"A Hundred Million Hydrogen Bombs": Total War in the Fossil Record

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Doomsday Summer

When Disney Studios threatened to destroy the world in the summer of 1998, only NASA could save it. Blockbuster producer Jerry Bruckheimer took an old movie and made it new for Disney's *Armageddon*, strapping rocket engines on the Dirty Dozen and sending them on a suicide mission against the one foe left after the Cold War that could menace the entire continental United States—an asteroid "as big as Texas." Bruckheimer hired a space-shuttle astronaut and NASA's former director of advanced concepts to serve as the film's scientific advisors, and Disney premiered the film at an exclusive gala at the Kennedy Space Center. Stars dined under the sublime exhaust nozzles of a Saturn V before heading out to a specially designed theater to watch a crew of oil-platform roughnecks blow up an incoming "global killer" with nuclear weapons. NASA loved it. As the agency's publicist crooned: "we sort of save the planet. We at NASA team up with the oil drillers for the good of the planet. That's not fiction. That sort of thing NASA is known for: overcoming obstacles, teaming up together."[1] NASA, far from being an institution without a mission after the Cold War, got to play at being the first line of planetary defense.

Armageddon's producers may have wrapped their product in Big Science, but as numerous critics quickly pointed out, there is very

1. Amy Wallace, "Blast Off!: Who Needs a PR Agency When There's Hollywood? Premiere of *Armageddon* at the Kennedy Space Center Is the Latest Example of NASA Getting a Boost," *Los Angeles Times*, June 27, 1998, sec. F, p. 1.

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little science in the film. There is, however, a massive amount of conspicuous destruction. Throughout the film asteroids rain down like smart bombs, homing in on the world's major urban areas, toppling landmarks such as New York City's Chrysler Building, and incinerating the hub of Paris. People die just as they died in all of the twentieth century's strategic bombing campaigns: as targets, and often without knowing what hit them. Director Michael Bay offers us quick views of the cosmic assault from vantage points reminiscent of war reporting, intercutting unsteady ground footage with static long shots familiar to atomic tests. The finest and most crowd-pleasing moments of *Armageddon* are its documentary scenes of death from above. That cities are the primary targets of Outer Space's bombing campaign should come as no surprise, for (aside from being more exciting than blowing up fields of tundra) cities have been the presumed targets of strategic bombardment ever since German Zeppelins terrorized Londoners at the onset of the First World War—a presumption driven further home by the fire and atomic bombing campaigns of the Second World War. In a cruel coincidence, the first city utterly destroyed in *Armageddon*, Shanghai, also happens to be the one of the first cities ever subjected to a truly massive aerial bombardment, by the Japanese in the summer of 1937—the year when the aerial bombing of cities and civilians became a commonplace of modern warfare.

Armageddon is not a scientific film; it is a war film, and in particular a nuclear war film, with Outer Space cast as the ruthless enemy behind an apocalyptic bombing campaign. Disney Studios actually chose to raise *Armageddon*'s death-toll in order to compete at the box office, when their film was scheduled to open a month after another impact disaster film, Mimi Leder's surprisingly popular *Deep Impact*. Director Bay flew crews to Paris and Shanghai less than a month before *Armageddon*'s opening in order to shoot extra location footage for additional bombardment sequences.[2] The story told by the retooled *Armageddon* reiterates Cold War fears of nuclear escalation: a limited meteor strike (against where else but New York) is followed by increasingly destructive strikes against disparate nations' cities; more and more countries are drawn into the fray until, finally, global destruction threatens.

While *Armageddon*'s familiar tale of commando heroics may be simply one more instance of Hollywood's reliance on the proven formula, the likeness of its asteroid threat to a Cold War story of nuclear destruction actually tells us as much about the science that in-

2. Bernard Weinraub, "Asteroid Season: One Too Many?" *New York Times*, May 22, 1998, sec. E, p. 12.

spired the film as it does about Hollywood. For *Armageddon* serves as loud witness to how the Cold War continues to influence scientific representation. The threat of a massive impact and the threat of a nuclear war indeed are, in many ways, the same thing, and the Doomsday Summer of 1998 thus enters the annals of the history of science as our most popular record of how the science of cataclysmic impacts has come to understand the threat of such impacts. *Armageddon* was inspired by the popularity of the science of impact-extinction theory, the much-publicized theory that an asteroid or comet impact caused the mass extinction of the dinosaurs 65 million years ago. While it was hardly apparent at the time, with the publication of "the Alvarez thesis" in 1980 by the father-and-son team of Luis and Walter Alvarez and two nuclear chemists from the Berkeley Lawrence Radiation Laboratory, the Cold War had finally come to paleontology. Catastrophic impacts may look like World War III on the silver screen—but only, as I will argue, because by the summer of 1998 asteroid and comet impacts themselves already looked a good deal like World War III, visiting destruction upon the earth in a way very much like that threatened by the policy of strategic nuclear deterrence.

In this paper I will show how impact-extinction theory emerged from the Cold War's state of conflict, and in the process turned that conflict's nuclear threat into a state of nature. Viewed from inside the trenches of the debate over the causes of mass extinctions that it started, the Alvarez thesis may not look like a party to the Cold War, but it does look like the beginning of a scientific revolution. "The new paradigm . . . has arrived," paleontologist Karl Flessa half-jokingly announces at the opening of the Geological Society of America's Special Paper 247, a volume devoted to the tenth anniversary of serious debate over impact-driven extinctions.[3] The Alvarez thesis did arrive, but as a theoretical gauntlet tossed by a group of physicist and chemist outsiders at paleobiology's patient narrative of life on earth. It was intended to incite investigation and bring the debate over mass extinction to the larger geological community, and it surely did. Yet its ensuing study resulted in far more than that: it rallied the resources of a scientific community that had otherwise been doing the science needed to fight World War III, and ultimately taught statesmen how that war might end in a nuclear winter. The history of life on earth, it is fair to say, would never be the same.

3. Karl W. Flessa, "The 'Facts' of Mass Extinctions," in *Global Catastrophes in Earth History; An Interdisciplinary Conference on Impacts, Volcanism, and Mass Mortality,* ed. V. L. Sharpton and P. D. Ward, Geological Society of America Special Paper 247 (Boulder, Colo.: Geological Society of America, 1990), p. 1.

Walter Alvarez has already detailed impact-extinction theory's internal development in his own charming, sensationally titled scientific autobiography, *T. rex and the Crater of Doom*.[4] I will explore here how that history is party to other histories not exclusively of science, but also of military institutions, of mass culture, and, fundamentally, of Cold War politics. The road from Alvarez's first thesis to a full-fledged impact-extinction theory wends through the institutions of American nuclear arms production and is marked with signs of total war-fighting all along the way. Built on the science of impacts developed in national weapons laboratories, the theory is the wide province of planetary scientists, nuclear chemists, and weapons specialists who over the last two decades have become familiar comrades to the more sedimentary petrologists and paleontologists.

As impact-extinction theory drew the study of the deep past into the networks of Cold War science, it cast the Cold War's nuclear threat into the planet's history. The death of the dinosaurs becomes an atomic war story as researchers across disciplines mobilize the models and metaphors of nuclear war-fighting to read the earth's ancient record of catastrophic impacts. Finding total war in the fossil record, we may now read the history of impact-extinction theory for its own atomic war story. Representations of the threat posed to Earth by asteroids and comets reflect impact-extinction theory's atomic-age history and remain coded by the science and fiction of nuclear war. So it seems that projecting nuclear war onto an asteroid or comet is not as unscientific as it first seems on the silver screen, for it was projected there by earth scientists first—only not so literally.

Connecticut Yankees in the Cold War

Few traces of the Cold War are visible in impact-extinction theory's insider history. To see how the theory is connected to the history of science and culture in the Cold War, we have to dig behind the story of individual talent presented in such works as Walter Alvarez's *T. rex and the Crater of Doom*. From the point of view of its creators and celebrants, impact-extinction theory originated in late June 1978 with a chance discovery in a sample of clay that Walter Alvarez collected while working in the Italian Alps, doing the normal business of fine-tuning the time lines of geological history.

Geology is a science of history as well as of rock. Its time lines consist of stratigraphic boundaries, which are layers of rock found in various parts of the world that bear common recognizable features. Geology's boundaries were originally based on the different kinds of

4. Walter Alvarez, *T. rex and the Crater of Doom* (New York: Vintage Books, 1997).

rock that early researchers had access to, but they also often mark divisions between distinctive kinds of fossils, and thus serve as indices of how life evolved over Earth's history. The boundary that interested the first impact-extinction theorists is the Cretaceous-Tertiary boundary, or K-T boundary, which is marked by a layer of clay found at the same geologic moment on several continents. The K-T clay also marks a very rare event: a mass extinction, in which not just single species died out, but whole classes of life such as dinosaurs, and new classes of life, such as mammals, began their rise to the top of the food chain. Before Alvarez and his team began working on it, no one seriously considered a causal connection between the K-T clay and a mass extinction. The clay was simply a convenient chronological marker laid throughout the world's marine sediment.

When a colleague pointed out the layer of 65-million-year-old K-T clay in the rock face that he and Alvarez were studying, Alvarez initially saw an opportunity to apply his work in geochronology, the science of measuring the age of rocks, to the mass-extinction problem. Precisely how much time did that half-inch layer of clay sandwiched between different species of limestone fossil foraminifers represent? Walter turned to his father, Luis Alvarez, an atomic scientist also at Berkeley, for advice, and Luis suggested measuring the amount of iridium in the clay. Iridium is a heavy element that is not present in significant amounts on the surface of the earth, but that rains down from space at a more-or-less constant, measurable rate. It makes a fine 65-million-year-old stopwatch, assuming one lives in a uniformly raining world.

Fortunately, Walter Alvarez was at Berkeley, where he could team up with two nuclear chemists at the Lawrence Radiation Laboratory, Frank Asaro and Helen Michel, and use the laboratory's neutron-activation equipment to measure the amount of iridium in the K-T clay. The sample went off the scale: there was far too much. After some false starts, the Alvarez-Berkeley team hypothesized that the excess iridium was from the pulverized remains of a giant bolide—an asteroid or a comet. A massive impact right at the moment of a mass extinction could not be a coincidence. Father and son developed a simple climatological model of a two-year-long "cosmic winter" to describe how the dustcloud from the impact could have caused the mass extinction. Iridium in their clay and deadly model in hand, they sent off their results for publication in *Science*.[5]

5. L. W. Alvarez, W. Alvarez, F. Asaro, and H. V. Michel, "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction: Experimental Results and Theoretical Interpretation," *Science* 208 (1980): 1095–1108.

In order to help confirm the Alvarez thesis, impact-extinction proponents mobilized an international network of radiation laboratories to scour the world with neutron-activation analysis for iridium signatures. By 1981, anomalous iridium had been found at four independent K-T sites[6] (by 1996, that number had climbed to 103[7]). All that the researchers had to do now was find the crater, assuming it had not been erased on the ocean floor due to continental drift and seafloor subduction. Over the next few years, independent K-T samples indicated that the bolide had hit a coastline. In particular, in 1984, U.S. Geological Survey researchers found shocked quartz at the K-T boundary, which proved to be a sure sign of a continental impact, for quartz is a felsic mineral found primarily in continental crust.[8] That, coupled with new evidence published in 1985 of massive tsunamis in Haiti and Texas right at the K-T boundary,[9] led researchers to look in the Gulf of Mexico for a large crater. Geologic Survey of Canada geologist Alan Hildebrand unearthed some old surface-gravity surveys of the Yucatán Peninsula that revealed a 180-kilometer-wide buried crater centered at Puerto Chicxulub. To produce such a large crater, the impactor had to have been approximately ten kilometers across.[10] Its blast would have measured 10^8 megatons, the equivalent of, in Alvarez's colorful description, "a hundred million hydrogen bombs."[11]

The original Yucatán gravity surveys had been done in the 1950s by Mexican Petroleum geologists who were prospecting for oil. Ironically, PEMEX geologists who resurveyed the area in the 1970s had already identified this area as a buried crater in a talk in 1981, but their work went unnoticed until Hildebrand tracked them down personally and eventually published the "smoking gun" Chicxulub crater paper with them in 1991.[12] The rest of the empirical pieces fell into place: Walter Alvarez went down to the Yucatán and learned that other PEMEX geologists had already found impact melt droplets at the K-T boundary, but had not known what they were; the PEMEX

6. Alvarez, *T. rex* (above, n. 4), p. 81.

7. David E. Fastovsky and David B. Weishampel, *The Evolution and Extinction of the Dinosaurs* (New York: Cambridge University Press, 1996), p. 405.

8. Alvarez, *T. rex* (above, n. 4), p. 97.

9. Ibid., p. 108.

10. J. Harte, *Consider a Spherical Cow* (Mill Valley, Calif.: University Science Books, 1988), p. 8.

11. Alvarez, *T. rex* (above, n. 4), p. 5.

12. A. R. Hildebrand et al., "Chicxulub Crater: A Possible Cretaceous/Tertiary Boundary Impact Crater on the Yucatán Peninsula, Mexico," *Geology* 19 (1991): 867–871.

company drill cores from 1952 were finally tracked down, and they were filled with impact melt;[13] and the rest is history—of science.

