Comet and Asteroid Threat Impact Analysis

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[Abstract] A comet or asteroid impact event can release tremendous destruction which has been compared to the damage released from a very large thermonuclear explosion. This is a fairly useful analogy. The nuclear explosion effects are a well-studied science that can be directly applied to the study of impacts. This paper provides formulas for converting impactor size, speed and density into impact energy (megatons of TNT equivalent). The level of impact energy is then applied to nuclear weapon effects tables to provide estimates for the magnitude of damage as a function of distance from point-of-impact. As a means of validating the threat model, the analysis of damage effects integrates information gleaned from eyewitness accounts of impacts within recorded history and from geological information from early impact events. Impact effects are broken down into five main areas: shock wave, thermal radiation, debris and aerosols, electromagnetic effects and secondary effects. The shock wave section describes the atmospheric blast wave, ground shock and the water compression wave (tsunami). The thermal radiation section describes the flash and fireball. As the asteroid or comet strikes the Earth, the tremendous heat produced by the impact will melt and vaporize rock. The blast will also eject debris into the upper atmosphere and into space in a ballistic trajectory. The debris and aerosols section will cover this effect. The electromagnetic effects section describes the electromagnetic pulse, ionizing radiation and electrophonic bursters. The final section describes secondary effects including mass fires (conflagration and global firestorms); secondary earthquakes, landslides, volcanoes, & lava flows; dust & impact winter; gas evolution and acid rain (large volumes of gases can be released by an impact including nitric oxide, nitrogen dioxide, carbon dioxide, sulfur dioxide, carbon monoxide, hydrogen sulfide, hydrogen chloride and hydrogen fluoride – some are hazardous or poisonous); upper atmospheric effects (such as expansion of the stratospheric envelope); oxygen depletion; magnetic pole reversals; energetic weather conditions (such as black rain); starvation and plagues. These effects are discussed in detail and an analytical assessment is provided. The following impact scenario is included as an Appendix within the paper. An asteroid strikes the Earth without warning. The asteroid 5.8 kilometers in diameter crashes into the Atlantic Ocean at Longitude 72° 49' West, Latitude 28° 0' North. The asteroid is traveling at a velocity of 20 km/s and has a density of 2.0 g/cm^3. The asteroid is spherical in shape. It is not a binary asteroid. The impact occurs at 9:45 PM Eastern Time in the middle of June. The asteroid collides with Earth nearly head-on (2 degrees from true vertical) in a slight East to West direction. The scenario is assessed at the following locations: Bermuda, Washington D.C., New York City, town near Indianapolis, Chicago, Dallas, Lincoln, and Los Angeles. This scenario is beneficial to the discussion because it portrays the interconnectivity and timing of hazards and provides a methodology for describing the effects. An accurate assessment of impact hazards is absolutely critical in developing comprehensive disaster preparedness planning.

Nomenclature

d	=	diameter of the impactor (asteroid/comet)
D	=	density of the impactor
E	=	kinetic energy released from an impact
h	=	deepwater wave height
v	=	velocity of the impactor relative to Earth

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I. Introduction

HAVE you ever watched a shooting star in the night sky? In general, a shooting star is the size of a single grain of sand. As it hits the atmosphere at very high velocities, its kinetic energy is transformed into thermal energy, which produces the brilliant streak across the sky. When a large asteroid or comet impacts the earth, the same process occurs. But the impactor may not burn up completely in the atmosphere. Much of its energy will be released as it impacts the planet sending shock waves over the surface of the Earth and through the fragile Earth's crust and into its mantel & core and by sending trillions of tons of debris into the atmosphere and into deep space.

Both asteroid & comet impacts and very large thermonuclear explosions share similar damage effects. The primary exception to this analogy is impact events do not produce radioactive fallout. The nuclear explosion effects are a well-studied science that can be directly applied to the study of impacts. By viewing an impact event in terms of equivalent energy release from a thermonuclear explosion, a method exists for quantitatively forecasting impact damage effects.

A. Scope of Impact Threat

Near Earth Objects (NEO) comprise Long-Period Comets (LPC), Short-Period Comets (SPC) and Asteroids. NEO pose a collision threat with Earth which can generate high-energy shock waves (within the atmosphere, continents, and oceans) and release thermal & electromagnetic energy. Equation (1) defines the kinetic energy released on impact (E) as a function of the diameter of the asteroid/comet (d), the velocity of the impactor relative to Earth (v), and the density of the impactor (D). Kinetic energy release is expressed in megatons of TriNitroToluene (TNT) equivalent, where d is expressed in meters, v is expressed in km/s, and D is expressed in g/cm^3.

$$E = 6.256 \bullet 10^{-8} d^3 v^2 D \tag{1}$$

The derived formula assumes that 1 megaton of TNT is equivalent to 4.185 x 10^{22} ergs. This estimate is based on the assumption that the impactor is spherical in shape and a non-binary system. Many asteroids and comets have irregular shapes, which can affect impact energy calculations. Approximately 16 percent of Near Earth Asteroids larger than 660 feet (200 m) are binary systems.[1]

The kinetic energy equation shows that released energy levels are highly sensitive towards NEO size (diameter component is cubed), somewhat sensitive towards NEO speed (velocity component is squared), and less sensitive towards NEO density (density is a linear component). In general, LPC because of their larger size and higher speeds produce greater release of impact energy than asteroids even though generally the comet's density is less.

Table 1 provides a general estimate of Kinetic Energy for three categories of impactors: Asteroids, Short Period Comets, and Long Period Comets. One of the variables in the equation is density. It is theorized that the density of comets range from that of a fluffy snowball (~0.1 g/cm^3) to the density of sheets of ice and dirt (~2.0 g/cm^3).[2] Delay Doppler radar is one of the tools used to assess and measure asteroid & comet density. Dr.

Table 1. Typical Kinetic Energy Released by Various Size Impactors.

Kinetic Energy (Equivalent Tons of TNT)	Asteroid Diameter	Short Period Comet Diameter	Long Period Comet Diameter
1 Megaton	89 feet *27 meters*	123 feet *38 meters*	67 feet *20 meters*
10 Megatons	192 feet *58 meters*	266 feet *81 meters*	144 feet *44 meters*
100 Megatons	413 feet *126 meters*	573 feet *175 meters*	311 feet *95 meters*
1,000 Megatons	890 feet *271 meters*	1,235 feet *376 meters*	670 feet *204 meters*
10,000 Megatons	0.36 miles *585 meters*	0.50 miles *811 meters*	0.27 miles *440 meters*
30,000 Megatons	0.52 miles *843 meters*	0.73 miles *1.2 kilometers*	0.39 miles *635 meters*
100,000 Megatons	0.78 miles *1.3 kilometers*	1.1 miles *1.7 kilometers*	0.58 miles *948 meters*
1,000,000 Megatons	1.7 miles *2.7 kilometers*	2.3 miles *3.8 kilometers*	1.3 miles *2.0 kilometers*
10,000,000 Megatons	3.6 miles *5.8 kilometers*	5.0 miles *8.1 kilometers*	2.7 miles *4.4 kilometers*
100,000,000 Megatons	7.8 miles *13 kilometers*	11 miles *17 kilometers*	5.9 miles *9.5 kilometers*
300,000,000 Megatons	11 miles *18 kilometers*	16 miles *25 kilometers*	8.5 miles *14 kilometers*
1,000,000,000 Megatons	17 miles *27 kilometers*	23 miles *38 kilometers*	13 miles *20 kilometers*

Steve Ostro (NASA- JPL) provided a closer estimate of the density range as 0.5 to 1.0 g/cm^3 based on radar data. The estimate contained in the table will use the midpoint (0.75 g/cm^3) for the short period comet (SPC) and long period comet (LPC). According to Steve, asteroids range from 1 to 7 g/cm^3, with the majority around 2 g/cm^3. The table was developed using 2 g/cm^3 for estimated asteroid density. Another variable in the equation is speed. Here again, delay Doppler radar provides the most accurate estimates. In Dr. Ostro's judgment typical impact velocities are roughly 45,000 mph (~20 km/s) for asteroids and SPC and roughly 110,000 mph (~50 km/s) for LPC.[†] These values were used in developing this table.

Benny Peiser (CCNet) recently wrote, "In contrast to most other, more frequent natural disasters (such as earthquakes, volcanic eruptions, tropical storms, tsunami, etc.), we have very little empirical knowledge, let alone experience of NEO impacts and their secondary environmental and societal effects."[3] This is the primary reason conflicting information permeates the study of asteroid and comet impacts. It is far from being an exact science.

The information contained in this paper provides my best assessment of the impact threat. The assessment is based on thermonuclear damage effects, paleogeophysical analysis and information gleamed from eyewitness accounts from past small impact events.

In general, a comet or asteroid impact will only create a regional zone of devastation (defined as the area within the blast wave 1-psi peak overpressure). This zone of destruction is caused primarily by the shock wave with a contributing component from thermal radiation, debris and electromagnetic effects. On rare occasions a massive comet can deeply penetrate the Earth's crust. Deep penetrations can be modeled by underground nuclear explosions; with the major effect being focused ground shock. The impact shock wave can pass through the Earth rupturing the crust on the opposite side of the planet. Vast flows of volcanic magma would be released. The gases generated from this magma release are the prime culprits of global mass extinctions.[4,5]

B. Analysis Structure

An outline of these impact effects is provided below with a detailed discussion following.

- Shock Wave
  - Air: Blast Wave
  - Ground: Ground Shock
  - Water: Water Compression Wave – Tsunami
- Thermal Radiation
  - Flash
  - Fireball
- Debris & Aerosols
- Electromagnetic Effects
  - Electromagnetic Pulse (EMP)
  - Ionizing Radiation
  - Electrophonic Bursters
- Secondary Effects
  - Mass Fires
  - Earthquakes/ Landslides/Volcanoes/Lava Flows
  - Dust & Impact Winter
  - Upper Atmospheric Effects
  - Oxygen Depletion
  - Gas Evolution & Acid Rain
  - Magnetic Pole Reversals
  - Energetic Weather Conditions
  - Starvation and Plagues

II. Shock Wave

The kinetic energy released by the impact of a comet or asteroid with Earth will produce a continuously propagated pressure wave in the surrounding medium. There are three types of shock waves possible from an impact event. These are a function of the medium impacted: air, earth, and water. The shock wave in air is referred to as the Blast Wave. The shock wave in the earth is referred to as Ground Shock. The shock wave in water is

[†] Private correspondence between J. A. Marusek and Dr. Steve Ostro (NASA JPL).

called a Water Compression Wave. As a Water Compression Wave approaches a shoreline, it can produce a Tsunami.

A. Atmospheric Blast Wave

The blast wave has incredible force near the impact point. Objects within the path of the blast wave are subjected to a short transient wave with very high peak overpressures and to extraordinarily severe transient winds. As the wave moves outward from the impact point, the overpressure and the wind speed drops significantly. Generally, the blast wave damage is a function of the peak overpressure (expressed in psi).

For impacts less than global extinction events, the atmospheric blast wave is the primary cause of damage & loss of life.

Table 2 defines the distance from the point-of-impact for various atmospheric blast wave peak overpressures as a function of the kinetic energy released by the impact.[‡]

Table 2. Atmospheric Blast Wave Peak Overpressure Radius as a Function of Impact Energy

Kinetic Energy	1 psi	3 psi	5 psi	10 psi	50 psi
1 Megaton	8 miles *13 kilometers*	4.6 miles *7.4 kilometers*	3.4 miles *5.5 kilometers*	2.4 miles *3.9 kilometers*	1.0 miles *1.6 kilometers*
10 Megatons	18 miles *28 kilometers*	10 miles *16 kilometers*	7 miles *12 kilometers*	5.3 miles *8.5 kilometers*	2.2 miles *3.5 kilometers*
100 Megatons	38 miles *62 kilometers*	22 miles *35 kilometers*	16 miles *26 kilometers*	12 miles *19 kilometers*	4.8 miles *7.7 kilometers*
1,000 Megatons	83 miles *134 kilometers*	47 miles *76 kilometers*	35 miles *57 kilometers*	25 miles *40 kilometers*	11 miles *17 kilometers*
10,000 Megatons	182 miles *292 kilometers*	103 miles *166 kilometers*	77 miles *123 kilometers*	55 miles *88 kilometers*	23 miles *37 kilometers*
100,000 Megatons	397 miles *638 kilometers*	225 miles *363 kilometers*	167 miles *269 kilometers*	120 miles *193 kilometers*	50 miles *81 kilometers*
1,000,000 Megatons	866 miles *1,393 kilometers*	492 miles *792 kilometers*	364 miles *586 kilometers*	261 miles *420 kilometers*	109 miles *176 kilometers*
10,000,000 Megatons	1,890 miles *3,040 kilometers*	1,070 miles *1,730 kilometers*	780 miles *1,280 kilometers*	570 miles *920 kilometers*	240 miles *380 kilometers*
100,000,000 Megatons	4,120 miles *6,630 kilometers*	2,340 miles *3,770 kilometers*	1,740 miles *2,790 kilometers*	1,240 miles *2,000 kilometers*	520 miles *840 kilometers*
1,000,000,000 Megatons[§]	< 9,000 miles *< 14,500 kilometers*	< 5,100 miles *< 8,200 kilometers*	< 3,800 miles *< 6,100 kilometers*	< 2,700 miles *< 4,400 kilometers*	< 1,100 miles *< 1,800 kilometers*

Table 3 & 4 describes the damage caused by the blast wave as a function of peak overpressure. Table 4 also provides peak wind velocity as a function of peak overpressure. Note that near the point-of-impact (100-psi overpressure), the blast wave is moving at an incredible speed of 2,200 mph (3,540 km/h), but further away (1-psi overpressure), the speed of the blast wave has diminished to 35 mph (56 km/h). At a large distance from the impact, of the three types of shock waves, the atmospheric blast wave will be the last to arrive.

