Calculating Damage from Asteroid Impacts

H. J. Melosh
Purdue University
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Impact Effects can be divided into two basic categories:

Local or Regional:

- Thermal radiation
- Seismic shaking
- Ejecta Deposition
- Airblast
- (Tsunamis)

Global:

- Thermal IR pulse
- Dust in the atmosphere
- Climatically active gases
- Acid Trauma
- Biological turnover

Purdue ImpactEarth! Calculator

www,purdue.edu/impactearth/ or impact.ese.ic.ac.uk

Goal

- ***Provide an easy-to-use web-based program to calculate various pertinent environmental consequences of a given impact event on Earth at a specified distance away***

- The principal environmental effects, in usual order of occurrence near the impact site, are:

    Thermal radiation

    Seismic shaking

    Ejecta deposition

    Airblast waves

    Tsunami, if a water impact

Input parameters

We ask users for:

- Impactor density, ρ_i, in kg/m^3. This depends on the Impactor diameter, D.

- impactor composition.

- Impact velocity, v. Typical velocities for impacts on Earth are 15-20 km/s for asteroids and 30-50 km/s for comets.

- Impact angle. The most probable angle of impact is 45°

- Target composition: water (depth), sedimentary rock, or crystalline rock

- Distance away from impact.
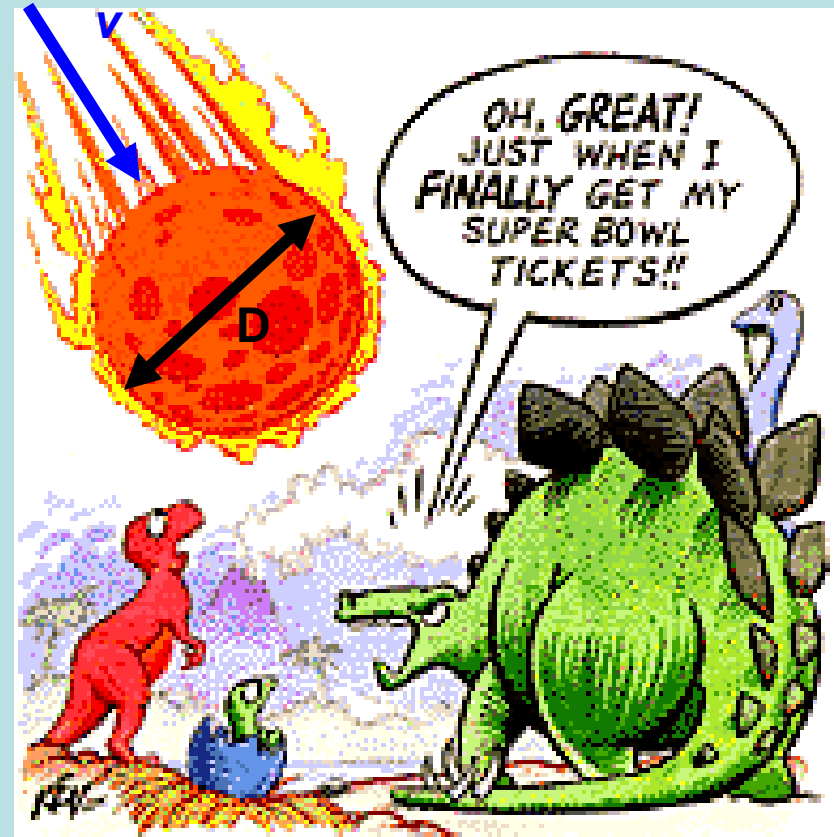
Large impacts create large craters, The impact calculator focuses on local effects at the moment (except for *really* large effects, like changing the Earth's rotation or "knocking it out of its orbit").
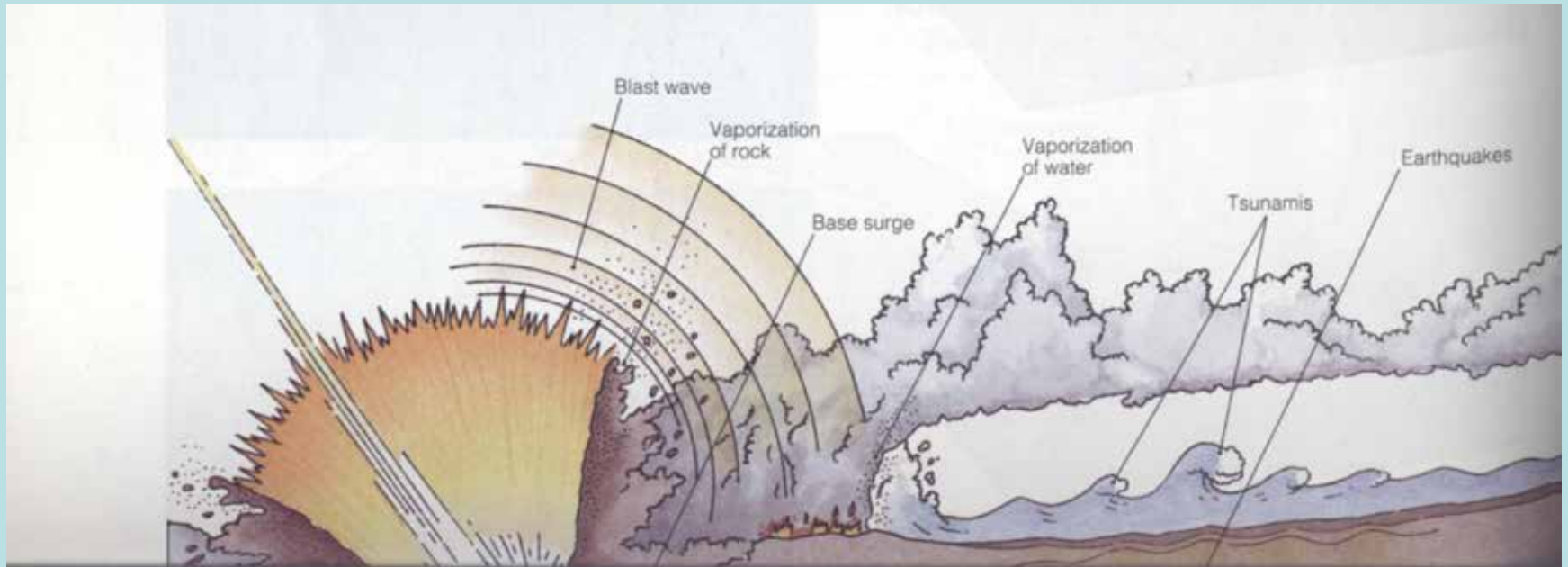
- Thermal Radiation from the fireball
- Seismic shaking
- Ejecta deposition and burial
- Airblast
- Tsunamis
- Long-lived hydrothermal systems

