# The Frequency and Consequences of Cosmic Impacts Since the Demise of the Dinosaurs

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## ABSTRACT

65 million years ago a huge asteroid collided with the Earth and ended the long reign of the dinosaurs. In the aftermath of this catastrophic event the mammals arose and eventually mankind came to dominate the surface of the planet. The Earth, however, has not been free from severe impacts since the time of the dinosaur killer. We examine the likely frequency of major impact events over the past 65 million years, the glimpses of evidence of these impacts and the predicted consequences of various types of impacts.

It is evident that the mammals had to survive frequent severe disruptions to the global climate and it is likely that over the past 5 million years hominids were faced with several life-threatening global events. Smaller but strategically located impact events could bring down our civilisation if they occurred today. Mankind has recently developed the expertise to predict and mitigate future impacts but political and financial support is lacking.

## INTRODUCTION

The story of life on Earth has seen the rise and demise of countless species. The fossil record reveals a generally continuous low level turnover of species punctuated by occasional mass extinction events. The demise of a species might be due to catastrophe or a combination of more subtle factors, such as inability to adapt to a changing habitat or competition from another species. Such a combination is more likely to occur at times of environmental stress, when a particular species that is well adapted to its habitat suddenly finds environmental conditions have changed and the competition is better able to cope with the changed conditions. Even transient environmental stresses that interfere with food chains or breeding cycles may be sufficient to tip the balance in favour of a competing species. Collisions between the Earth and comets or asteroids (collectively called "microplanets" in this paper) produce a wide range of environmental stresses and are therefore potential sources of new evolutionary directions.

The last major mass extinction, as evidenced by the fossil record, occurred 65 million years ago at the Cretaceous-Tertiary (KT) boundary. It was associated with the disappearance of some 40% of fossilizable genera and some 75% of species, including the dinosaurs (Marshall 1998). In the early 1990s a large impact crater was discovered at Chicxulub in Mexico. It has been dated to the KT boundary. The association of an impact with the KT boundary was first postulated by Louis and Walter Alverez in 1980 when they discovered a concentration of iridium in clay deposits that span the boundary. Subsequent studies of the effects of such a large impact have shown that the global environmental effects of the Chicxulub impact (discussed in more detail later) could easily account for the observed extinctions. While a range of alternative causes of the KT extinctions continue to be put forward there is an accumulation of multi-disciplinary evidence pointing to the Chicxulub impact as the main culprit.

There is also mounting evidence that other mass extinction events are associated with huge impacts by microplanets (Becker 2002). Figure 5 (page 11) shows the timing of known impact events over the past 300 million years and possible correlation with mass extinctions. While mass extinctions are important factors in the overall evolution of life on Earth consideration needs to be given to the effects of lesser impacts on the evolution of particular species, such as mankind. Of interest are the frequency and consequences of the smaller cosmic impacts that have occurred since the Chicxulub impact - an event that that created an opportunity for the rise of mammals.

## FREQUENCY OF COSMIC IMPACTS

The frequency of collisions between microplanets and the Earth can be estimated from crater counts on airless solar system bodies, such as the Moon and Mercury or from astronomical observations of the number of objects in the Earth's region of the solar system (Atkinson and others 2000). These independent measurements are in reasonable agreement and produce the impact frequencies shown in Figure 1 (lower, brown line). Also shown are known impact craters on Earth. Except for "Eltanin", these are all land impacts. Since only about 30% of the Earth's surface is land the frequency of crater formation can be expected to be about 30% of the overall impact frequency. Furthermore, craters on the Earth's surface tend to be eroded, covered or subducted in a geologically short period of time. Smaller craters generally disappear more quickly than larger craters (Grieve 1984), although there is considerable uncertainty about actual rates (Hughes 2000). Allowing for these factors gives the crater preservation rate indicated by the upper, green line. It can be seen that the most recent craters of each size range are in reasonable agreement with the expected preservation rate.

The impact rates described in the following pages are based on Atkinson (2000). A recent paper by Morrison and others (2002) indicates that rates for the smaller microplanets could be less. However, with even the most optimistic estimates of impact rates, the consequences of all but the smallest impacts