Table 3. Morbidity as a Function of Blast Wave Overpressure.

Blast Wave Pressure	Damage Effect [6,7]
1.5 psi (unobstructed)	Second degree burns.
1 to 2 psi	25% injuries.
2 psi	Fine kindling fuel ignites.
2.5 psi	30% trees blown down.
2 to 5 psi	5% fatalities, 45% injuries.
5 to 12 psi	50% fatalities, 40% injuries.
10 psi	Most combustible materials will ignite and burn.
> 12 psi	98% fatalities, 2% injuries.

[‡] This table was derived by extrapolating Figure 3.1 "Weapon Overpressure as a Function of Distance from a Surface Burst" contained in Oak Ridge National Laboratory *Civil Defense Shelters: A State-Of-The-Art Assessment - 1986*.[8]

[§] Comets of this size are deep impactors that can penetrate the Earth's crust and produce massive mantle plume volcanism. These impacts generally result in global mass extinction events. Atmospheric blast range will be dramatically less than depicted on this row of the table. Energy is primarily converted to ground shock beneath the Earth's crust in this instance.

Table 4. Structural & Physical Damage Effects as a Function of Blast Wave Overpressure.

Blast Wave Pressure**	Peak Wind Velocity	Damage Effect [6,9]
1 psi	35 mph	Light damage to structures (i.e. houses). People endangered by flying glass and debris.
2 psi	65 mph	Severe damage to structures. Windows blown out. Interior walls of house blown out. Furniture and contents swept out to far side of house. Masonry walls collapse.
3 psi	95 mph	Walls of a typical steel frame building are blown away. Very severe damage to residences. Winds sufficient to kill people in the open.
5 psi	160 mph	Houses collapse or are blown off their foundations. People exposed to blast wave are thrown hard and if they impact a solid object, death likely to occur. Lightly constructed commercial buildings and typical residences are destroyed. Heavier construction is severely damaged. Automobiles are damaged to the point they can no longer be driven.
10 psi	290 mph	Most factories and commercial buildings collapse. Small wood framed and brick residences destroyed and distributed as debris.
20 psi	470 mph	Reinforced concrete structures are leveled. Damage to physical body is significant. The pressure ruptures the walls of the abdominal and thoracic cavities causing hemorrhaging. Air is actually forced into the circulatory system. Human soft tissue and skeletal structure suffers severe damage.
50 psi	1,000 mph	(This is about the limits of a good underground expedient shelter)
100 psi	2,230 mph	

B. Ground Shock

The shock wave that passes through the Earth is referred to as Ground Shock. During the impact, the kinetic energy of the asteroid/comet is transmitted directly into the ground, producing compression and shear motions, which propagate radially outward and vertically inward from the point-of-impact.[8] Ground shock is similar to an earthquake. Ground shock propagates very quickly. At large distance from the impact site, ground shock will be the first shock wave to arrive. The speed of the ground shock is estimated using analogous earthquake formulas. Earthquakes are delineated into two categories: Primary and Secondary.

Primary earthquakes travel at 13,500 mph to 29,000 mph (6 to 13 km/s). These earthquakes penetrate through the crust of the earth and travel through the molten mantel. A large ocean impact will produce a ground shock similar to a Primary earthquake due to the fact that the Earth's crust is very thin under the ocean. I expect the Primary ground shock from a large ocean impact to be the main trigger in producing the following secondary effects: earthquakes, volcanoes, lava flows and underwater landslides.

Secondary earthquakes move at a speed of 8,000 mph to 12,000 mph (3.5 to 5.5 km/s). These earthquakes will travel horizontally across the Earth's crust. A large land impact will produce a ground shock similar to a Secondary earthquake. Experience from nuclear weapons testing shows this Secondary ground shock is an extremely damaging shock wave near the impact site. The ground shock at the equivalent 75-psi blast overpressure is sufficient to snap an individual's legs in two if they are standing on a concrete floor within a blast shelter.[8] But this shock wave effect rolls off very quickly, such that at the equivalent 50-psi range, the effect is minimal.

In my assessment ground shock is a major component of the primary threat from a deep impact. This type of very large impact produces global mass extinction events.

C. Water Compression Wave – Tsunami

Since 72 percent of the Earth's surface is covered with oceans, there is a 72 percent random probability that a comet or asteroid impact will occur in the ocean.[2] An ocean impact would excavate a large transient cavity approx-

** The distance from point-of-impact as defined by the overpressure (in psi) from the air blast wave will be used as a standard unit of measure to define affected areas for several impact effects.

imately 20 times the diameter of the impactor.[10]

An ocean impact will create a compression wave in the water. The compression wave may be sufficient to implode deeply submerged objects, such as submarines.

A large ocean impact will produce a large tsunami. Tsunami is Japanese for "harbor wave". Tsunami generally travel quickly across the ocean, typically at speeds of 380 mph (0.17 km/s).[11] In deep water the impact tsunami height might be several thousand feet high for a Cretaceous/Tertiary (K/T) size impactor, but the height may increase dramatically as the waves reach the shoreline because the wave slows in shallow water and the energy becomes more concentrated. The impact tsunami may produce several mile high wave fronts that could travel several hundred miles inland.[12] Tsunamis are of concern because they propagate over great distances and much of the world's populations are located near coastal regions.

Equation (2) predicts the height (h) of a deepwater wave (tsunami) 621 miles (1,000 km) from an asteroid/comet point-of-impact. This equation was derived by Jack Hills from Los Alamos National Laboratory.[13] The deepwater wave height from an impact is a function of the diameter of the asteroid/comet (d), the velocity of the impactor relative to Earth (v), and the density of the impactor (D). The deepwater wave height h is expressed in meters, where d is expressed in meters, v is expressed in km/s, and D is expressed in g/cm^3.

$$h = 1.0081 \bullet 10^{-5} \left[d^3 v^2 D \right]^{0.54} \tag{2}$$

Table 5 applies this formula on a spherical non-binary asteroid with a density of 2 g/cm^3, and a velocity of 20 km/s. The table defines deepwater wave height at 621 miles (1,000 km) from the point-of-impact.

Table 5. Tsunami Deepwater Wave Height as a Function of Various Size Asteroid Impacts.

Asteroid Diameter	Deepwater Wave Height	Asteroid Diameter	Deepwater Wave Height
200 meters	*2 meters*	660 feet	7 feet
300 meters	*4 meters*	980 feet	12 feet
400 meters	*6 meters*	1,310 feet	20 feet
500 meters	*9 meters*	1,640 feet	29 feet
600 meters	*12 meters*	1,970 feet	39 feet
700 meters	*15 meters*	2,300 feet	50 feet
800 meters	*19 meters*	2,630 feet	62 feet
900 meters	*23 meters*	2,950 feet	75 feet
1 kilometer	*27 meters*	0.6 miles	89 feet
2 kilometers	*83 meters*	1.2 miles	272 feet
3 kilometers	*160 meters*	1.9 miles	525 feet
4 kilometers	*255 meters*	2.5 miles	837 feet
5 kilometers	*366 meters*	3.1 miles	1,200 feet
6 kilometers	*490 meters*	3.7 miles	1,600 feet
7 kilometers	*630 meters*	4.4 miles	2,100 feet
8 kilometers	*780 meters*	5.0 miles	2,600 feet
9 kilometers	*950 meters*	5.6 miles	3,100 feet
10 kilometers	*1.1 kilometers*	6.2 miles	3,700 feet
11 kilometers	*1.3 kilometers*	6.8 miles	4,300 feet
12 kilometers	*1.5 kilometers*	7.5 miles	5,000 feet
13 kilometers	*1.7 kilometers*	8.1 miles	5,600 feet
14 kilometers	*1.9 kilometers*	8.7 miles	6,400 feet
15 kilometers	*2.2 kilometers*	9.3 miles	7,100 feet

The deepwater wave amplitude is a function of the distance from the impact point. The closer to the point-of-impact, the higher the deepwater wave amplitude and vice-versa.

The deepwater wave amplitude is the maximum height of the wave above sea level when in deep water. The run-up height is the vertical height above sea level of the tsunami at its furthest point inland. The run-up height will help to determine how far the tsunami will penetrate inland. The run-up factor is the run-up height divided by the deepwater wave amplitude. The run-up factor will vary significantly by local topography and wave direction. Crawford and Mader estimated a typical run-up factor from two to three.[10] But measured run-up factors as high as 40 have been observed in Hawaii.[††]

Hills & Mader estimated that for a typical coastal plain a 33 ft (10 m) tsunami (deepwater wave height) would penetrate about 0.6 miles (1 kilometer) inland and a 328 ft (100 m) tsunami would penetrate about 14 miles (22 km) inland.[††]

[††] Michael Paine, "Australian Spaceguard Survey, Tsunami from Asteroid/Comet Impacts", URL: http://users.tpg.com.au/users/tps-seti/spacegd7.html [cited 1 Dec. 2006]

Significant variability exists in deepwater wave amplitude predictions made by experts in the field. A recent paper by H. J. Melosh indicates the tsunami impact threat is exaggerated.[14] Impact generated tsunami are expected to behave similarly to tsunami produced by nuclear explosions. The waves generated in this manner are highly dissipative (decays rapidly) and very turbulent.[11] An early Office of Naval Research Report studying the tsunami hazard from nuclear explosions showed the wave structure had shorter wavelengths (with a periods of 20 to 100 seconds) than earthquake or landslide generated tsunami (with a period of 100 seconds to 1 hour).[15] Due to the "Van Dorn effect", these shorter wavelength impact waves are expected to break on the outer continental shelf minimizing damage onshore.

III. Thermal Radiation

An asteroid or comet impact will produce high levels of thermal radiation when it strikes the Earth. This radiation will come from the Flash and the Fireball.

A. Flash

As the comet or asteroid enters the atmosphere, it will produce a flash of very intense ultraviolet light. The light will be many times brighter than the sun. The flash lasts only several millionths of a second. Indirect exposure can produce temporary injury called flash blindness which will last a few minutes. Direct exposure can cause permanent damage to the retina; by producing choriretinal burns.[9] The curvature of the Earth will limit this effect significantly. In general, anyone outside ~100 miles (161 km) from point-of-impact would not directly see the flash. Individuals in aircraft or spacecraft may be affected at far greater distances.

The ultraviolet thermal radiation from the flash can result in very intense heating of the skin, called "flash burns". Shielding of even the most insubstantial type (for example, sheets of paper or thin cloth) is effective at minimizing the effects of "flash burn".[16]

When the impact occurs, the sound of the flash will begin to make its way around the world. The sound has been described as a thunderclap or as a gun being fired. In general, this sound will travel at approximately 764 mph (0.34 km/s).

B. Fireball

The fireball will produce large quantities of visible and infrared thermal radiation that can generate instantaneous fires. Air is essentially transparent to thermal radiation. The thermal radiation affects exposed surfaces, producing instantaneous damage by rapid heating. The effects of thermal radiation can be reduced dramatically (65%) if the atmosphere is foggy or cloudy. At blast wave overpressure greater than 10-psi, most combustible material will ignite and burn. Easily ignitable, dry materials (such as, dry leaves, dry grass, old newspapers, thin dark flammable fabrics, tar paper, etc.) can be ignited at overpressures as low as 2-psi to 3-psi and produce fires. Refer to Table 3.

IV. Debris & Aerosols

The blast will eject debris into the upper atmosphere and into space in a ballistic trajectory. At impact, the comet or asteroid will be instantly vaporized along with material from the impact crater/cavity. The diameter of crater/cavity created will typically be 20 times the diameter of the impactor. This debris will be heated to temperatures exceeding 9,000°F (5,000°C).[‡‡] The debris following a ballistic trajectory will reach the other side of the planet in 45 to 60 minutes.[2] The debris from a large impactor will blot out the sun, the moon and the stars and turn the Earth dark as night. The vaporized rock cloud will rapidly cool and condense in space and form droplets that solidify into spherules (tiny glass beads about 1 mm in diameter). Over the next several hours and days, much of this debris will rain back down over the entire surface of the Earth. This returning debris will be fairly light and will be slowed significantly as it falls through the atmosphere and should not present a significant secondary impact hazard.

The area around the impact site will become a major debris field. Some of this debris may be the size of large boulders. Massive debris will be deposited over short distances within the atmosphere. The debris field will taper off as a function of distance from point-of-impact. This debris will cause extensive damage.

Whereas an ocean impact will create a vast amount of superheated steam, an impact on land will eject significantly greater solid debris into the atmosphere.

[‡‡] Sandia National Laboratories, "Real (Not Reel) Deep Impacts: Sandia Scientists Predict What an Asteroid Strike Would Look Like, Really.", 5 May 1998, URL: http://www.sandia.gov/media/comethit.htm [cited 1 Dec. 2006]

V. Electromagnetic Effects

In general, electromagnetic effects will not directly harm people but the effect can be deadly to electronics and inhibit electronic communications.

A. Electromagnetic Pulse

An Electro-Magnetic Pulse (EMP) is produced by a nuclear explosion. Analogously an EMP may be generated from the energy release from an asteroid/comet impact. Of the impact effects described within this paper, this effect is theoretical and has the least level of certainty attached. If this effect materializes, I would expect a high altitude bolide explosion to produce an EMP to a far greater range than a surface impact.

If an EMP is produced, the pulse would occur almost instantaneously at time of impact. This pulse would be typically of a very short duration, approximately 1 μs and is caused by the Compton-recoil electrons and photoelectrons from photons scattered in the surrounding medium. The resulting electric and magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges. This pulse is not harmful to humans but it is deadly to electronics, especially transistors, semiconductors and computer chips. The scope of this effect has been only minimally studied. Comparing a surface impact to a nuclear weapon EMP can provide a crude measurement of the effective range of this effect. A ground-level nuclear explosion will produce a Source Region Electro-Magnetic Pulse [SREMP] as far as the distance at which the peak overpressure is 2-psi.

