mainly by their size – the larger objects falling at higher speeds. This is borne out in the visible impressions they have left on the EM stubs in our experiments. The smallest particles produced no visible depression on the graphite, while the larger particle impacts have left evidence ranging from minor, hardly perceptible depressions to craters. In this paper we discuss the physics of micrometeoroid impacts on the graphite surfaces of E stubs exposed at 27–23km altitudes.

2. Collection Technique

The recovery of cometary meteoroids directly onto carbon EM stubs by means of a device lofted by balloon into the stratosphere has been described in earlier papers in this series (Wainwright et al, 2013a, b). The technique involved impacts of vertically falling particulates at various speeds onto the stubs. The relative speed of impact is a factor that is important in determining whether or not such particles survive or retain their integrity. At sufficiently high impact speeds the kinetic energy will be high enough to volatalise part of the incident particle and also part of the graphite surface beneath. The question of the viability of embedded microorganisms remains unresolved, and in the present series of experiments this has not been addressed. However, it should be recalled that bacteria embedded in pellets fired at speeds as high as 5 km/s appear to have maintained their integrity and viability to a significant degree (> 10^{-5}) (Burchell et al, 2004). Shock pressures of 10–30 GPa appear on this evidence to have little or no effect on viability of the bacteria embedded in pellets of radii exceeding 50μm. In other experiments Al-Mufti, Hoyle and Wickramasinghe (1986) found that bacteria embedded in KBr discs retained viability after flash heating to 1120K for 60 seconds.

The terminal speed at which such a cometary micrometeoroid falls though the stratosphere can be calculated from formulae set out by Kasten (1968) and tabulated atmospheric data (Cole, Court & Kantor, 1965). This falling speed (which scales with the average density of the meteoroid) thus computed for heights of 41, 27, 23km in the stratosphere is displayed in **Fig. 1** and **Table 1** for various particle radii.

From this calculation we find that a 3μm radius particle of unit density falls to ground from 27km in 46.5 days, whilst a particle of radius 50 μm will fall in 4.1 hours. From this simple calculation it becomes amply clear that at least the largest of our collected particles could not be interpreted as a residue from any past volcanic eruption, or the lofting from ground over plausible timescales.

3. Survival of enclosed biological entitities

We next turn to the survival of microorganisms within impacting meteoroids of various radii. For a microbe or microbes embedded within particles comprised of water-

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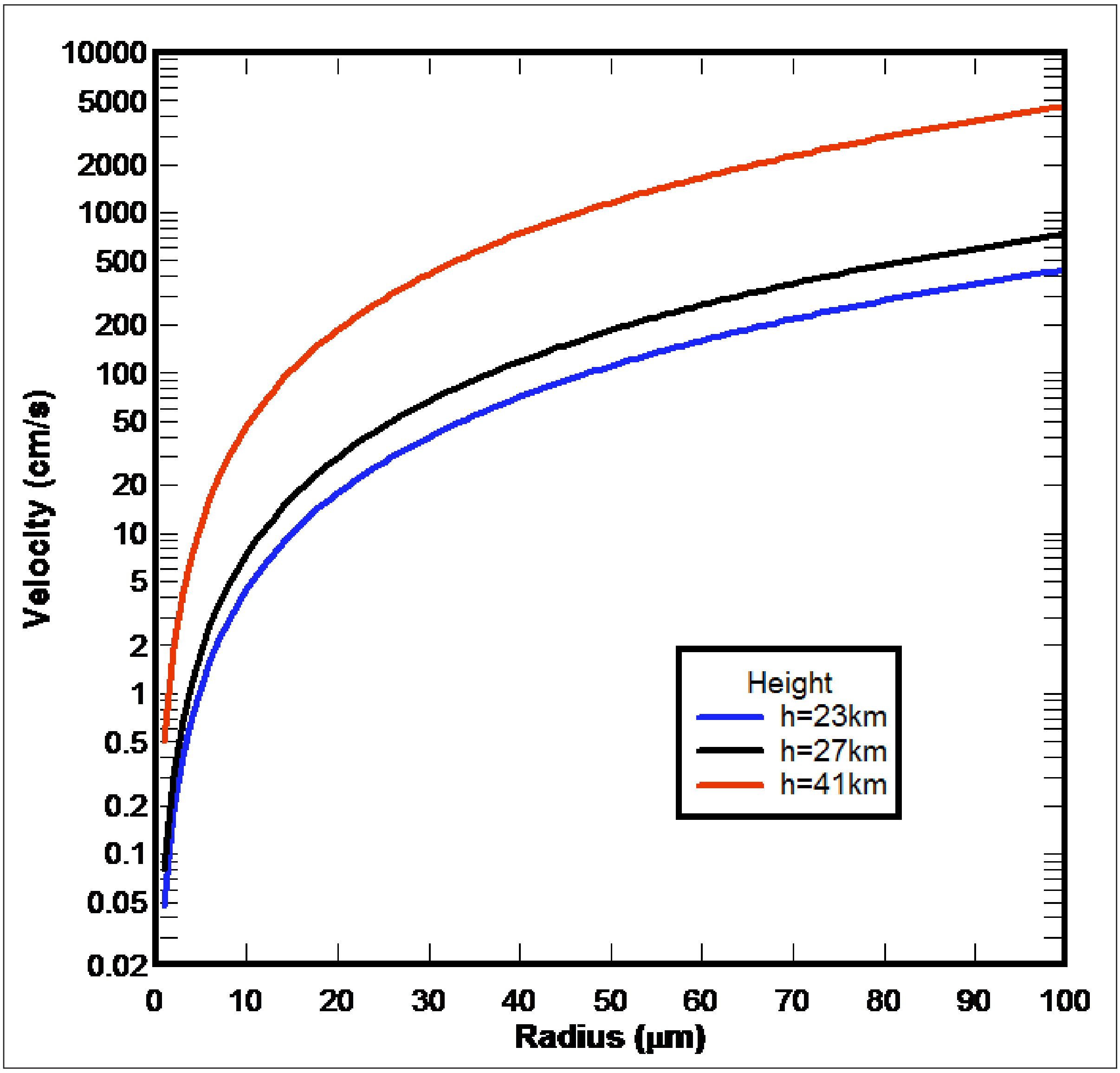

