THERMAL HISTORY OF SMALL FRAGMENTS DURING THE CHELYABINSK METEORITE FALL.

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Introduction: Small fragments of the Chelyabinsk meteorite found a few days after the fall by geologists from the Vernadsky institute were incorporated into dense snow cones [1-2]. The mechanism of cone formation is still not clear, although two hypotheses, mechanical and thermal, are discussed: 1) an impact into a fluffy snow results in substantial compaction of snow; 2) fragments are warm enough to cause partial snow melting followed by freezing/recrystallization. The latter mechanism is supported by eyewitnesses claiming that the fragments were "warm" immediately after the fall [1]. To clarify the situation we modelled heating of fragments in the hot cloud immediately after the catastrophic fragmentation, their cooling during free fall in atmosphere, and their penetration through the snow cover. We use the point-mass approximation to describe ablation and deceleration of fragments; then we solve the one-dimensional heat transfer equation (HTE) to calculate temperature distributions; the penetration process is modeled with the iSALE code. We consider various initial fragment masses, all numbers below are for fragments with initial masses of 40-g and 10-kg (in parentheses). Their final diameters are 1.3 and 8.5 cm, respectively.

Deceleration and free-fall time: Shortly (1-3.5 s) after the catastrophic disruption, individual fragments lose 90% of their mass, are decelerated below 2 km/s, and ablation cease. The free-fall time in atmosphere is about 8 (3) minutes; fragments reach the surface vertically with the velocity of 28 (74) m/s.

Heating and Cooling: Using the HTE with typical for stony meteorites parameters and the external radiation flux (T_r= 8,000 K) we can reproduce the same mass loss during the same time interval as above. At this step temperature below a very thin (<0.1 mm) layer is still at the space level (~200 K). Additional heating by hot (3000K) vapor creates a ~1-mm-thick ablation crust and heats the interior: 84 (21) % of the total mass is above 300 K. We also model simplified T-distributions: a fragment is heated up to the melting point or a cold fragment is surrounded by a molten 1-mm-thick crust. Finally, fragments cool down during their free fall in the atmosphere (T=250 K). In all but one (molten large sphere) variants the cooling time interval is substantially shorter than the time interval of free-fall.

Penetration: The process depends on fragment velocities and snow properties which are not well-known. We vary impact velocities from 30 to 100 m/s and snow porosity from 40 to 80%.

Discussion: In contrast to stable deceleration/ablation models, the HTE is very sensitive to poorly known thermal properties of meteorites. However, we are certain that fragments < 5 cm in diameter reach the surface being in thermal equilibrium with the atmosphere. The mechanism of cone formation requires further research.

References: [1] Ivanova M. et al. 2013. 76th Meteoritical Society Meeting, Abstract # 5366. [2] Popova et al. 2013. *Science* 342: 1069-1073.