DECELERATION HEATING OF INTERPLANETARY DUST IN THE EARTH'S ATMOSPHERE, AND ITS SIMULATION USING ANALOG MATERIALS,

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An important unknown in the study of interplanetary dust particles collected in the stratosphere is the extent to which heating on atmospheric entry has modified the particles [1,2]. Since individual particles have different entry parameters, it is important to identify internal "thermometers" which gauge the extent of heating. Measurements of entry heating for an arbitrary set of stratospheric micrometeorites would also allow a direct test of models for the heating process. The distribution of temperature maxima [3] is a simple function of the maximum temperature reached divided by the temperature a given particle would reach on impact with the atmosphere at normal incidence and earth escape velocity. Entry heating data on a collection of particles whose surface densities have been measured [4] should allow empirical determination of that function. Experiments on analog materials reported here indicate i) that the solar flare track record is likely to be erased by atmospheric entry for particles with surface densities above $1 mg/cm^2$, and ii) that temperatures above 1000 C produce crystalline droplets in "chondritic" particles of a sort not commonly seen in collected micrometeorites.

1. A Pulse-Heating Oven.

To investigate heating effects we constructed a resistively heated tantalum ribbon oven capable of pulse heating into the 400 to 1100 C range. Samples are mounted in support films on conventional electron microscope grids, and placed between two tantalum ribbons which have been folded so as to completely enclose the grid when in place. The oven is operated in the bell jar of a vacuum evaporator to allow control of atmosphere during heating.

Calibration experiments have been performed with three thermocouples (0.5 to 1 mil chromel-alumel), one of which is attached to the oven, one to the grid, and one which is free floating between. Peak temperatures measured by these thermocouples generally agreed within 50 C. Simulation of atmospheric entry for 10 µm particles requires temperature maxima lasting only several seconds. Because of their high surface/volume ratios, the temperature of micron sized particles on grid support films will follow closely that of their surroundings. Heat-up and cool-down times for the oven are on the order of seconds. However at lower temperatures the grids lag behind the ribbon and require longer times to achieve steady state (e.g. ~15 s to reach 350 C during a 400 C pulse).

For simplicity, pulse durations of ~30 s were used for all annealings to insure that oven and grid spent at least 10 seconds at temperature maximum. Depending on i) their location with respect to grid bars, and ii) the peak temperature of the pulse, micron sized specimens were therefore subjected to the temperature maximum for between 10 and 25 seconds. It may be possible to achieve shorter pulse durations for 10 µm particles mounted directly on the tantalum ribbon, but the advantages of detailed structural study in the transmission electron microscope (TEM) prior to heating will be lost.

2. Annealing Temperatures for Solar Flare Tracks in Particle Silicates.

Pulse heating experiments on magnesium-rich olivine and pyroxene, two silicates often seen in "chondritic" micrometeorites, have been performed to investigate the effect of atmospheric heating on solar flare particle tracks as observed in the TEM. Sequential heatings at roughly 100 C intervals were performed on four dispersed terrestrial specimens, two each of forsterite and enstatite, which had been previously irradiated with 0.6 and 0.1 MeV/amu Fe ions ($\sim 10^{10}/cm^2$) at the Superhilac in Berkeley [5]. Examinations of these mounts in a conventional (100 keV) TEM before and after each heating have shown that iron-ion tracks remain detectable for temperature maxima up to ~600 C in both forsterite and enstatite. The tracks were no longer visible in specimens heated significantly above 600 C.

3. Pulse-Heating Experiments of Meteoritic Analogs.

Some preliminary heating studies have been carried out on small fragments of the meteorites Murchison and Orgueil. The fragments were first crushed between glass plates and then suspended across TEM grids in an evaporated carbon film. The Murchison sample consisted of fines from a previous freeze-thaw disaggregation.

Specimens of both meteorites heated into the 6-700, 8-900, and 10-1100 C ranges were examined. In preliminary comparisons of the average elemental EDX peak ratios observed for heated and unheated specimens, the only obvious change was a decrease in the S/Fe ratio of 50-90% for Murchison upon heating into the 800-1100 C range. Structural changes as observed in the TEM were considerably more noticeable. Between 800 and 900 C significant textural changes, including some apparent flow and recrystallization, had occurred in both meteorites. These changes were accompanied by significant changes in selected area diffraction patterns of individual clumps. The addition of new diffraction spots, especially spots with olivine spacings, was particularly noticable. Specimens of both meteorites heated above 1000 C showed the ubiquitous presence of small irregular crystalline droplets (Fig. 1). Although crystalline droplets have been occasionally observed in "chondritic" micrometeorites, the actual shapes, textures, and mineral associations in them were quite different [6]. To the extent that the meteorites provide reasonable analogs, the results suggest that 10 μm "chondritic" particles which have been heated above 900 C on atmospheric entry are rare in the collections.

The heatings reported above were done in an oil diffusion pump vacuum (~30 μtorr), although a forepump vacuum (20-30 mtorr) may better simulate the collison rate of particles with atmospheric molecules during entry. Studies are also planned on the heating of uncrushed 10 μm particles to test the relevance of heatings in this dispersed, grid-mounted configuration. Subsequently, sequential pulse heating experiments on individual micrometeorites are planned. The category of particles with high S/Fe ratios which are mostly noncrystalline [7] make particularly promising specimens for monitoring the effects of pulse heating over a wide range of temperatures.

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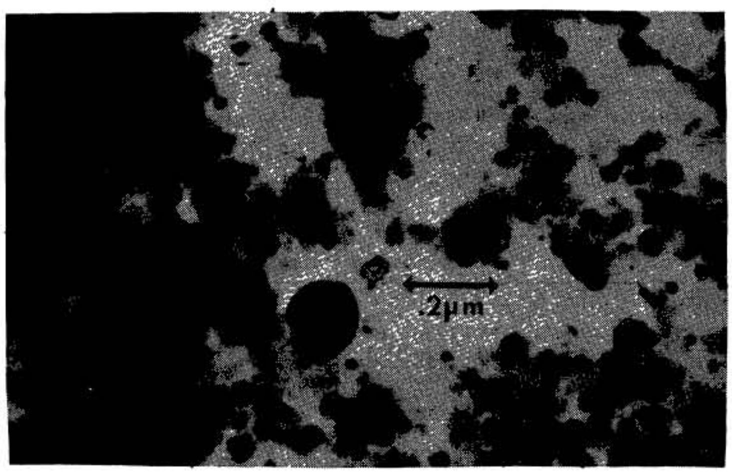

Figure 1. Small irregular crystalline droplets in a fragment of the Murchison meteorite which has been heated to ~1070 C for ~20 seconds. Judging from selected area diffraction patterns of such regions, many of the droplets are probably olivine. Similar droplets have been observed in fragments of Orgueil pulse heated above 1000 C, but have not been seen in examined "chondritic" micrometeorites.