Even before the projectile reaches the surface it interacts with the atmosphere

Airbursts and clusters form when an incoming projectile breaks up in the atmosphere

The cluster on the surface is widest when it breaks up at about two scale heights.

The altitude of breakup is controlled mainly by the projectile strength.

In the impact calculator, strength is correlated with density to avoid user confusion about poorly known parameters
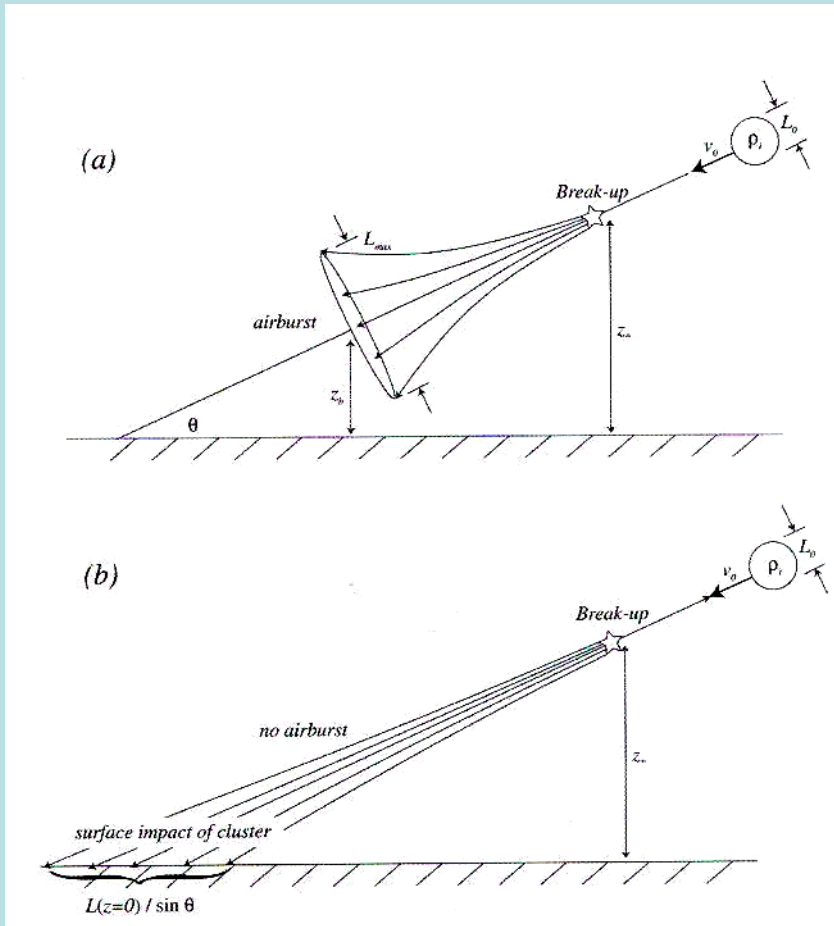
Mars offers ground-truth illustrations of projectile dispersion at low atmospheric masses, ~200 now known
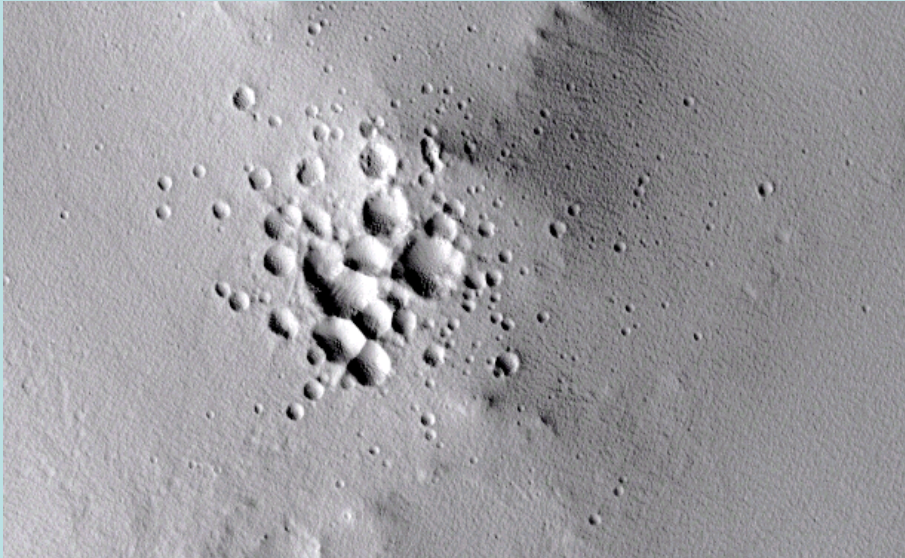
PSP_003259, inclination ~45°

