Effects of an impact event: an analysis of asteroid 1989FC

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Abstract
It is said that we live in a cosmic shooting gallery, under constant threat of orbital bombardment by the many objects that hurtle through the Solar System at breathtaking speeds each and every day. Near-Earth asteroids (NEAs) have collided with our planet throughout its existence; more frequently during some time periods than others. Astronomers have discovered over 3000 NEAs of all sizes, including over 1500 NEAs with a diameter greater than 1 km - the so-called extinction event asteroids. The consequences of an impact for our civilization cannot be overstated, yet, as encounters with NEAs are so rare, no government strategy exists to deal with one. This paper considers one of these objects that caught the public eye and attention, and examines what the likely sequence of events would be had that asteroid impacted with the Earth. It also discusses the response to the threat of an impact by those international bodies and scientific agencies that have a remit to negate the hazard.
Keywords: impact, asteroid, Asclepius, 1989, Earth, detection, E.L.E., hazard.

Introduction

Observed for more than 25 years, and well tracked, the Apollo[1] asteroid 1989FC has thus been assigned a permanent catalogue number and renamed Asclepius[2]. Therefore the correct way to refer to this asteroid is now (4581) Asclepius; the number 4581 refers to the order that Asclepius was moved from its provisional designation to its new name under the guidelines of the International Astronomical Union. Heralding straight from ancient Greek mythology, Asclepius is not only the god of medicine but is also the love-child of Apollo, himself often associated with the heavens and the sun. Both Apollo and Asclepius are bound together in the Hippocratic Oath that all doctors know by rote; *I swear this oath by Apollo physician, by Asclepius, by health and by all the gods and goddesses*. It is therefore perhaps a historical irony that Holt and Thomas would choose this particular name for a potential harbinger of death and destruction (Temkin, 2002).

Composition

There were initially several conflicting definitive statements regarding the size of Asclepius. The American Institute of Aeronautics and Astronautics issued a paper the year after discovery stating the diameter to be anywhere between 300 and 800 m (AIAA, 1990), and NASA reporting in 1989 that the asteroid was '*a half-mile or more in diameter'* (NASA, 1989) – the equivalent to at least 800 m. However, from its brightness in the sky of an absolute magnitude of 20.4[3], we can state with some confidence that Asclepius has a diameter of at least 250 m. In the unlikely event that it is a dark (low albedo) object[4], Asclepius could be as large as 500 m. Yet scientific consensus today, with little accepted exception, agrees that Asclepius is more likely to be only 300 m in diameter or perhaps slightly smaller (Harris, 2007).

[1] A series of Earth-crossing Near Earth Asteroids - themselves defined as objects having perihelion distances (point of closest approach to the sun) less than 1.3 AU (1 AU is the distance from the Earth to the Sun) - that have orbital semi-major axes larger than Earth's. Apollo objects have orbits further from the sun than the Earth and orbital periods greater than one standard year (McGuire *et al*., 2002).

[2] So done by Henry E. Holt and Norman G. Thomas; co-discoverers. The initial name was given as 1989FC due to '1989' being the year of discovery, 'F' denoting discovery in the sixth-half of the year (end of March), and 'C' to indicate that the asteroid was the third discovered in that period (IAU, 2007).

[3] This is a measure of the inherent luminosity of a celestial object; the visual magnitude observed if the asteroid were at a distance from the Earth equal to that of the sun (1 AU).

[4] A low albedo asteroid would reflect very little sunlight and would likely be comprised of darker elements such as carbon (such C-type asteroids are the most common and have the lowest albedo).

There have been no significant recorded observations of the physical structure of Asclepius; therefore any notions regarding presumed composition (and associated effects of an impact) are based primarily on speculation. Though the most populous of the asteroid families are those of the low albedo carbonaceous variety (C-type), these are largely confined to the outer regions of the main asteroid belt and as a result rarely move into Earth-crossing orbits. The majority of Apollos are understood to be stony, although comprising a smaller percentage of the total population of asteroids, and as such the default assumption of the structure of Asclepius would be similar. Consequently, the following statements are based in the speculative and hypothetical, and represent the views of the author.

