When Disaster Rains Down from the Sky

Scientists think that they know how often large objects collide with Earth, but no one knows where they come from

Half a million megatons of destruction are hurtling toward the planet Earth. A cataclysm, so vast that no civilized being has ever witnessed such an event, threatens to devastate an entire hemisphere, perhaps an entire world. Unimaginable shock waves, heat, and dust will assault the world as walls of water hundreds of feet high wash over the coasts of four continents, unless . . . unless a brilliant scientist and an international task force manage to deflect the onrushing mile-wide asteroid before it smashes into the Atlantic.

That is the basic story line lifted by moviemakers for *Meteor*, the latest disaster movie, from a 1968 study by MIT graduate students. The engineering students, as an assignment in a course on Advanced Space Systems Engineering, had to devise a plan to prevent the asteroid Icarus from hitting Earth. Hollywood, in the interest of greater drama, took the students' scenario, enlarged the asteroid from 1 to 5 miles wide, and compressed the warning time from 70 weeks to 6 days. Although neither Icarus nor any other asteroidal body is known to be on a collision course with Earth, these plots are not impossible. Even asteroids the size of the one in *Meteor* have hit Earth in the past and more will do so in the future.

By counting the number of meteorite craters that are still recognizable on the surface of Earth, researchers have reached some agreement on how often such large objects smash into our planet. According to a recent summary prepared by Richard Grieve and Blyth Robertson of Canada's Department of Energy, Mines, and Resources (DEMR) in Ottawa, 91 proven or probable impact craters and another 50 possible ones have been identified around the world.

Barringer, or Meteor, Crater in Arizona, the most familiar meteorite crater, is not typical of those on Grieve and Robertson's list. Although the largest crater containing fragments of the original meteorite, it is small (1.2 kilometers in diameter) and rather new (a few tens of thousands of years old) compared with most craters. More typical of the craters found in the geologic record is the now-obscure remains of a 13-kilometer-wide crater 110 kilometers south of Chicago. It was formed about 300 million years ago. The biggest of the listed craters, caused by asteroids like the one in *Meteor*, are two 140-kilometer behemoths, one near Sudbury, Canada, just north of Lake Huron, and one 100 kilometers outside of Johannesburg, South Africa. Since both of them formed about 1.9 billion years ago, no rimmed crater remains, only the rock shattered by the impact. By comparing the size of meteorite craters with those of nuclear explosions, Jon Bryan and his group at Lawrence Livermore Laboratory have estimated that the energy of 50 million megatons of TNT was released during each collision.

Obviously, such catastrophes do not occur every day. Grieve and Michael Dence, also of the DEMR, conclude from a study of the number, size, and age of recognizable impact craters that a body 1 kilometer wide or larger (big enough to release 100,000 megatons of explosive power and leave a crater at least 20 kilometers wide) collides with Earth only once in 600,000 years, give or take 150,000 years.

Although no one has ever observed an asteroid hitting Earth, enough are thought to cross Earth's orbit to account for the craters found on its surface. Most asteroids orbit the sun between Mars and Jupiter, but a few orbit close enough to the sun to pass inside the orbit of Earth. The number of known Earth-crossing asteroids, now totaling 28, continues to grow since the first, named Apollo, was accidentally discovered in 1932.

Estimates of the number of large, undiscovered Earth-crossing, or Apollo, asteroids have also grown. Two different but not entirely independent estimates now place their number at about 750. In one study, Eugene Shoemaker, Eleanor Helin, and S. Gillett of the California Institute of Technology considered how thorough the search for small, fast-moving objects near Earth had been. They concluded that 800, plus or minus 300, objects larger than 1 kilometer remain undetected. George Wetherill of the Carnegie Institution of Washington arrived at a generally similar figure by calculating how many Apollos must exist to make it likely that only one, called Ra-Shalon, has ever been observed twice. Eight hundred is hardly an astronomical number, but Shoemaker estimates that, if the Apollo objects are distributed over

Meteor Crater in Arizona. An iron-nickel meteorite formed this crater (1.2 kilometers wide, 150 meters deep) a few tens of thousands of years ago. The collision released about 5 megatons of explosive energy. The largest craters ever found on Earth are 140 kilometers wide and were excavated by the release of 50 million megatons of energy. [U.S. Department of the Interior, Geological Survey]

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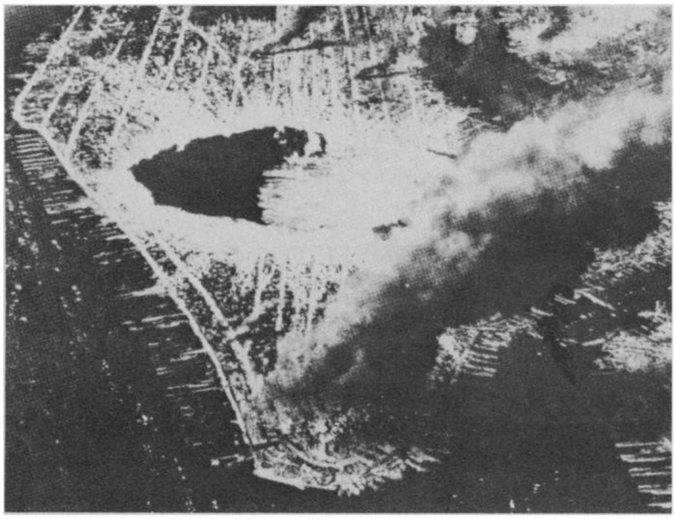

An artist's conception of lower Manhattan after the impact of a meteorite having the size and speed of the one that produced Meteor Crater in Arizona. [American International Pictures, Inc.]

a reasonable size range, there would be 100,000 Earth-crossing objects 100 meters or more in diameter. Such a diameter is large enough to produce a crater at least one and a half times the size of Barringer Crater.