Note that the airmass is too small for aerodynamic sorting of fragment size

Mars surface pressure = Earth atmosphere at 50 km

PSP_005375, inclination ~40°

Ivanov and Melosh (2008-2011) analysis shows that the observed clusters on Mars were created by objects with:

- Density 1000 to 3000 kg/m^3

- Crushing strength 0.5 to 1 bar, similar to that of Earth impactors

- Diameter 0.3 to 1 m

- Entry angles from 15 ° to 45°

When an impact occurs, it initially shock materials to high pressure and temperature, while a crater begins to open
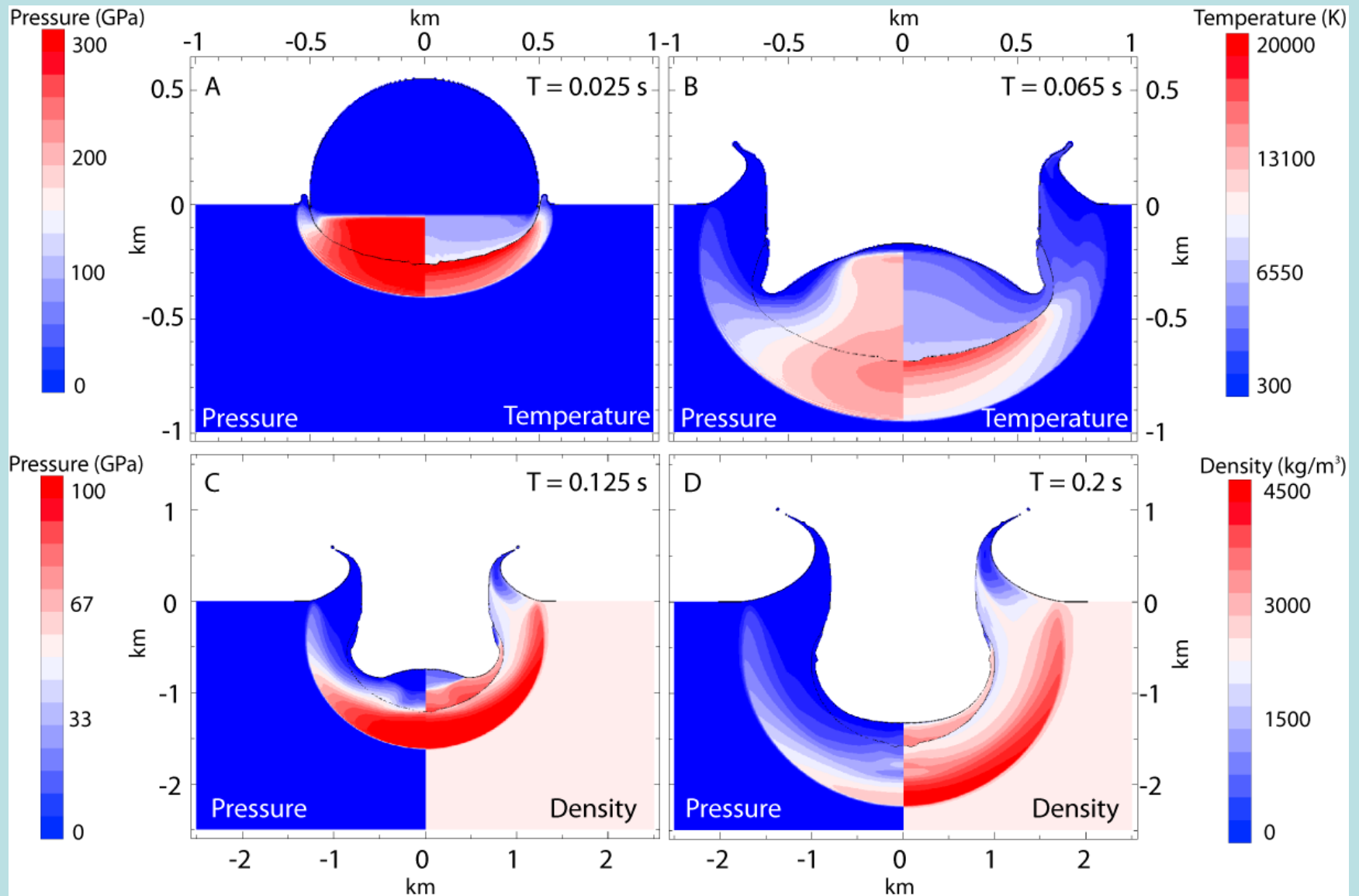
Thermal radiation from the fireball is the first potentially damaging effect to arrive at a given site