Alvarez has written a fine scientific detective story, but in the end it leaves its readers with a question that only a larger Cold War story can answer: why did the impact-extinction thesis have to wait until the 1980s to become such a compelling scientific concept? After all, the premise that a comet could devastate the earth is a very old idea. William Whiston speculated in his 1696 *New Theory of the Earth* that the Noachian deluge was caused by a near miss with a comet, which washed the globe and shifted its orbit.[14] Laplace studied the close pass of Lexell's Comet by the earth in 1770 and wrote in his *System of the World* that comets might strike the earth and thus would "whole species [be] destroyed; all the monuments of human industry reversed."[15]

The latter half of the twentieth century is peppered with reasonable scientific impact-extinction scenarios. In a paper delivered in 1942 to the Society for Research on Meteorites entitled "Cataclysm and Evolution" (later printed in *Popular Astronomy*), meteorite researcher H. H. Nininger argued that large impacts may have had an influence on the evolution of life. Extrapolating from the close encounter of Earth with Hermes (an asteroid discovered in October 1937 that passed Earth within twice the distance to the moon), Nininger reasoned that if "the visit of the little planetoid . . . had been timed slightly differently, a few billion tons of meteoric matter might have smacked the Earth in a single lump!"[16] Nininger thus concludes:

> It seems here that we have here an adequate explanation of . . . the sudden blotting out of the fauna and flora of certain great areas which the fossil records suggest. . . . Violent climatic changes would have resulted, locally at least, from the heat of the impacts and from changes in the content of the atmosphere. . . . Species would have disappeared and new ones would have developed to take their places.[17]

Speculation about the impact threat resumed after World War II. Geochemist Allan O. Kelly and amateur astronomer Frank Dachille

13. Alvarez, *T. rex* (above, n. 4), pp. 113–127.

14. William Whiston, *A New Theory of the Earth*, book 2 (London: R. Roberts, 1696), pp. 126–156.

15. Cited in Carl Sagan and Ann Druyan, *Comet!* (New York: Ballantine Books, 1997), p. 279.

16. H. H. Nininger, "Cataclysm and Evolution," *Popular Astronomy* 20 (1942): 270.

17. Ibid., pp. 271–272.

self-published in 1953 an entire book devoted to the comet threat, entitled, appropriately, *Target Earth*.[18] Digby McClaren's 1970 presidential address to the Paleontological Society described various mechanisms by which an oceanic impact could have caused the Frasnian mass extinction.[19] In 1973, Harold Urey even proposed in the journal *Nature* that a comet impact had caused the K-T extinction. Urey had previously speculated that all "geological periods were terminated by such collisions, but this was published in the *Saturday Review of Literature*, and no scientist except me, so far as I know, reads that magazine."[20] The idea of a catastrophic impact has indeed inspired a lot of speculative literature, but none of these proposals generated a fraction of the scientific interest that the Alvarez thesis did.

The Alvarez-Berkeley team had several advantages over prior nonstarters, due both to the way they formulated and presented their theory and to their location in the larger context of the history of geology and, in particular, impact science. One initial advantage they had was Luis Alvarez. Walter Alvarez describes impact-extinction theory's development as an internal affair: the scientific furor that the team's work raised, he holds, stemmed from the intrinsic interest the geological community took in their *Science* article and a few previous iridium-spike papers.[21] Yet Nobel laureate Luis Alvarez, not Walter, gave the first public presentation of the impact-extinction thesis five months before the *Science* article was published[22]—and it was not at a geology meeting, but at the American Association for the Advancement of Science meeting in January 1980, with the world press present. Members of the scientific press remember Luis Alvarez, not only for flying as a scientific observer alongside the Enola Gay and for winning the Nobel Prize, but also for his scientific detective work on the Zapruder film of the Kennedy assassination, as well as for his attempts to take X-rays of the Pyramid of Chephren, using cosmic rays in search of pharaoh's gold. Impact-extinction theory became news. The story was immediately reported in *Science*

18. Allan O. Kelly and Frank Dachille, *Target Earth* (Carlsbad, N.M.: Target Earth, 1953).

19. Digby J. McLaren, "Presidential Address: Time, Life, and Boundaries," *Journal of Paleontology* 44:5 (1970): 812.

20. Harold Urey, "Cometary Collisions and Geological Periods," *Nature* 242 (1973): 32.

21. Alvarez, *T. rex* (above, n. 4), p. 82.

22. Luis W. Alvarez, *Alvarez: Adventures of a Physicist* (New York: Basic Books, 1987), p. 258.

News,[23] was covered in the *New York Times* five months later,[24] and finally made it to PBS's *Nova*.[25]

Of course the Alvarez-Berkeley team's theory was of deep scientific interest too. A more crucial methodological point is that it was unique among impact-extinction theories because, as William Glen stresses, it was testable.[26] The Alvarez-Berkeley team, in their unusually long article, reasoned like physicists—not only writing a plausible historical narrative, but also laying out a list of theoretical predictions that could be observationally confirmed. Fifteen of their predictions were actually confirmed, the most important of which was the presence of iridium spikes at the K-T boundary over much of the world.[27]

Luis Alvarez writes that it took a village to do this kind of science: "We needed Walt's geologic expertise, Frank's and Helen's nuclear and chemical competence, and my background in physics and astronomy. If any of this knowledge had been unavailable, the theory might have been a long time coming."[28] Yet in addition to an astute local community, the theory also had history on its side. The Alvarez thesis inherited a Cold War scientific and cultural legacy, and that is a narrative that is dormant in the popular and inside histories of K-T field geology. It takes only a small leap back into history, though, to connect a layer of clay in the Italian Alps to the nuclear war machine.

Laboratory Ground Zero

Impact-extinction theory may have originated in the summer of 1978, but it is also the interdisciplinary scion of the science of cratering developed in national laboratories during the first decades of the Cold War. The 2,500+ papers and books that have followed up on the Alvarez-Berkeley team's work[29] have been generated in Los Alamos supercomputers and NASA research laboratories as much as they have emerged from the warrens of relatively autonomous universities such as U.C. Berkeley (itself a prominent Big Science institution). An institutional beneficiary of the nuclear arms race, im-

23. "Now—Asteroid-Caused Extinctions," *Science News* 117:2 (1980): 22.

24. Walter Sullivan, "Two New Theories Offered on Mass Extinctions in Earth's Past," *New York Times*, June 10, 1980, sec. C, p. 3.

25. "The Doomsday Asteroid," *Nova* #2212G (PBS, April 29, 1997).

26. William Glen, "What the Debates Are About," in *The Mass-Extinction Debates: How Science Works in a Crisis*, ed. idem (Stanford: Stanford University Press, 1994), p. 9.

27. Alvarez, *Alvarez* (above, n. 22), p. 258.

28. Ibid., pp. 257–258.

29. William Glen, "Introduction," in Glen, *Mass-Extinction Debates* (above, n. 26), p. 2.

pact-extinction theory had also been a party to the Cold War ever since the Alvarez thesis became linked with theories of nuclear winter in the early 1980s. The study of impact-induced extinctions and nuclear winter fed back in support of one another throughout the 1980s, forging a scientific link between the death of the dinosaurs and the effects of nuclear war.

Parallels between impacts and nuclear explosions were drawn at the very start of the atomic age. Captain William Parsons, who personally assembled the Little Boy uranium bomb while en route to Hiroshima, boasted upon his return: "if the Japs say a meteor has hit them, we can tell them we have more where this one came from."[30] The continued development of nuclear weapons over the following two decades would make a full-fledged science of that metaphor. In the planetary sciences, impact craters and explosive craters are now treated as basically the same object: the same general theory and a common kit of hydrodynamic equations are used to model each. The similarity is natural—but nevertheless, the connection had to be made, and it was first made on the moon.

An oblique link between projectile weaponry and lunar cratering effects dates back to at least the seventeenth century, where we find Robert Hooke in his *Micrographia* of 1664 describing how he dropped bullets into wet clay to simulate the pitted face of the moon. Ironically, Hooke dismissed this successful demonstration in favor of an out-gassing theory for the origin of lunar craters: he could not plausibly extend the mechanism of his own impact events to lunar events, since, "considering the state of and condition of the Moon, there seems not any probability to imagine, that it should proceed from any cause *analogus* to this [bullet]; for it would be difficult to imagine whence those should come, and next, how the substance of the Moon should be so soft."[31] In 1873, British astronomer Richard A. Proctor posited—to the chagrin of many fellow astronomers[32]—that lunar craters were formed by an incoming "plash of meteoric rain" rather than by volcanoes.[33] Proctor's ideas were revised twenty

30. Quoted in William L. Laurence, *Dawn over Zero: The Story of the Atomic Bomb* (New York: Knopf, 1946), p. 220.

31. Robert Hooke, *Micrographia: or, Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses with Observations and Inquiries Thereupon* (London: Royal Society of London, 1664), p. 243 (emphasis in original).

32. Ursula B. Marvin, "Impact and Its Revolutionary Implications for Geology," in Sharpton and Ward, *Global Catastrophes* (above, n. 3), p. 150.

33. Richard A Proctor, *The Moon: Her Motions, Aspects, Scenery, and Physical Condition* (London: Longmans, Green, 1873), p. 345.

years later by the eminent American geolgist Grove Karl Gilbert, who suggested that the face of the moon was marred by plunging moonlets swept up from earth orbit.[34]

The analogy of impacts to weapons' effects was taken more seriously in the twentieth century as the study of lunar craters shifted from a gentlemanly to a military affair. Up until then, the consensus was that lunar craters were volcanic and relatively peaceful. In order to prove an explosive-impact origin for lunar craters, physicists and astronomers had to get at big craters in-process, and the best place for that was the high-explosives battlefield and Cold-War proving ground. Impact science became explicitly connected to weapons science through the scientific analogy of impacts and explosions. This analogy was first developed by the Russian E. J. Öpik in 1916, and then independently developed in 1919 by an American physicist working on explosions at Langley Field, Herbert E. Ives.[35] Ives first noted in the *Astrophysical Journal* that bomb craters have radiating streaks and central peaks much like lunar craters. Given that meteors strike the earth's atmosphere at between 16 and 64 kilometers per second, Ives figured that the resulting heat from an impact upon the airless moon would gasify the impacting material and produce an explosion.[36] The first comprehensive collection of data on the dimensions of lunar craters, known terrestrial impact craters, and explosive pits was published in 1949 by Ralph B. Baldwin in his text *The Face of the Moon*. Baldwin graphed the three classes of craters together and demonstrated that their relative dimensions are the same: "Such a crater may be produced by bomb or shell, military mine or meteorite; the effect is the same. Fortunately" (Baldwin continues, with a nod to the two branches of the military then armed with high-explosives), "during the recent war period tremendous amounts of knowledge were gathered concerning the properties of mortar and artillery shells and bombs, both army and navy."[37] In the face of such work, by the 1950s the theoretical case for an explosive-impact rather than a gradual-volcanic origin for lunar craters was becoming quite strong.

34. Grove Karl Gilbert, "The Moon's Face: A Study of the Origin of Its Features," *Bulletin of the Philosophical Society of Washington* 12 (1893): 241-292.

35. H. J. Melosh, *Impact Cratering: A Geologic Process* (New York: Oxford University Press, 1989), p. 5.

36. Herbert E. Ives, "Some Large-Scale Experiments Imitating the Craters of the Moon," *Astrophysical Journal* 50 (1919): 249.

37. Ralph W. Baldwin, *The Face of the Moon* (Chicago: University of Chicago Press, 1949), p. 127.

The case was strengthening in the field as well, as more and more terrestrial craters were being recognized as impact rather than volcanic structures. Small meteorite falls had been observed as such since the beginning of the nineteenth century, but the first link between a sizable terrestrial crater and a meteor impact was established at Coon Butte, Arizona, now known as Meteor Crater. In 1905 D. M. Barringer made the first good published case for an impact origin for this structure, and indeed for any large terrestrial crater, by studying the pulverized rock and the meteoritic iron scattered over the crater rim.[38] Barringer wanted to get rich by mining the nickel-iron that he and his colleagues theorized would be buried inside the crater; however, he was not aware of the impact-explosion analogy—it had not yet been formulated—and he overestimated how much mass would be required to blast such a hole (and also, incidentally, to blast the projectile).[39]

Equipped with their powerful impact-explosion analogy, geologists began reinterpreting dozens of huge so-called cryptovolcanic structures around the world as impact structures. Specifically, they looked for two things: shattering, and the central uplift characteristic of explosion craters, but not of volcanic craters. Shattered cones of rock had been found in the field early in the twentieth century, but their origin remained an enigma until after World War II. R. S. Dietz was the first to theorize in 1947 that shatter cones occurred only in impacts because they all pointed inward, toward ground zero.[40]

Planetary scientists got their first good look at ground zero in 1957 with the inauguration of the Atomic Energy Commission's Project Plowshare, a program devoted to the peaceful use of nuclear explosions for Brobdingnagian acts of excavation.[41] Planetary geology itself became an atomic science when Eugene Shoemaker put field studies of impact craters in dialogue with Lawrence Radiation Laboratory reports on nuclear explosions, comparing Meteor Crater, Arizona, to the

38. D. M. Barringer, "Coon Mt. and Its Crater," *Proceedings of the Academy of Natural Sciences of Philadelphia* 57 (1905): 861–886.

39. Melosh, *Impact Cratering* (above, n. 35), p. 6.

40. Robert S. Dietz, "Meteorite Impact Suggested by Orientation of Shatter Cones at the Kentland, Indiana, Disturbance," *Science* 105 (1947): 42–43. See also idem, "Shatter Cones in Cryptoexplosion Structures," in *Shock Metamorphism of Natural Materials: Proceedings of the First Conference Held at NASA, Goddard Space Flight Center, Greenbelt, Maryland, April 14–16, 1966*, ed. Bevan M. French and Nicholas M. Short (Baltimore: Mono Book, 1968), pp. 267–285.