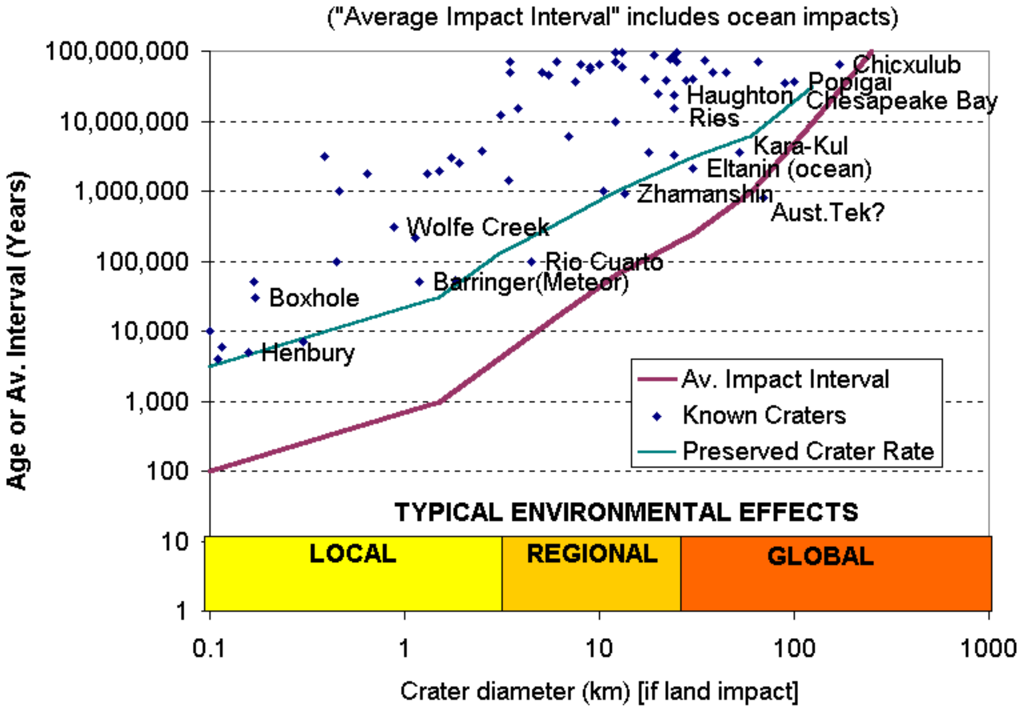


Figure 1. Estimated frequency of microplanet impacts compared with known Earth impacts.
(Asteroid diameter is approximately one twentieth of the crater diameter.)

are potentially such that they represent a risk that would be clearly unacceptable for any man-made hazardous event such as a nuclear accident.

## ENVIRONMENTAL CONSEQUENCES

Environmental effects of microplanet impacts can be classified as physical, chemical and climatic (Gerasimov 2000).

Physical effects include the vaporisation of the microplanet and most of the material in the impact crater, blast waves through the atmosphere, debris thrown out at supersonic speeds, severe dust and debris fallout, seismic waves through the ground (equivalent to earthquakes) and radiant heat from several sources: the huge meteor just prior to impact, the explosion fireball and "shooting stars" that form when ballastic ejecta re-enters the atmosphere. These cause direct physical damage to organisms.

Chemical effects include the release of a range of hazardous gases, particulates and toxins into the atmosphere. These may be directly harmful to organisms, such as by poisoning or respiratory failure or they may cause indirect effects such as acid rain or destruction of the protective ozone layer.

Climatic effects include immediate regional or global cooling due to dust, soot and particulates in the atmosphere and, for the larger impacts, delayed global warming due to the release of carbon dioxide, water vapour and oxides of nitrogen.

The magnitude, geographic range and duration of these environmental effects are dependent on many factors. Most are poorly understood and the resulting estimates are subject to considerable uncertainty (Toon 1997). Subject to these reservations, the environmental consequences from major microplanet impacts are set out in the Appendix. Consequences of smaller impacts are described below. Figure 2 illustrates the radius of destruction for physical effects (based on Steel 1995, Toon 1987, Lewis 2000).

In Figure 2 (overleaf):

- "Trees felled" is the radius for a 1psi wave front that is sufficient to knock down trees and weak buildings and shatter window glass. Severe, life-threatening injuries could be expected within this zone.