July 8, 1956: 1.9 MT Apache nuclear fireball

Fig. 2. The development of the explosion with energy $2 \cdot 20^{21}$ J and initial mass of the comet plasma $0.8 \cdot 10^{12}$ kg.

Nemtchinov et al. 1998 computation.
Temperature contours in eV.
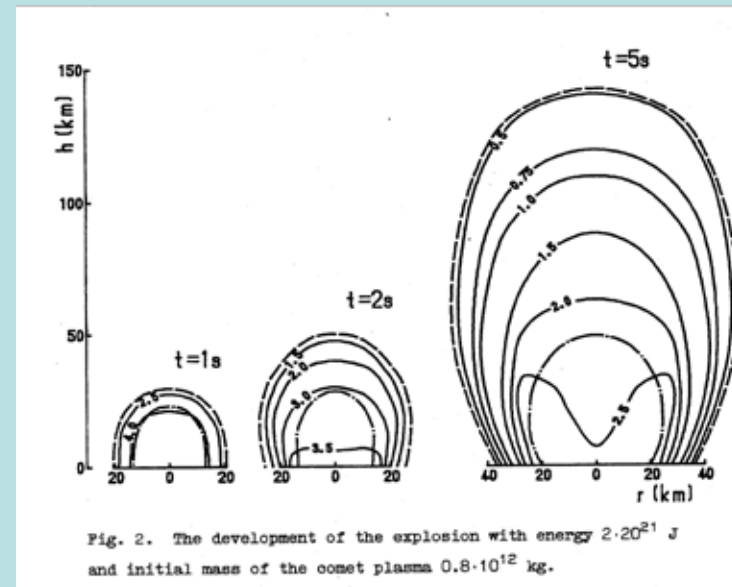1 eV = 11,605 K

Thermal Radiation Damage

Figure 7.28a. Thermal effects on wood-frame house 1 second after explosion (about cal/cm²).
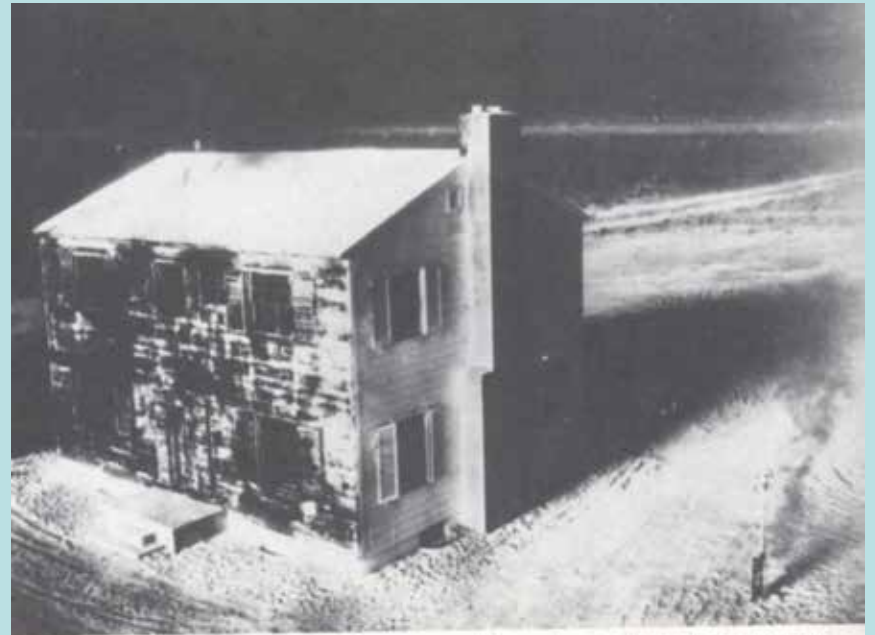
Figure 7.28b. Thermal effects on wood-frame house about ¾ second later.

