METAL BEAD SEPARATION IN S-TYPE COSMIC SPHERULES DURING ATMOSPHERIC ENTRY: IMPLICATIONS ON THE ORIGIN OF LIFE. Isabelle S. Mattia[1], Matthew J. Genge[2], [1]Department of Earth Sciences, Imperial College London, Exhibition Rd, London SW7 2BX, [2]Impact and Astromaterials Research Centre (IARC), Department of Earth Sciences, Imperial College London, Exhibition Rd, London SW7 2BX

Introduction: Micrometeorites (MMs) are cosmic dust particles <2mm in size that survive atmospheric entry [1] and originate from asteroidal collisions and cometary out-gassing. They are largely samples of primitive solar system objects often containing high concentrations of carbonaceous material, including complex organics such as amino acids and polycyclic aromatic hydrocarbons [2]. Micrometeorites recovered from sediments are mostly cosmic spherules (CSs): silicic (S-type) or iron-rich (I-type) particles that have experienced high degrees of melting during entry heating to produce sub-spherical droplets, often containing immiscible beads of FeNi and FeS metal [1]. As cosmic dust grains undergo atmospheric deceleration, these dense metal droplets travel towards the surface of particles [3, 4]. The absence of these metal beads in the majority of CSs may be explained their separation from particles during atmospheric entry [5].

This paper investigates the mechanisms of metal ejection in S-type CSs using numerical simulations of bead migration during entry heating. The effects of surface tension forces have been incorporated to assess how bead composition and size influence separation. Since ejection causes compositional and morphological changes to CSs, it alters their ability to act as catalysts for biochemical reactions. The impact of metal bead loss on possible abiogenic processes on early Earth are thus also considered here.

Methods: *Entry heating and settling model.* The numerical models used for this study are based on those of silicate particles discussed in [6 & 7]. Atmospheric deceleration was obtained using a simulation based on the model of Love and Brownlee [8]. The applied bulk composition corresponds to an ordinary chondrite spherule from [9] and the temperature-dependent phase abundance, density, and viscosity are acquired from [6]. The motion of metal beads of various sizes in particles with different initial radii during atmospheric entry were calculated by numerical integration of Stokes' law as used in [6].

Surface tension. The maximum resisting surface tension occurs when the interface between the liquid metal and silicate melt is at its largest, but this is complex to assess due to geometry changes in the spherule and bead during ejection. A simplified threshold for separation is thus utilised where the force on the bead due to deceleration is larger than the force applied by surface tension. The latter can be calculated from the maximum circumference of the bead at its junction with the spherule assuming zero spreading has taken place, and is given by circumference multiplied by surface tension, which is 0.2N/m for silicic melts [10].

Results: Surface tension for a range of bead sizes were compared with the deceleration forces calculated from the numerical model (Fig 1.). For bead sizes reported for MMs, deceleration forces at any displacement value are at least an order of magnitude lower than the surface tension forces acting on the same bead, except for those with low entry velocities and angles, where particles undergo limited partial melting.

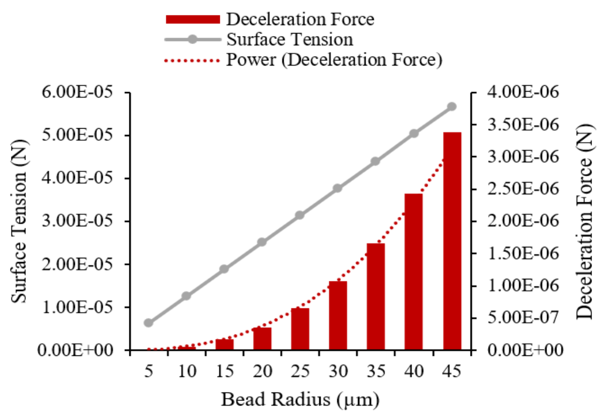

Fig 1. Surface tension and deceleration forces for FeNi beads in CSs with 100µm initial radii, 45° entry angle, and 12km/s entry velocity.

Discussion: Although metal beads can reach the surface of spherules solely due to deceleration, results show they cannot separate owing to surface tension, thus another mechanism must be responsible. Previous studies indicate that if particles are rotating during atmospheric entry, centrifugal forces acting on beads would also influence their dynamics [5].