41. Ralph Sanders, *Project Plowshare: The Development of the Peaceful Uses of Nuclear Explosions* (Washington, D.C.: Public Affairs Press, 1962).

1.2 kiloton Teapot Ess and Jangle U nuclear explosion craters.[42] Through these comparative studies, Shoemaker built a case for how both impact and manmade explosive craters are formed primarily through shock mechanisms—thus setting the foundation for the modern theory of impact cratering.[43] In 1962, he applied his analysis of terrestrial shock mechanisms to the lunar crater Copernicus and showed how the same structural processes at work on Arizona were at work on the moon.[44] With the "Sedan" test in July of that year (the first Plowshare nuclear cratering experiment), the phenomena of explosive melting, shattering, flow, and fallout were all rigorously studied by AEC geoscientists for peaceful applications.[45] By 1962, the same shocked materials that would later be found at the K-T boundary were already being produced at laboratory ground zero.

The military, of course, along with the space program, had good reason to be interested in the science of impacts and cratering during the Cold War. Two kinds of impact science in particular were developed for weapons design and defense: large-scale nuclear tests were studied to learn how to defend hardened installations from nuclear attack. Small-scale high-velocity-impact tests, in their turn, were used to refine armor-penetrating weapons, and were then expanded in institutions such as NASA's Ames Research Center with its Vertical Gun Range to include studies of the meteoroid hazard to space vehicles, satellites, and ICBMs. Cratering research on the private front also did some of the work of nuclear defense. In 1947, the Panama Canal Company initiated a series of high-explosive tests to study the vulnerability of the Panama Canal to nuclear attack; it was

42. Shoemaker's comparative studies span a number of successive papers: E. M. Shoemaker, "Structure and Quaternary Stratigraphy of Meteor Crater, Arizona, in the Light of Shock-Wave Mechanics," *Geological Society of America Bulletin* 70:12 (1959): 1748; idem, "Penetration Mechanics of High Velocity Meteorites, Illustrated by Meteor Crater, Arizona," *21st International Geological Congress Report* 18 (1960): 418–434; idem, "Interpretation of Lunar Craters," in *Physics and Astronomy of the Moon*, ed. Z. Kopal (New York: Academic Press, 1962), pp. 283–380; idem, "Impact Mechanics at Meteor Crater, Arizona," in *The Solar System*, vol. 4: *The Moon, Meteorites, and Comets*, ed. B. M. Middlehurst and G. P. Kuiper (Chicago: University of Chicago Press, 1963), pp. 301–336; idem, "Structure of the Jangle U and Teapot Ess Nuclear Explosion Craters," in French and Short, *Shock Metamorphism* (above, n. 40), p. 627.

43. Ronald E. Doel, *Solar System Astronomy in America* (New York: Cambridge University Press, 1996), p. 179. For further discussion of the history of cratering theory, see also David J. Roddy, "The Flynn Creek Crater, Tennessee," in French and Short, *Shock Metamorphism* (above, n. 40), pp. 291–322.

44. Shoemaker, "Interpretation of Lunar Craters" (above, n. 42).

45. Glenn T. Seaborg and William R. Corliss, *Man and Atom: Building a New World Through Nuclear Technology* (New York: Dutton, 1971), pp. 100–104.

from this and related high-explosives work commissioned by the National Research Defense Committee during World War II that C. W. Lampson developed a scaling law, published in 1950, that succeeded in correlating the dimensions of craters produced by different-sized charges.[46] Scaling laws were refined by researchers at the Sandia Corporation and Lawrence Radiation Laboratory working with the latest high-explosive and nuclear-crater data sets,[47] further honing the ability to extrapolate crater damage in different surface materials without having to do full-scale nuclear tests. To counter the threat of nuclear war, cratering had become a predictable science.

With the 1963 Nuclear Test Ban Treaty, American and Soviet nuclear tests either went underground or went virtual. Equations of state for metals had been devised by theoretical physicists for research on nuclear weapons design and were tested in shock-wave experiments; these equations then became the code for hydrodynamic calculations of impacts and explosions.[48] By the time of the Nuclear Test Ban Treaty, computers were becoming capable of solving the hydrodynamic equations that govern cratering—meaning that research on surface cratering carried on, but with numerical hydrocodes and high-explosive simulations to model nuclear explosions. The first numerical simulation of a nuclear explosion was performed in 1960 by H. L. Brode and R. L. Bjork at RAND,[49] and, as if to drive home the discursive unity of impacts and nuclear explosions, in 1961 Bjork used the same code to do a numerical simulation of the Arizona Meteor Crater impact.[50]

The Apollo missions between 1969 and 1972 shuttled shocked moonrock back from the lunar surface, closing the historical circle of cratering science by confirming the impact origin of its original object, lunar craters. Dated through radiometric analysis, the Apollo samples lent corroborating evidence to terrestrial impact theories by showing that many lunar craters were of relatively recent origin. By the mid-1970s, large impact craters had been recognized as a rather common feature on the surface of the earth.

46. Melosh, *Impact Cratering* (above, n. 35), pp. 9–10.

47. For example, see M. D. Nordyke, "An Analysis of Cratering Data from Desert Alluvium," *Journal of Geophysical Research* 67:5 (1962): 1965–1974.

48. Melosh, *Impact Cratering* (above, n. 35), p. 11.

49. Ibid., p. 10.

50. R. L. Bjork, "Analysis of the Formation of Meteor Crater, Arizona: A Preliminary Report," *Journal of Geophysical Research* 66 (1961): 3379–3387.

Global Killing Mechanisms

While impact science was developing as a serious field for planetary geologists, the rest of the geologic community did not pay it much mind because the plate tectonics revolution was heating up at the same time as the Apollo missions, and that work consumed most of the community's effort from the late 1960s throughout the 1970s.[51] Impact-extinction theory, in its turn, inherited the new and so-far-neglected knowledge about impacts generated in nuclear weapons laboratories and space science institutes. Impact-extinction theory in the 1980s, unlike similar scenarios advanced before the 1960s, was able to draw not only on that new knowledge base, but also on many resources that Big Science institutions had to offer. If you are a K-T researcher and need to do neutron-activation analysis, walk down the hall. More importantly, the research and supercomputing facilities at institutes such as Los Alamos Laboratory and NASA could now be mobilized to model the K-T impact's killing effects.

At the first conference devoted to impact-extinction theory, held in Snowbird, Utah, in October 1981, the productive relation of national laboratory resources and field K-T studies was directly borne out both in empirical work and in new theoretical developments.[52] Research teams from Los Alamos, working with the U.S. Geological Survey, were busy doing the normal science of theory confirmation. They had drilled New Mexico's Raton Basin and found iridium in a continental as opposed to an ancient oceanic site, adding one more pellet to the K-T impact's smoking gun.[53] One team of Los Alamos researchers in the theoretical division had modeled a killer stratospheric dustcloud based on optical data for atmospheric aerosols gathered by the Air Force Geophysics Laboratory.[54] The Los Alamos theoretical team had confirmed that airborne dust would indeed block light and stop photosynthesis. Brian Toon at NASA Ames had organized a team of university and industry scientists to perform similar computational work, and figured that the global dustcloud

51. Alvarez, *T. rex* (above, n. 4), p. 53.

52. Leon T. Silver and Peter H. Schultz, eds., *Geological Implications of Impacts of Large Asteroids and Comets on the Earth,* Geological Society of America Special Paper 190 (Boulder, Colo: Geological Society of America, 1982).

53. C. Orth et al., "Iridium Abundance Measurements across the Cretaceous/Tertiary Boundary in the San Juan and Raton Basins of Northern New Mexico," in ibid, pp. 423–433.

54. Siegfried A. W. Gerstl and Andrew Zardecki, "Reduction of Photosynthetically Active Radiation under Extreme Stratospheric Aerosol Loads," in ibid, pp. 201–210.

would largely settle out in under six months—although those early months would be rather dark.[55]

One question the Alvarez-Berkeley theory faced concerned how iridium could be spread over the entire planet. The Alvarez team assumed that it was transported in the global dustcloud they had theorized was responsible for the dinosaurs' death. Soviet hydrogen bomb tests in the 1950s created large quantities of measurable airborne carbon 14 and demonstrated that material suspended in the atmosphere takes more than a year to spread from the Northern to the Southern Hemisphere.[56] If iridium dust needed a year to cover the globe, that meant the Toon team's computational work had just shot down Alvarez's dustcloud as a mechanism for iridium transport.

Teams from Los Alamos and NASA each came up with a new way for iridium to be tossed around the world, not in a year but in an hour: through ballistic transport, just like an ICBM. NASA high-velocity gun tests showed how sufficient velocities could be generated within a fireball.[57] Los Alamos researchers used their laboratory's hydrodynamics program called YAQUI to model the lifting power of a 100-million-megaton fireball as well (YAQUI had originally been developed to model the forbidden experiment, a 500-megaton nuclear surface burst).[58]

With such institutional and theoretical ties, impact-extinction science begins to look like a species of Cold-War Big Science that owes a considerable debt to both the sciences and the institutions of nuclear arms production. The science is personally connected to atomic warfare through Luis Alvarez, who as a Manhattan Project scientist personally flew along with the Hiroshima atomic bombing mission to measure blast yield. Peering from his B-29 at the reified lifeworld of Target Japan, Alvarez had the Master's view of atomic war. It would be a too-perfect Cold War story if, thirty-four years later, those unthinkable moments still haunted him and, like a postmodern Mary Shelley, the aged scientist was suddenly overcome in the buried halls of Lawrence Radiation Laboratory by a waking dream of nature's own kind of monstrous strategic air war. That, however, is

55. O. B. Toon et al., "Evolution of an Impact-Generated Dust Cloud and Its Effects on the Atmosphere," in ibid., pp. 187–200.

56. Alvarez et al., "Extraterrestrial Cause" (above, n. 5), p. 1105.

57. Peter H. Schultz and Donald E. Gault, "Impact Ejecta Dynamics in an Atmosphere: Experimental Results and Extrapolations," in Silver and Schultz, *Geological Implications* (above, n. 52), pp. 153–174.

58. Eric M. Jones and John W. Kodis, "Atmospheric Effects of Large-Body Impacts: The First Few Minutes," in ibid., pp. 175–186.

not what happened: "Dad worked hard at finding a global killing mechanism," Walter Alvarez tells us. Luis Alvarez war-gamed new killing scenarios with his colleagues on a daily basis, devising and discarding ways to win a total war against dinosaurs with nature's own arsenal, and finally came up with a plausible mechanism by making a clever—although ultimately flawed—analogy with a famous old volcano.[59]

While impact-extinction theory's professional development has proceeded in the institutional footprints of Big Science, its conceptual development falls squarely within the domain of the metaphor theory of innovation. Geoscientists of course have access to only the imperfect traces of the K-T impact preserved in the geological record. Read in terms of nuclear war, those traces become a rich and violent text. As is common with metaphors in science, the mechanics of nuclear warfare serve a catachretic function in impact-extinction theory,[60] providing a variety of potential referents for the ancient and largely unseen mechanics of catastrophic impacts—as in the above examples where nuclear fireball simulations were used to model the K-T impact fireball, airborne carbon 14 produced in nuclear tests served as a (failed) proxy for iridium dust, and ballistic transport provided a new means for global iridium distribution. The linguist Benjamin Hrushovski describes metaphors as working by merging conventionally distinct "frames of reference," the continua of referents to which parts of any text relate.[61] Nuclear war-fighting may be understood as one of the primary frames of reference within which impact-extinction researchers situate the geological text of the K-T world. Framing the K-T impact in the "continuum of referents"—cultural and scientific—of the nuclear threat makes a wide array of semantic resources available, from theoretical models and violent imagery to new literary devices and scenarios. The whole "world-experience"[62] of the nuclear threat is at the geoscientist's disposal to flesh out the remains of K-T world.

59. Alvarez, *T. rex* (above, n. 4), p. 77.

60. Richard Boyd discusses the catachretic function of metaphors in science in his article "Metaphor and Theory Change: What Is 'Metaphor' a Metaphor for?" in *Metaphor and Thought*, 2nd ed., ed. Andrew Ortony (New York: Cambridge University Press, 1993), pp. 481–532. Boyd is extending, primarily, Max Black's interaction theory of metaphor to scientific discourse. On interaction theory, see Max Black, *Models and Metaphors: Studies in Language and Philosophy* (Ithaca, N.Y.: Cornell University Press, 1962).

61. Benjamin Hrushovski, "Poetic Metaphor and Frames of Reference," *Poetics Today* 5: 1 (1984): 12.

62. Ibid., p. 11.

As the effects of nuclear war are used to describe the K-T impact, the knowledge that is generated in that process often trades symmetrically between the geological and Cold War records. The two contexts of study interact, as Karin Knorr-Cetina states in her study of scientific innovation, "in a *literal way*, which means that the observed situation tends to be absorbed in the similarity class that is applied to it."[63] Likewise, a model initially used to do the work of theoretical classification may itself be modified by what is observed in the situation at hand, resulting in the formulation of a new theoretical class. The history of the development of a general theory of cratering is a good example of just such a symmetrical, interactive process. Herbert Ives made his first case for an impact-origin for lunar craters by making meteors become literal bombs, although to do so he turned to "a scientific by-product of the Great War," the experimental high-explosive bomb craters at Langley Field, Virginia, now observable for the first time from the air.[64] In order to dispute the commonly held view that lunar craters were volcanic, Ives laid aerial photographs of bomb craters alongside photographs of the lunar surface and carefully detailed their resemblance. "It may at first thought seem far-fetched to liken meteors to explosive bombs," he notes, except for the fact that "our calculation leads to the conclusion that a meteor striking the moon, with even the lowest velocity at which these are observed, would become a very efficient bomb."[65] Lunar craters remained independent objects, but for theoretical purposes they had been absorbed into the class of manmade bomb craters.