Thermal Radiation

- **Fireball Radius**. We estimate the fireball radius at the time of maximum radiation using yield scaling, in which the radius is proportional to the cube root of the impact energy.

- **Thermal Exposure**. The thermal energy per unit area arriving at the specified distance r is found by scaling the impact energy by the thermal efficiency, taken to be 3 x 10^{-4}, and dividing by the area over which it is spread (the surface area of a hemisphere of radius r).

- **Duration of Irradiation**. The duration of the heating from the fireball is estimated by dividing the total thermal radiation emitted by the rate of emission, given by the fireball surface area times sT_*^4, where T_* is the temperature at which most light is emitted (3000 K).

Seismic Effects – Ground Shaking

- **<u>Seismic Magnitude</u>**: The classic Gutenberg-Richter magnitude energy relationship is used to compute the seismic magnitude M from the impact energy E, with an assumed seismic efficiency of 10^{-4}

  Seismic Magnitude
  $$M = 0.67 \ log_{10} \ E - 5.87$$

We calculate a Moment Magnitude for the impact by assuming seismic energy is some fraction (presently, 10^{-4}) of the kinetic impact energy
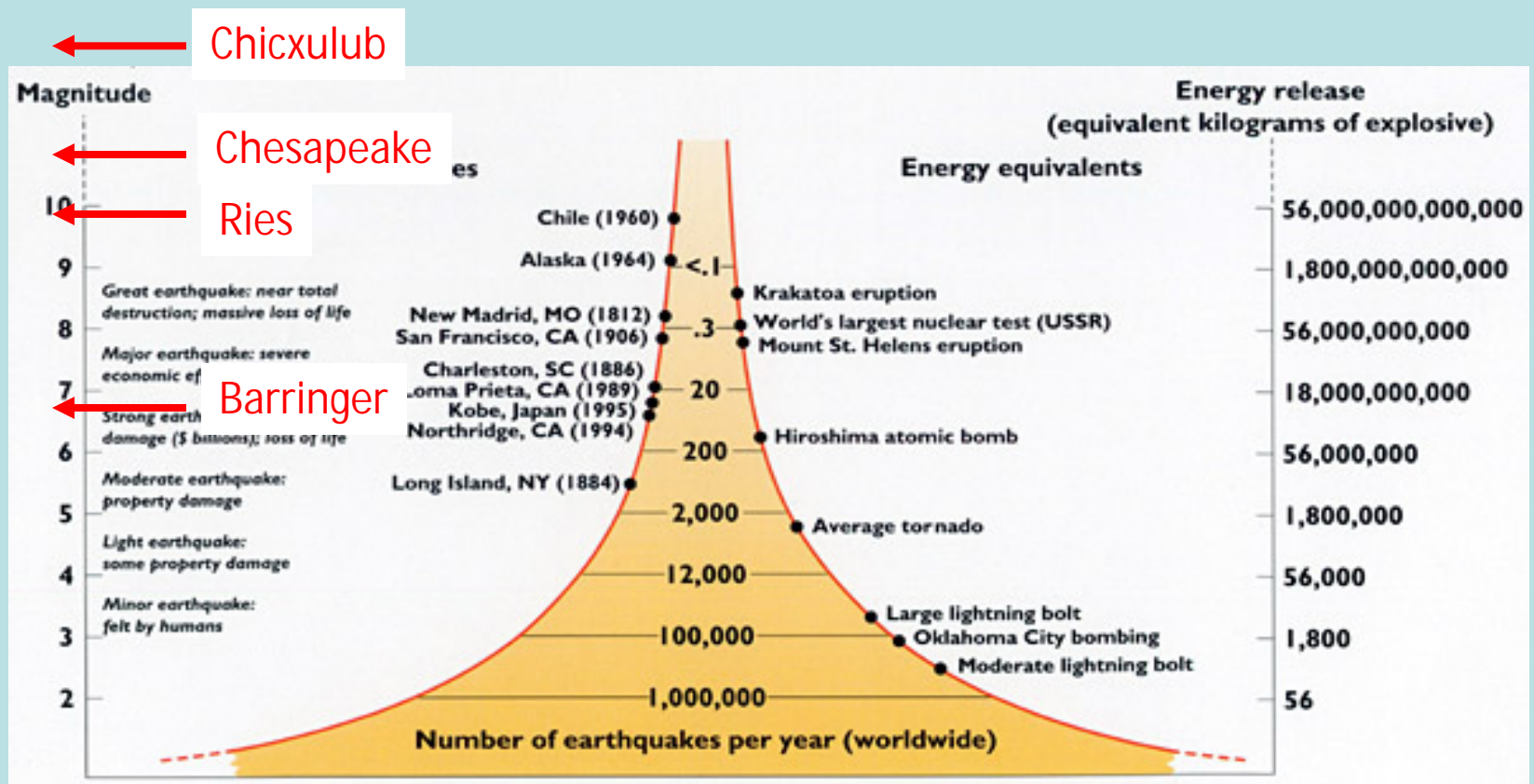
Seismic Effects

- **Arrival Time**. We assume that the major seismic shaking induced by an impact is due primarily to surface waves with v_{sw} = 5 km/sec.