The maximum limit for spin rates maintained by particles is that which causes centrifugal disruption, and is ~580,000rad/s for particles with low tensile strengths equivalent to sandy shale [5]. Assuming droplets do not spread on the surface of particles, spherules larger than 50µm in radius would require angular velocities less than ~220,000rad/s for beads to eject, which is below the disruption threshold (Fig 2.). Therefore, the spin of particles may be a valid explanation for metal separation during atmospheric entry.

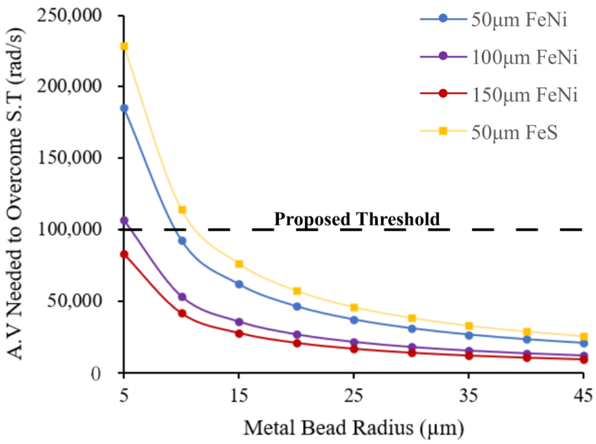

Fig 2. The angular velocity (A.V) required to overcome surface tension (S.T) for FeNi and FeS beads of different sizes in CSs with radii of 50, 100 and 150µm. Since most beads in MMs are larger than 10µm in radius, a sufficient threshold of particle spin for ejection to take place could be ~100,000rad/s.

Implications: *Causes of spin in cosmic dust.* The main causes of cosmic dust spin are net torques initiated by either off-centre molecular collisions or by radiation pressure on an asymmetric micrometeoroid in space [11]. Consequently, particles with prolonged exposure to solar wind, or particles closer to the Sun, could experience higher torques resulting in elevated spin rates. However, pre-atmospheric dust rotation is dampened over time by interactions with the interplanetary magnetic field and induced fields within particles [12]. The effects of magnetic dampening would then suggest interplanetary dust particles (IDPs) with adequately high angular velocities, which promote bead ejection, would have been recently released from their parent bodies when dust densities and collisional rates are elevated [13].

Micrometeorites as catalysts for life-forming processes. Micrometeorites have been previously proposed to function as microscopic chemical reactors based on their unequilibrated fine-grained assemblages where carbonaceous material is in close conjunction to hydrous minerals and potential catalysts such as ferrihydrite [2]. Ferrihydrite contains abundant nanotubules, increasing porosity, and point defects in its crystal structure, making it an excellent absorbent for phosphate and organic materials. The enrichment of phosphorous, a limited yet key element for biomolecules, allows CSs to overcome a substantial barrier for generating early P-based metabolisms, which offers a unique route for oligomerization of amino acids into polypeptides – a catalytic reaction demonstrated in iron hydroxides [14]. Ferrihydrite is also present in the core of the universal intracellular protein ferratin, suggesting it may have been an important compound associated with the formation of life in Hadean Earth.

Since research currently indicates the origins of life ensued during the late bombardment (4.1-4.2 Ga [14]) when extra-terrestrial dust flux was significantly larger than present [15], the search for geochemical environments suggestive for autogenesis may no longer be limited to specific locations such as hydrothermal vents. This allows a wider range of environments to be considered to contribute to the formation of life on terrestrial planets. The increased dust flux, and thus collision and spin rates, would have enhanced the likelihood of metal ejection, which would raise the exposed surface area to volume ratios of ferrihydrite weathered beads, causing them to absorb further key biogenic elements and compounds and generate more sites for polymerisation. Therefore, a high flux of interplanetary dust with elevated spin rates would likely promote the possibility of successful abiogenesis.

Conclusions: Numerical simulations of metal droplet dynamics during entry heating indicate atmospheric deceleration is not adequate to allow its separation from CSs. The calculated angular velocities of micrometeoroids necessary to overcome surface tension forces on a range of bead sizes was below the threshold that would cause centrifugal disruption. Therefore, sufficient pre-atmospheric spin, likely instigated from collisions between newly formed IDPs, is suggested to cause bead ejection following displacement, consequently altering spherules' functionality as catalysts for biochemical reactions.

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