Turning to a scientific by-product of the Cold War, Eugene Shoemaker likewise compared lunar craters to explosive craters—this time produced by nuclear charges. Shoemaker's interactive analysis actually led him to dispute Ives's analogy between exploding meteors and exploding bombs,[66] but in the process it also greatly "extended" (to use Knorr-Cetina's term) the overall knowledge about cratering mechanics. A nuclear bomb, Shoemaker found, does not produce the same crater as an impact at the same depth because a bomb vaporizes more material than a meteor does. An impacting meteor simply cannot explode like a bomb. However, it can *shovel*

63. Karin D. Knorr-Cetina, *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science* (New York: Pergamon, 1981), p. 51 (emphasis in original).

64. Ives, "Some Large-Scale Experiments" (above, n. 36), p. 247.

65. Ibid., p. 249.

66. Shoemaker, "Interpretation of Lunar Craters" (above, n. 42), p. 316.

like a bomb: bomb craters look like meteor craters because both bomb explosions and hypervelocity impacts compress and eject the material of their "target rocks" through flows of shock energy.[67] Having shifted his focus from analyzing nuclear and lunar craters as necessarily explosive pits to analyzing them as shock-effect structures, Shoemaker could then analyze the Teapot Ess and Jangle U nuclear explosion craters as scaled-down versions of the lunar crater Copernicus, and could consequently formulate a theory of ejection mechanics that worked equally well on the nuclear proving ground and the moon.[68]

Nuclear craters served as profitable models of lunar craters for planetary scientists drawn to nuclear test sites at the close of the first long, hot decade of the Cold War in the early 1960s. At the beginning of the second heat-up of the Cold War in the 1980s, impact-extinction theory served, in its turn, as a fruitful analogue of nuclear war for scientists working to put an end to the nuclear threat. Luis Alvarez developed the idea of a dustcloud to explain both what killed the dinosaurs and what transported iridium around the world, and in the process initiated a process of analogical extension and interaction that led to the formulation of the nuclear winter theory (itself a potent metaphor).[69] Alvarez did not use an analogy with nuclear war to describe his dustcloud. Rather, he turned to one of *his* father's old books, the 1888 Royal Society volume on the environmental effects of Krakatoa.[70] Krakatoa's global dustcloud served as an analogue of the impact event. But that analogue was soon dumped as a transport mechanism—which brings us back to Brian Toon, the physicist at NASA's Ames Research Laboratory in Sunnyvale, California, who had just computed that the K-T impact would have produced six months of perpetual night.

In the process of modeling the longevity of the K-T impact dustcloud, Toon and his teammates made a more immediate analogical leap: they realized that the same kind of cloud might be produced in an all-out nuclear war. Toon quickly called his old thesis advisor, Carl Sagan, who had studied the climatic effects of dustclouds on Mars and was thinking about nuclear war as well. Toon and Sagan realized that nuclear fireballs would not lift enough dust into the at-

67. Ibid., p. 319.

68. Ibid., p. 330.

69. On the use of the term "winter" as a metaphor in its own right, see William A. Ausmus, "Pragmatic Uses of Metaphor: Models and Metaphor in the Nuclear Winter Scenario," *Communication Monographs* 65 (1998): 68–82.

70. Alvarez, *Alvarez* (above, n. 22), p. 256.

mosphere, but that soot from burning cities would certainly do the job.[71] In 1983 their teams published the first series of nuclear-winter papers in the same journal that had launched impact-extinction theory, *Science*.[72]

The nuclear-winter models served to give both theoretical and computational weight to Alvarez's initial simple model. They provided a new plausible clouding mechanism: global burning. Evidence from the K-T boundary in turn served to confirm at least part of the nuclear-winter thesis: In a 1985 paper in *Science*, University of Chicago geologists reported that they had found soot in the K-T clay. In fact, the layer is between 0.3% and 0.5% soot. To generate such a large amount of soot, the equivalent of 10% of Earth's present total biomass must have been burned by the fireball and by superheated ejecta.[73] The Chicago team's work served as further confirmation of the Alvarez impact theory, but it was also marshaled to support the nuclear-winter thesis. As physicist Richard Muller puts it, "an experiment with extensive burning of the Earth's surface had already been performed, by Nature, and it made the reality of the nuclear winter more compelling."[74]

The Terms of Mass Extinction

As the nuclear threat provides theoretical models for an impact's killing mechanisms, it also brings with it an array of violent terminology, literary forms, and imagery that turns the scientific narrative of impact into a terrifying and all-too-plausible total war story. The dramatic form of the impact trades on the dramatic form of a nuclear battlefield, each figuring as an act of sudden and ruthless mass victimization. Consider Walter Alvarez's eerily familiar description of the moment of the K-T impact:

> In the zone where bedrock was melted or vaporized, no living thing could have survived. Even out to a few hundred kilometers from ground zero, the destruction of life must have been nearly total. . . . Animals living just over the horizon first witnessed a flash of light in the sky, then a last moment of calm. Then, as the ground began to shake uncontrollably from the passing seismic

71. Richard Muller, *Nemesis, the Death Star: The Story of a Scientific Revolution* (New York: Weidenfeld and Nicolson, 1988), p. 15.

72. R. P. Turco, O. B. Toon, T. P. Ackerman, J. B. Pollack, and Carl Sagan, "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," *Science* 222 (1983): 1283–1292.

73. Wendy Wolbach, Roy Lewis, and Edward Anders, "Cretaceous Extinctions: Evidence for Wildfires and Search for Meteoritic Material," *Science* 230 (1985): 167–170.

74. Muller, *Nemesis* (above, n. 71), pp. 170–171.

> waves, the sky itself turned lethal. . . . Soon the Earth's surface itself became an enormous broiler—cooking, charring, igniting, immolating all trees and all animals which were not sheltered under rocks or in holes. . . . Entire forests were ignited, and continent-sized wildfires swept across the lands. The ejecta particles had barely fallen to Earth and the lethal, incandescent sky returned to normal, when the air was blackened by rising plumes of soot from fires which were consuming the forests and removing the oxygen from the atmosphere.[75]

Cold War subjects have heard this before, as they have already encountered the narrative of ground zero in hundreds of journalistic, cinematic and literary treatments of nuclear war (Paul Brians's annotated bibliography lists more than seven hundred works of fiction in the English language alone that depict the destruction of civilization in a nuclear war).[76] For the Cold War generations, the scenario of sudden global slaughter is a commonplace literary device, if not a fact of life.

Alvarez's narrative of a last normal moment swept away by blast effects finds its literal precedents in nuclear-activist literature and journalism. In *The Fate of the Earth* (1982), Jonathan Schell uses a single sentence to capture the age's devastating new temporality: "Now we are sitting at the breakfast table drinking our coffee and reading the newspaper, but in a moment we may be inside a fireball whose temperature is tens of thousands of degrees."[77] Both Schell and John Hersey begin their best-selling journalistic accounts of nuclear war with a vignette of the moment of explosion,[78] employing a device that the Physicians for Social Responsibility have dubbed "the bombing run" in their own literature: a narrative time line that moves progressively through blast, fire, darkness, terror, and death.[79] "Let me drop a 20 megaton bomb on a major city," Dr. Helen Caldicott requests in the opening pages of *Missile Envy* (1984), from which point she then likewise charts the stages of damage as her blast travels through space and time.[80] (Readers may also recall, as cinematic counterparts, similar depictions of atomic attack in *Fail-Safe* [1964], *The Day After* [1983], and *Terminator 2* [1991], along with

75. Alvarez, *T. rex* (above, n. 4), pp. 11–12.

76. Paul Brians, *Nuclear Holocausts: Atomic War in Fiction, 1895–1984* (Kent, Ohio: Kent State University Press, 1987).

77. Jonathan Schell, *The Fate of the Earth* (New York: Knopf, 1982), p. 182.

78. John Hersey, *Hiroshima* (New York: Modern Library, 1946), pp. 3–23.

79. Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1996), p. 199.

80. Helen Caldicott, *Missile Envy: The Arms Race and Nuclear War*, rev. ed. (New York: Bantam Books, 1986), p. 9.

the now-ubiquitous Nevada test-range footage of livestock and homesteads suddenly mauled by shockwaves.) Dinosaur or man, the bombing run is much the same.

Catastrophic impacts are routinely conflated with Cold War threats in works of popular science. The contents of planetary scientist John Lewis's *Rain of Iron and Ice: The Very Real Threat of Comet and Asteroid Bombardment* exhibit a number of military "pedagogical metaphors"[81] and literary allusions, with chapters entitled "Target: Earth," "Stealth Weapons from Space," and—echoing Robert Jungk's popular 1958 tract on the Manhattan Project—"Brighter than a Thousand Suns."[82] Lewis's metaphoric and allusive language not only describes impacts, but gives them character. Asteroid and comet orbital dynamics become clear and present dangers, which is precisely the point of Lewis's thoughtful piece of asteroid-defense advocacy.

While imagery associated with nuclear weapons and war-fighting may liven up popular impact literature, it also pervades the expert texts of impact-extinction science. Signs once limited to strategic bombing analysis and war reports, such as "lay-down" circles on maps that plot the radius of various blast effects, are now included in college textbooks about dinosaurs (Fig. 1). Earth history, too, has its dangerous characters. Surveying the papers from the second interdisciplinary conference on impacts and extinctions held in 1990 in Snowbird, Utah,[83] we find "target properties," "projectiles," "shatter cones," "shock features," "shock compression," "shock metamorphism";[84] "fallout;"[85] a "killing mechanism;"[86] "the period known as 'late heavy bombardment,'" "the time of environmental trauma;"[87] and the "extinction of life on Earth triggered by an impact."[88] We are

81. Boyd, "Metaphor" (above, n. 60), p. 485.

82. John S. Lewis, *Rain of Iron and Ice: The Very Real Threat of Comet and Asteroid Bombardment* (New York: Addison-Wesley, 1996), p. ix.

83. Sharpton and Ward, *Global Catastrophes* (above, n. 3).

84. V. L. Sharpton and R. A. F. Grieve, "Meteorite Impact, Cryptoexplosion, and Shock Metamorphism: A Perspective on the Evidence at the K/T Boundary," in ibid., pp. 301–304.

85. P. E. Olsen, S. J. Fowell, and B. Cornet, "The Triassic/Jurassic Boundary in Continental Rocks of Eastern North America: A Progress Report," in ibid., p. 585.

86. Peter Douglas Ward, "The Cretaceous/Tertiary Extinctions in the Marine Realm: A 1990 Perspective," in ibid., p. 425.

87. Nadine G. Barlow, "Application of the Inner Solar System Cratering Record to the Earth," in ibid., pp. 182–184.

88. Lubomir F. Jansa, Marie-Pierre Aubry, and Felix M. Gradstein, "Comets and Extinctions: Cause and Effect?" in ibid., p. 223.

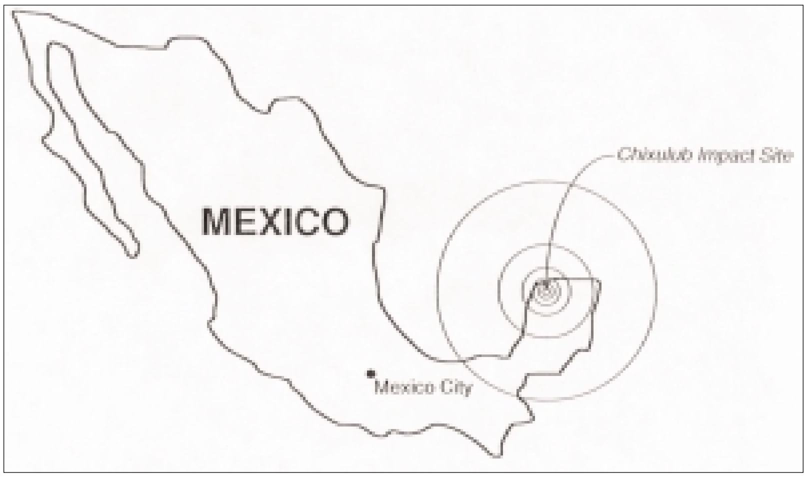

Figure 1. "Bullseye indicating location of Chicxulub site on the Yucatan Peninsula, Mexico." From David E. Fastovsky and David B. Weishampel, *The Evolution and Extinction of the Dinosaurs* (New York: Cambridge University Press, 1996), p. 408. (Reprinted with the permission of Cambridge University Press.)

told of how "planetesimals have plunged through the crust" and "structures are deep scars,"[89] the result, of course, of "shooting stars."[90] By 1990, researchers had amassed "much documentation on [the K/T event's] survivors and victims"[91] and felt confident to note that "direct evidence for . . . mass death and rapid burial has been obtained . . . [for] the last generation of the Mesozoic, which briefly struggled and then succumbed in the post-impact environment."[92]

Such models and metaphors illustrate the broad net of impact-extinction theory's discursive formation, whose new professional alignments drew astronomers, nuclear weapons scientists, paleobiologists, and paleontologists alike to Snowbird, Utah. The interdisciplinary conversation fosters the study of relations between previously unrelated fossil classes, mineral deposits, and extraterrestrial objects. The fossil record takes on new meaning with the discovery of blast effects at the K-T boundary. Evolutionary significance is read into what had previously been of strictly explosive significance.