- **Intensity:**   The intensity is determined by finding the ground acceleration at the specified distance. This is then mapped to the appropriate intensity in the Mercalli Scale.

Ejecta Deposition

This ejecta falls back to the surface as a continuous blanket close to the crater and as scattered fragments further out.

Ejecta Deposition

- **<u>Crater Diameter</u>**. We estimate the crater diameter and ejecta volume using Holsapple-Schmidt-Housen Pi scaling methods.

- **<u>Ejecta Thickenss</u>**. The thickness of the ejecta deposit is presumed to follow the $1/r^3$ relation inferred for lunar craters and from ejecta scaling relations (scaled to crater diameter by gravity scaling relations).

- **<u>Ejecta fragment Size</u>**. Estimated from fragment size/velocity relations deduced from the ejecta deposits of Venusian craters with fresh, well-preserved ejecta blankets
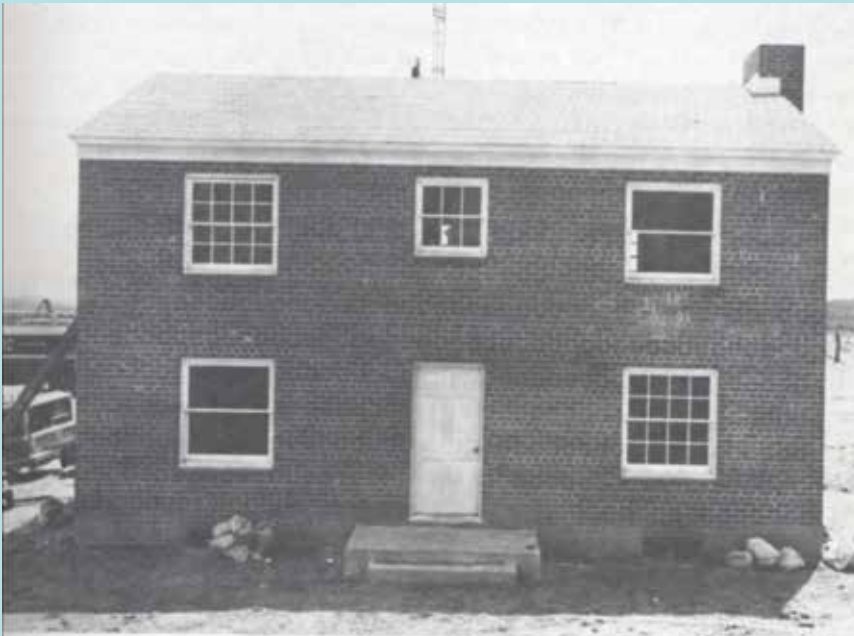
Airblast

Figure 5.66.   Unreinforced brick house before a nuclear explosion, Nevada Test Site.

Figure 5.67.   Unreinforced brick house after a nuclear explosion (5 psi peak overpressure).

The airblast and ensuing winds can cause significant damage to buildings and trees…

Airblast Effects

- **Overpressure and Wind Velocity**. We estimate the airblast overpressure using tables from the classic Glasstone and Dolan book (Effects of Nuclear Weapons). These tables assume a point source of energy at a given altitude and range from the target, scaled to the energy release in the atmosphere

- **Airburst Computation**. We assumed that all the energy is released at a point at the altitude where the fragmentation cascade ceases (at its most intense point).

- **Crater Computation**. The energy is assumed to be released in a manner similar to a surface nuclear explosion and the overpressure is scaled to the energy released in the impact.

Impact Tsunami?

Impact-generated Tsunamis may occur, but their importance is currently a matter of hot debate
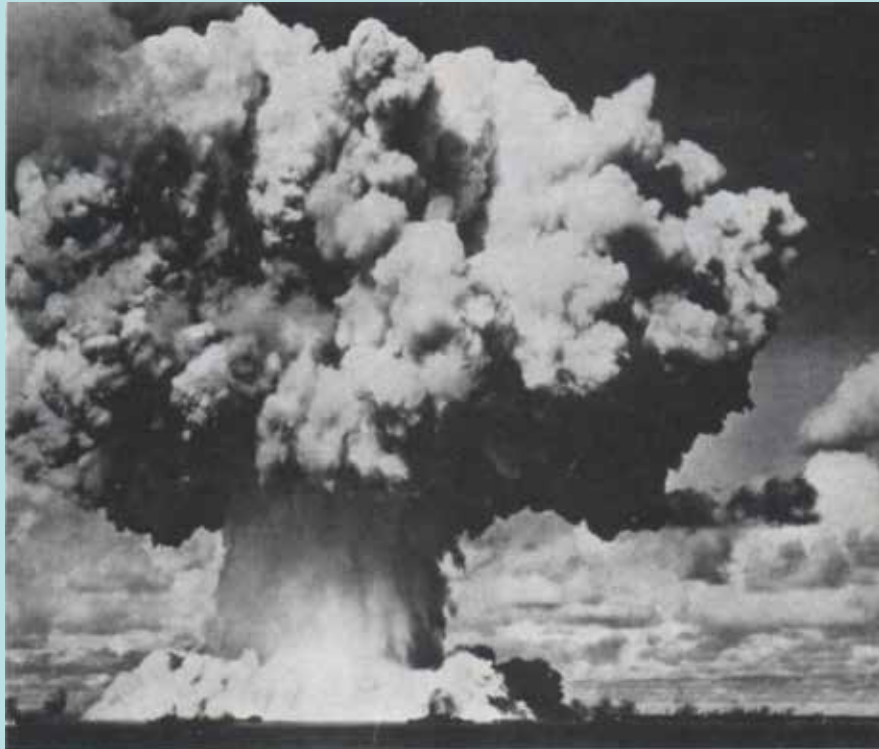

