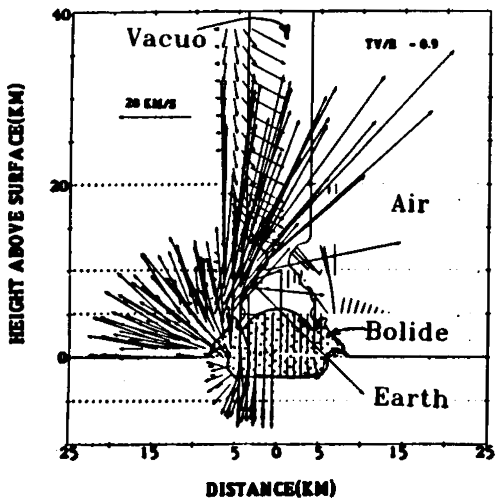
ENVIRONMENTAL EFFECTS OF LARGE IMPACTS ON THE EARTH...RELATION TO EXTINCTION MECHANISMS, John D. O'Keefe, Thomas J. Ahrens, and Detlef Koschny+, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125 (+ permanent address: Technische Universität, München, Federal Republic of Germany).

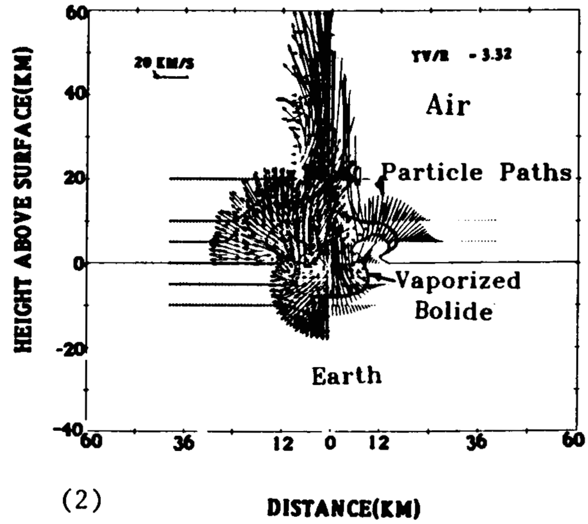
Since Alvarez et al. (1) and others discovered a worldwide ~ cm-thick layer of fine sediments laden with platinum group elements in approximately chondritic proportions exactly at the Cretaceous-Tertiary (CT) boundary, and proposed bolide-impact as triggering mass extinctions, many have studied this hypothesis and the layer itself with its associated spherules (2) and shocked quartz (3). At issue is whether the mass extinctions, and this horizon has an impact versus volcanic origin (4). A critical feature of the Alvarez hypothesis is the suggestion that the bolide or possibly a shower of objects (5) delivered to the earth $\sim 0.6 \times 10^{18}$ g of material which resulted in aerosol-sized ($<1\mu m$) ejecta (launched and remained at stratospheric heights) such that global insolation was drastically reduced for significant periods. Such an event would lower temperatures on continents and halt photosynthesis in the upper 200 m of the ocean. The latter would strangle the marine food chain and thus produce the major marine faunal extinctions which mark the C-T boundary. Crucial issues we examined include: What are the dynamics of atmospheric flow occurring upon impact of a large bolide with the earth? What is the size distributions of the very fine impact ejecta and how do these compare to the models of ejecta (previously derived from volcanic ash) which are used to model the earth's radiative thermal balance? We calculated the flow field due to passage of a 10 km diameter bolide through an exponential atmosphere and the interaction of the gas flow and bolide with the solid earth (6). The shock in front of the bolide reflects from the planet and reverberates between the bolide and surface. Upon impact a strong conical shock is driven upward in the air as the bolide penetrates the surface. The radially expanding gas drives a hemi-spherical shock away from the impact site (Figure 1). This shock propagates away from the impact site before the surface rock ejecta plume starts to evolve. Much of the high velocity initial flow does not entrain ejecta particles. The evacuated region in the atmosphere is filled in by gas that are moving radially inward and downward. The downward moving gas stagnates at the surface and results in a strong shock around the projectile. When this shock reaches the evacuated region it accelerates an annular region of gas upward that collides with the downward moving gas as observed in the experiments of Schultz and Gault (7). Eventually all of the downward moving gas is stagnated and turned upward (Figure 2).