89. Marvin, "Impact" (above, n. 32), pp. 152, 153.

90. Jansa, Aubry, and Gradstein, "Comets" (above, n. 88), p. 230.

91. Ward, "Cretaceous/Tertiary Extinctions" (above, n. 86), p. 426.

92. Iain Gilmour, Wendy S. Wolbach, and Edward Anders, "Early Environmental Effects of the Terminal Cretaceous Impact," in Sharpton and Ward, *Global Catastrophes* (above, n. 3), pp. 386–388.

Bringing the once-discrete professional discourses of nuclear weapons effects and fossilized remains to bear on the same geological moment, the Cold War's killing mechanisms become nature's too, as fallout is found to have shrouded the dinosaurs long before it landed on the unfortunate Japanese sailors of the *Lucky Dragon* fishing for tuna downwind of the "Bravo" hydrogen bomb test at the Bikini Atoll on March 1, 1954.

It is not uncommon for a new science to frame its object within the grand concerns of its moment. In *Who Wrote the Book of Life?* Lily Kay describes the development of genetics as a product of the information age: genes become a writing technology, as geneticists represent the mechanics of heredity with models and terminology drawn from cybernetics and information theory.[93] Edmund Russell III describes a similar development as he charts the modal and metaphoric trade between insecticides and chemical warfare before World War II: chemical warfare becomes a form of pest control as the terms of insecticide are applied to humans on the battlefield, and insecticides become a military technology as pest control is represented in terms of total warfare.[94] Both genes and insecticides speak within the social and technological horizons of their age.

Impacts speak their nuclear age, and the study of their role in Earth's past has changed the way in which geoscientists speak about earth history. Many of the violent terms listed above can be found scattered throughout the history of geology, and some are already familiar to students of impact science. Yet they have a deeper significance when they are deployed together in the discourse of impact-extinction science, for they are changing the "character" of the natural world. "Shock," "scar," "kill," "bombard," "trigger," "struggle," "burial," "trauma"—and there are many more—are all anthropomorphic terms of deadly intent and bodily harm. While previously used to describe animals possessed of tooth and claw, and, on occasion, individual crater sites, they are now deployed on a previously forbidden scale, describing global populations and the earth itself. For the first time since "catastrophism" became a geological dirty word, an anthropomorphic language of violence is being used routinely throughout the earth sciences to represent the history of the living planet as a whole.

93. Lily Kay, *Who Wrote the Book of Life? A History of the Genetic Code* (Stanford, Calif.: Stanford University Press, 2000).

94. Edmund P. Russell III, "'Speaking of Annihilation': Mobilizing for War against Human and Insect Enemies, 1914–1945," *Journal of American History* 82:4 (1996): 1505–1527.

The terms of mass extinction have become more violent as the cause of mass extinction has moved off-planet. When geologists describe mass extinctions caused by biological sources or by changes in sea level, they commonly represent the earth in terms of biomass support. As sea levels change, land bridges form, and diseases sweep the land, the body of the planet can handle only so much. The earth in these scenarios is represented as a limited, self-contained support vehicle, more and less accommodating to its more- and less-healthy inhabitants.[95] When an impact is figured into a mass-extinction scenario, that supportive planetary body becomes part of an extended, and not always so supportive, solar family.

Walter Alvarez and Frank Asaro treat the K-T mass extinction as a drawing-room murder-mystery when explaining their theory in *Scientific American*. The job facing scientists of Earth's past truly is to uncover what *killed* the Cretaceous:

> About 65 million years ago something killed half of all the life on the earth. This sensational crime wiped out the dinosaurs, until then undisputed masters of the animal kingdom, and left the humble mammals to inherit their estate. . . .
>
> We now believe that we have solved the mystery. Some 65 million years ago a giant asteroid or comet plunged out of the sky, striking the earth at a velocity of more than 10 kilometers per second. The enormous energy liberated by that impact touched off a nightmare of environmental disasters, including storms, tsunamis, cold and darkness, greenhouse warming, acid rains and global fires.[96]

The paleobiologist's Earth is no longer alone in the universe: it is in a figurative relationship with agents that make bodily contact with it and mean it harm. Well before the publication of the Alvarez thesis, planetary science had already begun to class the earth in the category of the solar system's planets, all of which share histories of early and continuing bombardment.[97] It's *war* in the family of planets. As impact-extinction theory draws paleobiology into dialogue with planetary science, it brings the planetary scientist's tough-love narrative of global accretion firmly back down to earth.

95. See, for example, David M. Raup, *Extinction: Bad Genes or Bad Luck?* (New York: Norton, 1991), pp. 133, 145.

96. Walter Alvarez and Frank Asaro, "An Extraterrestrial Impact," *Scientific American,* October 1990, p. 78.

97. Ronald E. Doel, "The Earth Sciences and Geophysics," in *Science in the Twentieth Century*, ed. John Krige and Dominique Pestre (Paris: Harwood Academic, 1997), pp. 391–416.

Drawing from the same semiotic kit as Alvarez and Asaro, Ursula Marvin reviews the damage visited by an impact upon the body of the earth for the participants of the second Snowbird conference:

> this process brings with it visions of random violence to the Earth on a scale never before contemplated: meteorite or comet impacts scar the lithosphere and generate towering tsunamis; exceptional impacts trigger magmatism, or shroud the globe in darkness and cold, poisoning life on land and in the sea or igniting wildfires that incinerate the world's flora to ash.[98]

A rhetoric of bodily harm makes an ancient impact event a cruelly comprehensible event, as Earth is acted upon in all the ways that man acts lethally upon man. Impact-extinction theory's Earth is the victim of repeated assaults—and especially that most deadly of assaults, total nuclear war. Alvarez and Asaro are right: the K-T mass extinction is a murder story.

Discipline and Revolution in Modern Geology

Precisely because of its sweepingly destructive claims, many paleontologists rejected the Alvarez thesis from its inception and continued to fight it throughout the 1980s. Volcanist-extinction theorists Charles Officer and Charles Drake, for instance, argued that the faunal transitions recorded in the K-T clay range over thousands of years,[99] as do the deposition rates for iridium.[100] Given the relative gradualism of these rates, "it seems more likely that an explanation for the changes during the transition will come from continued examination of the great variety of terrestrial events that took place at that time, including extensive volcanism, major regression of the sea from the land, geochemical changes, and paleoclimatic and paleoceanographic changes."[101] Others have been somewhat less constant, dubbing killer comets and asteroids dei ex machina conjured up by physicists,[102] accusing prominent scientific journals of bias for splashy, simplistic theories, and charging influential physical scientists with tampering with peer reviews and blocking the promotions of their fossil-hunting foes. In a 1985 *New York Times* interview, the

98. Marvin, "Impact" (above, n. 32), p. 153.

99. Charles B. Officer and Charles L. Drake, "The Cretaceous-Tertiary Transition," *Science* 219 (1983): 1383–1390.

100. Charles B. Officer and Charles L. Drake, "Terminal Cretaceous Environmental Events," *Science* 227 (1985): 1161–1167.

101. Officer and Drake, "Cretaceous-Tertiary Transition" (above, n. 99), p. 1383.

102. Digby J. McLaren, "Impacts and Extinctions: Science or Dogma?" in Glen, *Mass-Extinction Debates* (above, n. 26), p. 130.

charismatic vertebrate paleontologist Robert T. Bakker railed against planetary scientists who make claims for his field:

> The arrogance of those people is simply unbelievable. They know next to nothing about how real animals evolve, live and become extinct. But despite their ignorance, the geochemists feel that all you have to do is crank up some fancy machine and you've revolutionized science. The real reasons for the dinosaur extinctions have to do with temperature and sea-level changes, the spread of diseases by migration and other complex events. But the catastrophe people do not seem to think such things matter. In effect, they're saying this: "We high-tech people have all the answers, and you paleontologists are just primitive rock hounds."[103]

Certainly there was a good deal of disciplinary gatekeeping involved in the paleontological community's resistance to impact-extinction theory. After all, here are chemists, physicists, and planetary scientists claiming to have found paleontology's grail—and without the help of any paleontologists. Professional reputations were at stake. (Luis Alvarez calling paleontologists "stamp collectors" in a *New York Times* interview,[104] and abusing his theory's critics in his autobiography and elsewhere, certainly did not help matters either.)

Beyond the paleontologists' not wholly unjustified demands for professional jurisprudence, though, there are other, more conceptual reasons for their resistance to impact-extinction theory. Paleontologist David Raup uses a metaphor to describe why many of his colleagues did not accept the theory at first: "the Alvarez proposal was simply not within the accepted coordinate system governing inferences used to understand Earth history."[105] Mike Davis makes a similar argument in *New Left Review*:

> the neo-catastrophist reinterpretation of the stratigraphic record . . . is a lesson, of course, that many geologists, as well as geographers and historians, have great difficulty accepting. Even more than plate-tectonics, an "open system" view of the Earth that recognizes the continuum between terrestrial and extra-terrestrial dynamics threatens the Victorian foundations of classical geology. To cite only one example, a single impact event can compress into minutes, even seconds, the equivalent of a million years or more of "uniformitarian" process.[106]

103. Quoted in Malcolm W. Browne, "Dinosaur Experts Resist Meteor Extinction Idea," *New York Times*, October 29, 1985, sec. C, p. 3.

104. Malcolm W. Browne, "The Debate over Dinosaur Extinction Takes an Unusually Rancorous Turn," *New York Times*, January 19, 1988, sec. C, p. 4.

105. David M. Raup, "The Extinction Debates: A View from the Trenches," in Glen, *Mass-Extinction Debates* (above, n. 26), p. 145.

106. Mike Davis, "Cosmic Dancers on History's Stage? The Permanent Revolution in the Earth Sciences," *New Left Review* 127 (1996): 49–50.

Perhaps this is what led the neo-Victorian *New York Times* editorial board in 1985 to flat-out dismiss five years of solid impact-extinction science and boldly claim: "Terrestrial events, like volcanic activity or changes in climate or sea level, are the most immediate possible causes of mass extinctions. Astronomers should leave to astrologers the task of seeking the cause of earthly events in the stars."[107] Mass extinction in a day? Not in the geology I grew up with.

I have been using a Kuhnian language of revolution and paradigm to describe the development of impact-extinction theory, and this is indeed how both historians and geologists routinely describe its place within the history of geology, as well as the reasons for its rough reception. The theory's champions are keen to discuss the sociology of its new interdisciplinary partnerships and revolutionary conceptual structure. It is presented throughout its celebrants' historical literature as a challenge to what Thomas Kuhn calls the rules of permissible puzzle solving, a field's normal methodological conventions and metaphysical commitments,[108] which in the present case are often disparagingly summed up as "uniformitarian dogma."[109]

Impact-extinction theory's champions are correct in claiming that it challenges deep structures of belief about the character of the natural world, for it relies upon a form of natural agency that defies geology's conventional sense about the patient, endogenous mechanisms that have been held to author the geologic record. To fully understand why it took until the tail end of the Cold War to recognize earth history's other authors—its global genocide mechanisms—we must understand the conceptual origins of modern geology, two of which concern us here: the formulation of a concept of geologic time, or "deep time," and the formulation of a concept of geologic state, known as "uniformity." Impact-extinction theory contradicts each on a global scale (although it may ultimately retain both on a cosmic scale if, as we shall see, the distribution of these singular events over deep time proves to be periodic after all).

Thinking in terms of deep time means understanding the earth not as thousands of years old, but as millions, and even billions, of years old. The concept of deep time enabled early earth scientists to explain for how sedimentary rocks thousands of feet high could have formed, and how fossils of fish could be found in rocks on top

107. "Miscasting the Dinosaur's Horoscope," *New York Times*, April 2, 1985, sec. A, p. 26.

108. Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2nd ed., enl. (Chicago: University of Chicago Press, 1970), pp. 37–42.

109. As, for instance, by Digby J. McLaren, "Impacts and Extinctions" (above, n. 102).

of the Alps. Sedimentation is a slow process; mountains move even more slowly. The earth must be pretty old. Deep time abandons the use of theological chronologies to describe geologic events, replacing them with mechanistic chronologies of ancient physical processes and cycles. The founding metaphysic of modern geology posits

> a world machine of erosion, deposition, consolidation, and uplift; continents and oceans change places in a slow choreography that can never end, or even age, so long as higher powers maintain the current order of nature's laws. Deep time becomes a simple deduction from the operation of the world machine.[110]

While deep time is a concept far removed from human experience, geology's guiding trope of the record provides epistemic access to its passage by rendering it in familiar terms. Deep time becomes an old, old book. The participants of the second Snowbird conference routinely employ terms associated with manuscripts, authorship, and narrative to describe their access to a 65-million-year-old history: the geologic record is commonly "interpreted," although a "literal reading of the fossil record is made difficult";[111] "the primary signal to be read from the distribution of vertebrate fossils is likely to be that of the sedimentary system";[112] "this active environment has erased evidence of events occurring prior to about 3.5 Ga. [billion years ago]";[113] "sedimentological factors can overprint primary paleontological signals."[114] In one paper, the authors refer to anti-impact researchers "perhaps reading the biostratigraphic record in a more literal light," remark that "rocks of the crater floor record the spatial variation of shock pressures," and refer to the "geochemical signatures of meteorite impact";[115] "if, however, one could somehow translate thickness of rock into elapsed time, the rapidity with which the K/P [Cretaceous/Permian] extinctions took place could be calculated";[116] "the coccoliths tell the same story."[117]

110. Stephen J. Gould, *Time's Arrows, Time's Cycles: Myth and Metaphor in the Discovery of Geological Time* (Cambridge, Mass.: Harvard University Press, 1987), p. 66.