The types of equipment damaged or destroyed by an EMP includes:

- Energy Infrastructure: electrical power grids, power generating stations, the control systems in nuclear power plants, charge controllers & voltage converters in solar & wind generating electrical systems, oil and gas delivery systems, advance computer control systems.
- Communications Infrastructure: television and radio broadcasting facilities, radios, cell phones, televisions, computers and networks, Internet, digital telephone switching systems, commercial telephones, microwave and satellite communications, police scanners.
- Automobiles – cars manufactured after 1985 contained a variety of electronics including engine computers, electronic ignition, fuel injection systems, anti-lock breaking systems, electronic automatic transmissions, computer controlled active suspension, and four wheel steering.
- Transportation Infrastructure: other forms of transportation (airplanes, buses, trucks, rail, ships), road and rail signaling, gasoline pumps, global positioning systems, radar systems, navigational aids.
- Economic Infrastructure: automated machinery, banking, finance industry, stock market, computer systems in factories and offices, inventory maintenance, medical pumps and monitors, medical systems, government and corporate databases, electronic controllers used in manufacturing, chemical, petroleum product industries and metallurgical industries.

Long conductors such as power lines, communication cables, radio towers, railroad tracks, large antennas, pipes, cables, metal fencing and the electronic equipment attached to them are particularly susceptible to EMP.

B. Ionizing Radiation

Large quantities of ionizing radiation will be produced by the impact and can severely change the environment of the upper atmosphere, producing heavily ionized regions, which can disrupt electromagnetic waves passing through those zones. The trapping mechanism for these high-energy electrons may be similar to that which produces the Van Allen radiation belts. This radiation will cause significant interruption of communications. This will interfere with all surviving telephone, television, computer and radio traffic. There will be so much static in the signal that it will be almost unintelligible. For a large impact, these disturbed regions can easily be global in size and can persist for tens of hours. This could essentially temporarily shut down all worldwide communications.

C. Electromagnetic Bursters

An impact can produce phantom sounds similar to a crackling or clicking sound. These strange sounds can be heard by one individual and yet another individual a few feet away will hear nothing. These sounds are commonly called electrophonic bursters. These sounds occur instantaneously at impact. It is theorized these sounds come from very low frequency (VLF) radio waves at frequencies of 10 hertz to 30 hertz that are produced during impact. These radio waves require a suitable transducer that will act as a loudspeaker to convert the electromagnetic signals into audible vibrations. Several items have been shown to work including aluminum foil, thin wires, pine needles, dry frizzy hair, and even a pair of eyeglasses.[17] In another theory, they are caused by the generation of short-lived transient pulses in electric field strength.[18]

VI. Secondary Effects

Secondary effects (mass fires, earthquakes, volcanoes, lava flows, underwater landslides, impact winter, acid rain, stratospheric effects, oxygen depletion, magnetic pole reversal, energetic weather patterns, starvation and plagues) may be triggered from the Primary effects (shock waves, thermal radiation, debris and electromagnetic effects) from a large comet or asteroid impact

As a general rule, secondary effects produce minimal damage for small impacts. They will enhance damage for medium to large impacts. Secondary effects are dominant for very large impacts that rupture through the Earth's crust producing massive mantle plume volcanism on the other side of the world triggering great mass extinction events.

A. Mass Fires

It has been theorized that a large comet or asteroid impact (such as the Chicxulub impact) would produce a great global firestorm. The large impact would instantly vaporize several hundred cubic miles of water, earth and other debris at temperatures greater than 9,000°F (5,000°C) and ejected this superheated material through the atmosphere and space in a ballistic trajectory. Over the course of the next several hours after the impact, much of this debris would rain down over the entire surface of the Earth. The heavier debris would fall like burning rocks from the sky, killing and destroying almost everything exposed above ground. The heat would incinerate cities and forests. Approximately 50 to 100% of the forest in the world will be burned up simultaneously.[2] The air temperature will rise significantly, to the temperature of an oven set to broil. A global firestorm would result in the combustion of much of the organic material present on the surface of the Earth.[19] The global firestorm theory is interesting. I feel in time this theory will be thrown out because geological evidence and impact modeling will prove this theory lacks merit.

There are the two types of mass fires: conflagration and firestorms. In a conflagration, fire spreads along a moving fire-front driven by ambient winds. The San Francisco Earthquake Fire is an example of a conflagration. Many forest fires are conflagrations. Conflagrations take several hours to develop and inflict few immediate or direct casualties because there is adequate time for populations to flee. In a firestorm, the violent inrushing of winds creates an extremely hot fire. Temperatures can reach 1,500°F – 5,400°F (800°C – 3,000°C). The winds prevent the fire from spreading outward. The fires continue until all combustibles are exhausted. An example is the Hamburg firestorm in World War 2. A firestorm is extremely deadly to individuals because of the very high temperatures generated, the inability to evacuate, and the threat of asphyxiation.[6]

I believe the potential for a global firestorm is overstated. Thermal radiation from the impact fireball will spawn massive fires in the vicinity of the impact. At the distance defined by the blast wave overpressure greater than 10-psi, most combustible material will ignite and burn. Easily ignitable, dry materials can be ignited at overpressures as low as 2-psi to 3-psi and result in fires.[8]

Most of the superheated ejecta material that is flung into the atmosphere and into space in a ballistic orbit will fall back to Earth. The initial wave of debris will be very hot. Most of this debris will fall near the point-of-impact, well within the zone of destruction defined by the 1-psi overpressure area. But some of this debris will be flung into the stratosphere and into deep space and that debris will takes several hours or days to return to the Earth surface. That debris will have cooled down substantially before reentry. The longer this material resides in deep space, the colder the material will become, because this ejected debris will radiate heat. As the ejected material is drawn back to Earth by gravity, the material will have significantly less kinetic energy, than the original asteroid or cometary mass, because it now has a much lower velocity and this slow returning debris will not produce radical heating of the Earth's atmosphere.

This belief is supported by impact modeling conducted by V.V. Shuvalov, Institute of Dynamics of Geospheres, Moscow, Russia which showed that the mass of high velocity ejecta from the Chicxulub impact appears to be rather small, a few percent of the impactor mass, and could not be responsible for global wildfires. The critical ignition value of incident radiation energy is estimated to be 20-100 joules/cm^2 and is a function of forest type, moisture and other conditions. He estimates firestorms from the Chicxulub impact could only arise up to a distance of 1,250-1,900 miles (2,000-3,000 km) from the impact site.[20]

Another indicator that a global firestorm did not occur during the K/T Boundary comes from the study of fossilized ferns spores. A global firestorm would have destroyed nearly all living plant life. After the total devastation from the K/T impact, the first plant to rebound would have been the fern. One would expect the total pollen/spore count to rise sharply in the years immediately following the impact. According to "K/T Boundary Impact Hypothesis" by Ralph E. Taggart, that was the case, but only for the area within 2,100 miles (3,400 km) of

the Chicxulub impact site.[§§] That zone did show a "fern spike" which peaked at 70-100% of the total pollen/spore count immediately after the impact. In general, areas outside the 2,100 miles did not exhibit this "fern spike". A global firestorm would have produced a global "fern spike" and that was not the case. The 2,100-mile radius corresponds roughly to the 3-psi overpressure from a blast wave created by an impact that produced a kinetic energy equivalent of 100,000,000 megatons of TNT (the theorized size of the K/T impactor).

Analyzing the global firestorm theory from another perspective, spherules are small beads of melted rock, ejecta from the impact. Spherules are present in and define the geological boundary layer for major impact events. If this debris had been in a melted state when it returned to the surface of the planet, it would have fused with any material it came in contact with. Spherules have a characteristic round shape. Therefore it is logical that this impact debris had rapidly cooled prior to being deposited all over the world and as a result was unable to ignite worldwide firestorms.

I feel scattered fires will occur after an impact outside the 2-psi blast range. Some of these may even become mass fires. Most of these fires will be a conflagration, but a few may become firestorms. Generally these fires will be a result of secondary effects, such as volcanic and earthquake damage. For example, a gas line is broken and leaking natural gas is ignited by a flame. Communications is down. The fire department is not alerted and cannot respond. The fire burns down one house and spreads to the next. Soon an entire neighborhood is ablaze. Or a lightning strike sets a field ablaze; soon the unchecked fire grows into a massive fire that consumes many acres of farmland.

A few years ago, I was asked the question: "Will the oceans burn during a global firestorm?" I thought what a strange question. Let me broaden the question and discuss mass fires for the following 6 zones: ocean, desert, grassland & farmland, cities, forest, fuel reserves.

- Ocean: The obvious answer is "no". Oceans represent 72 percent of the Earth's surface.
- Desert: The sand in the deserts will not burn. They represent approximately 5 percent of the Earth's land area.
- Grassland & Farmland: To assess this, I will call on personal experience. I have a 5-acre field in front of my home. I burned the shrub in the springtime to clear the land (a common practice in the countryside). I would factor in the wind direction and light the fire at the downwind end to create a firebreak and then I would light the fire from the upwind side. The fires would burn from both ends towards the middle. One year the fire nearly got away from me. The flames shot up 30 to 40 feet in the air. The fire spawned a whirlwind (miniature tornado). The interesting observation is that the intense fire only lasted a short time, less than 30 minutes. Thirty minutes after the fire burned out, one could walk unharmed among the ashes. A fire in grassland or farmland could turn into a conflagration if unchecked but not a firestorm and the fire would be short-lived.
- Cities: The effects of a large comet impact have been compared to the effect of a very large nuclear explosion. The Office of Technology analyzed the potential for a nuclear weapon to produce a firestorm. Their report summarized their assessment as: "Some believe that firestorms in the U.S. or Soviet cities are unlikely because the density of flammable materials (fuel loading) is too low – the ignition of a firestorm is thought to require a fuel loading of at least 8 lbs/ft^2 (Hamburg had 32), compared to fuel loading of 2 lbs/ft^2 in a typical U.S. suburb and 5 lbs/ft^2 in a neighborhood of two story brick rowhouses." In summary, most cities lack the fuel density to create a firestorm. Most fires within cities if unchecked could grow into conflagrations.[6]
- Forest: If a fire occurs in a forest and is left unchecked, it could develop into a forest fire, which is a type of mass fire called conflagration. Forest within the 10-psi blast wave could produce a firestorm.
- Fuel Reserves: Mass fires could occur in reserves of fuel including coal, oil and natural gas. It might also be reasonable to lump large tire dumps in this category. The fuel loading of these reserves can exceed 8 lbs/ft^2. Thus there is the potential of creating a localized firestorm. But in general, many of these reserves are buried underground, therefore the release of fuel will be limited and a fire similar to the oil field fires at the end of the Kuwaiti war is more likely.

Vast quantities of methane hydrate are located under the sea floor. The methane was formed from decomposing organic matter in ocean sediment. The amount of carbon contained in these deposits exceeds the amount of all known coal, oil and gas reservoirs. It has been suggested that an impact could release large volumes of methane gas, that would rise to the surface, ignite and burn.[21] Referring back to the study of fern spore, the data implies that a global firestorm did not result at the K/T boundary.

[§§] Ralph E. Taggart, "K/T Boundary Impact Hypothesis", URL: http://taggart.glg.msu.edu/isb200/kt.html [cited 1 Dec. 2006]

In summary, the area within the zone of destruction defined by the 1-psi overpressure will be subjected to significant thermal radiation and to the fallout from very hot debris. This will spawn very energetic fires including firestorms. The area outside this zone of destruction will be subjected to scattered fires generally as a result of secondary effects such as earthquakes, lightning strikes, etc. Many fires will spread because of lack of emergency responders. These fires could develop into mass fires, typically conflagrations.

B. Earthquakes, Landslides, Volcanoes & Lava Flows

A large impact may trigger a variety of secondary effects including earthquakes, landslides, volcanoes and lava flows. These secondary effects would be triggered by the Primary Impact Ground Shock. The following are examples of secondary effects that might follow a large asteroid or comet impact in the Atlantic Ocean.

- A large ocean impact could break through the Earth's crust. This would expose the ocean to the molten lava beneath. The lava could flow up forming a new large volcanic island. The volcano would spew significant amounts of sulfur dioxide into the atmosphere.
- The Hawaiian Islands were formed from massive volcanoes. If the water in the ocean were removed, the Hawaiian Islands would be the tallest mountains on the surface of the Earth, over 5 miles (8 km) high. Geological evidence has shown that over time, individual islands will break apart through large landslides. Great chunks, the size of New York City, can break off and tumble 5 miles to the bottom of the ocean floor. When this landslide occurs, it displaces a large volume of water. This would create a large tsunami that would affect the entire Pacific Rim. A large crack with several feet of separation has already formed in the Big Island of Hawaii. The Primary Ground Shock from a large ocean impact (even though it occurred on the other side of the United States) would travel though the molten mantel and could trigger this landslide resulting in a tsunami that would devastate the cities along the west coast of the United States, including Los Angeles, San Diego and San Francisco along with coastal areas of Japan, Asia, and Australia.
- The impact could trigger a landslide and volcanic activity on the Teide volcano on Tenerife in the Canary Islands. This is the 3rd largest volcano on Earth. If the asteroid impact triggered this landslide, the result would be a tsunami that will primarily affect Northwestern Africa and Western Europe. The volcano would erupt and send significant amounts of sulfur dioxide into the atmosphere.
- The impact could reactivate the Yellowstone volcano. This is the largest volcano in North America.
- The impact could produce large earthquakes in the Reelfoot Rift that is commonly called the New Madrid fault. This is a large earthquake fault line that runs down the center of the U.S. A large earthquake in this fault would generate significant earthquake damage from Chicago to New Orleans.
- Likewise the impact could produce large earthquakes in the San Andreas Fault system in California.