Impact Event

The impact of a 300 m diameter stony asteroid would not likely result in an Extinction Level Event[5] (ELE) such as those portrayed in two well-known 'disaster' movies of the last decade. Too often public perception, fuelled by the media, focuses on the effects of these large scale impacts involving objects over 1 km in diameter. All too familiar are the storylines; debris ejected into the stratosphere, global heat pulses forcing planetary biomass to burn for weeks on end, day turning to one endless night as dust and soot shroud the planet, and photosynthesis grinding to a halt causing food chains to collapse as average temperatures plummet (Morrison & Chapman, 1992). These events, depicted in Hollywood, only occur with asteroids of much larger proportions than Asclepius – a breach of a threshold diameter barrier of 1 km is required for this kind of global devastation (Lewis, 2000). However, it is certain that a large impact event would severely stress the environment and would lead to drastic population reductions of both terrestrial and marine life.

Now that it is clear what would not happen in the unlikely event that Asclepius, or similarly proportioned object, impacted with the Earth in the future, what can be expected? This is a question that depends on the nature of the impact, of which there are three possibilities – an oceanic impact, a land impact, and a non-impact event (atmospheric explosion).

Upon impact, travelling at a typical speed of 25 km s^{-1} (Solem, 1993), the asteroid will instantaneously release enormous kinetic energy into the target rock, somewhere upwards from 1,000 Mt TNT equivalent (Harris, 2007). Dr Andrew Glikson, of the National Australian University, has stated in his own impact studies that an asteroid the size of Asclepius could release up to 30,000 Mt TNT equivalents (Glikson, 1997). Harris (2007) dismisses Glikson and others, contradicting them by stating that if one makes extreme assumptions of size (corresponding to a dense body as dark as charcoal so the asteroid is larger than expected), it may be possible to rework the impact energy up by a factor of ten to 10,000 Mt, but that 30,000 Mt is likely to be a significant overestimate. Conversely, to assume an impact velocity somewhat below average of around 15 km s^{-1}, the impact energy can be reduced by almost a factor of two. Therefore, for a nominal diameter of 300 m, the impact energy would be best estimated at around 600 Mt and should not be more than a few thousand Mt, even if the asteroid were to be of an unexpectedly low albedo and/or high density (Harris, 2007).

Regardless of the impact zone, the associated flash and blast would destroy the surrounding area up to a radius of 60-70 km, and would excavate a crater several km in diameter within seconds (Glikson 1998).

Oceanic Impact

For an impactor of this size, the most devastating type of collision would be oceanic. This is also the statistically most probable as just over 70% of the Earth is covered by oceans. The principle effect, after several million tonnes of seawater had been flash-boiled, would be the generation of a tsunami[6] that would wreak catastrophic destruction upon coastal cities and generate human casualties all along the affected coastlines. It has been calculated than an asteroid roughly the size of Asclepius would generate waves carrying more than 300 times the energy of the 2004 Asian Tsunami (Chesley and Ward, 2006). Their paper, entitled '*A Quantitative Assessment of the Human and Economic Hazard from Impact-generated Tsunami*', goes further to

[5] Defined as the extinction of all or part of life on Earth; such events have occurred at the K-T boundary (the Cretaceous-Tertiary extinction event) 65 mya and during the Great Dying of the P-Tr (Permian-Triassic extinction event) 251 mya – in both events, upwards of 50% of all species extant at the time die out.

[6] Huge sea waves caused by large-scale disturbances of the ocean floor; the word is Japanese and means 'harbour wave'. From an initial tsunami generating source area, waves travel outward in all directions (NOAA, 2006).

state that such an impact in the Atlantic ocean would create a deep water wave, upon penetration of the impactor into the sea floor, of between 2-3 m high travelling at speeds of above 450 km h^{-1}. Upon hitting the continental shelf on both seaboards the accentuation of deep-water amplitude (due to a retardation of the leading edge over shallow water causing shortening of wavelength and growth in height) will run up a wave height of between 10-15 m depending upon coastal and ocean floor topography. About half the world's population lives within 200 km of the oceans (Hardy, 2003), and in excess of 650 million people living within 5 m of the high-tide mark along coastal regions globally (CMAR, 2008) would be vulnerable to such tsunami waves, although as Chesley and Ward (2006) state no single impact could affect them all. The predicted damage cost would be measured in the billions of dollars in terms of property damage and economic losses, perhaps much higher. The global insurance industry holds just over $300 billion in reserves to cover catastrophic losses brought about by natural disasters; consider the vulnerability of $2 trillion of insured assets along the Florida coastline, and the threat posed to the insurance industry that keeps less than $½ trillion to cover all disaster losses everywhere globally in any one year. Jeremy Leggett notes all of this, and goes further to state that the global reserve could easily be entirely wiped out by one or two "mega-cats" – catastrophes striking large metropolis or economic centres – or by a series of rapid-fire smaller catastrophes (Leggett, 2005). More significantly, additional recent studies show that an asteroid-induced tsunami exceeding 100 m in height would cause massive damage to low lying areas along the US east coast and could totally submerge vast areas of Europe such as Holland and Denmark. A 100 m tsunami would travel around 22 km inland, and a 200 m tsunami would travel up to 55 km inland. Worryingly, the same study suggests that such impacts occur every few thousand years and that we are now overdue (Hills and Mader, 1997).