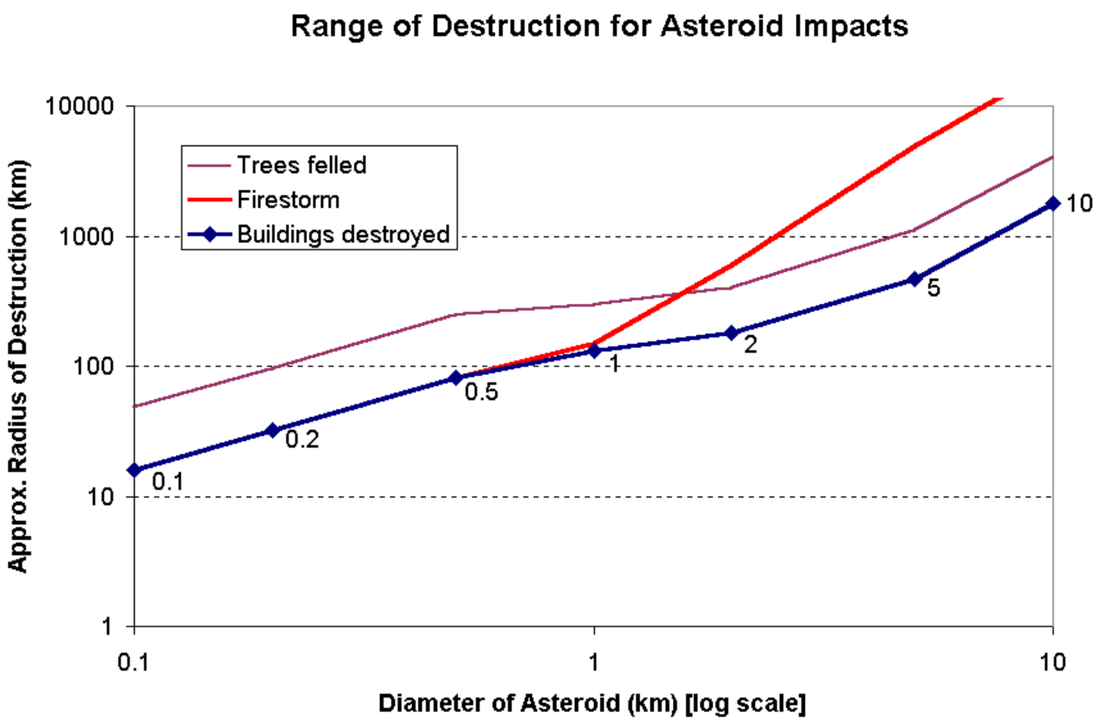


Figure 2. Estimated radius of destruction for various asteroid sizes

- "Firestorm" is the radius of ignition of combustible materials. Most surface life would perish within this zone.
- "Buildings destroyed" is the radius for a 3psi wave front that is sufficient to destroy reinforced concrete buildings (Lewis 2000). Most surface life would perish within this zone.

There is considerable uncertainty about the response of ecosystems to the environmental disturbances of microplanet impacts. At high latitudes the season of the impact would be important. In these regions an impact during winter, when plants and animals are dormant or hibernating, might not be as devastating as one during the short summer growing season. Moist tropical regions might be severely affected by the loss of sunlight and cooler conditions at any time of the year.

## EXPECTED FREQUENCY AND CONSEQUENCES

This section summarises the effects of impacts of various sizes. For the larger impacts more details about the mechanisms of destruction are given in the Appendix.

### *Events with an average interval of 1000 years or less*

Microplanets with a diameter of about 50m strike the Earth, on average, every century. On colliding with the atmosphere at speeds varying from 11km/s to 70km/s, most explode about ten kilometres above the Earth in an airburst that is similar in energy and destruction to that of a fusion bomb. Such an airburst occurred over remote Siberia in 1908 and flattened about 2000 square kilometres of forest (Steel 1985). Rare iron asteroids do survive the collision with the atmosphere and can cause a small crater on land. This happened 50,000 years ago in Arizona and resulted in the 1.5km Barringer Crater (also known as Meteor Crater). Barringer Crater has survived due to the low rate of erosion in this arid area. Lewis (2000) points out that these rarer strong asteroids, and those which collide at low speed or a very shallow trajectory and so penetrate deeper into the atmosphere, cause more destruction at ground level.

It is estimated that more than 50,000 impacts (mostly airbursts) in this range have occurred since the KT event.

The radius of destruction from these airbursts (due mostly to blast wave and radiant heat) is of the order of tens of kilometres. The effects are mostly very localised, although it has been reported that the Tunguska event caused a brief dip in the ozone shield.

Up until the last few decades the consequences of such events on life on Earth would have been minimal. The annual risk of a key location such as a city being affected is about 1 in 30 million (Paine 1999) - a much lower risk than many other natural hazards. However, within the last few decades, there is the additional risk (perhaps 1 in 10,000 per year) that a microplanet airburst over a politically sensitive nation could trigger an exchange of nuclear weapons, with much graver consequences.

### Events with an average interval of 5,000 years

Microplanets with a diameter of about 150m strike the Earth, on average, every 5000 years. They typically produce a crater about 3km across. It is estimated that more than 10,000 impacts in this range have occurred since the KT event, including some 3000 land impacts. Only 8 craters with diameters between 2km and 6km have been discovered so far. This is to be expected because most are likely to be eroded or covered within a few thousand years.

The effects from these impacts would be localised, with buildings destroyed some tens of kilometres from the centre and trees toppled up to 100km away. Dust and soot injected into the atmosphere may cause some mild global effects. The effects would be similar to moderate volcanic eruptions (such as the 1991 Mt Pinatubo eruption) that occur much more frequently (Lucht and others 2002).

### Events with an average interval of 50,000 years

Microplanets around 500m diameter strike the Earth, on average, approximately every 50,000 years. They typically produce a crater about 10km across. It is estimated that more than 1,000 impacts in this range have occurred since the KT event, including some 300 land impacts. Only ten craters with diameters between 7km and 14km have been discovered so far. Again the preservation of craters this size would generally be poor.

