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The Frequency and Predicted Consequences of Cosmic Impacts in the Last 65 Million Years

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Abstract. Sixty five 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 evidence for 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 catastrophic 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 are lacking.

1. Introduction

The record 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 (Rampino & Haggerty 1996). 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 that environmental conditions have changed, and that competing species are better able to cope with the changed conditions. Collisions between the Earth and comets or asteroids 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,

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including the dinosaurs (Marshall 1998; van den Bergh 1994). In the early 1990s a large impact crater was discovered at Chicxulub in Mexico.

Subsequent studies of the effects of such a large impact have shown that the global environmental effects of the Chicxulub impact could easily account for the observed extinctions (Toon, Morrison,Turco and Covey 1997). There is also mounting evidence that other mass extinction events are associated with large impacts by impactors (Becker 2002). 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, including humans.

2. Frequency of Cosmic Impacts

The frequency of collisions between comets and asteroids 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, Ticknell, & Williams 2000). These independent measurements are in reasonable agreement and produce the impact frequencies shown in Fig. 1 (lower line). Allowing for ocean impacts and the gradual obliteration of land craters produces the crater preservation rate indicated by the upper line in Fig. 1. 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 below are based on Atkinson et al. (2000). A recent paper by Morrison et al. (2002) suggests that rates for the smaller objects might be less.

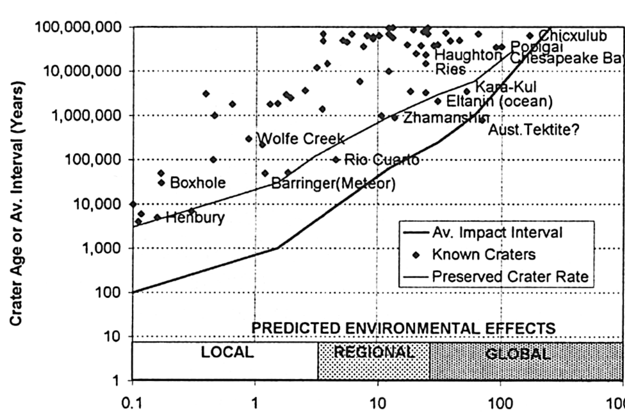

Figure 1. Estimated frequency of impacts (including ocean impacts) compared with known Earth impacts. Asteroid diameter is approximately one twentieth of the crater diameter. Estimated frequency based on Atkinson et al. 2000.

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3. Environmental Consequences

Environmental effects of impacts can be classified as physical, chemical and climatic (Gerasimov 2000). Physical effects include the vaporisation of the impactor and most of the material in the impact crater, blast waves through the atmosphere, debris thrown out at supersonic speeds, severe dust and debris fall-out, 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 the environment(Toon 1997). 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 (Toon 1997). 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).

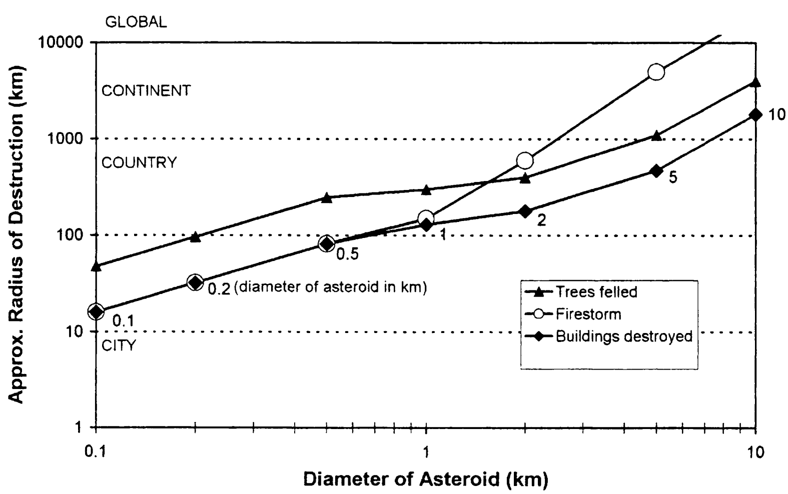


Figure 2. Estimated radius of destruction for various asteroid sizes. Based on Toon et al 1997.

Figure 2 illustrates the approximate radius of destruction for physical effects. "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 for many animals could be expected within this zone. "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.