Figure 2.68. The radioactive cloud and first stages of the base surge following a shallow underwater burst. Water is beginning to fall back from the column into the lagoon.

Figure 6.55. Waves from the BAKER underwater explosion reaching the beach at Bikini, 11 miles from surface zero.

Early estimates indicated that the devastation appeared to be truly staggering
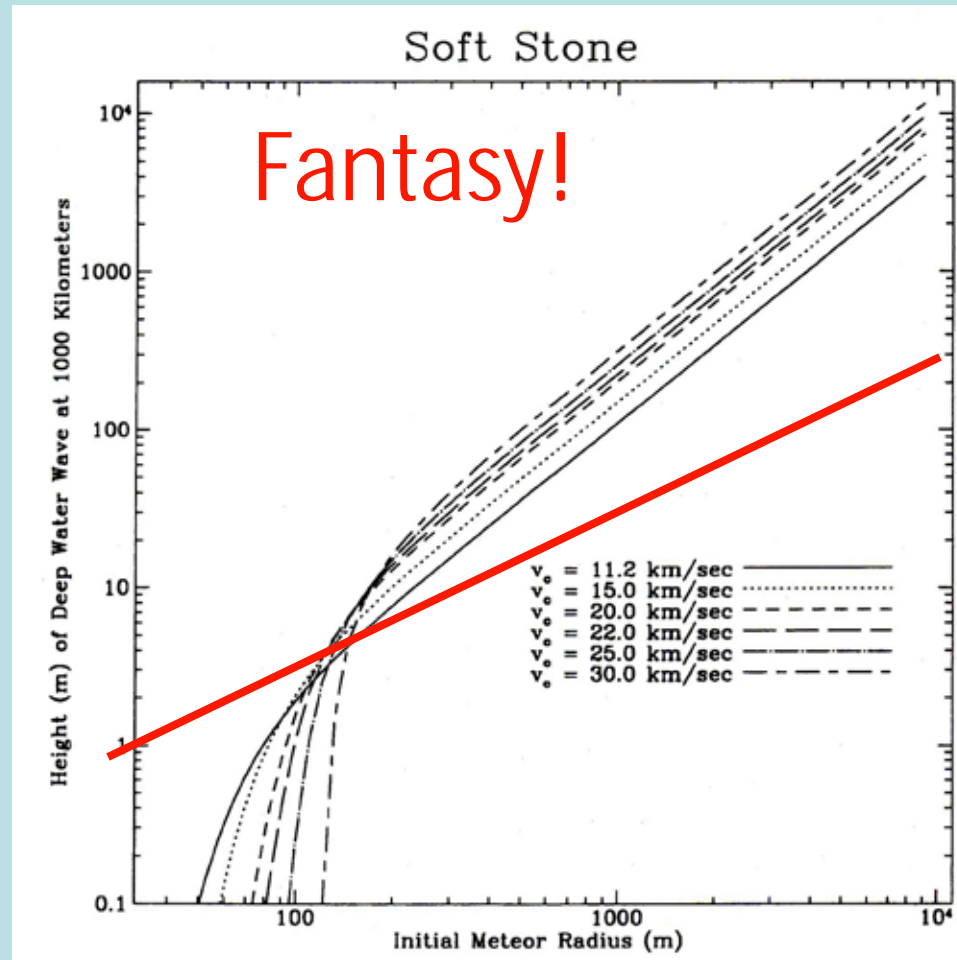
...but the authors did not notice that the height of the waves exceeded the ocean's depth for the initial stages of their travel.