These impacts would cause severe local devastation (buildings destroyed out to 100km, trees felled out to 300km), some regional cooling and storms over a period of weeks, but only mild global effects. Some regions might experience a "year without summer" and crop failures due to frosts. This would no more than the effects of large volcanic explosion such as the Indonesian Tambora eruption in 1815 (Harrington 1992 and Vrba 1995). An ocean impact would probably have less severe effects, except possibly for partial ozone depletion (from chlorine injection into the atmosphere) and short range tsunami affecting low lying coastal areas.

This type of impact could only be expected to have a severe effect on land dwelling species that were geographically confined and unlucky enough to be within the region of devastation. Severe volcanic eruptions with similar consequences occur more frequently (perhaps intervals of thousands of years) but are confined to geological active regions. Impacts are randomly distributed in time and location.

### Events with an average interval of 200,000 years

Microplanets around 1.5km in diameter strike the Earth, on average, approximately every 200,000 years. If they strike land they produce a crater about 30km across. About 300 impacts of this magnitude could be expected to have occurred over the past 65 million years, with about 100 being land impacts. Eight craters with diameters between 15km and 40km have been discovered so far. Also in this size range is the "Eltanin" ocean impact just over 2 million years ago (Gersonde 1987).

These impacts would cause severe regional devastation (buildings destroyed out to 200km, trees felled out to 500km and a similar radius for firestorms), severe regional cooling and storms over a period of months and mild global effects including a "year without summer". The smaller impacts in this range would produce global effects similar to a volcanic "super eruption" such as Tabo (Sumatra 73,000 years ago) that probably occur with greater frequency than impacts (Rampino 2002). However, the larger end of the scale involves greater global disruption than any known Earth-based natural disaster.

### *Events with an average interval of 1 million years*

Microplanets 3km in diameter strike the Earth, on average, approximately every 1 million years. If they strike land they will produce a crater about 60km across.

These impacts would cause very severe regional devastation and chemical poisoning. Global effects become significant. For several months after the impact skies around the globe would be darker than the darkest cloud cover and temperatures would drop several degrees. Severe ozone depletion would probably occur, particularly with ocean impacts.

Regional effects of this type of impact on a land dwelling species would be very severe and some regional extinctions are likely. Global food chains would be disrupted for years. Ozone depletion for several years would make daytime activities hazardous.

About 65 such impacts can be expected to have occurred over the past 65 million years, with about 20 of these being land impacts. Four craters with diameters between 41km and 100km have been discovered so far.

### *Events with an average interval of 10 million years*

Microplanets 7km in diameter strike the Earth, on average, approximately every 10 million years. If they strike land they will produce a crater about 130km across.

These impacts would cause very severe regional devastation (entire continents) and severe global effects. For many months after the impact skies around the globe would be as dark as night and temperatures would drop tens of degrees.

Global effects of this type of impact on a land dwelling species would be very severe and some mass extinctions are possible.

About 6 such impacts can be expected to have occurred over the past 65 million years, with about 2 of these being land impacts. One crater with a diameter between 100km and 150km has been discovered so far.

### *Events with an average interval of 100 million years*

Microplanets 16km in diameter strike the Earth, on average, approximately every 100 million years. If they strike land they will produce a crater about 250km across.

These impacts would cause very severe global devastation. For many months, perhaps years, after the impact skies around the globe would be as dark as night and temperatures would drop tens of degrees. Surface creatures around the globe would be subjected to fierce radiant heat, firestorms, earthquakes and tsunami then darkness and freezing conditions. Once the skies cleared greenhouse warming would commence due to elevated levels of carbon dioxide, water and methane. Ocean dwellers would be subjected to deadly toxins and acidity in the water and loss of sunlight.

One impact, the Chicxulub event, is known to have occurred during the last one hundred million years.

## DISCUSSION

### *A major impact 800,000 years ago?*

There is evidence of a major impact only 800,000 years ago but no crater has yet been found. For years scientists have been investigating the huge 'Australasian Tektite Strewn Field' that stretches from China to Australia, as well as large parts of the eastern Indian Ocean. Most tektites are glass beads or balls that are produced by ejection of material fused by large asteroid or comet impacts. Evidence points to an impact some 800,000 years ago in Indochina (Schmidt et al 1993, Hartung and Koeberl 1994, Schnetzler and Mchone 1996, Howard et al 2000, Glass 1999). However, the source crater is proving very elusive (Paine 2001). Working on the geographic variation in tektite concentration Glass and Pizzuto (1994) estimated the diameter of the impact crater to be between 32 and 114 kilometres. Schnetzler is currently investigating a 100km diameter circular feature off the coast of Vietnam (personal correspondence, reported in Meteorite, Vol.7 No.4).

If a 3 to 5km diameter stony asteroid did strike Indochina 800,000 years ago then dust, soot and sulphur oxides would have spread around the globe within days and turned day into night. Freezing conditions would have occurred, in even tropical locations. It would have been months before photosynthesis could start again. Weather patterns would have been severely disrupted for years leading to extreme droughts, hurricanes and floods.

