# Atmospheric entry of micrometeorites containing organic materials.

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**Constraints about the nature of micrometeorites and their ablation in the atmosphere.**

Micrometeorites with a chondritic composition and sizes of 100-300μm, were extracted from black dust ("cryoconite") collected on the west Greenland ice cap. Recent studies [1] have both revealed an unexpectedly large fraction (25-30%) of unmelted micrometeorites, and have shown that the flux of this cosmic dust component captured by the Earth is remarkably similar to the contemporary micrometeorite flux measured in space at 1 AU. These finds indicate that micrometeorites have only been weakly ablated during their capture by the Earth. Considering a micrometeorite with an initial speed of 20km/s, made of "compact-inert" stony material (density~3), which is crossing the "US Standard Atmosphere 1976", following a vertical trajectory, we deduce that micrometeorites with diameter > 10 μm should be melted. We have check that this type of evaluation, only valid for an "inert" particle for which fusion is the only ablating mechanism, yields predictions very similar to those of Whipple[2], provided that the same model of atmosphere to be used. The only other possibility allowing larger micrometeorites to survive the entry is to enter the atmosphere with a grazing incidence. But in this condition the possible domain of entry angle is very reduced, so the flux of Greenland micrometeorites would become about 50 times smaller than the measured value. The inadequacy of these modellings is even becoming worse after the recent discovery of big (mm-size) unmelted Greenland micrometeo-rites[3]. In the next section we summarize our recent electron microscope observations of a few big micrometeorites, leading to a model of "reactive" micrometeorite.

**Electron microscope observations of crushed fragments from big unmelted micrometorites.**

The SEM observations of fracture surfaces of the big micrometeorites (including the 3 ones reported before crushing in micrographs B, D and E of the reference 3), show an important residual porosity. In *figure 1A* to*1D* we report SEM and EDX observations dealing with thin deposits observed at higher magnification right on the surface of these residual pores that are observed at small and high magnifications in *A* and *D*, respectively. The drastic increase in noise of the EDX spectrum when the electron beam moves from a uncoated area (*figure 1B*) to the deposit (*spectrum 1C*), strongly suggests that they are made of low Z organic residues. These observations suggest that the parent body of the big chondritic fragment has a porous aggregate structure loaded with a pyrolysable component. This model is somewhat similar to the charring composites materials currently used as thermal protection on re-entry bodies. In particular ONERA has modelled such protections, composed of a renforcement of silica fibers containing about 30% of phenolic resin. In the next section we apply the "COKE" program [4] (already used at ONERA for modelling the reentry of such thermal protections in the atmosphere), to describe the thermal behavior of a synthetic micrometeorite made of the same material.

**Heating of a charring composite micrometeorite.**

The calculations of Whipple[2] yielding a critical size, consider an ablation resulting from the heating of micrometeorite above a temperature of 1600K, that trigger their melting, and then material is lost ("i.e. ablated") through aerodynamical shearing. But if micrometeorite are partly made of pyrolysable material, new complex mecanisms are activated for an increased thermal protection, such as : endothermal reactions during pyrolysis ; percolation of the resulting gases through the porous structure ; formation of a protective gas "gasket" due to the injection of pyrolysis gases in the air flow (see *fig.2* ). In *figure 3* we selected some results from these lengthy computations, relevant in fonction of trajectory time to both the thermal history of a micrometeorite : Temperature (1a, 2a, 3a, curves and the dotted line) and residual fraction of the organic component that did survive this heat history (1b,2b,3b curves) which varies from 1 -no pyrolysis- to 0, when all material has been completely pyrolysed and transformed in carbon. These curves have been computed for a synthetic micrometeorite of density 1.68, with a diameter of 60μm, an initial speed of 11.3 km/s (the lowest possible velocity), and a vertical trajectory. We considered two regimes where the micrometeorite just behaves either as a "compact-inert" chunk of meteorite (classical case of the "Whipple approximation" with no pyrolysis) or as a "reactive" object that undergoes pyrolysis. Our major results are : (a) The dotted curve shows that the temperature of the "inert" micrometeorite reaches the maximum value Tmax ~1600K ; (b) for the curves 1a, 2a, 3a we considered pyrolysis for different initial relative mass fraction of organic component, ranging from 30%, 50%, and 80%, respectively. The activation of pyrolysis and its correlated effects triggers a clear drop in Tmax, that slightly increases with increasing content of organic material ; (c) it might be that the formation of the gas "gasket" plays a major role in this additional cooling ; (d) the residual fraction of pyrolysable component for such a micrometeo-rite with 50% of pyrolysable component, heated up at ~1400K, is still appreciable at the end of the simulated tra-jectory through the atmosphere (fig. 2b). For comparison the same mate-rial is completely pyrolysed at 900K during laboratory tests conducted with much smaller heating rate. The explanation of this paradox is that the duration required for the activation of the whole set of pyrolysis reactions exceeds the duration of the pulsed heating suffered by the micrometeorite. This heat pulse is very short for vertical trajectories, along which micrometeorites might have higher survival rates than along grazing trajectories.

**Conclusions.**

We have presented a model that suggests (contrary to previous thoughts) that micrometeorites composed of porous aggregates of refractory material loaded with a concentration of pyrolysable component, have a higher survival probability against ablation than compact chunks of either chondritic or iron meteorites. In this model, which is supported with electron microscope observations of the pore structure of mm-size unmelted Greenland micrometeo-