111. Flessa, "'Facts'" (above, n. 3), p. 1.

112. David E. Fastovsky, "Rocks, Resolution, and the Record: A Review of Depositional Constraints on Fossil Vertebrate Assemblages at the Terrestrial Cretaceous/Paleogene Boundary, Eastern Montana and Western North Dakota," in Sharpton and Ward, *Global Catastrophes* (above, n. 3), p. 546.

113. Barlow, "Application" (above, n. 87), p. 181.

114. Ward, "Cretaceous/Tertiary Extinctions" (above, n. 86), p. 426.

115. Sharpton and Grieve, "Meteorite Impact" (above, n. 84), pp. 302, 307, 309.

116. Fastovsky, "Rocks" (above, n. 112), p. 544.

117. A. Hallam, "The End-Triassic Mass Extinction Event," in Sharpton and Ward, *Global Catastrophes* (above, n. 3), p. 580.

Charles Lyell codified geology's archival hermeneutic in his foundational 1830 text, *Principles of Geology*. In prose bearing the persuasive stamp of his early training as a barrister, he laid out the premises of modern geological study, dubbed "uniformitarianism" by William Whewell in his 1832 review of the *Principles*. Lyell rested his uniformitarian method on two sound interpretive dictates: assume that natural laws are constant in space and time, and do not invent causes for past phenomena, but rather base them on presently observable events. Yet he did not stop there. As Stephen Jay Gould documents in his textual study of geology's first principles, Lyell in effect overstepped his authority as the self-appointed father of an empirical science and proceeded to treat his new terms of analysis as terms of substance. He argued that because geologists should analyze the world based on constant laws and what they can currently observe, then that is the way the natural world is: constant, and as it currently appears.[118] Lyell took constancy as an article of faith, assuming, for his part, that "if in any part of the globe the energy of a cause appears to have decreased [or, conversely, increased], it is always probable, that the diminution of intensity in its action is merely local, and that its force is unimpaired, when the whole globe is considered."[119] Assuming the earth to be a closed steady-state system that operates over a period of deep time precludes the study of global catastrophe by fiat.

Although Lyell's presentist methodology has been indispensable for the development of modern geology, impact-extinction proponents such as Walter Alvarez and Ursula Marvin describe it as a metaphysical legacy that has dogged geology for one and a half centuries. Lyell's formulation of uniformitarianism *is* a discursive legacy, for geologists inherited his mechanistic terms as the only appropriate terms for natural causes. Certain concepts are unthinkable within a strictly uniformitarian discourse, particularly sudden changes of global state. Swift acts of worldwide destruction do not logically fit in a discursive formation dominated by gradual global mechanisms of stately preservation.

Lyell rejected global catastrophes in no small part because he was dueling with the scientific catastrophists of his day, including Whewell, Élie de Beaumont, Adam Sedgwick, Louis Agassiz, and Georges Cuvier. These men were not biblical literalists; rather, they took the empirical evidence of the field literally, reading its elevations, scars, and discontinuities as signs of sudden global violence in

118. Gould, *Time's Arrows* (above, n. 110), p. 105.

119. Charles Lyell, *Principles of Geology*, vol. 1 (London: John Murray, 1833), p. 165.

Earth's past. In all fairness, the continent of Europe observed by the catastrophists does happen to be a far more geologically tortured landscape than is Lyell's sedimentary England. Moreover, unlike Lyell, many of them relied upon a model of the earth based on the state-of-the-art physics of Lord Kelvin: the earth cooled thermodynamically, the core shrank, and the crust occasionally and suddenly cracked.[120] The catastrophists' Earth was as old as Lyell's, and subject to the same forces of weathering and erosion, but it was also visited by days of total disaster.[121]

The catastrophists wrote a kind of natural history that the Victorian presentist Lyell found simply unacceptable.[122] Many of them advocated the doctrine of "progressionism," viewing life as advancing in diversity and complexity through a process of violent uplift. Each global cracking spared only the more complex life-forms of a given niche, which were then "replaced" in new variety to await the next thermodynamic reckoning.[123] Catastrophist earth history, such as we find in the early work of Georges Cuvier, is revolutionary history:

> When a traveler crosses fertile plains, where the regular course of tranquil rivers sustains abundant vegetation, and where the land—crowded with numerous people and ornate with flourishing villages, rich cities, and superb monuments—is never disturbed unless by the ravages of war or by the oppression of powerful men, he is not tempted to believe that nature has also had its civil wars, and that the surface of the globe has been upset by successive revolutions and various catastrophes.[124]

Nineteenth-century geologic catastrophists regularly employed anthropomorphic metaphors of global destruction and progress, such as the metaphor of revolution itself.[125] While "revolution" was meant by Cuvier to imply a kind of Newtonian regularity for the world's occasional spasms,[126] it also represents earth history in terms

120. Martin J. S. Rudwick, "Darwin and Catastrophism," in *Understanding Catastrophe*, ed. Janine Bourriau (New York: Cambridge University Press, 1992), pp. 69–73.

121. Gordon L. Davies, *The Earth in Decay* (London: Macdonald, 1969), pp. 210–218.

122. On Lyell's presentism, see Roy Porter, "Charles Lyell and the Principles of the History of Geology," *British Journal for the History of Science* 9:32 (1976): 94–96.

123. Martin J. S. Rudwick, *The Meaning of Fossils* (Chicago: University of Chicago Press, 1985), pp. 142–149.

124. Martin J. S. Rudwick, *Georges Cuvier, Fossil Bones, and Geological Catastrophes: New Translations and Interpretations of the Primary Texts* (Chicago: University of Chicago Press, 1997), p. 186.

125. Rudwick, *Meaning of Fossils* (above, n. 123), p. 109.

126. Ibid., p. 132.

of purpose and direction. The planet itself is figured as *acting upon* life and driving species to diversify or, as the case may be, go extinct.

Lyell, for his part, caricatured the catastrophists with their progressive models of earth history as, in the apt words of one of his early reviewers, "miracle mongers."[127] In dismissing them, he was instrumental in dismissing the language of global intent—and, particularly, global destruction—from geological discourse. Understanding the world as a steady-state machine means that both progressive and destructive kinds of force become unthinkable, at least on a global scale. Progress and destruction are intentional concepts; to attribute either form of agency to natural events is a human conceit. Lyell saw no progressive changes in the fossil record (excluding, of course, man's geologically recent and exceptional emergence). Rather, the fossil record demonstrated that the various forms of past and present life are and have always been tailored to suit their proper environmental place. The state of these recorded *places* had gradually changed over deep time, and the inhabitants and their various descendants had merely moved on to their newly located allotments—*or*, as Lyell finally had to assent at the end of his career, evolved.[128] Everything, in other words, was as it should have been.

The discursive upshot of Lyell's anticatastrophist position is that language associated with any global intent, whether progressive or destructive, is simply not required in order to describe the earth's steady state. His nonprogressionism soon lost to the Darwinists, but his system won out. The Darwinists' gradual, steady-state natural selection mechanisms seized the ground from the progressionists' violent interventions. Evolution had found a place in Lyell's uniform schema, but revolution had not.

Total War in the Fossil Record

By the time the Alvarez-Berkeley team published their first impact-extinction paper, the globally destructive agency that their theory posited had been long banished from paleobiology's repertoire of global causes. A language of violent destruction cannot apply to an Earth apprehended as a whole, autonomous entity. Nothing acts *upon* such an Earth or its life, either figuratively or literally; things merely process on and in it, ever a part of its steady state. Incorporating a global killing mechanism into that steady state would

127. Leonard G. Wilson, *Charles Lyell, the Years to 1841: The Revolution in Geology* (New Haven, Conn: Yale University Press, 1972), p. 275.

128. Michael Bartholomew, "The Non-progress of Non-progression: Two Responses to Lyell's Doctrine," *British Journal for the History of Science* 9:32 (1976): 166–169.

make it an all-too-swift suicide machine. So, while scientists had been proposing impact-killing scenarios for centuries, there was in the final analysis no agreeable language for such a scenario, nor were there any analogical precedents for it. There was no global killing mechanism in the natural world—not until we built one.

As the superpowers developed their technological systems of nuclear deterrence and raced into space, geologists found themselves increasingly well equipped to find nature's own global killing machines. Writing a decade after the first publication of the Alvarez thesis, Alvarez and Asaro can comfortably evoke Cuvier as they place their theory within the history of geology and once again evocatively link the fate of the earth and the fate of man:

> in the century and a half since Lyell, human history has witnessed one violent turnover after another, and it is ironic that geologists should have maintained the uniformitarian faith through all those social disturbances. The Universe is a violent place, as astronomy has taught us . . . and we are now seeing that the history of the Earth has also had its violent episodes.[129]

Of course, it takes more than a leap of faith to turn a uniform machine into a global killer. Nature's machinery becomes a global killer specifically by emulating the modern human machinery of total warfare. Earth history has become a total warrior's history of mass killing, targeting, and bombing, with missiles and projectiles suddenly impacting upon the earth's patient living mechanisms of state. Framing the K-T impact within the nuclear threat has enabled geoscientists to metaphorically sneak the once-scorned language of global violent intent into geology's mechanistic discourse of steady states, and thus represent moments of global destruction, but *without* any literal purpose or direction. As ancient Mexico becomes a target and Cretaceous populations become masses of victims in a figurative strategic assault, an impact's global mechanisms become massively *destructive*. Of course ancient Mexico was nobody's target, nor were its inhabitants anybody's victims, but by employing the humanized language of destructive intent associated with modern strategic weapons systems, geologists can freely discuss them as if they were. Stripped of its political specifics, plucked from the Cold War and applied as the closest thing to nature's own global killing machine, the nuclear threat supplies models and metaphors that allow geoscientists to retain their mechanistic, purposeless system of earth history and talk about the destruction of life on Earth all the same.

129. Walter Alvarez and Frank Asaro, "The Extinction of the Dinosaurs," in Bourriau, *Understanding Catastrophe* (above, n. 120), p. 53.

Uniformity and deep time are not lost in this view so much as they are finally transferred to a much larger scale of interplanetary and interstellar processes. Geology's commitments to gradual geomorphic and paleobiological change had been steadily on the wane for decades before the publication of Alvarez's thesis. Studies of glaciation and orbit-induced climate variation have indicated, since Lyell and Darwin's time but especially throughout the latter half of the twentieth century, that the geologic record contains undeniable evidence of relatively abrupt climatological changes such as ice ages.[130] While geophysicists were delighting in the rigorously uniform flows of plate tectonics, paleontologists were already wrestling with another challenge to gradualism: Niles Eldredge and Stephen Jay Gould's theory of punctuated equilibrium. Based on their revisionist reading of overall patterns observable in the fossil record in toto, Eldredge and Gould argued that speciation is a relatively sudden process, because species types appear to remain basically stable for long periods of time and to then suddenly change to new types, with few traces of any gradual changes in between.[131] Punctuated equilibrium in itself had very little to do with the development of impact-extinction theory, for, as Gould points out, it is an entirely "different-scale phenomenon—it's just not about simultaneity in extinctions and originations, which is what the issue of mass extinctions is about"; what it does share with impact-extinction theory, though, is "a general philosophical approach to change."[132] Impact-extinction theory is the apotheosis of the geologist's punctuated philosophy, compressing the planet's operational time frame to single years and even days.

While ideas like Eldredge and Gould's eroded paleontology's attachments to causation over deep time, impact-science had already chiseled away petrology's. Explosive tests lent credibility to the idea of terrestrial impact-structures by showing analogous mechanisms at work in each, and in so doing demonstrated that large natural geologic structures could be created in seconds, not centuries. Geologists must now account for a new time frame as they read the earth's record of ancient cratering: ground-zero time. Representations of impacts and nuclear blasts themselves trade in the same temporal

130. Doel, "Earth Sciences" (above, n. 97), p. 397.

131. Niles Eldredge and Stephen J. Gould, "Punctuated Equilibria: An Alternative to Phyletic Gradualism," in *Models in Paleobiology*, ed. T. J. M. Schopf (San Francisco: Freeman, Cooper, 1972), pp. 83–115.