Terrestrial Impact

A land impact would likely result in only localised to regional damage, less widespread than an ocean impact, but equally as devastating for the affected area. Upon impact with a land surface a characteristic bowl-form crater several kilometres across and bounded by a structurally elevated rim would be excavated (Ahrens and Harris, 1992). The blast-wave would obliterate the immediate area, up to a radius of 75 km (Gritzner *et al.*, 2006), and probably severely devastate a much larger area up to 200 km in diameter (the size of a small US state such as West Virginia (Yabushita and Hatta, 1994)). The energy released would probably equal or surpass the total equivalent of the world's nuclear arsenal, and eject some millions of tons of rock and dust into the lower atmosphere (Pollack *et al.,* 1983; Hills and Goda, 1993). As both the impactor and target area become fragmented and vaporized, the sun would be clouded for a length of time measured in days and weeks, not months and years. If Asclepius made landfall in an area of high population density, such as the northeast corridor of the US, Los Angeles, or Tokyo millions would die instantly (U.S. Census Bureau, 2008). Indeed, even an impact outside of an urban area but within a 75 km radius of an urban conurbation would likely result in damage and fatalities on a currently unprecedented scale of natural disasters, particularly if there was little or no warning. The associated impact hazard, known as an 'urban firestorm', where ignition of combustible materials occurs spontaneously if enough heat energy is applied, would only add to the catastrophe. It is postulated that this would be similar to the effects experienced by survivors of Hiroshima (Chapman, 2004). The greatest harm though, according to Toon *et al*., (1997), would be caused if sub-micrometer dust was able to reach the stratosphere; due to its long residence time in the atmosphere it could cause a fall in global temperatures. This could begin to threaten worldwide agricultural production and supply in the short-term although, due to the small nature of this impact event, not to such an extent as to begin to seriously endanger global populations. Localised acid rain may be induced due to the reaction of nitrogen and oxygen in the atmosphere; acidifying lakes, soils, streams, and perhaps even the surface layer of the oceans for a short period. Again, however, this would not be a global event due to the size of Asclepius but affecting an area some hundreds, or perhaps thousands, of square kilometres around the impact site (Toon *et al.*, 1994). It is important to consider that an impactor of a diameter around 300 m is going to only affect local to regional scales. Beyond a radius of around 200 km from the impact site, the event would merely be mostly a frightening experience rather than a fatal one, and would not be expected to lead to long-term climatic effects.

It is possible, using an impact effect modeller from the University of Arizona, to simulate various different scenarios of an impact hazard for an asteroid similar to Asclepius. Owing to the unknown physical composition of the asteroid, in association with an unknown impact location, the nature of any impact of Asclepius can only be speculative. Following the example of John Lewis' (2000) attempts to predict impact consequences in his study '*Comet and Asteroid Impact Hazards on a Populated Earth*', the University of Arizona's model was run several times using different parameters (Marcus *et al.,* n.d.). Three impact scenarios are outlined in Table 1[7].

Table 1. Calculated effects at a 10 km distance from ground-zero by an Asclepius-sized asteroid impact event

Scenario	A	B	C
Asteroid Density	1500 kg m^{-3}	3000 kg m^{-3}	11000 kg m^{-3}
Impact Location	Liquid water Depth 300 m	Sedimentary Rock	Crystalline Rock
Target Density	1000 kg m^{-3}	2500 kg m^{-3}	2000 kg m^{-3}
Energy Released	1.11 x 10^3 Mt TNT	2.85 x 10^3 Mt TNT	1.16 x 10^4 Mt TNT
Crater Dimensions	Diameter 2.54 km Depth 0.54 km	Diameter 5.91 km Depth 0.51 km	Diameter 10.07 km Depth 0.61 km
Seismic Effects	Arrives at 2 secs Richter Scale 5.9 Light-to-moderate damage	Arrives at 2 secs Richter Scale 6.9 Moderate damage	Arrives at 2 secs Richter Scale 7.3 Severe damage; mass panic
Thermal Radiation Effects	Fireball is 74 x sun size Clothing ignites 3rd degree burns Grass ignites Deciduous trees ignite	Fireball is 104 x sun size Clothing ignites 3rd degree burns Grass ignites Deciduous trees ignite	Fireball is 165 x sun size Clothing ignites 3rd degree burns; flesh boils Grass ignites All woody plants ignite
Air Blast Effects	Arrives at 30.3 secs Wind speed 654 m s^{-1} Sound intensity 118 dB Windows shatter Multi-storey buildings distort; incipient collapse Highway bridges collapse >90% trees blown over	Arrives at 30.3 secs Wind speed 950 m s^{-1} Sound intensity 124 dB Windows shatter Multi-storey wall-bearing buildings collapse Steel-framed buildings collapse Highway bridges collapse >90% trees blown over	Arrives at 30.3 secs Wind speed 1660 m s^{-1} Sound intensity 133 dB Most masonry destroyed Serious damage to dams, dikes, and embankments Highway bridges destroyed Cars and trucks distorted 100% trees blown over