800,000 years ago our ancestors, Homo Erectus, were roaming Africa and Southern Asia. Those who survived the direct blast and firestorm effects of the impact probably had to endure extremely harsh global conditions for several years. A species that could control and use fire would have been at a major advantage during those dark, cold months. This impact may have been a very close call for the survival of mankind. Langbroek and Roebroeks (2000) state that it "must have had serious consequences for the paleo-environment and biogeographical history (perhaps including local hominid evolution) of South East Asia". However, in subsequent correspondence, Langbroek (2001) points out that, although the impact would have been very significant on a sub-continental scale, "there is no evidence that this led to long term effects in whatever way, notwithstanding that it was one of the largest [known] impacts in the time span of human evolution."

This is a very interesting impact event and there is still a great deal to be learnt about it.

### *Effects on human ancestors*

There is mounting evidence that environmental change has been a major factor in human evolution (Bobe and others, 2002, Schwartz 2002, Vrba 1995), although the effects of microplanet impacts do not appear to have been seriously considered by most working in this field. These impacts deserve greater attention. Over the past five million

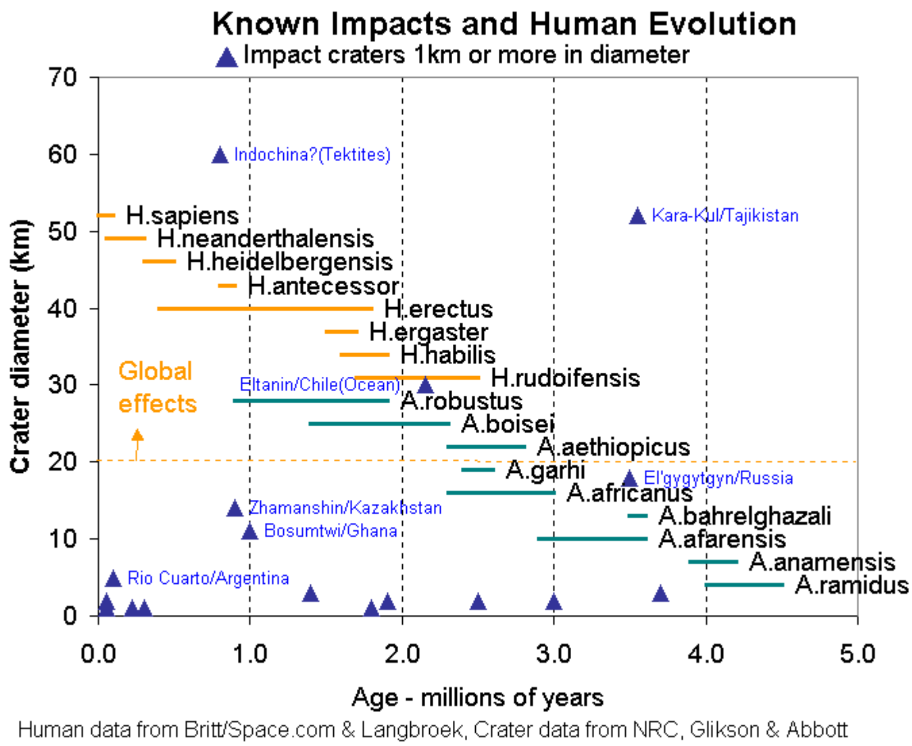


Figure 3. Known impacts and human evolution.

Note that any link between the impacts and speciation in hominids is speculative at this stage.

