THERMAL EVOLUTION OF IMPACT EJECTA IN FIREBALL.

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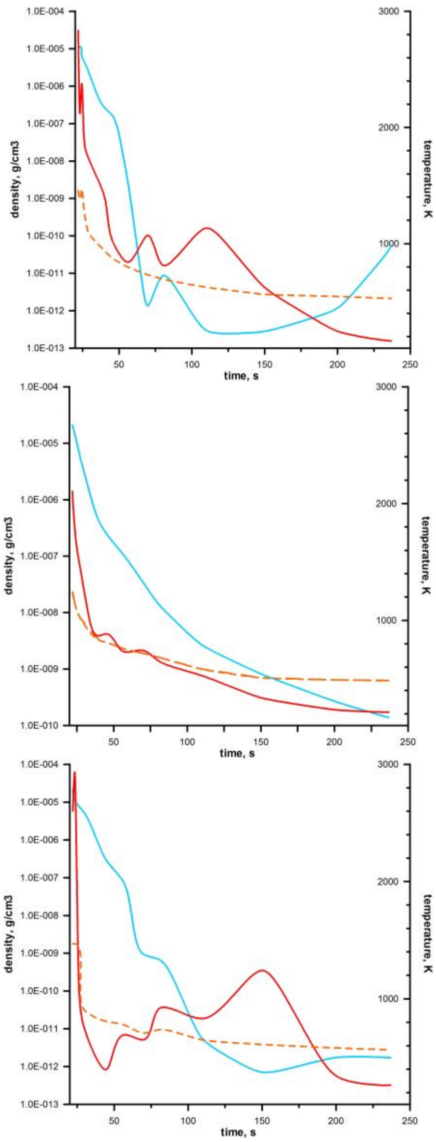
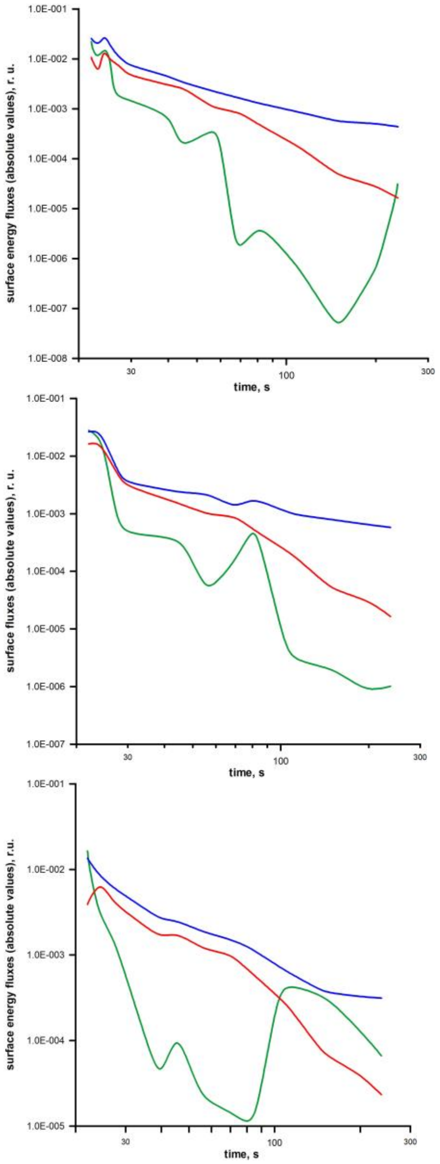
Introduction: Thermal evolution of solid ejecta in catastrophic impacts is interesting in considering melt coats over gneiss bombs deposited in suevitic breccias [1], in ablation of meteoroids impinging atmosphere [2], in origin of chondrules in jets after collisions of planetary embryos [3]. This work continues previous one [4], clarifying processes of thermal interaction ejecta with fireball.

Problem constraints: We consider ejecta after an oblique impact of 1 km diameter asteroid onto the Earth with speed of 20 km/s at an angle of 45 degrees, getting started at time of 21 s (initial parameters are defined by V. Shuvalov, shown in [4]). Solid ejecta experience gas drag, heat exchange and radiative interaction with a disturbed atmosphere and a cloud of target and impactor vapors. In figures stated below we demonstrate values of air density and temperature around selected pieces of ejecta, their surface temperatures, values of thermal and radiative fluxes onto their surfaces. In time the disturbed atmosphere expands, ejecta move through the atmosphere, so values and an importance of various energy fluxes also vary over time. To define radiation, air parameters around the ejecta, ejecta temperatures, a gas dynamic atmosphere evolution, non-ballistic displacements of the ejecta, radiative flux onto their surface and heat transfer in the ejecta pieces were calculated. Hydrocode simulations were made with SOVA [5]. Calculations were ran until time of 250 s after the impact, solid ejecta fragments with radii 3 cm, 10 cm, 30 cm were considered.