Atmospheric Impact

The third impact possibility is that of the 'non-impact event'; a bolide[8] exploding violently in the atmosphere above the surface of the Earth. Such episodes have been recorded in recent history, such as the 1908 bolide that exploded above Tunguska, Siberia and are traceable only through the telltale iridium anomaly (an unusual abundance of an element rarely found in the Earth's crust) on the ground as no fragmentary evidence is left. Indeed – some bolide impacts remain contentious due to the lack of any remnants from the asteroid/comet that exploded and alternative theories are frequently espoused (Cohen, 2008). A bolide event typically requires a significantly different asteroid composition; that of carbonaceous chrondite. Volatiles – compounds with low boiling points – under the asteroid surface would heat up as Asclepius grazed the Earth's atmosphere, forcing any hydrogen and carbon contained within to ignite. This would vaporize the asteroid into dust and gas in the lower atmosphere, leaving a layer of carbonaceous dust, melted metal silicates, and elements not typically found in the crust (Brown *et al*., 2002). The effects, according to Lewis (1996), would be dependent

[7] The presumed typical speed of Asclepius upon entry remained constant throughout the tests at 25 km s^{-1}. It should be noted that this is an unknown variable, as is the diameter of the asteroid (set at 300 m) and the angle of impact (constant at 45°).

[8] A generic term used to describe an impactor whose physical characteristics are not precisely understood.

upon the overpressure[9] of the blast but likely to be relatively wide-ranging. Potentially, these could include blast-wave acceleration of window glass, radiant ignition of fires, structural failure of buildings, eardrum rupture, and injury from the blast wave itself. The combined effects of which are highly similar to those of a nuclear detonation at a similar altitude without the associated gamma rays or neutron bursts. There is also the perception within the scientific community that there would be the associated production of an EMP[10] with bolide explosions, with an example of such a pulse as recently as 18th January 2000 in the Yukon Territory of Canada (France, 2000). This raises the unthinkable related hazard of a bolide blast being misinterpreted as the explosion of a nuclear weapon and the possibility of an auto-response by global powers before clarification is possible.

Current Threat?

There is no need for immediate panic. Based on its current orbital progression, there is no chance at all that this asteroid will impact the Earth in the next century, and likely not for a much longer period of time. The asteroid was brought to the forefront of the academic world, as well as creating a short-lived media hysteria, in 1989 when it was first discovered having passed within 700,000 kilometres of the Earth[11] (Marsden, 2003). Today, it is no longer considered even a remote threat, nor one needing further observation after early tracking by both the PCAS[12] and PACS[13] near-earth object observation programs. Furthermore, there are no current claims of possible impact; all have long ago been ruled out. By consulting a table of close passes by the Earth for the next century (Sansaturio, 2007) it can be seen that for each close approach listed also given is the absolute minimum distance that the asteroid could pass on that occasion – for Asclepius they are all hugely greater than the diameter of the Earth. Put simply – Sansaturio rules out any possibility that Asclepius could have passed within striking range of the Earth. The current 'poster child' for an impact hazard is (99942) Apophis (NASA, 2006; Harris,2007); an asteroid that caused considerable alarm in late 2004 when it was thought that there was a significant (1 in 40,000) chance that there would be an impact with Earth in 2036. Although this has been negated, the asteroid remains under scrutiny by NASA and other agencies.

