IMPACT OF AN ASTEROID OR COMET IN THE OCEAN AND EXTINCTION OF TERRESTRIAL LIFE

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One of the largest extraterrestrial objects (asteroid or comet) which appears to have interacted with the earth in the last 100 My has been the 10^{16} to 10^{18} gram object which produced the world-wide platinum-group element rich Cretaceous-Tertiary (K-T) (63 Ma) boundary material (1). The meteoritic association of elements at the K-T boundary has now been recognized in both marine and non-marine sediments and a number of mechanisms have been proposed to account for the massive but highly selective extinction of biota at sea and all of the large land animals including the dinosaurs. No terrestrial impact crater of precisely this age, in the expected diameter range of $\sim 10^2$ to 10^3 km, has been identified with the K-T object. We assume that such a crater may yet be undetected on land, or, exist, or have existed on the sea floor and been subducted. Some 51% of the sea floor existing at 63 Ma has subducted (2). We report calculations of the impact-induced flow field and energy partitioning from the impact of similar mass (1.5×10^{18}) 10 km diameter, silicate (2.9 g/cm^3) and 30.8 and 14.3 diameter, water impactors (density 0.1 and 1 g/cm^3) with a 5 km deep ocean overlying a silicate half-space and the trajectories of the resulting ejecta in the earth's gravity field. Porous (0.1 g/cm^3) water projectiles are shock vaporized upon impact with the ocean and only shallow depressions, usually less than a projectile diameter, are excavated in the sea floor. Silicate projectiles impacting at 30 km/sec penetrate some two projectile diameters into the solid earth before the downward particle motion ceases and the silicate vapor filled transient cavity is covered by a very large transient expanding steam bubble which extends into the stratosphere (Fig. 1). Upon expansion of the vapor filled cavity and steam dome, water ejecta amounting to 10 to 10^2 times the projectile mass, is lofted into or above the stratosphere.

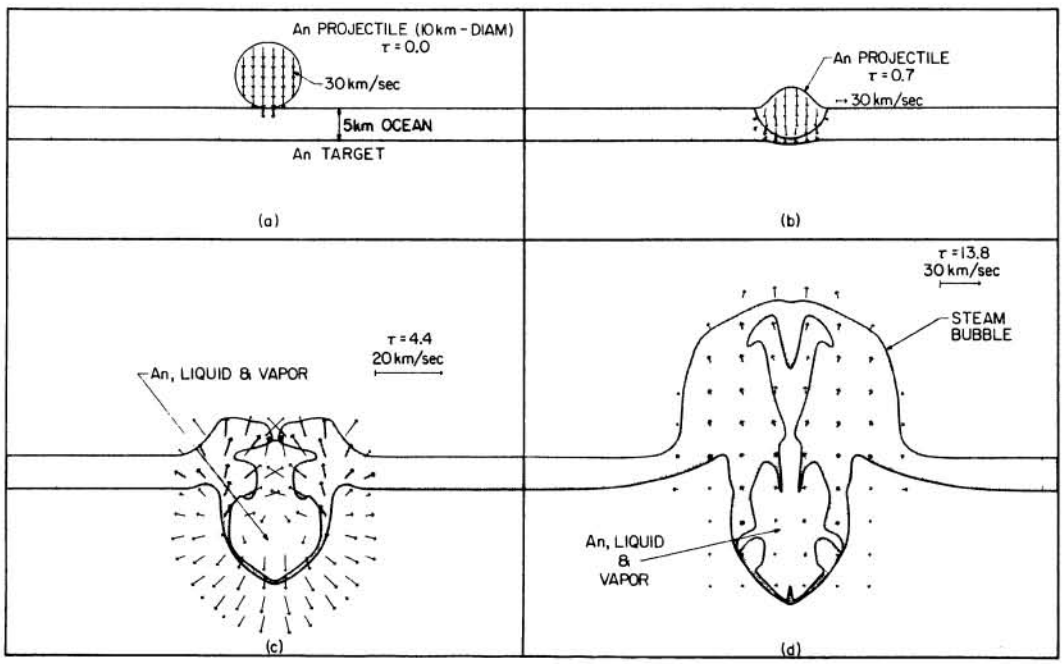

Fig. 1 Particle velocity flow field from 10 km diameter, 30 km/sec silicate projectile impacting 5 km deep ocean overlying a silicate half-space. Dimensionless time, τ, is real time times velocity ÷ projectile diameter.

After the initial shock interaction, which is marked by peaks in the projectile internal energy (IE, Proj.) and kinetic energy of the silicate underlying the ocean (KE, Target)(Fig. 2) some 12, 13 and 14% of the projectile energy resides in kinetic and internal energy of the ocean water for equal mass, 2.9, 1.0 and 0.1 g/cm^3, impactors. This impact induced energy if distributed over the upper 10 m of the world's oceans would give rise to $\sim 5^{\circ}$C temperature rise. Although this temperature rise would be sufficient to have caused the sudden death and subsequent extinction of many zooplankton, and the subsequent collapse of the marine food chain, the mechanisms for world-wide distribution of the water and silicate ejecta lofted to and above the stratosphere needs to be studied (Figs. 3 and 4). We have previously proposed (3) that the abnormally high concentration of extraterrestrial component (ETC) in the K-T boundary material represents that highly shocked ejecta which is launched, early in the flow, at high speed, into the stratosphere to be distributed globally. For 30 km/sec impactors, the fraction of ETC in the ejecta, versus, minimum ejection height (Fig. 5) for impact into the ocean is a factor of 1.5 lower than for terrestrial impact.

