MELTING OF SOIL RICH IN QUARTZ BY RADIATION FROM AERIAL BURSTS – A POSSIBLE CAUSE OF FORMATION OF LIBYAN DESERT GLASS AND LAYERED TEKTITES.

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Introduction: There is much evidence that tektites formed by melting (terrestrial) continental sediments (e. g., [1–4]). Although some researchers interpret geochemical arguments [5] and numerical modeling [6] to support the view that tektites are ejecta from impact craters, ^{10}Be data indicating an origin in surficial soils create problems for such models [7, 8]. It has been suggested that the layered (Muong-Nong-type) tektites from SE Asia and the Libyan Desert Glass had another origin – melting by radiation from aerial bursts produced by the breakup and atmospheric deceleration of meteoroids [9–11]. Some of the properties of layered tektites and LDG, first of all their internal structure with parallel layers, are well explained by melting followed by laminar flow and are hardly consistent with molten ejecta lumps [12]. One must explain their large thicknesses (up to 20 cm) though it has been suggested that these reflect flow into topographic lows. A more severe problem is to understand how they could have formed over large areas – about 7000 km^2 in the case of LDG and 7·10^5 km^2 for the layered tektites in SE Asia. In this study, we performed some estimates of possible scenarios.

Melt thickness: Most soils are opaque. It is impossible to melt minerals 1 cm thick by radiation (UV, visible, or IR) during a reasonable time because of small thermal conductivity. In contrast, quartz and silica glass are transparent. Measurements of light absorption [13–14] show that radiation mean free paths in LDG are about 1.5 cm in a wavelength range 0.4–3.5 microns. We solved numerically (by the method of [15]) the equation of radiation transfer in a half-space filled by LDG material. We assumed that the target surface is irradiated by a plane source with a constant brightness temperature T_e. Absorption coefficients were taken from [13–14] and it was assumed that the material (fine sand) is opaque prior to melting. After radiation heats a thin layer to the melting point, the surface transmits light and the next layer is heated; thus, a melting wave moves into the target. The hottest upper layers are partially vaporized and the vapor absorbs the radiation. When the vapor temperature becomes close to the source temperature, the vapor radiates back almost the same flux as the flux incident upon the target, and the process of ablation goes slower.

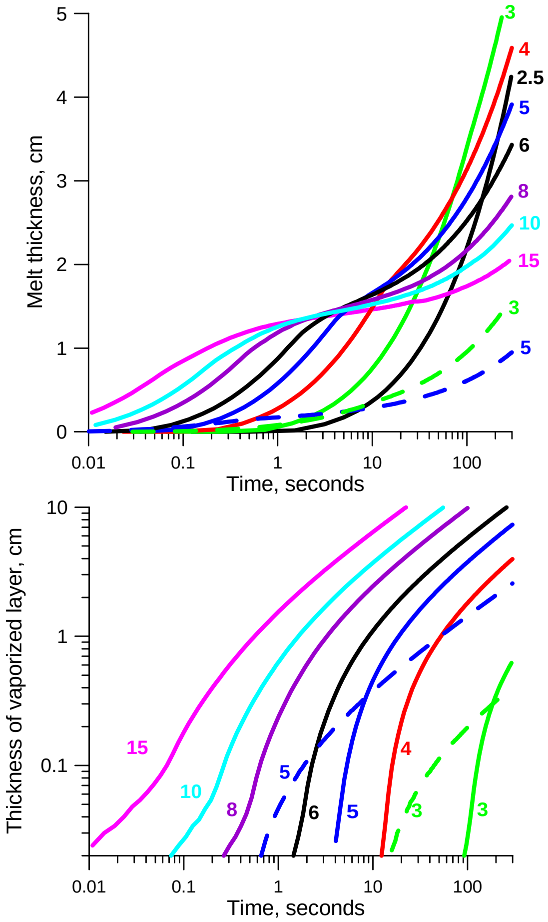

Fig. 1. Thickness of melted and vaporized quartz-rich soil layers under radiation of a blackbody source with a brightness temperature indicated in kK at the curves. Dashed lines show variants with higher (10X) absorption coefficients, which decrease degrees of melting. The melt thickness of opaque materials would be even lower.