Within human history many natural disasters have occurred. But we have yet to experience the depth and breathe of simultaneous disaster events that can be triggered by a large impact. Compounding multiple disasters will likely generate greater devastation, which will further complicate recovery efforts.

An impact can trigger very intense earthquakes. In a large earthquake, the land will take on the appearance of the ocean during a storm with large rolling waves. A deafening roar will precede by a few seconds each quake. Large areas of land will be uplifted or sunk. Landslides will occur. Deep fissures will open up in the earth. Sand blows or eruptions will cover some areas with sand and mud. Above ground and underground rivers will be rerouted. Some new ponds and lakes will form while others disappear.

Just as a massive earthquake will produce aftershocks, an impact from a large comet or asteroid can produce a sizeable increase in earthquake and volcanic activity. The core of the Earth may develop an oscillation or ring and as a result the pattern of earthquake/volcanic activity could develop a repetitious burst cycle of ~ 33-70 minutes.

Some of this activity will occur in or near the oceans. An impact can also induce underwater landslides. These events can produce secondary tsunamis. These secondary tsunamis may also be very destructive when compared to the primary asteroid/comet "impact tsunami" because they will possess longer wavelengths. Because these secondary tsunamis will occur in many parts of the globe, they represent a considerable threat to all coastal regions around the world for several months.

In my analysis ground shock is the major component of the primary threat from a deep impact, an impact that can physically penetrate through the Earth's crust. This type of very large impact can result in global extinction events.[4,5] The thickness of the Earth's crust is ~ 3 miles (5 km) under the ocean and ~ 20-35 miles (30-50 km) on the continents.[22] The ocean impact of a large comet or asteroid could puncture a hole through the Earth's crust penetrating into the molten mantel beneath. This type of impact will produce two areas of devastation. The first is at the site of the impact. The second is at the exit vector on the opposite side of the planet, where the Earth will be

turned into a jumbled debris field which will trigger mantle plume volcanism. The resulting massive lava flows at the exit vector represent the major cause of extinctions from an asteroid or comet impact because they result in a long-term global ecological damage. (There was a massive episode of lava flows in what is now India, producing huge sheets of volcanic material known as the Deccan Traps at the end of the Cretaceous Period. There was also a very massive episode of lava flows called the Siberian Traps at the end of the Permian Period.) This phenomenon is observed on other planets. On Mercury, a very large comet or meteorite impact formed the Caloris Basin. The shock wave from this impact traveled through the planet and produced a jumbled terrain on the opposite side of the planet.[19] This theory is supported by recent research findings that uncovered a strong correlation between major impact events and secondary volcanic activity. During the last 4 billion years on Earth, scientists have identified 10 major impact events caused by collision with comets/meteors. Nine out of ten of these large Earth impacts also correlate with intense periods of mantle plume volcanism.[23]

C. Dust & Impact Winter

It has been theorized that the impact of a large comet or asteroid and the resulting fires would throw up so much dust and ash in the stratosphere that it would shut off sunlight from the surface of the planet. This would plunge the Earth into a period of darkness lasting many months and even years. In the absence of sunlight, solar heating of the Earth's surface would come to a halt. This will lead to a severe cooling of the continents approximately 70°F (39°C) below normal and lead to an "impact winter".[2] An "impact winter" is similar to a "nuclear winter" but more severe, and could lead to a new Ice Age.

I feel that the threat of a dust generated "impact winter" is vastly overstated and that any dust generated "impact winter" will not be anywhere near as severe nor last as long as some predict.

- According to research from geologist, Kevin Pope, the K/T impact did not generate the quantities of fine dust needed to block the Sun completely and choke off photosynthesis. Approximately 99% of the debris produced was in the form of spherules, which are too coarse and heavy to remain suspended in the upper atmosphere for very long. Only 1% of the debris is fine dust generated from pulverized rock. If this fine dust were spread out across the entire globe, it would represent a thickness of ~ 0.001 inches (0.03 mm). Therefore the hypothesis of an "impact winter" is vastly overstated.[24]
- Just as dust that is kicked up into the atmosphere will block sunlight from hitting the earth, the dust will also act as an insulator trapping heat at the Earth's surface. This includes the heat from (1) the impact and fireball, (2) firestorms, (3) fuel fires – oil, natural gas, coal, timber, methane hydrate, and (4) lava flows and volcanoes. This trapping effect will slow the decent of the temperature fall, and retard the onset of the "impact winter".
- Some of my reasoning comes from reverse logic. The dust cloud is a global threat. It shuts off light from the entire surface of the Earth. It brings photosynthesis to a grinding halt. Several mammals and reptiles survived the asteroid that slammed into Mexico's Yucatan Peninsula 65 million years ago. We know this because the event did not result in total and complete extinction of all complex life forms. How long could these creatures survive without food? Several years seems like a very, very long time to go without food.
- The oldest tropical honeybees, Cretotrigona prisca, were studied by Jacqueline M. Kozisek. These honeybees survived the Cretaceous/Tertiary (K/T) extinction. The bees share a common ancestry tree with modern tropical honeybees making them an ideal subject for study. These bees rely on pollen for their energy source and do not store honey. They must have a constant source of blooming angiosperms to survive. They also require a temperature of 88-93°F (31-34°C) to maintain their metabolism. These insects are very sensitive to the environment changes. Covering the outer atmosphere with a dust layer, blocking off photosynthesis, and dropping tropical temperatures by 13°F (7°C) to 22°F (12°C) would have meant certain death for this species. If a global "impact winter" occurred, these honeybees could not survive years in the dark and cold without the flowering plants which they need to survive. But they did survive![25]

I feel the entire world will be dark within one hour after a large impact. The impact debris flung high into the stratosphere will cause this darkness. It will take several days for the majority of this debris to fall back to Earth's surface. I believe at about the third day after impact, some light will start to get through.

D. Upper Atmospheric Effects

The fireball composed of very hot gases will rise very high into the atmosphere (stratosphere, mesosphere, thermosphere), expand, and radiate heat into outer space. The fireball from a large impact when it reaches the stratosphere will result in an expansion of the stratospheric envelope, which can increase the orbit disrupting drag on spacecraft.

The debris ejected from a large impact, thermal radiation and the expanded upper atmosphere can create a hazard for satellites. Satellites have two types of orbits. Satellites in a Geostationary or Geosynchronous Equatorial Orbit are high above the Earth. Typically these are 22,300 miles (35,900 km) above the surface of the planet. These satellites are used for, telephone transmissions, television and radio program feeds, computer communications, maritime navigation, GPS, and military command & control. In general, these satellites will survive the effects of the impact. Satellites in a Low Earth Orbit (LEO) including Polar Orbit are close to the Earth. Typically these satellites are 200-500 miles (320-800 km) above the surface of the planet. They travel at high speeds ~17,000 mph (7.6 km/s). These satellites are used for remote sensing and weather. These satellites will be particularly vulnerable to collisions with impact debris blasted into space. The collision with this debris field will disable or destroy many of these LEO satellites within a few hours. The International Space Station and Space Shuttle also falls into this category.

E. Oxygen Depletion

The oxygen in the atmosphere is currently stable at 21% by volume. As a general rule, an asteroid or comet impact will not dramatically alter the current oxygen level. But there is an exception. Two of the past mass extinction events (the end-Permian and the end-Cretaceous) have been linked to a dramatic decline in atmospheric oxygen. Oxygen levels fell from approximately 35% to 15% during the end-Permian extinction.[26] This represents a major decline of 200,000 ppm. Oxygen levels may also have fallen from approximately 30 % to 15 % during the end-Cretaceous extinction.[27,***] The end-Cretaceous extinction has been tied to a massive K/T impact event.[28] The end-Permian extinction has been theoretically tied to a series of massive impact events.[4,5]

An atmosphere containing less than 19.5% oxygen is considered oxygen-deficient. Loss of consciousness, asphyxiation and, death can also occur in a matter of minutes due to oxygen starvation. Table 6 describes the effects of oxygen deprivation.

Table 6. Effects of Oxygen Deprivation on Humans as a Function of Atmospheric Oxygen Concentration.

Atmospheric Oxygen by Volume	Symptoms or Effects
16% - 12%	Breathing and pulse rate increased, muscular coordination slightly disturbed.
14% - 10%	Emotional upset, abnormal fatigue, disturbed respiration.
10% - 6%	Nausea and vomiting, collapse or loss of consciousness.
Below 6%	Convulsive movements, possible respiratory collapse and death.

The most massive impacts, those that penetrate the Earth's crust, can produce dramatically reduced oxygen levels by triggering massive mantle plume volcanism. The *Russian-Ukrainian Theory of Deep Abiotic Petroleum Origin* explains why the atmosphere suffered a dramatic decline in oxygen levels and why the oceans became anoxic/superanoxic after massive impacts. According to this theory, petroleum is not a fossil fuel. Petroleum comes from hydrocarbons that were basic components in planet creation. These hydrocarbons exist in a stable form under extreme pressures and temperatures on the underbelly of the Earth's crust. These hydrocarbons bleed into the magma during volcanic eruptions. The hydrocarbons in the magma combust and burn when they are exposed to the oxygen in the atmosphere. Several gases released during volcanic eruptions, such as carbon dioxide and carbon monoxide, rather than originating as compressed gases from deep within the Earth, are in reality, a product of a combustion process near the Earth's surface. The combustion process, not only injects acidic gases into the atmosphere, but bleeds oxygen from the atmosphere, which in turn removes oxygen from the oceans.

F. Gas Evolution & Acid Rain

The ionization of the air during a large comet or asteroid impact will produce large volumes of nitric oxide and nitrogen dioxide carrying it well up into the stratosphere, where these aerosols will severely damage and destroy the ozone layer.[29] As a result; high levels of ultraviolet radiation, that is normally shielded by the ozone layer, will reach the surface of the Earth. Ultraviolet radiation can cause serious sunburn, increased incidences of skin cancer and eye damage. Ultraviolet radiation can cause some genetic damage in plants, but the damage will be limited. The ozone molecules will be steadily regenerated by solar radiation after the impact. Complete regeneration and recovery could take several years.[30]

*** Landis, G. P., "Understanding Our Planet Through Chemistry", U. S. Geological Survey, Chap. 2c (Air Bubbles, Amber, and Dinosaurs), URL: http://minerals.cr.usgs.gov/gips/na/0amber.htm [cited 4 Dec. 2006]

Mass fires and volcanic activity can produce large volumes of hazardous or poisonous gases including carbon dioxide, sulfur dioxide, carbon monoxide, hydrogen sulfide, hydrogen chloride and hydrogen fluoride.[2,31,32] Breathing several of these gases can result in severe lung damage, lung edema and death.[2]

Fortunately, many of these very deadly gases will react quickly with moisture in the air and convert to a less dangerous acid mist. In normal to high humidity environments, this conversion will take place within 1 - 4 miles (1.6-6.4 km). But under the following conditions, the range will be significantly greater:

- Dry, arid desert environments.
- Winter freezing environments that produce very low humidity levels.
- High elevation in the atmosphere where the temperature is below freezing.
- Very dense gas cloud concentrations.

As these gases combine with the moisture in the air, strong acids will form. This intense acid rain including carbonic acid, nitric acid, hydrated sulfur dioxide, and hydrochloric acid will fall to earth.[2,12,31,32] Some of the most intense periods of acid rainfall may occur within the few days immediately following the impact. These acid rainfalls may be very intense localized concentrations and a function of prevailing wind patterns.

Acid rain can harm vegetation. Acid rain can pollute the waters in rivers, streams, lakes and oceans. This rainfall can contaminate drinking water for humans, mammals, amphibians, reptiles and birds. Slight acidification of the ocean can destroy calcareous nanoplankton. It can also produce large fish kills.

In my opinion, the evolved gases from the mantle plume volcanism and the resulting acidification of the terrestrial and marine environments and the corresponding draw down of oxygen levels are the primary killer of life during past impact induced mass extinction events. A deep impact from a comet that penetrates the Earth's crust can trigger massive mantle plume volcanism on the other side of the planet.[4,5] In general; volcanoes release minute quantities of magma. For example, the Mount St. Helen eruption of May 18, 1980 produced only 0.5 km^3 of magma. Large flood volcanic eruptions, on the other hand, can produce a significant up-tick of magma levels. The Lakagigar Eruption in Iceland of June 8, 1783, for example, produced 14.7 km^3 of basalt. This eruption had a major stranglehold on the Northern Hemisphere for several years. Large-scale flood volcanic eruptions such as those associated with the end-Permian extinction (the Emeishan & Siberian Traps) released 3 – 5 million km^3 of magma. The Deccan Traps associated with the end-Cretaceous mass extinction released 5 million km^3 of magma. Volcanic eruptions produce several gases: water vapor, carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrogen, hydrogen chloride, carbon monoxide, hydrogen fluoride and helium. Table 7 describes the gas concentration levels from volcanic activity similar to a mantle plume eruption.[32] Massive mantle plume volcanism will release very high concentrations of light sulfur gases that will rise high in the atmosphere driving Earth's albedo upward; blocking off sunlight. Very high concentrations of carbon dioxide being heavier than air will cling to the planet's surface acting like a thermal blanket, holding in trapped heat. Magma thermal heat will be released (for the end-Permian and end Cretaceous extinctions this was on-the-order-of 5 years of solar heat energy). This is a significant quantity of thermal heat if the magma was release during a short time interval. The magma heat will turn the area thousands of miles near the mantle plume volcanism into a dark inferno. Forest will die and become bone dry. Volcanic induced lightning will ignite these forests producing great mass fires that will add to the scope of the disaster. In my opinion, acidic gases released from magma were the leading cause of the past ocean and terrestrial mass extinctions.