IMPACT OF AN ASTEROID OR COMET

Ahrens T. J. and O'Keefe J. D.

This is opposite of what Smit (1980) (4) has suggested. The reason for this is that upon impact on silicate, and, water overlying silicate, peak shock pressures in the projectile will be 9.2 and 5.0 Mbar, respectively. The more intensely shocked and vaporized projectile material is launched to higher altitudes.

We note that the impact of an asteroid or comet of sufficient size to explain the K-T boundary layer as impact ejecta would induce a mechanical impulse into the earth equivalent to an earthquake of Richter magnitude 12. No evidence has yet been found in the geologic record of the expected submarine landslides turbidites and breccia deposits which would be triggered by such a huge equivalent earthquake. We calculate a "tsunami" (Fig. 6), initially ∿5 km high, decaying to an elevation of 150 m (halfway around the earth) which will propagate in the deep ocean (like a tidal bore) at a maximum speed of ∿0.2 km/sec. Such a water wave would have inundated all low lying continental areas on the earth within 27 hours. The effect of such a bore-like wave on the biota of low lying continental areas and the prevalent shallow continental seas existing in late Cretaceous times, when the earth was nearly polar ice-free, needs to be evaluated.

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References: (1) Russell, D. A., Scient. Am. (1982) 58-65; Alvarez, L. W., W. Alvarez, F. Asaro and H. V. Michel, Science, 208, (1980) 1095-1108; Ganapathy, R., Science, 209, (1980) 921-923; Smit, J. and J. Hertogen, Nature, 285, (1980) 198-200; Kyte, F. T., Z. Zhou and J. T. Wasson, Nature, 288 (1980) 651-656; Orth, C. J., J. S. Gilmore, J. D. Knight, C. L. Pillmore, R. H. Tschudy and J. E. Fassett, Science, 214, (1981) 1341-1343. (2) Parsons, B., J. Geophys. Res. (in press). (3) O'Keefe, J. D. and T. J. Ahrens, Abstracts 12 LPSC. (4) Smit, J. (1981) Ph.D. Thesis, University of Amsterdam.

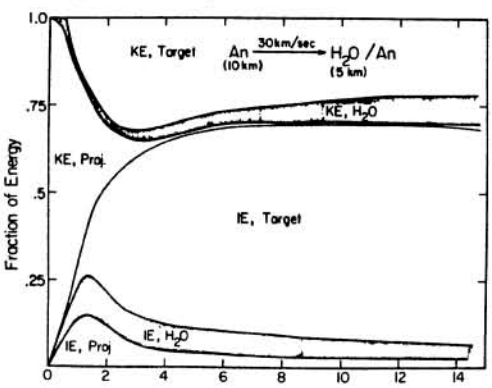

Fig. 2 Fraction of impact energy, versus, dimensionless time for flow depicted in Fig. 1.

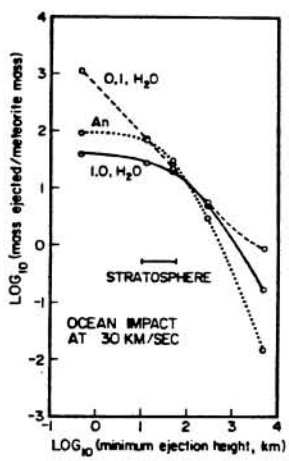

Fig. 3 Log_{10} (total mass ejected/ mass of meteorite), versus, log_{10} (minimum ejection height, km) for 30 km/sec impact of silicate (An), water (1.0, H_2O) and porous water (0.1, H_2O) impactors.

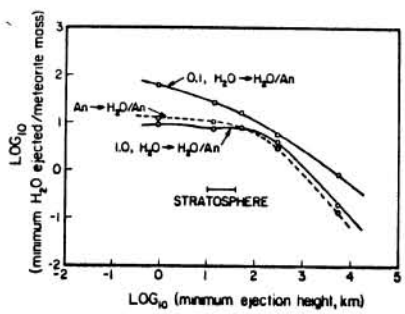

Fig. 4 Log_{10} (minimum water ejected/meteorite mass) versus log_{10} (minimum ejecta height, km).

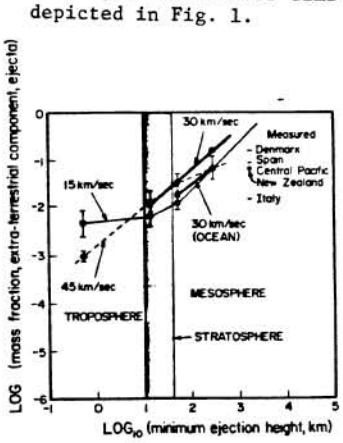

Fig. 5 Log_{10} (mass fraction, extraterrestrial material, ejecta), versus, Log_{10} (minimum ejecta height, km).

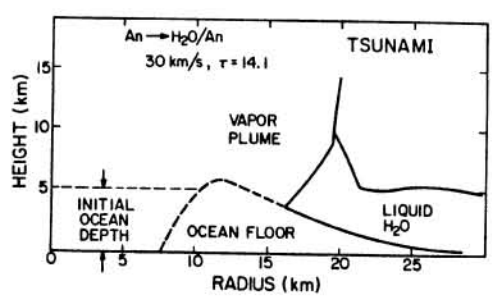

Fig. 6 Initial configuration of transient crater and water wave for impact flow depicted in Fig. 1.