Impact Tsunami

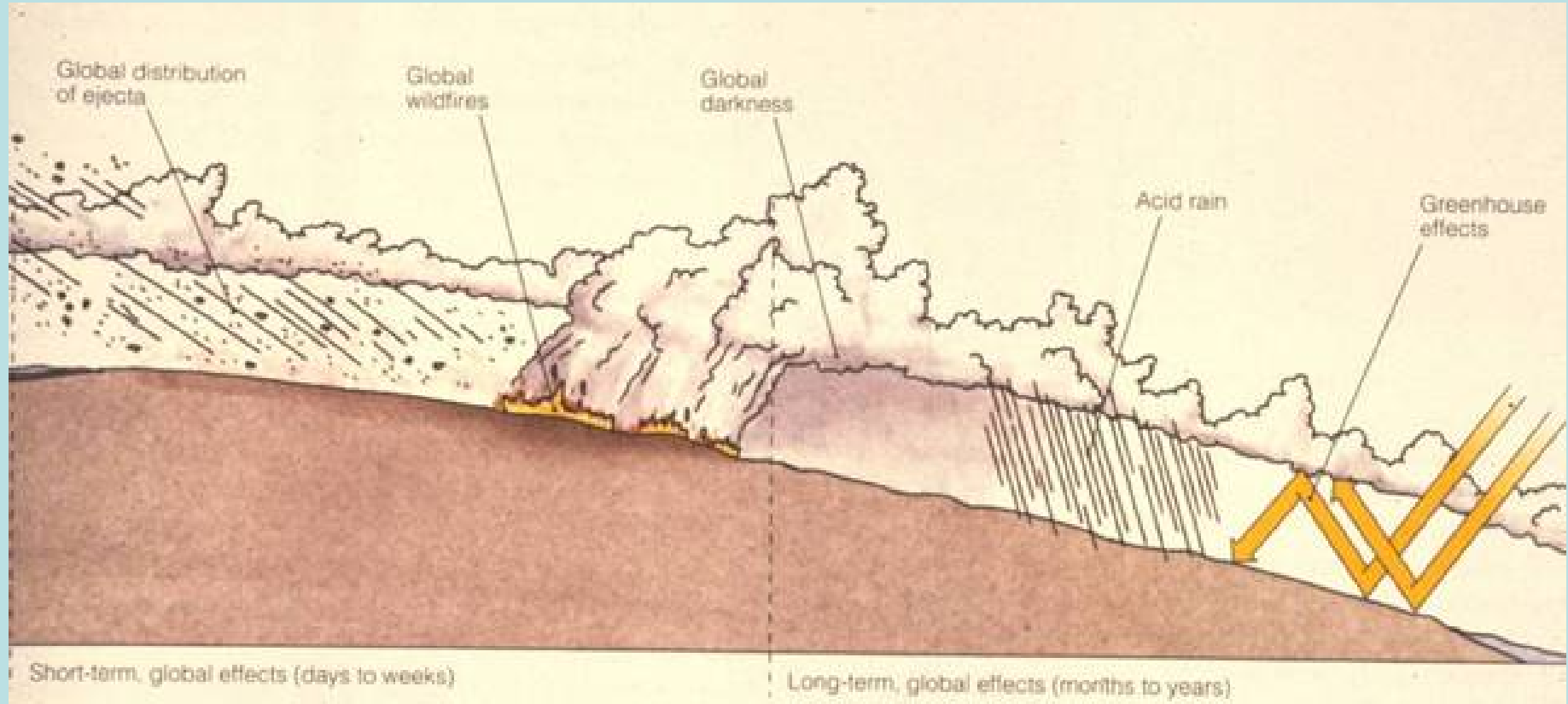- **<u>Initial Wave Height</u>** We use recent numerical simulations of impacts into water to estimate the starting height of the wave *after the amplitude has declined to a small fraction of the water depth*, so that linear tsunami theory can be used.

- **<u>Tsunami Propagation</u>**. We assume a constant water depth input by the user and a standard 1/r decline in amplitude as the wave propagates following the shallow water gravity wave velocity. This is a particularly crude approximation, but the demand for some kind of estimate of wave height was so strong that we felt that we had to provide some guidance.

- **<u>Shoreline Runup</u>**. A constant factor of 20 is assumed for the ratio of the runup height to the deep-water wave height. Again, an extremely crude approximation.

Global distribution of ejecta | Global wildfires | Global darkness | Acid rain | Greenhouse effects

Short-term, global effects (days to weeks) | Long-term, global effects (months to years)

Distal Effects are more complex and even less well understood!

- Reentry heating

- Aerosol blockage of sunlight

- Atmospheric chemistry changes

- Acid Rain, chemical rainout

- Short-term climate changes

Essentially every aspect of this impact effects calculation needs substantial improvement! My top list in each category is:

- Atmospheric Entry: Better models of fragmentation, evaporation, coupling of solids and air, shock wave formation and propagation, thermal radiation computation.

- Fireball: Include radiation from incandescent ejecta, better opacity modulation from both solids and vapor

- Seismic: Seismic efficiency factor is poorly known

- Ejecta: Improve treatment of distal ejecta, atmosphere/ejecta interactions should be treated more fully

- Airblast: Role of ejecta in modulating blast, inclusion of altitude effect, understand propagation in a realistic atmosphere over a spherical Earth.

- Tsunami: Better understanding of source, inclusion of realistic propagation models

The bottom line:

We presently have a fair understanding of the effects of large impacts on the Earth, but many gaps remain to be filled.