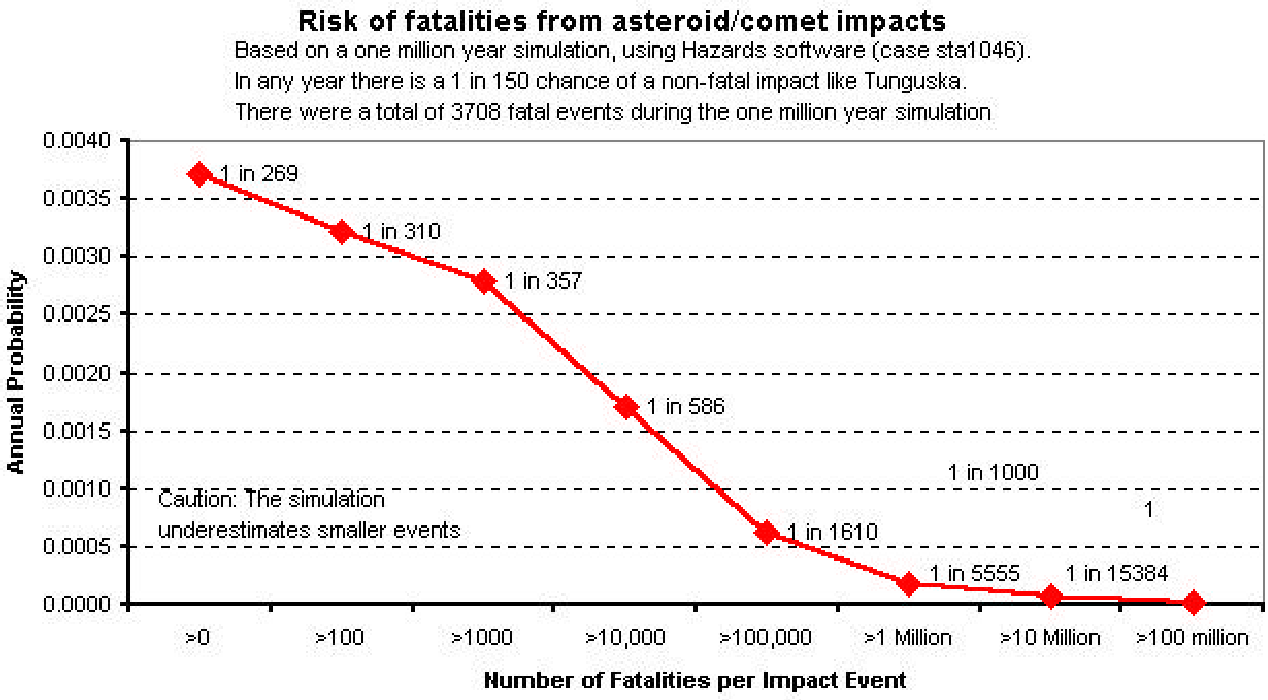


Figure 4. Estimated frequency of fatal events on a populated Earth

years at least 25 major impacts, sufficient to cause moderate to severe global climate disruption, can be expected to have taken place. We have suggested that such impacts, and perhaps smaller impacts occurring at crucial locations and times, may have punctuated human evolution (Peiser 2001). Known impacts over the past five million years are illustrated in Figure 3.

Hunter and gatherer tribes might have been less susceptible to the climate disturbances than modern society, which is so dependent on high intensity agriculture. However, for tribes that were already under stress from, say, encroaching ice ages or from other hominids, the consequences of an impact might have been crucial to survival.

On the other hand, Langbroek (2001) cautions that long term human evolution is characterised by speciation rather than extinction. It appears that mechanisms of extinction, such as impacts and ice ages, are therefore not necessary for explaining the bulk of human evolution. Similarly Dury (2001) expresses skepticism about the influence of microplanet impacts on human evolution and points out that considerable more data about climate, human genetics and extinctions of human and other fauna would be needed to establish any link with impacts.

Our point is that significant impacts must have occurred over the period of human evolution. They might be just "blips" in the geological and climate records but their sudden, drastic environmental effects would have placed great strain on land dwellers. Researchers studying human evolution should be alert to the possibility of changes brought on by microplanet impacts.

## *Response of modern society to an impact*

The above discussion deals with early humans who relied on local food resources and had minimal contact with, and dependence on, other groups of humans. Modern society is characterised by reliance on highly efficient agriculture and global trade and communications. Each of these is extremely vulnerable to the devastation and disruption arising from a major (or strategically placed) impact (Garshnek and others 2000).

Turco and others (1984) point out that the climatic effects of global nuclear war are similar to those of a microplanet impact. The comments of Turco on the effects on civilisation are still relevant:

> "The physical effects of nuclear war would be compounded by the widespread breakdown of transportation systems, power grids, agricultural production, food processing, medical care, sanitation, civil services and central government. Even in regions far from the conflict the survivors would be imperiled by starvation, hypothermia, radiation sickness [or toxins in the case of an impact - Gerasimov, 2000], weakening of the human immune system, epidemics and other dire consequences."

Much of the human population is now located in low-lying coastal areas. Many of these areas may be highly vulnerable to large tsunami generated when a microplanet strikes the ocean (Paine 1999). Generally an asteroid with a diameter of 1km or more can be expected to cause devastation across an entire ocean basin. Another problem for coast dwellers raised by Turco and others (1984 - in respect of a "nuclear winter") is that extreme temperature differentials between freezing inland locations and relatively warm air above the oceans would generate continuous hurricane-force winds along most coastlines of the continents.

Localised impact events also have the potential to traumatise society. An airburst event with an explosive yield equivalent to a fusion bomb (e.g. Tunguska in 1908) over a major city could easily cause one million fatalities. Based on Monte Carlo simulations of impacts with the current human population distribution of the Earth (software by Lewis, 2000), we have estimated that the chances of an impact event with one million or more fatalities occurring somewhere on Earth in the next twelve months is about 1 in 6000. The frequency for various degrees of fatal event are shown in Figure 4.

## Conclusions

The human species is here by a matter of luck - luck that a massive impact wiped out the ruling dinosaurs and luck that no major impacts have terminated our line during the intervening 65 millions years. In any case there have been numerous smaller impacts that may have had a profound effect on the survival of species.