Table 1. Expected frequency of impacts

Impactor Diameter	Avr. Int. (years)	No. KT event All (land only)	Crater D (No. Craters)	Effects
150 m	5000	10,000 (3000)	3 km (8)	Localised destruction (100km radius) Mild global effects, similar to Mt Pinatubo volcanic eruption (1991)
500 m	50,000	1000 (300)	10 km (10)	Regional destruction (300km radius). Mild global effects, similar to severe volcanic eruptions such as Tambora (1815)
1.5 km	200,000	300 (100)	30 km (8)	Regional destruction (500km r). Moderate global effects such as a "year without summer"
3 km	1 million	65 (20)	60 km (4)	Severe regional dest. (1000 km r) Moderate to severe global effects
7 km	10 million	6 (2)	130 km (1)	Continental destruction. Severe global effects. Regional extinctions.
16 km	100 million	-	250 km (1)	Global destruction. Mass extinctions.

4. Discussion

There is evidence of a major impact in South East Asia only 800 000 years ago but no crater has yet been found. (Paine 2001). Utilising the geographic variation in tektite concentration Glass & Pizzuto (1994) estimated the diameter of the impact crater to be between 32 and 114 kilometres. This impact must have had severe regional consequences (Langbroek & Roebroeks 2000), and may have been a very close call for the survival of mankind. Over the past five million years, at least 25 impacts, sufficient to cause moderate to severe global climate disruption, are predicted 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 or influenced hominid speciation (Peiser 2001). 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 located) impact (Garshnek et al. 2000).

5. 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 significant effect on the course of evolution. 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.

References

Atkinson, H., Ticknell, C., & Williams, D. 2000, Report of the Task Force on Potentially Hazardous Near Earth Objects, UK Government, September 2000

Becker, L., 2002, Scientific American, 286, 62

Garshnek, V., Morrison, D., & Burkle, F. 2000, J. Space Policy, 16, 213

Gerasimov, M. V. 2000, in International Conference on Catastrophic Events and Mass Extinctions: Impacts and Beyond, Vienna, Austria.

Glass, B.P. & Pizzuto J. E. 1994, J. of Geophysical Research, 99, 19075

Langbroek, M., & Roebroeks, W. 2000, J. Human Evolution, 38, 595

Lewis, J. 2000, in Comet and asteroid impact hazards on a populated Earth, (N.Y.: Academic Press)

Marshall, C. R. 1998, Nature, 392, 17

Morrison, D., Harris, A., Sommer, G., Chapman, C., & Carusi, A. 2002, Dealing with the impact hazard, Asteroids III (in preparation), (Tucson: University of Arizona Press)

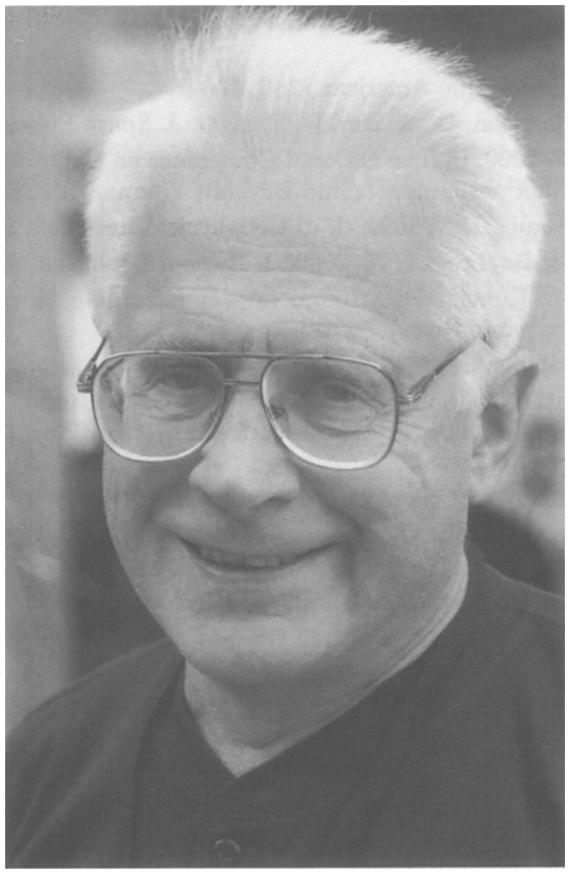
Paine, M. 2001, Source of the Australasian Tektites, Meteorite, 7, 1

Peiser, B. 2001, in BROHP Charterhouse Conference 2001, Godalming, United Kingdom

Rampino, M. R., & Haggerty B. M. 1996, Earth, Moon, and Planets 72, 441-460.

Toon, O., Morrison, D., Turco, R., & Covey C. 1997, Reviews of Geophysics, 35, 41

van den Bergh, S. 1994, in ASP Conf. Ser. 106, Astronomical Catastrophes in Earth History, 689



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