TEKTITE PRODUCTION IN OBLIQUE IMPACTS.

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Introduction: Tektites are naturally occurring glasses, generally less than several centimeters in diameter, found in four distinct strewn fields [1]. The tektites of each strewn field are close in their chemistry, age, petrologic and physical characteristics [2, 3]. Compositional data strongly suggest that tektites are derived from the melting of terrestrial sedimentary rocks during the impact cratering process. The European and the Ivory Coast strewn fields are located within a few hundred kilometers of their probable source craters - Bosumtwi and Ries, respectively. The meteoritical component contents in tektites is very low (<0.06 wt% for the Ivory Coast). Tektites differ from other kinds of natural glasses (eg. obsidians and impact melts) in extremely low water content (0.002-0.02 wt%), high degree of chemical and physical homogeneity. All these facts indicate that tektites originate from the high-temperature melt solidified in the upper Earth atmosphere with low oxygen. The study of cosmogenic radionuclides (^{10}Be and ^{26}Al) provides further proof of the terrestrial origin of tektites exclusively from the top few hundred meters of a target.

The production of tektites requires special conditions (only 4 of more than 150 known impact craters crater are related to tektites). We divides the process of the tektite strewn field formation into three stages - #1: near surface melt production and its ejection from the crater; #2: melt transport to higher altitudes, its disruption into a set of smaller particles of various sizes; #3: Motion of particles through the atmosphere, disturbed by the post-impact gas dynamic flow.

Here we present numerical modeling for the stage #1 for impacts with various impact angles and velocities. Estimates of the particles trajectory in the Earth atmosphere (stage #3) is also presented.

Hydrocode and EOSs in use: The melt production for the impact crater of constant size (but for various impact velocities and trajectory inclinations) is studied numerically with special efforts to separate melt produced in the upper surface layer (50-200 m).

3D oblique impacts are simulated with the SOVA code [4,5] complemented by ANEOS equation of state for granite [6]. The code allows us to model multidimensional, multimaterial, large deformation, strong shock wave flows. Spatial resolution of 10 cells per projectile radius (cppr) is used for all the runs. A set of special tracer particles mark the upper surface layer of 50 m depth. Analysis of the EOSs shows that the release from the shock pressures in the range from 100 to 300 GPa gives high-temperature melt needed for the tektite production. Thus, material from the upper target layer, compressed to these pressures, is referred here as "tektite" materail.

.**Bosumtwi crater modeling:** The 1 Ma Bosumtwi Crater in Ghana ($06^0$32'N, $01^0$25'W) is an 10.5-km-diameter complex well-preserved impact structure associated with the Ivory Coast tektite strewn field [7].

Croft's model [8] for Bosumtwi Crater gives the transient cavity diameter D_{tr} = 9 km. Scaling laws [9] define the projectile diameter: for various impact angles and velocities this diameter varies from 380 m (90^0, 40 km s^{-1}) to 1140 m (30^0 , 11.2 km s^{-1}).

Production of "tektite" material: Just after the projectile/target contact some downrange portion of the target material is compressed to the "tektite-productive" pressures. However this portion has rather low initial velocity, and no chance to reach the upper atmosphere. The real "tektite" material arises later just in front of the expanding projectile (approximately 1 km apart from the impact point). This part of ejecta reaches altitudes of about 1-2 km with a high velocity (2-12 km s^{-1}), having rather high temperatures (>1800^0). At these altitudes large melt bodies may be disrupted into particles of various sizes. We should continue to model the motion of particles in the post-impact gas flow. This part of work is in progress now.

Variations of impact angles. Fig. 1 shows the central cross-section of the post-impact flow for two impact angles. The target material compressed to 100-300 GPa is marked by the yellow circles. The part of this material, initially placed within the upper 50 m of the target ("tektite" material), is marked by red circles. The near surface melt arises after the impact with any impact angle θ, although the total amount of melted material strongly depends on θ. Table 1 summarize the results. The maximum melted mass is observed for the smallest impact angle of 15^o. It is not surprising: in the case of the grazing impact the projectile, sliding over the surface, produces the melt primarily from the upper layer of the target. At the same time the main portion of the vertical (or near vertical) impact melt is produced from deeper layers of a target, as the shock wave decays strongly near the free surface.