The society that has developed during the benign period of the last few centuries is likely to be extremely vulnerable to an impact event (irrespective of whether it triggers a nuclear war). For the first time in the history of life on Earth a species has the ability to detect and prevent a major cosmic impact. We have the chance to turn the odds in our favour. The necessary search effort could be undertaken for much less than the budget of Hollywood movies such as "Armageddon" and "Deep Impact". If an object is found to be on a collision course the task of nudging it into a safe orbit could probably be achieved for less than the cost of putting a man on the Moon.

The main obstacle we face is a political system that uses "uncertainty" as an excuse for doing nothing (Sagan 1997). However, it is certain that one day mankind will be faced with a major, devastating impact. The only uncertainties are when this impact will occur and whether there is sufficient time to prevent or mitigate it. Currently we are barely better off than the dinosaurs.

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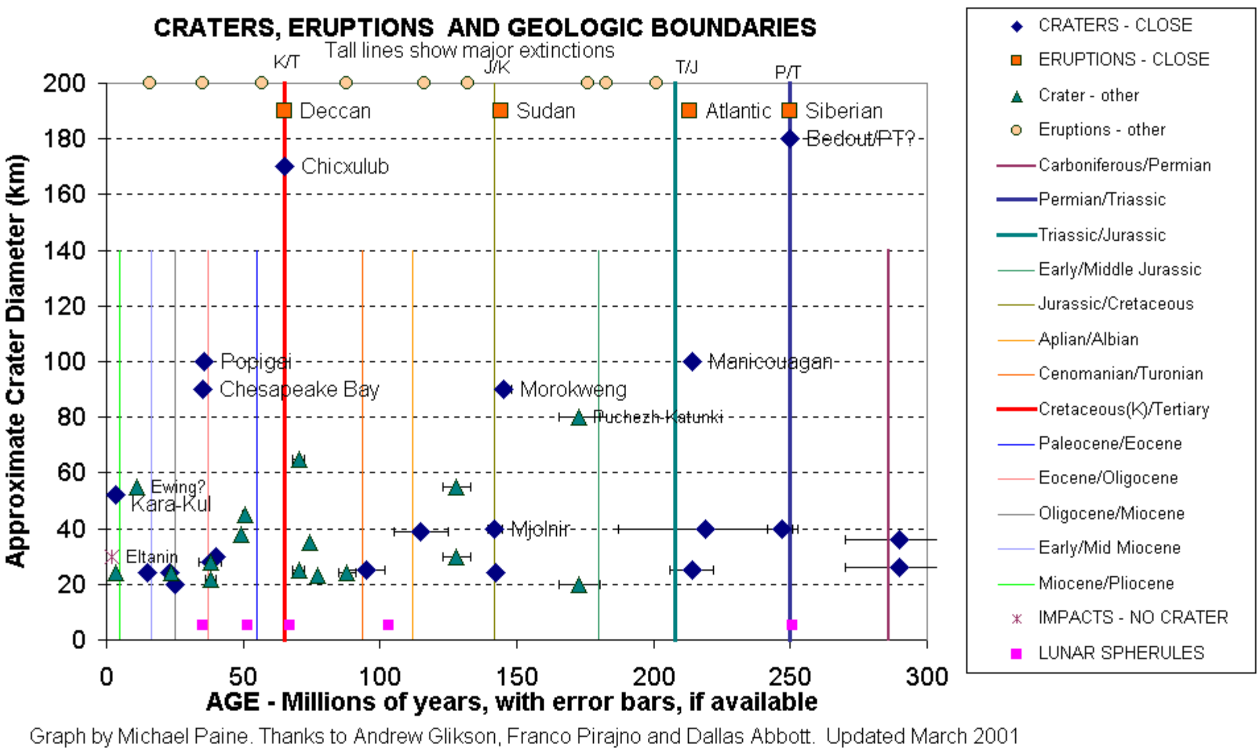


Figure 5 Known impacts over the past 300 million years, together with lava eruptions and geological boundaries (many of which mark extinction events)

### *Appendix - Environmental Effects of Impacts*

There are many environmental effects from the impact of a large asteroid or comet with the Earth. These effects depend mainly on:

- the characteristics of the asteroid or comet (size, speed, mass, material composition and strength, trajectory)
- the characteristics of the impact site (land, ice or ocean, latitude, types of rocks) and
- the prevailing climatic conditions (stage of ice age, association with other impacts, season).

There is, therefore, no such thing as a "typical" impact. Subject to this caution, and the speculative nature of many of the estimates, the following table sets out, in approximate chronological order, the expected environmental effects of a large stony asteroid with a speed of 22 kilometres per second striking land in the middle latitudes. See also similar tables by Steel (1995), O'Keefe and others (2000) and Chapman (2001).

