The Effect of the Atmosphere on Large-Scale Impacts - Extinction Mechanisms and The Origin of Tektites

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Alvarez[1] et al. and others[2-6] have provided physical evidence for the impact of an extraterrestrial object contemporaneous with the Cretaceous-Tertiary (K-T) boundary (63 Ma). A 1 to 150 cm clay layer, of global extent, is enriched in noble metals and other elements relative to crustal abundances by a factor of 5 to 1000. Because the clay layer is at the K-T boundary, it has been argued that the impact is the cause of the K-T extinctions of biota.[1] The most compelling evidence for the correlation of an impact event with the K-T extinctions is contained in the marine sediment record of the phytoplankton.[1,4] The extinction of phytoplankton has also been correlated with layers of microtektites[7,8], and small glass spherules (tektites?).[9]

We have examined the mechanics of large-scale (diameters $\gtrsim$ 10 km) asteroidal, cometary and meteorite swarm impact to determine whether or not the physical evidence is compatable with an impact event.

Our calculations show that during the initial penetration of the atmosphere, relatively little mass or energy is transferred from large bolides (~ 10 km).[10] The dominant mass and energy transfer processes occur upon impact with the Earth. The impact-induced flow field ejects 10 to 200 times the bolide mass into the atmosphere depending in detail upon the impact velocity and the bolide type. The ejecta that is propelled early in the cratering flow is enriched in bolide material and has concentrations in the range of those measured in the K-T boundary layer material.[10]. We infer that the extraterrestrial component is highly shocked and consists of vapor, melt and fine solid particles. The melted and vaporized ejecta which can be lofted to stratospheric heights (Fig. 1) contains a significant fraction of fine particles that couple mechanical and thermal energy to the atmosphere. The ejecta particle size distributions were estimated from nuclear explosions[11] and impact ejecta[12] studies (Fig. 2) and from droplet stability considerations (Fig. 3). The penetration of the atmosphere creates a hole in the atmosphere that is subsequently filled by a flow field that is inward and upward (Fig. 4). The upward component lofts the vapor, and fine melted and solid ejecta to heights greater than 10 km. This rapid upward and outward flow of the atmosphere along the path of the initial projectile is the primary mechanism for carrying impact melt (tektites) out of the upper atmosphere as depicted in Fig. 4. Because tektites are ejected along the direction of origin of the bolide, the east-west orientation of the strewn fields is interpreted as reflecting the preferred incidence of bolides from the plane of the ecliptic.

We estimate that 1 to 20 times the mass of the bolide is in fine particles less than 1 μm that can be lofted to heights greater than 10 km and thus be distributed world wide. Calculations of solar transmission reduction due to dust injection show that 10^6g, uniformally distributed, would reduce photosynthesis by a factor of 10^5. Although the atmosphere receives little energy upon direct interaction with the bolide, once impact upon the surface occurs, the subsequent ejecta transfers both its kinetic, and for small particles, its internal energy to the atmosphere. The energy transfer to the atmosphere was computed from transfer of kinetic energy by atmospheric drag and internal energy via thermal transfer, taking into account the particle size distributions for the vaporized, melted and solid ejecta. The fraction of bolide energy transferred to the atmosphere is ~ 15%. For 10^{31} erg impact this would result in a global average temperature increase of ~ 10°C. Although this temperature excess is radiatively lost in several days, Emiliani et al.[14] suggest that it might be intolerable for many biota [especially larger reptiles (> 25 kg)]. The tropospheric temperature may then sharply decline due to the dust injection in the upper atmosphere.[15]

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EFFECTS OF THE ATMOSPHERE ON LARGE-SCALE IMPACTS

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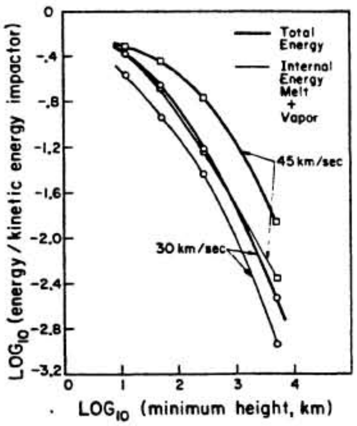

Fig. 1 Log_{10} (energy in melt and vapor ejecta, and total ejecta/initial meteorite energy), versus, $\log_{10}$ (minimum ejecta height).

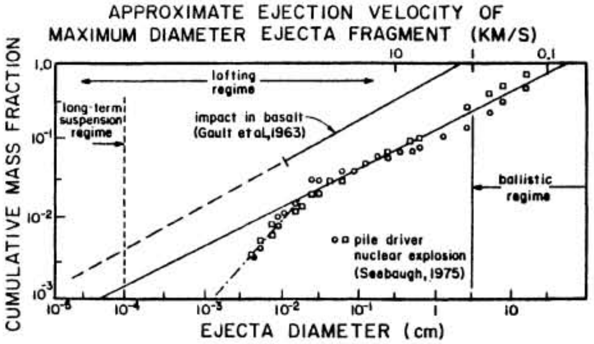

Fig. 2 Ejecta cumulative mass fraction, versus, ejecta diameter and maximum size fragment velocity.

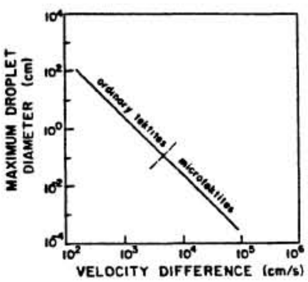

Fig. 3 Maximum droplet size, versus, flow velocity difference for dynamic stability for liquid silicate (300 d/cm) drops.

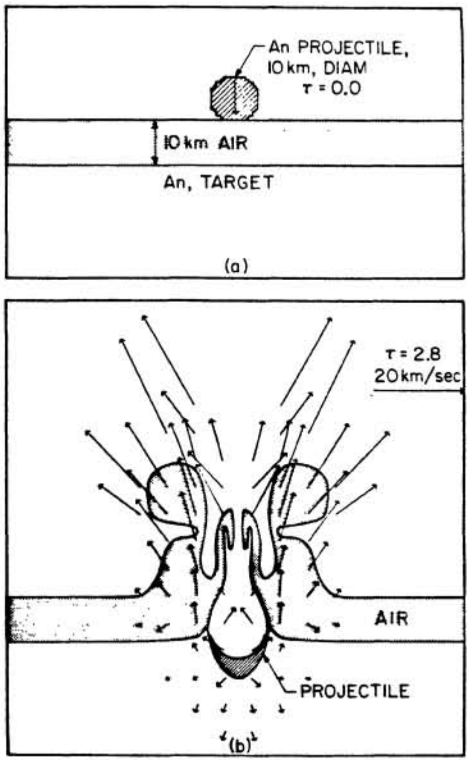

Fig. 4 Flow field for impact of 10 km diameter silicate (An) projectile onto a 10 km thick 0.001 g/cm^3 atmosphere overlying a silicate (An) half-space.