Results of modeling: Solid selected ejecta pieces had their initial temperatures, defined by equation of state higher than the Curie temperature. Ejecta with start vertical velocity exceeding 1.5 km/s flew in the upper atmosphere after 100 s for a rest of the time evolution. In figures 1-3 we show air densities (blue curves), air temperatures (red curves) around three ejecta fragments, surface temperatures of the 3 cm ejecta (orange dashed curves) over time of evolution. In figures 4-6 absolute values of energy flux surface densities are shown: incident radiative flux (red curves), always positive in simulaions of heat transfer in ejecta fragments, outgoing radiation from surface (blue curves), always negative, heat exchange flux due to molecular collisions or heat conductivity- convection (green curves), positive, if an ambient air is warmer, than the ejecta piece and vice versa. A sign of this flux is easily defined from figures 1-3: if the orange curve lies higher than the red curve, the flux is negative. As seen from the figures, the surface temperature depends mainly on these three processes, heat conductivity flux inside a fragment is less important. For the second fragment (fig. 2) surface melting occurs, because its temperature gains up to a temperature of melting (1470 K).



Figures 1, 2, 3. Air temperature K (a red curve), air density g/cm^3 (a blue curve) , surface temperature K (a dashed orange curve) versus time s for three selected pieces of ejecta.



Figures 4, 5, 6. Absolute values of energy flux surface densities in relative units versus time s: incident radiation (a red curve), surface radiation (a blue curve), heat conductivity (a green curve).

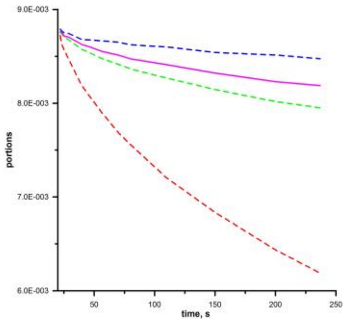


Figure 7. Mass portions of ejecta with temperature above the Curie temperature over time s.

A dashed red curve refers to 3 cm radii population, a dashed green curve- 10 cm radii ejecta, a dashed blue curve- 30 cm radii ejecta, a solid magenta curve- the mass portion, weighted over SFD.

Discussion: Radiative transfer equation over rays in the disturbed atmosphere was solved to define incident radiation flux onto the every ejecta piece, but without shading of one piece by another due to mutual arrangement. Absorption coefficients of hot air [6] were used in calculations.

Analysis of energy fluxes shows, that apparently, shock wave radiation doesn’t influence significantly on surface temperature of ejecta, but interaction with vapors and gas dynamic parameters of vapors or vapor-air mix are important. So the results of ejecta thermal evolution are applicable to impacts onto airless bodies, where ejecta interact with a transient atmosphere of vapors.

We also investigated how mass of demagnetized ejecta varies over time, because these rocks can acquire thermal remnant magnetization (TRM). In fig. 7 mass portions over time, summarized data on 354 pieces of ejecta are drawn. We considered the ejecta like spheres with radii 3 cm, 10 cm and 30 cm. Dashed red, green and blue curves refer to 3 cm, 10 cm and 30 cm bodies, respectively. A solid magenta curve presents the portion, weighted over size-frequency distribution (SFD) of ejecta pieces, which is a power function with exponent of -3.44. Since temperature varies in the surface layer thinner than 1 cm, the thermal evolution is more significant for the smallest fragments.

In this problem one of previous assumptions [4], that surface temperature follows the ambient air temperature is not eligible in hence of slow thermal reaction of solid fragments (can be valid for smaller fragments).

Melt coats over gneiss bombs deposited in suevitic breccias in Popigai crater were interpreted as an effect of a fireball heating [1]. Their sizes varied from 2 to 40 cm. This is a good match with results of our modeling. Even if impactor is larger than 1 km (the case of Popigai crater), then more energy is released in the impact, more hot and dense vapor is expected to react with solid ejecta, providing surface melting.

Conclusion: In interaction ejecta with fireball shock wave radiation is less important than interaction with vapor cloud at early stage of time evolution.

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