Fig. 1: Falling velocities of micrometeoroids of various radii falling through different heights in the stratosphere (average meteoroid density assumed to be unity).

a/µm h/km	1.0	3.0	10.0	20.0	30.0	50.0	100	200
23	0.048	0.41	4.47	17.8	40.1	111.1	444	1776
27	0.08	0.68	7.46	29.7	66.8	185.2	740	2960
41	0.5	4.27	46.6	185.7	417.2	1158.0	4627	18500

Table 1: Velocity of falling spherical particles (cm/s; 0.36km/hr)) of various radii, and with density 1 g cm^{-3}

ice of radius a, the kinetic energy of impact will go in part to sublimation of ice. The heat of sublimation of ice is ~540 cal/g = 5.4 x 10^9erg/g whilst the kinetic energy per unit mass is $v^2/2$ erg/g. The maximum fraction of the ice that could be sublimated is thus:

$$\frac{1}{2}v^2 \times \frac{1}{5.4}10^{-9} \approx 10^{-10}v^2 \qquad (1)$$

From Table 1 it is seen that this fraction remains negligible at an altitude of 27km unless the particles have radii >~50µm.

For a particle comprised of a more refractory material like quartz the heat of vaporisation is ~2802 cal/g = 2.8 x 10^{10} erg/g and the maximum fraction of sublimated material becomes:

$$\frac{1}{2}v^2 \times \frac{1}{2.8}10^{-10} \approx 10^{-11}v^2 \qquad (2)$$

Once again, only at the higher speeds and larger values of radius would this become relevant. Microorganisms within larger clumps of ice or siliceous material would in general remain protected from shock heating and sublimation.