## Summary of estimated environmental effects of major asteroid impacts

| **Environmental Effects$_1$** | **Asteroid Diameter** | | | |
|---|---|---|---|---|
| | **1 km** | **2 km** | **5 km** | **10 km** |
| Kinetic Energy (millions of megatons of TNT) | 0.1 | 1 | 10 | 100 |
| Average impact interval | 120,000 years | 400,000 years | 6 million years | 50 million years |
| Crater Diameter$_2$ - final rim to rim [transient - slumps within minutes] | 24 km [11 km] | 46 km [20 km] | 100 km [40 km] | 200 km [70 km] |
| Radius for ignition from fireball radiation$_3$ (within seconds) | 150 km | 250 km | 600 km (but see ballistic ejecta) | 1800 km (but see ballistic ejecta) |
| Blast radius for 4psi overpressure$_4$ - 500km/h winds, buildings destroyed. Also bombardment by debris (10s of minutes). [1 psi overpressure - trees knocked over, glass windows implode.] (hours) | 130 km [300 km] | 180 km [400 km] | 470 km [1100 km] | 1800 km [4000 km] |
| Dust and debris fallout cover the ground and cause severe mud flows. (months) | 300 km | 400km | 1100 km | 4000 km |
| Area for firestorm ignition due to radiation from reentry of ballistic ejecta$_3$ (within hours) | Local | Local (600 km radius) | Regional (5000 km radius) | Global |
| Earthquakes, hurricanes, torrential rain (muddy and highly acidic) and, for ocean impacts, tsunami (hours to months) | Regional | Regional | Global | Global |
| Dark skies and cooling from dust, soot and oxides of sulfur. | Regional freezing for weeks. Mild global effects for | Globally, skies darker than darkest cloud | Severe global effects, day becomes night for | Very severe global effects. Day becomes |

| Environmental Effects[1] | Asteroid Diameter | | | |
|---|---|---|---|---|
| | 1 km | 2 km | 5 km | 10 km |
| | weeks. | cover. Moderate global effects for months (no summer). | months. | night for months. Freezing conditions away from coastlines. |
| Acid rain, pyrotoxins (poisons from fires) and fallout of toxic heavy metals. | Regional for months | Regional for months | Global for months | Global for years |
| Destruction of ozone shield due to chlorine and oxides of nitrogen (hazardous UV radiation) | Partial global destruction for years | Severe global destruction for years | Total global destruction for years | Total global destruction for decades |
| Global greenhouse warming due to injection into the atmosphere of water, $CO_2$ and methane[5] | Negligible | Minor for years | Moderate for decades | Major for centuries |
| Plant growth and extinctions. | Plant growth disrupted for months. Some global crop failures. | Plant growth disrupted for years. Some regional extinctions. Global crops failures. | Photosynthesis stops for months. Decades for plants to recover. Major regional extinctions. | Disruption for hundreds of years. Global mass extinctions |

Notes:

1. Many of the values are very approximate and may vary by an order of magnitude.

2. Crater diameters were derived from the LPL Crater Calculator (http://www.lpl.arizona.edu/tekton/crater.html ), using dense rock impactor and target surface and a 45 degree impact angle. Two diameters are given, the transient crater formed at the instant of the explosion and the rim-to-rim crater that forms after the transient crater collapses, the ground slumps, usually in concentric rings, and the "rim" spreads further out. The transient crater is important for calculating environmental effects since it is associated with ejected material.

3. Fireball ignition radius and ballistic ejecta ignition radius from Toon Figure 16. There have been suggestions the radiation from the re-entry of debris from the Chicxulub (KT) impact was insufficient to *ignite* global firestorms. However Kring and others (2001) show that the debris was not distributed evenly and that local concentrations would have occurred that triggered firestorms. These would have then spread through the vegetation of most continents, which by then had been subjected to temperatures similar to those in a hot domestic oven.

4. 4 psi Blast radius from Toon Figure 5. The 1 psi blast radius is an estimate. There is considerable uncertainty about blast wave effects, which are scaled up from nuclear explosion data. Rock projectiles are assumed to be deadly over a similar range to the 4 psi blast wave. The dust and debris fallout is assumed to affect an area which is similar to that of the 1 psi blast wave, as was apparently the case with the Mt St Helens volcanic eruption.

5. Methane (a potent greenhouse gas) might be released through the seismic disturbance of undersea methane hydrate deposits.

## The authors

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Dr Benny Peiser is a social anthropologist with particular research interest in human and cultural evolution. His research focuses on the effects of catastrophic events on societal evolution and the rise and fall of civilisations. He is a Fellow of the Royal Astronomical Society and a spokesperson for Spaceguard UK. Benny is the founder and moderator of the Cambridge Conference Network (CCNet). It is in this capacity that a 10km-wide asteroid, Minor Planet (7107) Peiser, was named in his honour by the International Astronomical Union.