Table 1. Tektite material for various impact angles.

Angle	15	30	45	60
Mass (Mt)	51	34	23	14
V_{tek}/V_{pr}	0.1	0.25	0.24	0.23

Vickery (1993) shows that high-velocity jets are strongly contaminated with a projectile material (real tektites are not). Our results confirm these estimates.

Moreover, jets are moving along the surface in a rather dense atmosphere, having no chance to travel up to hundreds of kilometers. Impacts with angles >60^0 result in near vertical melt jets. These jets may reach the upper atmosphere only above the impact site - it is not clear how to deliver the melted material for a long distance. Only impacts with angles in the range of 30^0 to 50^0 may be considered as the best candidates for the "tektite parent" impact event.

Velocity variations. Table 2 shows the computed total mass of "tektites" for different impact velocities. The "tektite" material/projectile volume ratio at 11.2 km/s is 5 times smaller than for 40 km/s. Low-velocity impact melt conserves primarily within the crater while high-velocity impacts (40 km/s) result in high-velocity melt jets with good chances to transport the melt at large distances. Probability of asteroid impacts with v>35 km/s is less than 1% [9]. Thus, a possible tektite origin in high-velocity impacts together with a low probability of these impacts can explain deficiency of tektite strewn-field (only four) in comparison with impact structures.

Table 2. Melt production under velocity variations

velocity (km/s)	40	20	11.2
mass (Mt)	23	21	28
V_{tek}/V_{pr}	0.24	0.068	0.046

Target and projectile material variations. Preliminary simulations with wet tuff target shows an increase of vapor production and of the ejection velocity. While velocity increase is favorable for tektites, a lot of water in the plume leads to the fast disruption of the target melt [10]. Cometary impacts have higher velocity, but the massive release of volatiles may play the same role as the target water vapor while tektites are impact glasses of high quality with very low water contents and high degree of homogeneity. Tektite production from wet targets and/or with cometary impacts looks less probable and not studied here.

Trajectory of small particles in atmosphere. The principal objection against the impact origin of tektites concerns the motion of small particles through the atmosphere [11, 12]: liquid jets would break up into a fine mist before traversing hundreds of kilometers. The idea of a temporary atmospheric hole, created by a cometary impact [13] demands too high energy (diameter of the parent crater would be ~300 km). Nevertheless, numerical simulations of the Bosumtwi event, based on the SOVA code, show that the cm-sized particles move in the post-impact flow with local gas velocity without appreciable drag and their trajectory strongly resembles ballistic one.

Conclusion: The preliminary results of numerical modeling shows that high velocity (35-40 km/s) impacts into a dry target with impact angles of 30^0 to 50^0 may be considered as the best candidates for the tektite-productive events.

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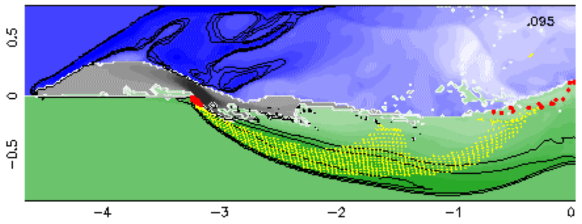

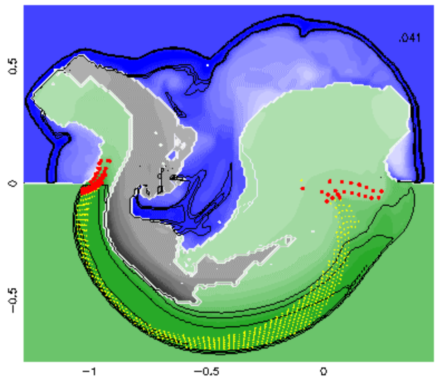

Fig. 1. Post-impact flow with tektite material (red tracers) for impact angles 15^0 (left panel) and 45^0 (top panel). Green color presents granite target, gray – dunite projectile, blue – atmosphere. Impact point is (0,0). Projectile moves from right to left.