132. William Glen, "Interview with Stephen Jay Gould," in Glen, *Mass-Extinction Debates* (above, n. 26), p. 255.

Figure 2. Sequence depicting the formation of Meteor Crater. Artwork by Don Davis. (Courtesy of Meteor Crater, Northern Arizona, USA.)

signs, foremost among them the device of framed sequence. Artwork by Don Davis displayed at Meteor Crater Museum (Fig. 2) represents the same sublime desert landscape as do test photos of Trinity (Fig. 3)—each blindingly lit at first, and then blasted through successive frames. All one has to do to get over the conceit of *global* causation over deep time is to change the scale: curve the horizon, multiply

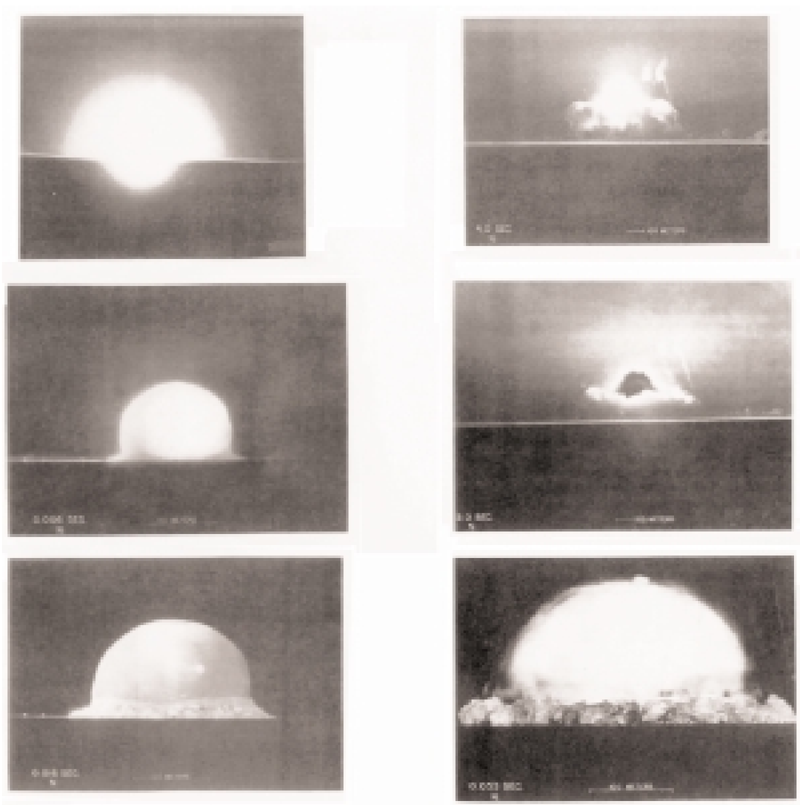

Figure 3. Photographic sequence of the Trinity test, the first nuclear explosion. (Los Alamos National Laboratory.)

the blast effects one hundred million times, and look at the same event from the space shuttle's view (Fig. 4).

Viewed from space, the earth becomes a part of the solar system's stately, largely uniform orbital dynamics, subject like all planets to a steady background of bombardment. Viewed statistically, the seemingly random processes of extinction may also exhibit regularity. In 1984, David Raup and J. John Sepkoski published a statistical analysis of the major extinctions that have occurred over the past 250 million years, demonstrating that extinctions occur in clusters every 26 million years.[133] In a fierce Socratic brainstorming session with his mentor Luis Alvarez,[134] Richard Muller devised a theoretical source

133. David M. Raup and J. J. Sepkoski, Jr., "Periodicity of Extinctions in the Geologic Past," *Proceedings of the National Academy of Sciences* 81 (1984): 801–805.

134. Muller, *Nemesis* (above, n. 71), p. 7.

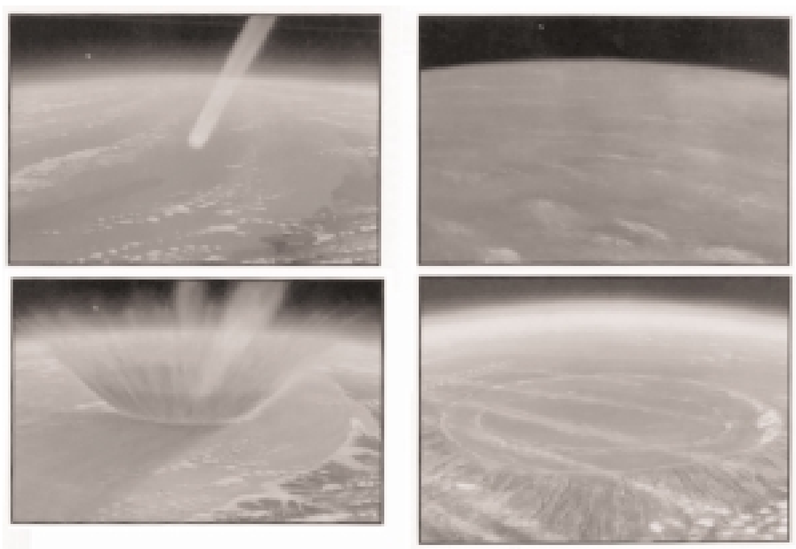

Figure 4. Sequence depicting the K-T impact. Artwork by William K. Hartmann. From Walter Alvarez, *T. rex and the Crater of Doom* (Princeton: Princeton University Press, 1997), plates 3–6. (Reprinted with the permission of Princeton University Press.)

for Raup and Sepkoski's observed periodicity: the Sun may have an errant sibling, dubbed Nemesis, whose orbit periodically brings it near enough to the solar system to deflect a storm of comets from the Oort cloud into the earth's path. Nemesis remains only a theory, but if verified it would push geology's uniform scale of causation even deeper into space. Large-body impacts, and impact-inducing extinctions for that matter, at first appeared to be random events. Putting them in the context of interplanetary and galactic orbits, and perhaps uncovering their cyclicity, brings them back into the fold of geology's senses of deep time and uniform state, although the purview of those senses is now greatly expanded and their rates are firmly cyclic. *Pace* the new catastrophists, impact-extinction theory may not be such a threat to the dictates of uniformity and deep time after all.

Impact-extinction theory *is* threatening, not solely because it is so interdisciplinary and counterintuitive, but also because the specter it raises is all too common. Many geoscientists and those otherwise informed in the 1980s did not want or need to imagine it, because imagining it would mean that nature could be as methodical and MAD as present-day Cold War man—for that is the deep lesson, the semiotic baggage and dubious moral of impact-extinction theory as

Figure 5. Agricultural impact of a nuclear war. "In a spring or summer war, subfreezing temperatures would kill or damage virtually all crops in the Northern Hemisphere. The low light levels would inhibit photosynthesis and the consequences would cascade through all food chains. Most farm animals would be destroyed or severely weakened by radiation. Those that survived would soon die of thirst, as surface fresh water would be frozen in the interior of continents." Artwork by Rob Wood—Wood Ronsaville Harlin, Inc. From Paul R. Ehrlich, Carl Sagan, Donald Kennedy, and Walter Orr Roberts, *The Cold and the Dark: The World After Nuclear War* (New York: W.W. Norton, 1984), fig. 2. (Courtesy of Porter-Novelli, Washington, D.C.)

a modern-day fable. Our planet is a far less secure place than the one theorized by terracentric earth sciences to be governed by the reliable mechanics of drift, subduction, renewal, selection, and uplift. Earth history suddenly becomes as anguished as recent history, complete with its own genocidal engines of mass destruction.

As nature's machinery emulates the human machinery of total warfare, impacts have become part of the cultural narrative of the nuclear threat, evoking its strategic promise to destroy the structure of society and even the order of the world. The same regime of signs is at work after a nuclear holocaust in the 1980s (Fig. 5) as after a catastrophic impact 65 million years ago (Fig. 6). The two visions summon a common pathos: Downtrodden triceratops and man trudge alone under darkened skies and through fields of frozen food. The vegetation's bare stalks and limbs have been bent into gallows. Something has gone terribly wrong here. The order of things has been broken. A tragic mistake has been made. Considering their—our—semiotically linked fate, we care about the last generation of

Figure 6. "A triceratops wanders forlornly over the frozen and darkened late Cretaceous landscape in this illustration of the probable consequences of a cometary impact 65 million years ago." Artwork by Don Davis. From Carl Sagan and Ann Druyan, *Comet!* (New York: Ballantine Books, 1997), plate xvii. (Courtesy of Don Davis and of the Estate of Carl Sagan and Ann Druyan.)

the Cretaceous just as we care about the last generation of Cold War man. Walter Alvarez certainly cares:

> Looking back across the abyss of time which separates us from the Cretaceous, we can somehow feel nostalgia for a long-lost world, one which had its own rhythm and harmony. We feel a special sadness when we think about its plants and animals, fish and birds—for most of the Cretaceous animals and plants are irretrievably lost. We can even feel some sorrow as we imagine the sun setting over a western ocean, painting the clouds with orange and red and yellow and gold, on the last evening of that world. For the Cretaceous world is gone forever, and its ending was sudden and horrible.[135]

Cold War Dinosaurs

If we take the interaction theory of metaphor seriously, then we have to grant that just as the threat of nuclear war describes elements of the impact world, impact-extinction theory's figurative war stories are also about our threatened world, and especially that long-lost world of the 1980s. In the long tradition of fable, animals live the trials of men, and their sometimes funny and often gruesome rewards serve as lessons for the proper order of human affairs. For

135. Alvarez, *T. rex* (above, n. 4), p. 5.

those who have fought and survived the Cold War, the dawning recognition that the animals of the Cretaceous lived and died much like Cold War subjects is variously seen as a reason to celebrate, to take urgent action, or, frankly, to do nothing at all. For those who suffer their lives under the delegated mechanisms of nuclear deterrence, finding total war in the fossil record underscores the innateness and *un*humanity of the world's nuclear arsenals. Making nuclear weapons "absolute weapons" was a historical choice, but in a world defined by Cold War politics it fast became a national imperative, and America's arsenal grew as if an object unto its own. With the discovery of nature's own total war machine, the massive destruction promised by nuclear deterrence becomes more than a protestable fact of geopolitical life and turns into a state of nature. The implicit meaning of impact-extinction theory is indeed a frightening one, for it means that we have always been living under the threat of a total war machine, and as a naturalistic fable the theory may make the nuclear war machine—and the society that built it—seem all that more natural, and even necessary.

In popular culture, the impact threat provides an occasion to crow about America's survival of the Cold War and commitment to nuclear weaponry. The post–Cold War headlines announcing the explosive death of the dinosaurs, along with Hollywood depictions of scrapes with planetary doom, such as the 1998 blockbusters *Deep Impact* and *Armageddon*, both exploit and assuage any fears left over from four decades lived under nuclear deterrence, leaving their audiences somewhat humbled but all the happier with the present nuclear peace. The death of the dinosaurs, when not put to earnest use by nuclear winter proponents, is a voyeuristic and macabre peek at a World War III that near-missed. The dinosaurs' explosive demise serves up a thrill for American audiences in particular because in American culture the dinosaur already has a very human presence. In his examination of the past century's fascination with dinosaurs, *The Last Dinosaur Book*, W. J. T. Mitchell details the abundant, contradictory ways in which the dinosaur has been rallied throughout the American popular imagination, from advertisements, films, political cartoons, and children's entertainment to, of course, museum displays and gift shops. The dinosaur represents size, strength, and ferocity—yet at the same time it is a model of failure and obsolescence. Civilization is defined both through and against the dinosaurs. Americans find these particular dead beasts so useful, Mitchell argues somewhat playfully, because they function in American culture as *the* totem animal of modernity. Like the totems of past tribes, the dinosaur has specific functions for modernity's tribe: it serves as the epitome of capitalism's temporal cycles of innovation and obsolescence, it embodies the sundry contradictions of modern life, and it figures in a number of enculturing rituals. Either through learning to count, to differentiate categories, and to sing with them as children, or by using them allegorically to justify planned obsolescence and social injustice, Americanized subjects find the meaning of their works and their lives in dinosaurs as in no other animal.[136]

While the story of the dinosaurs sets examples for the modern technocultural order of things, their newly imagined death through total war serves as a testimony to not just the mammalian order's natural fitness, but the United States' technocultural fitness. The dinosaur's and humanity's fates were joined in cosmic winter throughout the Cold War. That war's end gives the threat of cosmic winter a cheerful new meaning: the dinosaurs could not survive it, but our deep ancestors could—and America can, by adverting it through the combined strength of national character and Cold War technology. Throughout the Cold War the United States and its allies may have been in danger of going the way of the dinosaurs, but not any more. The West survived the Cold War's global threat by staying fit, mastering space, and arming itself to the teeth, and it can survive nature's too by wielding those very arms in space. After all, despite all of the world's cataclysmic historical revolutions—natural and social, ancient and modern—"we're still here," apparently to stay.

In the films and literature of planetary defense, the impact threat figures as a romantic struggle that defines the true character of American society. In 1993, two NASA committees reported to Congress: one on the prospects of detecting Near Earth Objects, and the other on ways to defend ourselves against them.[137] The intercept committee met at Los Alamos and debated ways to deflect asteroids and comets with nuclear weapons and other means. Adopting a term coined by science fiction author Arthur C. Clarke, the detection committee urged the construction of a large network of "Spaceguard" telescopes, which would keep a prudent, cost-effective eye out for Earth-crossing asteroids and distant comets. Both committees argued that we should get to know our enemy better through a manned mission to an asteroid. Mastering the ancient impact threat would not only ensure our survival, but would also be a defining small step. As radio astronomer and science writer Gerrit Verschuur

136. W. J. T. Mitchell, *The Last Dinosaur Book: The Life and Times of a Cultural Icon* (Chicago: University of Chicago Press, 1998), pp. 77–85.