Table 7. Volcanic Gases

Volcano	**Kilauea Summit**
Tectonic Style	**Hot Spot**
Temperature	**1170° C**
Carbon Dioxide	48.9%
Water Vapor	37.1%
Sulfur Dioxide	11.8%
Carbon Monoxide	1.51%
Hydrogen	0.49%
Hydrogen Chloride	0.08%
Hydrogen Sulfide	0.04%
Hydrogen Fluoride	Trace
Helium	Trace

G. Magnetic Pole Reversal

In general most impacts are too small to affect the Earth's magnetic pole. It has been theorized that a massive deep impact might shift the Earth's magnetic pole and may produce a pole reversal.[2,19] Earth has undergone magnetic pole reversals in the past and a large impact might trigger this type of effect. The Earth's magnetic pole deflects cosmic radiation. When the magnetic pole is weak or non-existent, such as at the mid-point of a pole reversal, charged particles from space can penetrate to the Earth's surface.[19] This cosmic radiation can cause direct harm to life on the planet and can also produce genetic damage in living creatures.

H. Energetic Weather Conditions

In the 1960's in Dallas Texas, I witnessed an unusual weather phenomenon, a mud storm. The storm rained mud for ~ 20 minutes. When it was over, everything was coated with a ¼ inch thick layer of mud. This unusual event was caused by a collision of a dust storm and a rainstorm. A similar type of weather phenomena called "black rain" may occur shortly after a large impact event. In this phenomenon, rain is mixed with the debris and ashes from the impact. This rain is very black and very sticky. The residue coats everything exposed on the outside and is very difficult to wash off.

If a large comet or asteroid impacts the ocean, I believe the heat of the fireball will evaporate large quantities of water. I feel that there will be significant rainfall immediately after the impact. The largest rainfall will occur in the region near the impact and this storm path will follow the prevailing winds.

I also expect ionization from the impact will result in massive lightning storms, the likes of which are rarely seen.

I. Starvation and Plagues

A massive asteroid/comet impact can produce a global catastrophe. Unfavorable weather conditions following a large impact will retard food production, processing and distribution. Acid rain will also contribute by destroying crops. The infrastructure will take a big hit from a large impact. Broken transportation lines will inhibit transport of grains to processing centers and then to population centers. Other damaged infrastructure (government, finance, communications, energy) will place most recovery efforts into shambles. The inability to quickly recover from the damaged infrastructure will lead to starvation and famines in the general population. A weakened population from starvation is vulnerable to disease, epidemics and plagues.

VII. Conclusion

The great majority of asteroid and comet impacts will produce only limited regions of great devastation. The effects from these impacts can be quantitatively assessed by comparing the effects from equivalent air and/or surface nuclear explosion. In my assessment, global mass extinction events are extremely rare and are caused by deep impactors, those that penetrate the Earth's crust. In general, these massive impacts are caused by inward falling comets from the Oort Cloud. The energy released by a deep impactor is split between surface effects and interior effects. The surface effects can be modeled a surface nuclear burst. The interior effects can be modeled by an equivalent underground nuclear explosions, the main component is a directional ground shock.

A deep impact produces two zones of destruction: one at the point-of-impact and the other on the opposite side of the globe. The destruction at the point-of-impact produces a regional area of great devastation that wrecks havoc for several days. The shock wave from the impacts traveled through the Earth fracturing the Earth's crust on the opposite side of the planet, producing a jumbled debris field and triggering massive mantle plume volcanism. The area of devastation on the opposite side of the Earth is significantly greater and the devastation is long-term extending thousands of years. It is this component that produces global devastation by releasing massive quantities of volcanic magma, which in turn generates acidic and poisonous gases. The gases combine with moisture to form acids that are primarily responsible for extinguishing life across the entire planet.[4] The gas generation is also responsible for the drawdown of oxygen levels below minimally acceptable levels. These deep impacts are not random. Rather they occur with regularity in geological time.[5]

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Appendix
Impact Scenario

An asteroid strikes the Earth without warning. The asteroid 3.6 miles (5.8 km) in diameter crashes into the Atlantic Ocean at Longitude 72° 49' West, Latitude 28° 0' North. The asteroid is traveling at a velocity of 20 km/s, has a density of 2.0 g/cm^3. The asteroid is spherical in shape. It is not a binary asteroid. The impact occurs at 9:45 PM Eastern Time in the middle of June. The asteroid hits the Earth nearly head-on (2 degrees from true vertical) heading slightly East to West.

The asteroid will impact with the kinetic energy equivalent to 10,000,000 megatons of TNT. This energy release is equivalent to 333 times the potential energy of all the nuclear weapons that existed in the world during the height of the cold war in the 1970's.

Secondary Effects:

I have introduced a number of secondary effects to interject some realism into the scenario. That is not to say that a 3.6-mile (5.8 km) diameter asteroid impact will produce these exact effects, but rather they will produce effects like these. These just happen to be on the minds of scientist at the moment, events that are likely to occur even without a triggering mechanism such as an impact.

- There is a crack that has formed on the Big Island of Hawaii. The gap is presently a few feet wide. If you remove the water from the ocean, Hawaii would be one of the tallest mountains in the world, over 5 miles (8 km) high. The islands were created from underwater volcanoes. In time as the islands age, they will fracture producing a large landslide. Part of the Big Island will break away and fall to the bottom of the ocean. This landslide will displace many square miles of water and produce a very large tsunami. This tsunami will threaten coastal areas of the West Coast of the U.S., Japan, Asia, and Australia. Within this scenario, the asteroid impact will trigger this landslide.
- The impact will also wake up the Yellowstone volcano, one of the largest volcanoes in North America.
- The impact will stress the Reelfoot Rift producing several earthquakes along the New Madrid fault line. This large earthquake fault runs down the center of the U.S. It has the capacity of generating significant earthquake damage from Chicago to New Orleans.
- The impact will produce large earthquakes in the San Andreas Fault system in California.

Bermuda

Jim Pidelo had completed his law degree at Harvard and took a detour to Bermuda for a little needed R&R before returning home to take the New York bar exam. He knew from the moment he stepped off the plane; this was a good decision. The ocean water was a deep blue and the weather was balmy. He settled in at the Elbow Beach Hotel. After registering at the front desk, he went up to his room, dropped the suitcases on the bed. Rummaging through his bags, he found his swim trunks and a bottle of sun tan lotion. The rest of the unpacking could wait until later. He made his way to the beach, found a chair and settled down for some serious sunbathing. This was paradise.

He woke up two hours later. His back was on fire. He looked up and before his eyes stood a beautiful angel. She was smiling "Your back looks like a boiled lobster." He replied, "I feel like one." She opened her beachbag. "I have some Aloe Vera. It will take some of the sting away. Would you like me to put some on your back?" He thought he remembered her from someplace. Oh, yes, he had caught a brief glimpse of her as he boarded the plane in Boston. He said, "My name is James, what's yours?" She said "Elizabeth. You can call me Beth." He said, "I will forever be grateful if you spread some of that magic lotion on my back."

Jim invited Beth to dinner and she accepted. They spent their meal discussing Boston, college life and what the future held in store for them. Darkness fell and they continued to lazily chat for hours while sipping elegant glasses of dry white wine in the lounge. He was dazzled by her looks. He felt comfortable with her, like they might have been made for each other, soul mates. He proposed a walk along the beach in the moonlight. She said that would be romantic.

The stars shined brightly in the crisp night's sky. They walked along the sandy beach hand-in-hand. The salty air was mixed with a blend of scents from tropical flowers. Her eyes sparkled in the moonlight. Her hands were small and soft. Jim found a path leading through a small forest of palm trees. They strolled through the trees until

the darkness completely enveloped them. He paused. She turned. He could see the thin outline of her eyes. He moved closer and pressed his lips against her. He held her close.

The sky became bright with intense light that filtered through the palm leaves. It took a few seconds before Jim realized something very strange was afoot. A whistling sound joined a chorus of off-key whistling sound producing an eerie wail. This sound grew to ear splitting intensity. It sounded like an ancient creature crying out in great pain. White ash drifted down from the sky. There was the sound of wind and small whirlwinds danced through the trees. It began to get hot, very hot. And then the ground shock so violently, they were both knocked off their feet. Beth was knocked headfirst into the base of a tree. She lay unconscious on the ground. Jim pulled himself up off the ground. He felt the scrapes on his knees and the wet blood oozing from the wound. Ash and small fragments of burning branches fell to the ground. The heat was becoming almost unbearable. A thick haze began to fill the forest. He decided to make a dash towards the ocean. He felt his way to Beth. He grabbed her hand and lifted her up over his shoulders in a fireman's carry. The ground was still moving. He swayed back-and-forth as he rushed to the shoreline. He reached the edge of the trees. The heat was intense. He ran until the ocean engulfed them. The cold water felt good.

His mad dash to the ocean was like walking through the fires of Hell. His clothes were burnt. He stood in the ocean half-naked where chucks of his clothes dissolved away in the surf. Some fused to his body. Although the ocean felt refreshing, his body began to absorb the seawater through his skin. Several large water blisters formed where his flesh had been exposed. He suddenly felt sick to his stomach. His hair had also been aflame and only blotches remained. Elizabeth was in worse shape. Her body had shielded his in the dash.

Elizabeth woke up and began talking incoherently, still in shock. Even though he knew it was the middle of the night, he couldn't fathom where or why the sun was there. Then it began to sink in that maybe this wasn't the sun. It was brighter, more intense than the sun. Whatever it was, it was set in a backdrop of black violent clouds.

Five minutes after they first kissed, the sky went dark. The only light was from the island, where vast fires raged out of control. The island was engulfed in a cloud of smoke. The winds picked up and rushed to shore. Elizabeth eyes grew large; she became lucid and coherent for a moment "What's happening?" He looked at her and could see she was in a lot of pain. He responded, "Something big, maybe a nuclear war!"

Elizabeth turned and faced him. Her stare was that of a person in a strange trance. She spoke softly "Hold me!" He wrapped his arms around her and they stood alone at the edge of the world. He pressed his body against hers tightly, so close that he could feel her heart beating. It was rapid like a quivering sparrow. He realized she was not holding him out of sense of romance but out of a ghastly fear and desperation. He knew this because he felt the same way.

Several minutes went by. He heard the earth groan and then he felt the sand beneath his feet rise abruptly upward. The fires picked up in intensity. A vast lightning storm approached the island from a distance. Another ten minutes passed in the blackness at the edge of the burning island. He felt the cool wind blowing against his back. Perhaps it was safe to return to the shore. The lightning storm had grown to an immense size and was about to swallow up the island. If they stayed in the ocean, he worried about being electrocuted. He took Beth by the hand and they returned to the beach. The sand was still very warm, too warm to stand on with his bare feet. Suddenly several loud deafening cracks of thunder echoed across the island.

He heard what he thought was a strong wind and then suddenly he was flying through the air. When he gained consciousness, intense pain shot up his arm. He could see by the reflected light from the fires that his right arm was dislocated from its socket. He tried to steady himself and get back on his feet. Beth had disappeared. He wandered about trying to locate her. Then he followed the edge of the island shoreline, trying to find other survivors. Almost forty-five minutes passed and he noticed the ocean water was receding from the shoreline. Then he heard a sound. He couldn't quite make it out at first. It was the roaring sound. In the final seconds of his life, he saw a giant wave bigger than any mountain on Earth wash ashore.

[The forest of palm trees provided an organic shelter that temporarily protected James and Elizabeth from the intense thermal radiation from the fireball. The heat turned the palm leaves into white ash. It also removed the moisture from the trees. During the drying, small cracks opened in the trees and the released moisture whistled, like steam from a teakettle. The thermal radiation also formed small whirlwinds. The primary ground shock knocked Elizabeth into a tree where she went unconscious. When they were in the ocean, the uplift was a reflected ground shock. The impact unleashed a massive magnetic storm hundreds of miles across that will last for over 6 hours and produce numerous lightning strikes. The loud cracks of thunder were the sound of the impact. The strong wind that dislocated Jim's right arm was the blast wave. The giant wave was the tsunami that completed the island's destruction.]

Location: Bermuda

Distance from Point-of-Impact: 570 miles (917 km)
Time of Impact: 10:45 P.M. local

Event	Timing of Event	Effect
Flash	Impact	Minimal. Someone would have to be facing the impact to receive indirect exposure and be injured by flashblindness.
Electrophonic Bursters	Impact	If outside at Impact, might hear a series of loud clicking or crackling sounds.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting). Automobiles are dead. Back-up power generators in hospitals are dead. Most electronics are destroyed by the EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	The fireball will emit intense thermal radiation for over 5 minutes. Most combustibles will ignite and burn.
Ground Shock	Impact + 1.6 minutes	Very violent ground shock that will level most buildings. The impact will produce a shock 11.9 on the Richter scale at the point-of-impact. The largest earthquake ever recorded is 8.9 on the Richter scale. Rocks are not strong enough for more. The ground shock will consist of several shock waves. The Primary wave will strike at 1.6 minutes after impact. Another strong shock, a reflected shock wave off the Earth's solid core, will arrive 20 minutes after impact.
Oxygen Depletion	Impact + 2 minutes	Nil. A thick haze (a product of numerous fires) will engulf the island shortly after impact. Due to dust, debris fallout and released aerosols, breathing will be difficult.
Mass Fires	Impact + 5 minutes	Thermal radiation will produce massive fires throughout the island within minutes, which will be extinguished by the tsunami.
Debris & Aerosols	Impact + 5 minutes	Several heavy fire-rocks will fall from the sky. The fireball will light up the sky. Debris will block some of this light. The debris will also create a backdrop to the fireball. The effect will be very eerie, like the end of the world. The debris will blot out the moon and the stars. The sky will appear ripped in two.
Sound of Impact	Impact + 42 minutes	The impact will sound like a series of thunderclap or guns being fired.
Blast Wave	Impact + 46 minutes	Would cause the damage of a 10-psi overpressure blast.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Tsunami	Impact + 1.5 hours	The deepwater wave height will be approximately 1,700 feet (0.52 km) high. The tsunami would totally destroy the island. Massive damage, massive destruction.
Triggered Earthquakes		Nil.
Triggered Landslides		Nil
Triggered Volcanoes		Nil
Triggered Lava Flows	Long Term Effect	The impact crater opens up a hole in the ocean floor that would take years to reseal. From this hole, lava, steam, sulfur dioxide and other aerosols will spring forth. Energetic storms and gas clouds will form and be carried by prevailing winds up the Eastern Seaboard.
Gas Evolution & Acid Rain	Impact + 1 day	Very high levels of acid rainfall and black rain. For several weeks after the impact, drinking surface water can result in sickness and death.
Energetic Weather Conditions	Impact + 3 days	Large amounts of water evaporated by the fireball, carried by prevailing winds up the Eastern Seaboard. This would produce very intense storms that would deposit unusually high amounts of rainfall.
Magnetic Pole Reversals		Nil
Starvation		No survivors left to starve.
Plagues		No survivors left to become sick.
Dust & Impact Winter	Several weeks	Food crop destroyed for current year. Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.