Recently, Asada (8) and Koschny et al. (9) examined the fine ejecta from laboratory experiments on silicate targets in the 1 to 4.3 km/sec range. They found that the mass fraction of $<1\ \mu m$ ejecta was $\sim 7 \times 10^{-6}$ of the total ejecta in agreement with earlier studies from nuclear explosions (11). A change in the distribution occurs at diameters of 30 to 100 μm (Figures 3 and 4). Impact ejecta distributions differ from those found in volcanic ejecta (12,13), where the $<1\mu m$ fraction is 1.7×10^{-3} of the total ejecta mass (10). Condensation of impact induced vaporized rock (14) from a 10km diameter 30 km/sec silicate impactor, indicates that nucleation and condensation will occur only upon expansion of the cloud to altitudes above ~35km and the resulting condensate has liquid drop sizes, which are more like tektites (1 to 10 cm). These break-up to possibly form microtektites, but not, aerosols. Although ejecta having total mass of 5 to 200 times the mass of the bolide are launched to altitudes of 10 to 60 km, most of this ejecta is in ballistic trajectories and only a fraction (10^{-5} to 10^{-6}) is sufficiently small ($<1\ \mu m$) to remain in the atmosphere. Thus, worldwide climate effects form impact-induced dust may have been overestimated.

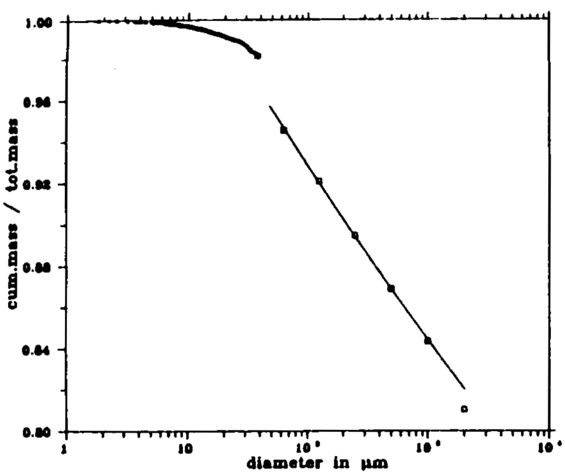
We have also modeled (15) the CO_2 released upon impact onto shallow marine carbonate sections (1 km) and found that the mass of CO_2 released exceeds the present 10^{18} g CO_2 budget of the earth's atmosphere by several times. Moreover, unlike H_2O, CO_2 is not rapidly returned to the surface or earth's interior. Using the calculations of Kasting and Toon (16) to compute the temperature rise of the earth's surface as a function of CO_2 content, we find that sudden and prolonged (10^5 year) global increases of 2 to 13K are induced from impact of 20 to 50 km radius projectiles and propose that sudden terrestrial greenhouse-induced heating, not cooling, produced the highly variable extinctions seen at the C-T boundary.



(1)



(2)



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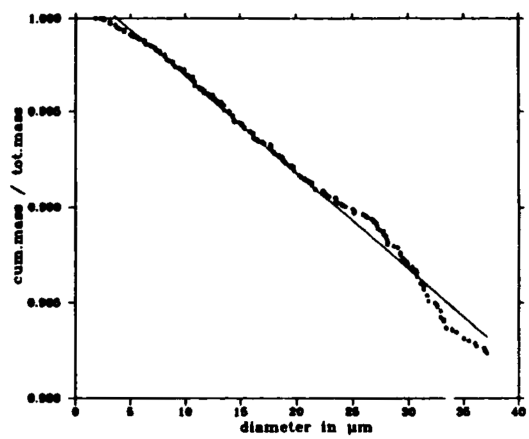

(4)

Fig. 1. Flow field for impact of 10 km silicate bolide with exponential air atmosphere and silicate earth at 20 km/sec. Flow is at dimensionless time 0.9. Arrows on left hand side show particle velocity. Dots on left indicate position of marker particles. Lines on right hand side indicate path of marker particles. **Fig. 2.** Flow field at dimensionless time 3.32. **Fig. 3.** Mass distribution of ejecta for 1 km/sec impact into gabbro. Data points for 38 μm and larger (marked with squares) were obtained by sieving and weighing, and for smaller diameters (marked with asterisks) by size measurements using SEM images. **Fig. 4.** Mass distribution for sizes smaller than 38 μm same distribution as Fig. 3. Solid line represents a linear fit, $y = A + Bd$, with $A = 1.001$ and $B = -0.0005$ for d in μm.

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