137. Duncan Steel, *Rogue Asteroids and Doomsday Comets: The Search for the Million Megaton Menace That Threatens Life on Earth* (New York: Wiley, 1995), pp. 208–209.

describes it, our future victorious struggle against nature will make us what we are:

> this plan, if implemented, would, for me, represent the coming of age of the human species. Walking on the moon was dramatic, but walking on a near-earth asteroid during its flight about the sun and past the earth would signify that our species had come to recognize that we do not live in splendid isolation from space and that we need to understand near-earth objects, comets and asteroids, if we are to live with them for a very long time into the future.[138]

Bringing the impact threat to bear directly on ourselves, the latest round of Hollywood impact doomsdays serve up epic tales of nationalist bravura. *Armageddon* is ultimately averted not by Science, but by American working-class muscle. Sweating NASA eggheads eagerly watch at their booths as Bruce Willis and his team of rugged oilmen screw a warhead into an asteroid. When their remote triggering technology invariably fails them, Willis martyrs himself on the asteroid, and with his last breath bequeaths his only daughter to his roughneck protégé. Major Kong's doomsday ride in *Dr. Strangelove* duly mocked, Willis fathers the next American generation by pushing the button.

Deep Impact, an action-adventure film tailored more for the working mom, averts doomsday in a somewhat less brutish and more professional fashion, but it presents a similarly bombastic and penetrating narrative as its comet assault proves to be a problem that only nuclear weapons and nuclear families can fix. After a joint U.S.-Russian intercept mission fails to destroy an incoming comet, the remaining Americans and lone Russian hurry home, hot on the comet's tail. Before they can catch up to it, the combined force of the world's nuclear arsenal is futilely launched at the aggressor bolide in a recapitulation of the Cold War's threats of massive retaliation. As Earth looms ever larger in the background, the astronauts unanimously decide to sacrifice themselves by driving their space shuttle deep into the body of the comet to personally blow it up with a nuclear warhead. Back on Earth, the impact threat had already prompted the State Department to build a $200 billion fallout shelter system of the sort that RAND strategist Herman Kahn first recommended in 1957 to the Gaither Committee on Civil Defense,[139] but the shelter can hold only so many citizens, so this demands sacrifice on the homefront as well. As a remaining splinter of the comet

138. Gerrit L. Verschuur, *Impact! The Threat of Comets and Asteroids* (New York: Oxford University Press, 1996), p. 211.

139. Fred Kaplan, *The Wizards of Armageddon* (New York: Simon and Schuster, 1983), p. 226.

crashes catastrophically into the Atlantic Ocean, families put aside their squabbles, bonding with one another and making heroic sacrifices. The major cities of the American eastern seaboard fall, one by one (interestingly, in the very way depicted in Albert Einstein's famous letter urging President Roosevelt to develop atomic weapons: they are smashed by giant waves from an offshore explosion). Yet though cities fall and oceans rise, as *Deep Impact*'s poster informs us, "hope survives." The world may descend into chaos, but the film's featured victims achieve a state of grace at the end of their lives—or if not that, then at least a state of glamour, as they dress in their best for doomsday.

Viewed through Hollywood's ahistorical optics, we find more hope than fear in these post–Cold War atomic attacks. Nuclear war, nostalgically twisted in the figurative lens of an impact, is winnable, and may even make America stronger by bringing out the best in its people. America's survival requires only that its citizens continue to assert some familiar qualities of Cold War national character: vigilance, industry, family values, a large defense budget, and a willingness to absorb casualties.

Hollywood is not the only entity recycling the Cold War through the discovery of an ancient comet threat: nuclear weapons boosters and Strategic Defense Initiative advocates mobilize the threat, not to write wide-screen apologias for the Cold War, but to fight it again. While most concerned scientists have advised Congress to make money available for Spaceguard and otherwise urge us take the threat seriously, the more aggressive asteroid-shield boosters want to point SDI outward and are lobbying once again for an atomic presence in space, for more hydrogen bomb research, for nuclear testing in the asteroid belt[140]—all in order to wage another Cold War, this time as a united Earth against Outer Space. The twenty-first century's asteroid scare may even mean a new strategic mission for the U.S. Air Force, for according to its futurological publication, *SPACECAST 2020*, "although not a traditional 'enemy,' the asteroids are nonetheless a threat that the Department of Defense should evaluate and prepare to defend against."[141] Winning the Cold War did not make the threat of global apocalypse go away. In the popular imagination, in the military, in the scientific community and the science press,[142] the threat just became one hundred million times bigger.

140. Davis, "Cosmic Dancers" (above, n. 106), p. 49.

141. Quoted in Verschuur, *Impact!* (above, n. 138), p. 210.

142. A large body of literature aimed to educate a general audience about the impact-threat was published in the 1990s. Many of these works are reviewed in Mike Davis,

Bonus Damage

Dubbing impact-extinction theory a species of Cold War Big Science is an admittedly ironic gesture, for the science had very little to do with the course of the Cold War or with how World War III would have been fought—although it did indicate how it might have ended. The term "Cold War science" is a marker of science's ties to military research and development following World War II. In the historiography of science, though, it is also a form of judgment, not only about the positive or negative effects of the Cold War upon science, but about the nature of science. Paul Forman's "distortionist" hypothesis is perhaps the most notorious of such judgments. The hypothesis is actually an implication that historians draw from Forman's study of quantum electronics, in which he argues that military funding has permanently damaged the practice of basic physical research. During the Cold War, he says, physicists were lured by the siren song of military funding and labored under the false consciousness that they were using the military to pursue the ends of fundamental research. Yet not only did sponsoring agencies such as the Office of Naval Research push 95 percent of quantum electronics research toward strictly military applications such as radar, lasers, and masers, but the 5 percent of funding that was labeled "basic research" was already co-opted because the physicists were materially committed and mentally predisposed to pursue problems that were intrinsically related to military work.[143] The physicists' pursuit of knowledge "fragmented," leading to the production, not of unified basic theory, but of "a kind of instrumentalist physics of virtuoso manipulation and *tours de force*, in which refined or gargantuan technique bears away the palm."[144] As Stuart Leslie argues in his analysis of MIT's and Stanford's Cold War indenture, this was a pattern that was repeated throughout the military's academic fiefdom.[145] Under the military's regime of command performance, instrumental paradigms replaced theoretical paradigms, leaving little room for the next Einstein.

"Stone Killers," *Nation*, October 28, 1996, pp. 38–42. See also Peter Grego, *Collision Earth: The Threat from Outer Space* (London: Blandford, 1998); John Gribbin and Mary Gribbin, *Fire on Earth: Doomsday, Dinosaurs, and Humankind* (New York: St. Martin's, 1996); Lewis, *Rain of Iron and Ice* (above, n. 82); Steel, *Rogue Asteroids* (above, n. 137); Verschuur, *Impact!* (above, n. 138).

143. Paul Forman, "Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960," *Historical Studies in the Physical and Biological Sciences* 18:1 (1987): 216.

144. Ibid., p. 224.

145. Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press, 1993).

Forman makes a good case that military funding biased the context of discovery of quantum electronics by encouraging physicists to work on problems intrinsically related to military applications, in the process blurring whatever distinction there may have been between the field's basic and applied science. Yet Forman's ethical thesis seems less applicable to fields such as impact-extinction science that have benefited from their connections to military institutions and knowledges but do not have military applications—or, as was the case with the development of the nuclear-winter thesis, even provide evidence that can be used against the state's defense policies by its own employees. Somewhere beyond quantum electronics, we are left wondering where the boundaries of Cold War science properly may be.

When applied to the postwar market, the idea of distortion is known as "crowding out": the Cold War single-buyer defense market is argued to have sucked labor from commercial technology firms, inflated research costs, decreased worker autonomy, and hampered the production of consumer goods.[146] The contrary hypothesis is that of "spillover." In this view, which is based on the self-evident history of new industries that were spurred by governmental support, military R&D is represented as a rich crib from which all kinds of beneficent technologies spring—from jet aircraft and computers to the staple crop of the science museum, Astronaut Ice Cream. Applied back to the laboratory, spillover becomes a celebration of the Cold War state's commitment to basic research. The military and the Atomic Energy Commission are understood as "benign patrons"[147] committed to supporting a small number of elite "best-science" institutions.[148] Scientists and administrators, in this view, are represented as having had relatively free reign to further, not so much the

146. For variations on the crowding-out thesis, see Seymour Melman, *The Permanent War Economy: American Capitalism in Decline* (New York: Simon and Schuster, 1974); David Noble, "Command Performance: A Perspective on the Social and Economic Consequences of Military Enterprise," in *Military Enterprise and Technological Change: Perspectives on the American Experience*, ed. Merritt Roe Smith (Cambridge, Mass.: MIT Press, 1985), pp. 329–346; Robert A. Solo, "Gearing Military R&D to Economic Growth," *Harvard Business Review* 55 (1962): 49–54; Senate Committee on Labor and Public Welfare, Subcommittee on Employment and Manpower, *Selected Readings on Employment and Manpower*, vol. 2, *Convertibility of Space and Defense Resources to Civilian Needs: A Search for New Employment Potentials*, 89th Cong., 2nd sess. (Washington, D.C.: Government Printing Office, 1964).

147. Roger L. Geiger, *Research and Relevant Knowledge: American Research Universities since World War II* (New York: Oxford University Press, 1993), p. 333.

148. Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America* (New York: Knopf, 1977), p. 397.

ends of the war machine, but their own independent research interests, careers, and institutions—at least until counterculture movements in the late 1960s, coupled with new financial ties with private industry, undermined the terms of the university's egalitarian contract with the military.

Each of the above positions is rooted in a politicized sense of what science is, how it works, and what it should properly do. In the distortionist hypothesis, science is either pure or instrumental; and if instrumental, then it should be instrumental for civil society, not the war machine. In the spillover theoretical framework—which is used by historians who want to find some value in the Cold War, or at least to mollify the doves—scientific and technological development are understood as initially uncontrollable, autonomous processes that are not so much commanded as they are nurtured and then capitalized upon by both the military and commercial industry. None of these narratives of the history of science in the Cold War does justice to the development of impact-extinction theory. The concept of distortion is problematic because it implies that science not under military pressures develops as a strictly internal affair and to its own undistorted ends. Impact-extinction theory clearly is not distorted science; it is as unified and basic as science gets. Yet given its disciplinary and institutional ties to the Cold War machine, as well as its semiotic debts to the nuclear threat, we may rightly wonder if the theory could have been developed in its present formulation without the many "outside" resources that the Cold War offered.

Spillover may seem the more accurate concept for the case of impact-extinction theory, but it is misleading for precisely the opposite reason: it puts the theory too much in debt to the state and in the service of the market. In devising ways to account for K-T iridium spikes and the killing off of the dinosaurs, none of the first impact-extinction researchers were actively appropriating vast pools of military funding for their own professional ends—nor has there been any great rush to fund Spaceguard, let alone build it. Further, while the science that Walter Alvarez and his team started was made possible by the resources that the Cold War military-academic economy provided, it was picked up, developed, and finally used by those working in opposition to the nuclear sector of the Cold War economy. So far, the only one making any money from impact-extinction theory is Hollywood.

Impact-extinction theory did not spill out of the Cold War: it spilled *into* the Cold War. The *state of conflict* itself enabled the theory's development. As a term of analysis, "Cold War science" does not go far enough; it locates science in history, but does not describe any particular relation to that history. What we need here is a good metaphor, one that address the military contexts of impact-extinction theory and locates the new science squarely within the ironic and troubled progress of Cold War history. Impact-extinction science becomes a part of that history when we move beyond the cause-and-effect terms of good or bad governmental parenting and represent how the science both emerged from and gave meaning to the Cold War.

Works in the "Santa Cruz school" of science studies have been particularly effective in representing the trade of scientific ideas across Cold War history because they read the history of science as a process of producing, at one and the same time, knowledge and cultural narratives. Cold War history becomes, also, "cyborg history" in Paul Edward's *The Closed World*. Edwards traces the development of computers as a complex flow of materials and ideas between machines built for defense and models of the mind. The requirements of national defense informed the design of the first computers and networks, whose cybernetics offered potent models for the emerging field of cognitive science, which in turn defined Cold War man in the terms of his own thinking machines.[149] Donna Haraway weaves a similar account in sections of *Primate Visions*, darting into the traffic between nature and culture to pluck—among other things—Cold War America's concepts of self out of primatology's science of Edenic others. Chimpanzees rocketed into orbit model not only the effects of weightlessness on man, but a way to claim space as a natural refuge for Cold Warriors dreaming of a safe future built atop ballistic missile systems.[150] Telling the histories of computing and primatology as stories about building cyborgs and finding Edens describes how the knowledge generated about computers and primates fits into Cold War culture by serving, just as crucially, as models and metaphors—as the imagined hopes and limits—of Cold War society.

To find a metaphor that expresses impact-extinction theory's fit with the Cold War, perhaps we may be well served by the nuclear deterrent's own language, nuclear strategy. In the mid-1950s the Strategic Air Command's intentions may have been total war, but its war plans were ostensibly organized around the strategy of "counterforce" fighting, meaning that target programmers aimed to kill Soviet bombers and bases in order to counter the threat of Soviet mili-

149. Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, Mass.: MIT Press, 1996).

150. Donna Haraway, *Primate Visions: Gender, Race, and Nature in the World of Modern Science* (New York: Routledge, 1989), p. 137.

tary force at war's start. However, Soviet airfields were often located just a few miles from major cities. In such cases, SAC targeteers would move their aim points slightly away from base and closer to city in the hope of killing both with one big bomb. The resulting civilian death and destruction was figured as "bonus damage" above and beyond the war plan's counterforce objectives.[151] So, too, may we consider impact-extinction theory, with a sense of dark irony, as bonus damage from the Cold War.

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151. Kaplan, *Wizards* (above, n. 139), p. 211.