Washington D.C.

The President of the United States was attending a State Dinner at the White House. The food was prepared and the aroma drifted into the historically elegant dining room. The waiters stood patiently in the corridors for the queue to commence serving. The President was giving a short humorous speech when the room lunged into darkness. After a few seconds of mumbled silence, a flashlight moved through the room. The aide holding it approached the President and whispered something into his ear. The President said, "Please excuse me" and he left with the aide and the room was once again plunged into darkness. As the President made his way through the narrow corridor, he stumbled into a tray of succulent roast beef that crashed into the floor. He kept moving. They wound their way through the narrow corridor and then dropped three flights of stairs to a secured Comm Room. Technicians were busy changing out a fiber optic converter attached to a network hub.

The President asked "Status!" The technician turned around and was a little startled. "All systems are down. The backup generators are off-line. We are operating on battery power. Computer systems were fried. Network is off-line. Satellite Comm links are down. Phones are dead along with most of the radios. The few radios that are alive are overdriven with static. Other than that everything is fine. Give me 3 minutes. I am trying to reestablish communication with Cheyenne Mountain."

An advisor had quietly entered the room. He said, "Mr. President, I believe we have been hit with an EMP." The President said "Nuclear?" The advisor responded, "Need more data." The President said "Where?" The aide responded, "There's a fireball lighting up the sky in the South. The heat is fairly intense outside."

The President turned to his FBI security agent and said, "Would you please bring my wife downstairs.

The FBI agent responded, "It is already being done Mr. President as we speak." At that moment the ground shock violently. It became impossible to stand or walk. Objects fell from shelves and rattled across the floor. The motion lasted for a full 60 seconds.

An aide stumbled into the room a few moments after the earthquake stopped and said, "The west wing has collapsed."

A few seconds later, the President's wife entered. The President turned to her and took her by the hand. She said, "I'm O.K. Get on with your work."

A few minutes passed and network communications was reestablished with Cheyenne Mountain. As the President spoke, an operator keyed in the narrative.

President, "Who am I speaking with?"

Cheyenne Mountain Air Force Base, "General Ken Allison. I also have General Stevens and General Atwater by my side."

President, "What happened?"

Gen. Allison, "A large asteroid impacted in the Atlantic Ocean between the Bahamas and Bermuda.

President, "What's your present status?"

Gen. Allison, "Difficult. RF Interference raising havoc with communications, satellite reception . . . Mr. President your life is in danger. I advise you evacuate White House immediately."

President, "Understood. Ken, how big was this thing?"

Gen. Allison, "Large. Large enough to destroy the entire Eastern Seaboard."

President, "Understood."

The President turned to the FBI agent; "I need to evacuate the area. Arrange transportation to Air Force One."

The agent said, "I'll get right on it." He rushed out of the room.

President, "General, can you give me a damage report?"

Gen. Allison, "Interference on RF communications is extensive. Our ability to analyze the situation is degraded, very degraded. Satellite imagery shows extensive fires in Florida, the Carolina's and Cuba. A minute ago, we received unconfirmed reports of the destruction of the Hawaiian Islands."

President, "Your recommendations for evacuation point?"

Gen. Allison, "Recommend you establish command center at Northern Command."

The FBI agent reappeared, "Mr. President, follow me sir."

The agent led the President, his wife and his aides up the stairs. The sight was chaotic as individuals suddenly appeared on their route to fight fires or engage in search and rescue operations. The agent led them out to the back where several Washington policemen were lined up on their Harley Davidson motorcycles. When the agent came to a stop and turned around, the President asked, "Where is the transportation?"

The agent responded, "This is the transportation. The vehicles in your motorcade are inoperative."

The policeman took off his helmet and handed it to the President. "Put this on sir."

The convoy of cycles made their way slowly towards the airport. The earthquake shattered many buildings. Fires were burning everywhere, many out of control. Those that survived were on the streets, terrified of the aftershocks. Stalled automobiles littered the streets. Smoke was pouring into the sky. Except for the burning fires, the entire area was enveloped with total and complete darkness. It was an end of the world disaster being played out in slow motion. The motorcycle convoy came to a halt. The bridge in front of them had collapsed. The President looked down at the pavement. The pavement was so soft due to the heat that the tire tracks left depressions in the asphalt. Thirty minutes later the convoy arrived at Air Force One. The plane was readying for take off.

They were quickly escorted aboard the plane. The runway was dark. The President took his seat and the plane took off. The plane flew in a westerly direction. The impact produced a large magnetic storm that interfered with the plane's magnetic compass. Many of the instruments onboard Air Force One were inoperative. RF static degraded communications. In addition air traffic control systems on the ground were knocked out. The pilot was essentially flying blind. Many hours passed. Debris from the asteroid impact was sucked into the jet engines and the engines began heating up. The fuel ran low. The Earth below was dark. Before the plane crashed, the few parachutes on board were distributed. The hatch was opened and the President jumped into the darkness below. The chute opened. A few minutes later, the President was on solid ground, alone in the darkness. It was cold. He reached down and touched the ground. It was ice.

[The EMP destroyed most computer and communications equipment. Fiber optic lines remained intact but the fiber optic converters needed replacement. The EMP destroyed integrated circuits and computer modules within most vehicles effectively disabling them. Generally, motorcycles were unaffected unless they possessed electronic ignition systems. Shortly after Air Force One took to the skies, the city of Washington D.C. was hit with a strong blast wave that leveled much of the buildings throughout the city. There were very heavy causalities. Thirty minutes later, the city was hit with a tsunami, which completed the destruction. Although Air Force One successfully took off, it never arrived at its destination. It crashed landed in the far North. The President and Vice President along with most members of Congress failed to survive. The administration of the government passed onto the Northern Command, which coordinated recovery efforts with military precision for 3 years until the government could be reconstituted.]

Location: Washington D.C.

Distance from Point-of-Impact: 780 miles (1,255 km)
Time of Impact: 9:45 P.M. Eastern

Event	Timing of Event	Effect
Flash	Impact	Minimal. Someone would have to be facing the impact to receive indirect exposure and be injured by flashblindness. (For example, someone looking out of a tall high-rise building.
Electrophonic Bursters	Impact	Too much traffic noise to detect this effect.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting). Automobiles are dead. Back-up power generators in hospitals are dead. Most electronics destroyed by EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	The fireball will emit intense thermal radiation for over 5 minutes. Many combustibles will ignite and burn triggering numerous fires.
Ground Shock	Impact + 2.2 minutes	Violent ground shock. In general, earthquakes don't kill, the collapse of buildings do. The ground shock will consist of several shock waves. The Primary wave will strike at 2.2 minutes after impact. Another strong shock, a reflected shock wave off the Earth's solid core, will arrive 20 minutes after impact.
Debris & Aerosols	Impact + 8 minutes	The fireball will light up the sky. Debris will block some of this light. The debris will also create a backdrop to the fireball. The effect will be very eerie, like the end of the world. The debris will blot out the moon and the stars. Minimal heavy debris.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 1 hour	The impact will sound like a series of thunderclap or guns being fired.
Blast Wave	Impact + 1.7 Hours	Would cause the damage of a 5-psi overpressure blast.
Mass Fires	Impact + 2 hours	Many fires will ignite houses and buildings. They will quickly grow into massive fires that will threaten to engulf the entire city, due to the inability of the fire department to respond.
Tsunami	Impact + 2.1 hours	The deepwater wave height will be approximately 1500 feet (0.46 km) high. North Carolina and Virginia absorb a good degree of the tsunami wave damage but it fails to prevent the cities total destruction. Massive damage, massive destruction.
Triggered Earthquakes		Nil.
Triggered Landslides		Nil.
Triggered Volcanoes		Nil.
Triggered Lava Flows	Long Term Effects	The impact crater opens up a hole in the ocean floor that would take years to reseal. From this hole, lava, steam, sulfur dioxide and other aerosols will spring forth. Energetic storms and gas clouds will form and be carried by prevailing winds up the Eastern Seaboard.
Oxygen Depletion		Nil. Due to dust, debris fallout and released aerosols, breathing will be difficult.
Gas Evolution & Acid Rain	Impact + 1 Day	Very high levels of acid rainfall and black rain. For several weeks after the impact, drinking surface water can result in sickness and death.
Energetic Weather Conditions	Impact + 3 days	Large amounts of water evaporated by the fireball, carried by prevailing winds up the Eastern Seaboard. This would produce very intense storms that would deposit unusually high amounts of rainfall.
Magnetic Pole Reversals		Nil
Starvation		No survivors left to starve. The tsunami will devastate the entire East Coast of the U.S. For several years after the impact, the land will be unable to support crops due to salt-water contamination, high concentrations of acid rain and heavy metal pollution.
Plagues		No survivors left to become sick.
Dust & Impact Winter	Several weeks	Food crop destroyed for current year. Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.

Location: New York City, New York

Distance from Point-of-Impact: 885 miles (1,424 km)
Time of Impact: 9:45 P.M. Eastern

Event	Timing of Event	Effect
Flash	Impact	Nil. Local rainstorm blocks the effect.
Electrophonic Bursters	Impact	Too much traffic noise to detect this effect.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting) Automobiles are dead. Back-up power generators in hospitals are dead. Most electronics are degraded or destroyed by the EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	The local rainstorm above NYC will minimize the ignition of combustibles.
Ground Shock	Impact + 2.5 minutes	Violent ground shock.
Debris & Aerosols	Impact + 9 minutes	The rainstorm will reduce visibility so much of this effect will be hidden. The fireball will energize the rainstorm. Little heavy fallout.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 1.2 hours	The impact will sound like a series of thunderclap or guns being fired.
Mass Fires	Impact + 2 hours	Several fires will engulf houses and buildings primarily due to inability of fire department to respond.
Tsunami	Impact + 2.3 hours	The deepwater wave height will be approximately 1,400 feet high. The tsunami would destroy New York City completely. Massive casualties/massive destruction.
Blast Wave	Impact + 2.4 hours	Would cause the damage of a 4-psi overpressure blast.
Triggered Earthquakes		Nil.
Triggered Landslides		Nil.
Triggered Volcanoes		Nil.
Triggered Lava Flows	Long Term Effect	The impact crater opens up a hole in the ocean floor that would take years to reseal. From this hole, lava, steam, sulfur dioxide and other aerosols will spring forth. Energetic storms and gas clouds will form and be carried by prevailing winds up the Eastern Seaboard.
Oxygen Depletion		Nil. Due to dust, debris fallout and released aerosols, breathing will be difficult.
Gas Evolution & Acid Rain	Impact + 1 day	Very high levels of acid rainfall and black rain. For several weeks after the impact, drinking surface water can result in sickness and death.
Energetic Weather Conditions	Impact + 3 days	Large amounts of water evaporated by the fireball, carried by prevailing winds up the Eastern Seaboard. This would produce very intense storms that would deposit unusually high amounts of rainfall.
Magnetic Pole Reversals		Nil.
Starvation		No survivors left to starve. The tsunami will devastate the entire East Coast of the U.S. For several years after the impact, the land will be unable to support crops due to salt-water contamination, high concentrations of acid rain and heavy metal pollution.
Plagues		No survivors left to become sick.
Dust & Impact Winter	Several weeks	Food crop destroyed for current year. Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.

Small Town outside Indianapolis, Indiana

Debbie McCalister was out on the porch relaxing in the cool night's air. She laid back on her lawn chair, occasionally swatting any mosquito that came too close. The day had been a hot humid June day. A storm had blown through and cooled the air off. The storm moved on and the wind cleared away the clouds to reveal a canopy of stars. Her husband, George, was inside watching the news on TV.

They lived in a small hamlet in the back hills of Indiana about 50 miles from the capital, Indianapolis, as the crow flies. But they weren't crows, and a trip to Indy was an hour and a half drive by car. The northern half of the state was flat farming country. The southern half was a patchwork of hills, trees, and creeks interspersed by tracks of farmland. They lived in the southern part with their home set against a steep hill. It was quiet and peaceful. Occasionally you could hear a truck rumbling down the main road a mile away or a train passing through town five miles away. But mostly all you heard was the birds or the water rippling through the creek down below.

Their daughter, Tasha, was all grown up, married with a daughter all her own. She lived in a suburb of Indianapolis called Greenwood. Their track house was on a cul-de-sac with a small pond in their backyard where the duck would gather and float away the hours.

Debbie thought about going inside, picking up the phone and calling her daughter. Suddenly, she heard a series of loud clicks and all the lights in the house went dark. The dogs began to bark and howl. The sky lit up for a few moments as if it was daylight. George appeared at the doorway. "What's going on?"