Although the probability of an impact, even by an Asclepius-sized asteroid, is actually relatively small, the consequences of such an impact are enormous. It can be said that the risk to the individual is average and comparable to the risk taken when flying in an aeroplane (France, 2000) (due to the product of the extremely low impact occurrence probability and the extremely high casualty expectancy). There is therefore a finite risk to the population of the Earth. The greatest challenge is intellectual; reconciling the exceptionally low annual probability of being killed by an asteroid impact against the almost unparalleled consequences of such an impact; it was the gradual hazard awareness of the late 80s and early 90s that prompted action to improve and expand detection of Near-Earth Objects. This was specifically outlined by Congressional reports submitted by the US House of Representatives' Committee on Science, Space, and Technology – advocating that NASA engage in workshops to detect and intercept NEOs. The paper commissioned in 1990 by the American Institute of Aeronautics and Astronautics (AIAA) that looked at dealing with the threat of an asteroid striking the Earth put forward two disquieting points. The first was that the PCAS and PACS projects are estimated to have discovered half of the known Earth-crossing asteroids; the second was that they project that an object the size of Asclepius comes by undetected once every 2-3 years (AIAA, 1990). The saying goes that 500 m asteroids are a "dime a dozen" in the Solar System.

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[9] The difference between ambient pressure and blast-wave pressure, known as the peak overpressure; this needs to exceed 27.5kPa (or, in old money, 4 pounds per square inch).

[10] Electro-Magnetic Pulse; a transient pulse of electromagnetic energy that has the effect of rendering electronic equipment within the affected area useless – similar to that of a low-yield nuclear device.

[11] Asclepius was not discovered until well after the point of closest approach with the Earth some eight days later on the 31st March 1989.

[12] Planet Crossing Asteroid Search; initiated in 1973, this was the first of two surveys by Eugene Shoemaker using the telescopes situated atop Palomar Mountain in California. Now defunct.

[13] Palomar Asteroid and Comet Survey; the second of Shoemaker's surveys using the Palomar telescopes, this program started in 1982. Like PCAS, it was terminated in 1994.

To reiterate, the probability that Asclepius will impact by the close of this decade is negligible, as is the probability that this asteroid will impact the Earth at any point within the next century. Yet, if such an impact were to occur – there are four key potential hazard targets that would either exacerbate the effects of the actual impact or prevent effective handling of the disaster. These include (i) sensitive national security sites such as national capitols or command centres, the total destruction of which (and associated decapitation of a highly centralized government) would contribute disproportionately to the chaos; (ii) sites with hazardous materials that may be released by impact such as nuclear power plants or weapons depots, chemical plants and oilfields; (iii) geologically sensitive sites such as volcanoes and earthquake regions; (iv) sites with essential roles for food production, storage, or distribution – food interruption generates the threat of starvation and societal disorder (Lewis, 2000). Whilst an international response may be effective for regional-scale impacts, there would be no recovery for a devastating larger impact; the question of just how resilient our agriculture, commerce, economy, and societal organisation might prove in the face of an unprecedented catastrophe remains unanswered. As of now, FEMA (the Federal Emergency Management Agency, a division of the U.S. Department of Homeland Security) have no hazard mitigation or contingency plans in place to deal with the threat of an asteroid impact and the associated dangers. Equally, the United States Strategic Command (USSTRATCOM, which absorbed the U.S. Space Command in 2002) makes no mention of planetary defence in its Long-Term Vision, although the ability to detect Earth-crossing objects is listed amongst its deficiencies.

Conclusions

Events of the size described are expected, on average, once every 100,000 years or so; whilst most astronomers would say that we are “over-due” for such a sizeable impact, we can be by no means certain when that impact will occur. There are still untold numbers of asteroids (estimates range up to some ten thousand) that remain either undiscovered or uncharted, many of which will be of a similar size to Asclepius or larger. It is perhaps recklessly irresponsible that the findings and reports of the organizations whose very remit is space exploration – agencies with such spine-tingling titles as the AIAA (American Institute of Aeronautics and Astronautics) and NASA (National Aeronautics and Space Administration) – are widely ignored by the elected officials, committees, and public bodies with oversight on planetary defence. There have been continued cuts in funding since the late 1990s for both civil and government space programs like the NEAT[14] system under Administrations with other agendas. With intense competition between more traditional recipients of what little NASA funding is available, those bodies responsible for detection have found it harder year-on-year to continue progressively scanning the skies above for potential asteroid threats. It is more and more likely that the events of March 1989 will be repeated, only next time with potentially devastating results. We, as a species, could find ourselves learning of an impact event only after it has occurred.

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[14] Near Earth Asteroid Tracking; a program begun in 1995 by Eleanor Helin as part of the Spaceguard Survey, aimed at taking over and consolidating the studies of PCAS and PACS.

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