The thickness of melted layers as a function of time is shown in Fig. 1. If T_e and the flux density σT_e^4 are high, the melt forms rapidly but then the vapor screens the target from the source. For T_e >5000 K the thickness of melt is 1–1.5 cm in several seconds. This is a typical duration of a radiation impulse from a 20-kt nuclear explosion, and, indeed, trinitites (glasses formed after the detonation of the first atomic bomb) have such thicknesses. At high fluxes, much soil vaporizes and may later condense. However for formation of thicker melt layers sources with lower brightness temperature (3–6 kK) and longer duration are preferable due to lower energy requirement. In addition, long radiation impulses enhance the loss of volatiles such as H_2O .

Heated atmosphere: If the atmosphere is heated over a large area, it expands upward and cools by radiation. About half of radiated energy can reach the ground and melt proto-LDG soil. We modeled, using the hydrodynamic and radiation transfer equations, a situation when an air layer of constant thickness is heated over the whole atmosphere at certain altitudes *h*. We varied the energy of the layer, its specific internal energy *e* from 4 to 25 kJ/g, and *h*. The computations show that the thickness of melted soil exceeds 5 cm if the released energy per unit area in the layer is above 1 Mt/km^2 and e > 7 kJ/g (T>4000 K). Energy release at higher altitudes and higher temperatures is more effective, however most important is the amount of energy. For the SE Asia area of $7{\cdot}10^5$ km^2 the energy release necessary for 5-cm-thick melting will be $3{\cdot}10^{21}$ J that is close to the kinetic energy of a 3-km-diameter stony asteroid with a velocity 11 km/s. It is unlikely, though not impossible, that the Earth directly collided with a dispersed object which broke up in space some time before the impact. However, such heating of air over a large territory could result from ricochet after an oblique impact [16] or a grazing impact [17]. Estimates based on a simple model [17] show that, if a 3-km-diameter asteroid having a velocity at infinity 1 km/s approaches the Earth along a trajectory with a perigee which lies from 15 to 30 km above the Earth's surface, the asteroid flies through the atmosphere, decelerates and continues the motion. Its strongly dispersed debris can land at some distance from the entry place; some fragments may go into orbit prior to accreting and heating the atmosphere. In this case, the heated patches can cover a large area.

Impacts at small angles: We estimate that an impact energy of $3{\cdot}10^{19}$ J is sufficient for creation of LDG strewn field by radiation. A comet with this energy (0.35 km in size at 50 km/s) fully vaporizes and decelerates in air if the entry angle is lower than 10–15°. Such an impact does not produce a crater. We performed simulations of an explosion with $3{\cdot}10^{19}$ J energy, which show that the fireball dimensions are commensurate with the LDG strewn field (Fig. 2.) Calculations show that a flat layer of melt several cm thick can be created over the area 50–100 km in diameter. Thicker LDG samples are attributable to downslope flows.

Conclusions: Oblique impacts at small angles can melt relatively thick (several cm) layers of soil rich in quartz directly by radiation from air heated by meteoroid debris. Impacts that are more energetic can produce radiation impulses which act on a larger area and last longer. With increasing duration of the heat pulse, the melts lose more volatiles, and the product becomes more similar to splash-form tektites.

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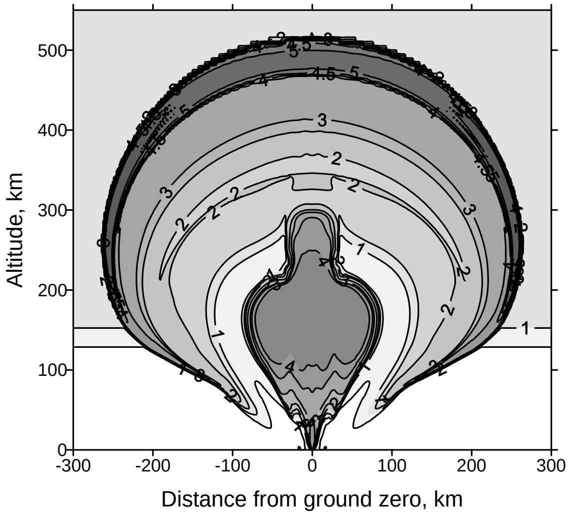

Fig. 2. Temperature contours in the atmosphere in 45 s after the explosion with an energy $3{\cdot}10^{19}$ J at a height of 5 km. The initial temperature in the fireball was assumed 40 kK. The labels indicate temperature in kK.