"Something" she paused for a moment "strange!"

"Power's out!" George walked outside and stared at the sky for a few moments. In the southeasterly direction the sky was glowing red. It grew brighter and became awash in colors.

"What is it?" Debbie said.

In his mind, George went through a check list. *Maybe there was a twister buried in that storm and it struck electrical power lines*. That would explain the outage but not the brilliant lights. *A large explosion!* Maybe! George went back into the house, fumbled around until he found the flashlight and then went looking for the portable radio. He turned the radio on and moved the dial through the stations. "Debbie, all the stations are dead!"

"What does that mean?" She asked him

He thought to himself EMP. George said "It might be a nuclear explosion!"

"What!", "Who?" She said.

George explained "Things may get rather nasty!"

Debbie grabbed the flashlight from George, raced into the house and tried to use the portable phone to call her daughter. It was dead. The phone didn't even light up.

George said "Try the old phone in the living room, it has a direct connection."

She disappeared into the enveloping darkness within the house. She yelled back to George. "It's dead too!"

George thought what's next! He yelled out. "Ground Shock!"

Debbie appeared. "What?"

He said. "Ground shock, the first thing that will hit is ground shock".

A low subsonic subterranean growl followed by a strong lateral ground shock occurred. It seemed to last forever. After the motion finally stopped, they got back on their feet and peered inside the house. It was a total mess. The refrigerator was completely emptied. A large mound of food and broken jars formed a large heap on the floor. She shined the light at the cabinets. The doors stood open and the cabinets were bare. They walked into the house and saw heaps and heaps of broken dishes.

Debbie instinctively started to clean up. George said. "Don't bother. It's not over yet!"

George found a second flashlight. He ran to the large 500-gallon propane tank next to the house. He lifted the metal lid and shut the valve off. He looked up at the sky. It looked fierce and threatening. Colors were swirling. He forced his mind to think. *Five minutes. Five minutes went by between the loss of the TV and the ground shock. That means it's very, very far away.* It's too big to be a nuclear explosion. He raced back to the front of the house and accidentally collided with Debbie.

The ground began to rumble again as a strong aftershock hit. When the motion died down and they got back on their feet, George said. "That explosion was too far away and too big to be a nuke. Maybe it's an impact."

"What kind of impact?" Debbie said.

"I'm thinking an asteroid." George shined the light back into the house.

She said. "What do we do?"

"There is a large blast wave headed towards us. It might strike in a couple hours. We need to dig in and dig in fast." He explained. "If we can survive the blast wave, we should be O.K." George ran to the pole barn to retrieve

a couple shovels with Debbie following close behind. They dug a small trench, placed a sheet of plywood over it and buried it under a couple feet of dirt. "I'm glad this isn't the middle of winter when the ground is frozen solid."

When the shelter was complete George said. "Debbie get inside. I'll finish up. It's getting closer."

She crawled inside the makeshift shelter. George went back into the house and found some pillow cases which he brought outside and filled with loose dirt. He used these like sandbags to seal up the front of the shelter.
The blast wave struck suddenly and flung George ten feet through the air, unfortunately he landed against a tree, and was knocked unconscious. A few minutes later Debbie emerged out of the shelter and made her way to her husband's body.

Hours passed as she held him tight and wept. He began to moan and move a little and finally regained consciousness. "What . . . happened?" He whispered.

"I was afraid . . . I was going to lose you." She explained.

George steadied himself and tried to stand up but quickly fell back to the ground. He rested a few minutes and then tried again. He finally made it to his feet and together they surveyed the damage. "I guess someone will try to blame this on global warming." He said. The wind had blown part of the roof off the pole barn along with a few sidewall sections. But the frame was still intact. The house faired better. Several of the windows were broken and a tree had fallen onto the house. His Jeep was in the driveway on its side.

It could have been worse. The hill took the brunt of the blast wave. "Well let's go find the chainsaw." He said. George stumbled and fell on his way back to the pole barn.

Debbie helped him back to his feet and said. "George the only place you're going is to lie down and rest. I almost lost you once today and I am not going to go through this again."

"But the tree!"

"It can wait until tomorrow. I'm sure it won't get up and walk away in the meantime." She said as she went back into the house to retrieve a blanket and some pillows.

Debbie worked through the night cleaning up the mess, salvaging anything she could. By daybreak she was exhausted. But daybreak wasn't really daybreak. It was still very dark and the constant aftershocks began to wear on her nerves.

George woke up. He located the chainsaw and demolished the tree. He used log chains and a 2-ton come-a-long to pull the Jeep over. In the back of the Jeep was a used steel ammunition can. He opened it and removed a small transceiver which he plugged into its chassis in the Jeep. He turned it on and said. "Kilo, Bravo, Niner, November, Victor, Hotel. Kilo, Bravo, Niner, November, Victor, Hotel. This is Whisky, Alpha, Niner, Foxtrot, Bravo, Bravo." All he heard was squelch and static. He tried again and again and again.

Over the course of the next few days, they went round and visited the neighbors lending help where it was needed. They repaired the house using limited supplies and a little ingenuity. There was no electricity or running water. George repaired the leaks to the propane line. They hauled water up from the creek by hand and cooked outdoors. Debbie used a ceramic filter to purify the water for drinking. Periodically George returned to the Jeep.

"KB9NVH, KB9NVH. This is WA9FBB"

On the third day he heard "WA9FBB this is KB9NVH. Over." It was his daughter Tasha.

"Are you O.K? How is Paul and little Z? Over."

"We are all fine, a little shaken but alive and well. Over." She said.

"Your mom and I are O.K. too. Over."

"What happened? Over." She said.

"Asteroid impact, I think." He said. "We will make our way up there in a few days. Is there anything you need? Over."

"There were a lot of injuries in the neighborhood. I have become the unofficial doctor. I even delivered a baby yesterday. They named her after me. If you can bring up any medical supplies, they are sorely needed. Over."

"Will do. Let's meet here in 24 hours, same frequency. Over." He said.

"Roger, dodger, Daddy-O. KB9NVH clear." She said.

"Bye little one. God bless you and keep you. KB9NVH this is WA9FBB clear and out."

[Prologue: Recovery is a slow process. Recovery happens one step at a time, like baby steps. The remainder of the year was harsh. The days were dark and gray. The farm crops were destroyed. Many people resorted to drinking untreated surface water in the days immediately following the impact. Many became sick and some died. The corn and the soybeans stored away in farm silos kept most people from starving at least until the fields could be replanted. City folks had it rougher than country folks. Eventually pockets of electricity were restored. Most people made do, thankful that they were still alive. But a few never recovered. They were walking ghosts, afraid of any loud noises. Unable to understand or comprehend the events which transpired, they lived in constant fear.]

Location: Small Town Outside Indianapolis, Indiana

Distance from Point-of-Impact: 1,112 miles (1,790 km)
Time of Impact: 9:45 P.M. Eastern

Event	Timing of Event	Effect
Flash	Impact	Nil.
Electrophonic Bursters	Impact	If outside at time of Impact, might hear a series of loud clicking or crackling sounds.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting). Automobiles are dead. Back-up power generators in hospitals are dead. Most electronics are degraded or destroyed by the EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	The fireball will light up the sky. Debris will block some of this light. The debris will also create a backdrop to the fireball. The effect will be very eerie, like the end of the world. Dry leaves, dry grass, old newspapers, thin flammable fabrics (for example, curtains), tarpaper can ignite and burn. Numerous small fires will occur.
Ground Shock	Impact + 3.1 minutes	Violent ground shock.
Triggered Earthquakes	Impact + 5.2 minutes	The ground shock triggers a very large earthquake in the Reelfoot Rift fault system, commonly referred to as the New Madrid fault system. Modified Mercalli Intensity Scale of VII. Difficult to stand during the earthquake. Furniture broken. Slight to moderate damage in ordinary structures, considerable damage in poorly built or badly designed structures. Weak chimneys broken at roofline. Fall of plaster, loose bricks, stones, tiles, cornices and unbraced parapets. Small landslides and caving along sand and gravel banks. Significant damage to structures, roads, dams, bridges and infrastructure.
Debris & Aerosols	Impact + 11 minutes	The light ballistic debris will blot out the moon and the stars. Minimal heavy debris.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 1.5 hours	The impact will sound like a series of thunderclap or guns being fired.
Blast Wave	Impact + 4.4 hours	Would cause the damage of a 3-psi overpressure blast.
Mass Fires	Impact + 1 day	The ground shock and earthquake will rupture gas lines. Numerous small fires will occur from thermal radiation. Several fires will engulf houses and buildings and then spread primarily due to inability of fire department to respond.
Tsunami		Nil. The Appalachian Mountains would restrict damage from the Atlantic tsunami.
Triggered Landslides		Nil.
Triggered Volcanoes		Nil.
Triggered Lava Flows		Nil.
Oxygen Depletion		Nil. Due to dust, debris fallout and released aerosols, breathing will be difficult.
Gas Evolution & Acid Rain	Impact + 1 day	Acid rainfall and black rain. Will result in fish-kills. Several plants and trees will die and the remainder will be weakened. Drinking surface water can cause sickness.
Energetic Weather Conditions	Impact + 3 days	Large storms will menace the area for several months. Tornadoes, large hailstorms, and very energetic lightning storms occur.
Magnetic Pole Reversals		Nil.
Dust & Impact Winter	Several weeks	Food crop destroyed for current year. Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.
Starvation	Impact + 1 month	Due to infrastructure damage and lack of grain transportation and processing, individuals will have to adapt or starve. Grain process may be done locally, using hand operated grain mills.
Plagues	Impact + 3 months	Population weakened by starvation, drinking contaminated water, eating contaminated food supplies, and stressed by shock & fear will open door to plagues, sickness and disease.

Location: Chicago, Illinois

Distance from Point-of-Impact: 1,293 miles (2,081 km)
Time of Impact: 8:45 P.M. Central

Event	Timing of Event	Effect
Flash	Impact	Nil.
Electrophonic Bursters	Impact	Too much traffic noise to detect this effect.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting). The power grid will be restored after a few hours but unstable. Intermittent black outs and brown outs. Most emergency back-up generators will be functional. Some electronics will be degraded or destroyed by the EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	The fireball will light up the sky. Debris will block some of this light. The debris will also create a backdrop to the fireball. The effect will be very eerie, like the end of the world. Dry leaves, dry grass, old newspapers, thin flammable fabrics (for example, curtains), tarpaper can ignite and burn. Several small fires will occur.
Ground Shock	Impact + 3.7 minutes	Violent ground shock.
Triggered Earthquakes	Impact + 5.4 minutes	The ground shock triggers a very large earthquake in the Reelfoot Rift fault system, commonly referred to as the New Madrid fault system. Modified Mercalli Intensity Scale of V. Some dishes & windows broken. Cracks in plaster. Unstable objects overturned.
Tsunami	Impact + 6 minutes	The Appalachian Mountains would restrict significant damage from the Atlantic Ocean Tsunami. The ground shock would produce a small tsunami in Lake Michigan that will impact the Chicago shoreline.
Debris & Aerosols	Impact + 12 minutes	The light ballistic debris will blot out the moon and the stars. Minimal heavy debris.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 1.7 hours	The impact will sound like a series of thunderclap or guns being fired.
Blast Wave	Impact + 6.5 hours	Would cause the damage of a 2-psi overpressure blast.
Mass Fires	Impact + 1 day	The ground shock and earthquake will rupture gas lines. Several fires will engulf houses and buildings and then spread primarily due to inability of fire department to respond.
Triggered Landslides		Nil.
Triggered Volcanoes		Nil.
Triggered Lava Flows		Nil.
Oxygen Depletion		Nil. Due to dust, debris fallout and released aerosols, breathing will be difficult.
Gas Evolution & Acid Rain	Impact + 1 day	Acid rainfall and black rain. Will result in fish-kills. Several plants and trees will die and the remainder will be weakened. Drinking surface water can cause sickness.
Energetic Weather Conditions	Impact + 3 days	Large storms will menace the area for several months. Tornadoes, large hailstorms, and very energetic lightning storms occur.
Magnetic Pole Reversals		Nil.
Dust & Impact Winter	Several weeks	Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.
Starvation	Impact + 1 month	Large city populations will be particularly vulnerable to starvation threat. Grain transportation and processing will be the significant issue within a very damaged infrastructure.
Plagues	Impact + 3 months	Population weakened by starvation, drinking contaminated water, eating contaminated food supplies, and stressed by shock & fear will open door to plagues, sickness and disease.