If at least 800 Apollo asteroids have existed over the last few hundred million years, they would suffice as a source of crater-forming objects, but the ultimate source of the Apollos themselves remains unknown. They cannot simply be left over from the formation of the solar system—the planets would have swept them all up by now. How they are being replaced is not a purely academic question. The Apollos, by fragmenting during their periodic forays into the main asteroid belt, probably supply a major fraction of the meteorites that are studied in laboratories for clues to the early history of the solar system.

One way to resupply the Apollos would be to somehow have them brought in from the asteroid belt. Knocking them out of their normal orbits by mutual collisions would yield nothing but dust, but James Williams of the Jet Propulsion Laboratory in Pasadena and Wetherill have shown that some main-belt asteroids can be nudged into Earth-crossing orbits by certain gravitational interactions with Jupiter, Saturn, and Mars. So far, the specific mechanisms examined could only account for about 10 percent of the 15 new Apollo asteroids needed every million years to replace those swept up by the planets.

This does not rule out the asteroid belt as a source for most of the Apollo objects. As Williams points out, theorists still have a limited understanding of how planets affect smaller bodies, whether they are baseball-sized chunks of ice in the rings of Saturn or 10-kilometer-wide boulders in the asteroid belt. For example, relatively empty lanes in the asteroid belt, known as Kirkwood gaps, have been known for 100 years. They are obviously cleared by some gravitational effect of Jupiter, but no one knows exactly how the process works.

In the absence of a proven means of transferring enough bodies from the asteroid belt, Wetherill favors the idea that Apollo objects are resupplied by comets that have been burned out during frequent passages near the sun. Most comets have such large, elongated orbits that they do not spend enough time near the sun to lose their volatile ices. Of the 600 known comets, only about 130 take fewer than 10,000 years to complete an orbit and return to the vicinity of the sun, but some follow such small orbits that they return every few years.

One of these, Comet Encke, may be well on its way to losing all of its volatile ices and becoming a new, dim asteroid, according to Wetherill. It is already in an Apollo-like orbit with a period of only 3.3 years and seems to have become dimmer over repeated sightings. Fred Whipple of Harvard University, who first suggested that Encke might be evolving into a new sort of object, and Zdenek Sekanina of the Smithsonian Observatory have suggested how Encke's orbit might have been changed from that of an ordinary comet. They point out that the gases released from the comet by the sun's heat could push it into a smaller orbit, as the gaseous exhaust of a rocket can change its course.

Although his hypothesis is consistent with the behavior of some comets, Wetherill notes that some evidence argues against a connection between comets, Apollo asteroids, and most meteorites. One problem is that some meteorites seem to have formed as part of planetary bodies at least as large as the largest asteroids. These bodies then became hot enough to create new minerals and even to melt and form an iron core, as Earth did. After cooling, these large bodies would have collided and formed the small pieces that end up as meteorites. Comets, on the other hand, are thought to have formed as small dusty balls of ice in the outermost reaches of the solar system. Although the composition of comets is not certain, many researchers cannot accept icy, primordial comets as the source of once-hot, geologically evolved rocks.

Not all the bodies on a collision course with Earth form craters. Most of the hundreds or thousands of tons of meteoroids that enter Earth's atmosphere every day never reach the ground, but their destruction can still wreak considerable havoc.

According to most specialists, the shattering explosion that flattened 1600 square kilometers of Siberian forest near the Tunguska River in 1908 was not a black hole, a hunk of antimatter, or a plummeting UFO, as have been suggested, but a natural body entering the atmosphere. Perhaps a small fragment of an extinct comet, it may have been only 40 meters in diameter, according to John Brown of Glasgow University and David Hughes of Sheffield University. But, when it disintegrated a few kilometers above the ground at a speed of perhaps 40,000 kilometers per hour, the Tunguska object converted most of its kinetic energy into a devastating explosion.

How often such a destructive but craterless collision occurs is not certain. Although the calculation is admittedly crude, Brown and Hughes estimate that a cometary body the size of the Tunguska object might enter the atmosphere once in 2000 years. Small stony bodies about the size of the Tunguska object could also produce the same effects because they do not seem to survive passage through the atmosphere as well as Apollo-sized objects. Often, these smaller bodies appear as fireballs that explode in a bright flare tens of kilometers above the ground. Harmless at such altitudes, their destruction close to the surface could have serious effects.

Geologic evidence and observations of the Apollo asteroids suggest that devastating collisions with Earth are nearly nonexistent on a human time scale. Recorded history likewise indicates that Earth's atmosphere is a good shield against smaller space debris. When something sizable does crash into the surface, as it inevitably will, the sheer emptiness of Earth may provide another buffer, as it did for the Tunguska object and Skylab.— RICHARD A. KERR