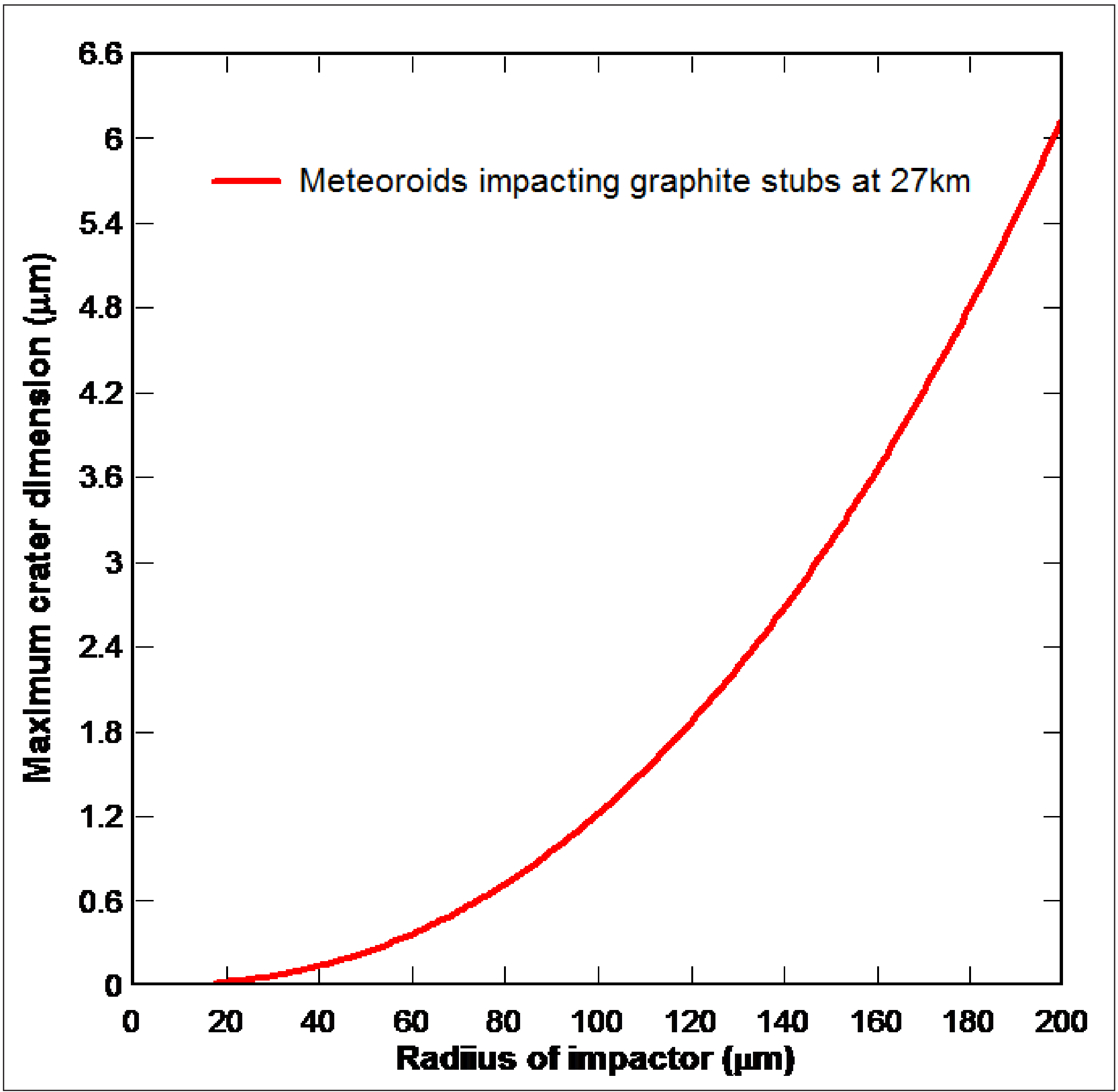

Fig. 2: Upper limit to crater dimension for impacting meteoroids of various radii at an altitude of 27km.

4. Cratering of the impacting surface

A part of the kinetic energy of the impacting particle would be transferred to the graphite stub as shock heating that could dislodge atoms from the graphite lattice, leading to indentation or crater formation. Assuming that half the kinetic energy of the impacting meteoroid contributes to sublimating or dislodging carbon atoms, we can estimate the volume of graphitic material displaced. Since the heat (enthalpy) of vaporisation of graphite is ~1.42 x 10^{11} erg/g (JANAF Thermochemical Tables) an upper limit to the mass of displaced stub material is:

$$\frac{1}{4}\left(\frac{4}{3}\pi a^3\right)v^2 / (1.42\times10^{11})\ \text{g} \qquad (3)$$

The corresponding volume of graphitic material (specific gravity ~2.25) is therefore estimated as ~d^3 with

$$d \cong \left(\frac{a}{\mu m}\right)(3.28)^{1/3}\times10^{-4}v^{2/3}\ \mu\text{m} \qquad (4)$$

This value of the maximum crater radius as a function of particle size calculated from (4) is plotted in **Fig. 2** for the case v = v(a) computed at the height of h = 27km (Fig. 1).

From Fig. 2 we see that the smaller meteoroids yield either no craters at all, or craters of negligible size compared to particles of radii >>50 µm. This is consistent with what we find in our experiments.

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