Location: Dallas, Texas

Distance from Point-of-Impact: 1,445 miles (2,326 km)
Time of Impact: 8:45 P.M. Central

Event	Timing of Event	Effect
Flash	Impact	Nil.
Electrophonic Bursters	Impact	A few people will report hearing a series of loud clicking or crackling sounds at the time of impact.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting). The power grid will be restored after a few hours but unstable. Intermittent black outs and brown outs. Most emergency back-up generators will be functional. Some electronics will be degraded or destroyed by the EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	The fireball will light up the sky. Debris will block some of this light. The debris will also create a backdrop to the fireball. The effect will be very eerie, like the end of the world. Dry leaves, dry grass, old newspapers, thin flammable fabrics (for example, curtains), tarpaper can ignite and burn. Several small fires will occur.
Ground Shock	Impact + 4.1 minutes	Violent ground shock.
Triggered Earthquakes	Impact + 7.1 minutes	The ground shock triggers a very large earthquake in the Reelfoot Rift fault system, commonly referred to as the New Madrid fault system. Modified Mercalli Intensity Scale of VI. Some heavy furniture moved. A few instances of fallen plaster and damaged chimneys. Windows, dishes, glassware broken. Weak masonry cracked.
Debris & Aerosols	Impact + 14 minutes	The light ballistic debris will blot out the moon and the stars. Minimal heavy debris.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 1.9 hours	The impact will sound like a series of thunderclap or guns being fired.
Blast Wave	Impact + 8.6 hours	Would cause the damage of a 2-psi overpressure blast.
Mass Fires	Impact + 1 day	The ground shock and earthquake will rupture gas lines. Several fires will engulf houses and buildings and then spread primarily due to inability of fire department to respond.
Tsunami		Florida will absorb most of the tsunami damage and protect the Texas coastline from severe damage.
Triggered Landslides		Nil.
Triggered Volcanoes		Nil.
Triggered Lava Flows		Nil.
Oxygen Depletion		Nil. Due to dust, debris fallout and released aerosols, breathing will be difficult.
Gas Evolution & Acid Rain	Impact + 1 day	Acid rainfall and black rain. Will result in fish-kills. Several plants and trees will die and the remainder will be weakened. Drinking surface water can cause sickness.
Energetic Weather Conditions	Impact + 3 days	Large storms will menace the area for several months. Tornadoes, large hailstorms, and very energetic lightning storms occur.
Magnetic Pole Reversals		Nil.
Dust & Impact Winter	Several weeks	Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.
Starvation	Impact + 1 month	Large city populations will be particularly vulnerable to starvation threat. Grain transportation and processing will be the significant issue within a very damaged infrastructure.
Plagues	Impact + 3 months	Population weakened by starvation, drinking contaminated water, eating contaminated food supplies, and stressed by shock & fear will open door to plagues, sickness and disease.

Location: Lincoln, Nebraska

Distance from Point-of-Impact: 1,634 miles (2,630 km)
Time of Impact: 8:45 P.M. Central

Event	Timing of Event	Effect
Flash	Impact	Nil.
Electrophonic Bursters	Impact	Several people will report hearing a series of loud clicking or crackling sounds at the time of impact.
Electromagnetic Pulse	Impact	Loss of electrical power grid. (No stoplights, no TV, no radios, elevators dead, gasoline stations without power, no indoor/outdoor lighting). The power grid will be restored after a few hours but unstable. Intermittent black outs and brown outs. Most emergency back-up generators will be functional. Most electronics will survive EMP.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	Nil.
Ground Shock	Impact + 4.6 minutes	Minor ground shock.
Triggered Earthquakes	Impact + 6 minutes	The ground shock triggers a very large earthquake in the Reelfoot Rift fault system, commonly referred to as the New Madrid fault system. Modified Mercalli Intensity Scale of VI. Some heavy furniture moved. A few instances of fallen plaster and damaged chimneys. Windows, dishes, glassware broken. Weak masonry cracked.
Triggered Volcanoes	Impact + 10 minutes	The impact will wake up the Yellowstone volcano, the largest volcano in North America. The volcano will spew forth lava, ash and a variety of gases including sulfur dioxide. This will affect the ecology near the volcano and spread over the northern hemisphere. The ash and aerosols will depress the temperature. High concentrations of acid rainfall produced near the volcano. Volcano will be active for several years.
Debris & Aerosols	Impact + 16 minutes	The fireball will light up the sky. Debris will block some of this light. The debris will also create a backdrop to the fireball. The effect will be very eerie, like the end of the world. The light ballistic debris will blot out the moon and the stars. Minimal heavy debris fallout.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 2.1 hours	The impact will sound like a series of thunderclap or guns being fired.
Blast Wave	Impact + 11.6 hours	Would cause the damage of a 2-psi overpressure blast.
Mass Fires	Impact + 1 day	Nil (Exception will be in large cities where fires will be caused by broken gas lines and grow into conflagration due to ineffectiveness of emergency response.)
Tsunami		Nil.
Triggered Landslides		Nil.
Triggered Lava Flows		Nil.
Oxygen Depletion		Nil. Due to dust, debris fallout and released aerosols, especially from the Yellowstone volcanic eruption, breathing will be very difficult.
Gas Evolution & Acid Rain	Impact + 1 day	Acid rainfall and black rain. Produces fish-kills. Several plants and trees will die and the remainder will be weakened. Drinking surface water can cause sickness.
Energetic Weather Conditions	Impact + 4 days	Large storms will menace the area for several months. Tornadoes, large hailstorms, and very energetic lightning storms occur.
Magnetic Pole Reversals		Nil.
Dust & Impact Winter	Several weeks	Food crop destroyed for current year. Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity. Effects will vary regionally. Lincoln will experience greater stress due to proximity to Yellowstone volcano and its release of debris, smoke and aerosols.
Starvation	Impact + 1 month	Due to infrastructure damage and lack of grain transportation and processing, individuals will have to adapt or starve. Grain process may be done locally, using hand operated grain mills.
Plagues	Impact + 3 months	Population weakened by starvation, drinking contaminated water, eating contaminated food supplies, and stressed by shock & fear will open door to plagues, sickness and disease.

Los Angeles, California

It was almost 7 PM. Thomas was wrapping up work at the art department of an advertising firm, when the power suddenly went out. He mistakenly figured it was a power blackout caused by the California energy shortage (probably due to manipulation from some large energy company trying to increase their profit margin). It was impossible to complete his work without electricity, so he decided to call it quits for the day. He exited the office and made his way to the asphalt parking lot next door. He unintentionally glanced up for a second and noticed something strange. A circular halo was forming around the setting sun to the West. But then he glanced to the East where the red glow of a rising sun began to take shape. He moved quickly to his car, opened the door and climbed inside. He started the car and turned on the radio. It crackled with static. He tried another, more static and another, more static. "What is happening around here?"

He headed off to his home in Woodland Hills, normally a one-hour drive in rush hour traffic. It was hot and smoggy, the end of a California summer day. Normally traffic made the commute home miserable. But today he sensed it was going to take a little longer than usual. The stoplights were out. Traffic was snarled in gridlock. Several minutes passed and he was still working his way through the first stoplight, when the ground shock violently. The stoplight swung from side to side. People ran outside into the open. Someone got out of their car and began directing traffic. Finally, Tom drove through that intersection. He thought to himself only three more stoplights to the freeway onramp and then he would be safe. The next earthquake hit two minutes later. This was no aftershock. This was THE earthquake, the One that everyone dreaded. The One that would split California in two and send it tumbling into the sea. The building to his left collapsed. As he passed the liquor store on his right, he could see rivers of alcohol winding its way to the gutter. He was watching as a woman and her child stood along the side of a brick building, and then the wall came down on top of them and they were gone. He thought of his wife and kids. He rummaged for his cell phone and dialed home. When he placed the phone to his ear all he heard was static.

The sky was beginning to get very dark. Suddenly, there was a flash of bright light and an explosion. He stared in the darkness where the flash used to be and finally made out the outline of a power transformer on a pole. The power company must be working to get the power up. A few minutes passed, and the stoplight in front of him came on. He moved slowly through the two remaining stoplights and onto the "405" freeway on-ramp. Traffic on the freeway was bad, but at least the cars were moving. As he drove at the snails pace, he would play with the radio trying to get any intelligent signal. Once and a while he thought he could pick up a word or two. He thought he heard "earthquake" and "electrical" and "emergency" and "freeway overpass". He kept trying to dial home but to no avail, so he finally gave up trying. Now and then he would hear a siren. He felt a degree of comfort that the police and firemen were responding to emergencies, getting us back on our feet again. Several hours went by and he passed the Santa Monica freeway and headed north past Westwood and through the pass. He heard several strikes of loud thunder echo off the canyon walls. He scanned the sky. No sign of lightning.

A few more hours and he made it through the pass. He felt comforted that the San Fernando Valley stretched out beneath him and it was all lit up. He went west on the "101" and exited onto Balboa Boulevard figuring he could make better time on the side roads. Tom noticed a pay phone next to the side of a minimart. He pulled over and called home. His wife answered, she was hysterical. From the way she spoke Tom could tell she had been in tears. She said "Tom, Keep your windows down. I had this dream. You need to keep your windows down." He tried to find out if the house was O.K. What about his two sons? Why didn't the radio work? Had she heard any emergency broadcast? What was happening? But she was hysterical and all she did was to continue to babble about her dream and the stupid car windows.

He got back into the car and slammed the door. The car was beginning to overheat because of the hours of stop-and-go traffic. He shut off the air conditioner. He thought, "I'll give the car a break." He rolled down the electric windows. He thought "I hope this makes you happy!" He took off his jacket and tie. Suddenly, the car was being tossed about. Water was everywhere. The car headlights went dead after a few seconds. Water began pouring into the car. It was cold, very cold. It tasted like saltwater. And now it was completely dark. He undid his seatbelt. He removed his shoes. He reached up and gobbled a breath from the air bubble that formed at the ceiling and pulled himself through the window and up from the bottom of the sea.

When he reached the surface, he was in black water and black sky. There was current. He began to swim in the dark not knowing where he was or where he was headed. There was a significant amount of debris floating in the water. He encountered a few boards and held onto them for flotation. He heard people screaming. He bumped into something. He reached over and felt it with his fingers. It felt like a body. Without thinking is the person alive or dead, he pushed away from it. He reflected. It wasn't moving. It was probably dead. After 30 minutes of floating, he could feel something under him. It was hard. He held on. After a few minutes the water level dropped slightly

and he realized he was on the roof of a house. He waited. A few hours pass. He lowered himself to the ground. He trudged through knee-deep water making his way as best he could onto dry land. He climbed up until he found what appeared to be a roadway. In the distance the headlights from a car was slowly making its way in his direction. When the car turned the last bend, it came to a dead stop. He was wet from head to toe and covered in slime and dirt. The woman inside the car look frightened as he approached. She held the steering wheel so tight that her knuckles were turning blue. He said, "Can you give me a ride?"

[Although Tom was sparred from the main brunt of the Hawaii landslide induced tsunami, he did encounter the backwash that flowed through the Los Angeles basin and then back up the San Fernando Valley. Added to this calamity was the loss of a major dam.]

Location: Los Angeles, California

Distance from Point-of-Impact: 2,712 miles (4,365 km)
Time of Impact: 6:45 P.M. Pacific

Event	Timing of Event	Effect
Flash	Impact	Nil.
Electrophonic Bursters	Impact	Too much traffic noise to detect this effect.
Electromagnetic Pulse	Impact	Nil.
Ionizing Radiation	Impact	Communications jammed for tens of hours.
Fireball	Impact + 30 seconds	Nil.
Ground Shock	Impact + 7.7 minutes	Very minor ground shock.
Triggered Earthquakes	Impact + 10 minutes	The ground shock triggers a very large earthquake in the San Andreas fault system. Modified Mercalli Intensity Scale of VIII. Considerable damage to ordinary buildings with partial collapse. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, and elevated tanks. Frame houses moved on foundation if not bolted down; loose panel walls thrown out. Significant damage to structures, roads, dams, bridges and infrastructure. Decayed pilings broken off. Branches broken from trees. Cracks on wet ground and on steep slopes. Several power transformers destroyed. Major dam breaks in the San Fernando Valley.
Debris & Aerosols	Impact + 26 minutes	The debris will blot out the sun. The effect will be very eerie, like the end of the world. Minimal heavy debris fallout.
Upper Atmospheric Effects	Impact + 1 hour	Several low earth orbit satellites destroyed. Ozone layer destroyed.
Sound of Impact	Impact + 3.5 hours	The impact will sound like a series of thunderclap or guns being fired.
Triggered Landslides	Impact + 6 hours	The ground shock will hit Hawaii 15 minutes after impact. This will trigger a large landslide on the Big Island sending an area the size of NYC down 5 miles to the bottom of the ocean. A large tsunami will result that will destroy large areas of the Pacific Ocean shoreline. This Pacific Tsunami will slam into Los Angeles 5 hours and 45 minutes later and drive 30 miles inland.
Mass Fires	Impact + 1 day	Nil (The fire department will find it difficult coordinating response to small fires that break out due to loss of communications and earthquake damaged infrastructure. They will adapt quickly to prevent mass fires.)
Impact Tsunami		Nil.
Blast Wave		Nil.
Triggered Volcanoes		Nil.
Triggered Lava Flows		Nil.
Oxygen Depletion		Nil.
Gas Evolution & Acid Rain	Impact + 1 day	Acid rainfall and black rain. Will result in fish-kills. Several plants and trees will die and the remainder will be weakened. Drinking surface water can cause sickness.
Energetic Weather Conditions	Impact + 5 days	Large storms will menace the area for several months. Tornadoes, large hailstorms, and very energetic lightning storms occur.
Magnetic Pole Reversals		Nil.
Dust & Impact Winter	Several weeks	Very dark for a few days. Hemispheric temperature drop primarily caused by sulfur gas emissions from secondary volcanic activity.
Starvation	Impact + 1 month	Large city populations particularly vulnerable to starvation threat. Grain transportation and processing will be the significant issue within a very damaged infrastructure.
Plagues	Impact + 3 months	Population weakened by starvation, drinking contaminated water, eating contaminated food supplies, and stressed by shock & fear will cause plagues, sickness and disease.

The Philippine Sea

The container ship “MV Arafura” was on route to Australia with 23 crewmembers and 4 passengers onboard. The ship was heading south in the Philippine Sea. The waves were choppy and a storm was developing. Fifty minutes after the asteroid impact (10:35 AM local time), the ship shook and the crew felt a strong uplift. The force was so strong that most crewmembers were knocked off their feet. Most objects, not nailed down, fell and rattled around the floor. Several crewmembers rushed to the top deck to uncover the cause. Several containers had broken loose and fallen into the ocean. As they hung on the railing, they witnessed the ocean boiling. The air was foul, smelling like rotten eggs. They found it difficult to breathe and they lost consciousness. A week later the ghost ship ran aground in Indonesia with all onboard missing or dead.

[Small impact damage zone on the opposite side of the planet.]