Background Reading: Craters

The Solar System is like a cosmic shooting gallery, with asteroids and comets whizzing through space, occasionally zooming perilously close to Earth. The cratered surfaces of the Moon, Mercury and Mars show the effects of cosmic collisions.

Impact craters are found on nearly all solid surface planets and satellites in our Solar System. Craters form when meteorites slam into a solid surface displacing rock and soil, creating a bowl-shaped hole or crater. While the Earth only has approximately 160 impact craters, objects like Mercury, Mars, and the Moon have too many craters to count. Impact craters vary in size from less than a millimeter (3 feet) to 2,100 km (1,300 miles) in diameter.

Studying meteorite impacts is important because they can cause catastrophic effects. For example, evidence supports that the demise of the dinosaurs was due to impact that hit the Earth 65 million years ago. The 12 km sized asteroid made a crater that was 180 km wide. Debris from the explosion was thrown into the atmosphere, severely altering the climate, and leading to the extinction of roughly three-quarters of species that existed at that time, including the dinosaurs.

Calculations indicated that for the first few hours after the impact, rocky debris would have fallen back into the high atmosphere, creating a storm of glowing fireballs in the sky. The radiant energy from these would have heated the surface to boiling temperatures for some minutes, and would have been enough to kill many animals and plants on the surface. However, in regions of heavy rainstorms or snowstorms, these organisms would have survived the first few hours. Sea creatures would have been buffered from effects in the first hours, but plankton on the surface might have died out over the weeks of darkness, decreasing the food supply for small fish, which affected the bigger fish, and so on.

But Where do Asteroids come from?

The vast majority of asteroids are found somewhere between the orbits of Mars and Jupiter. But there is a sub-class of asteroids, called Earth-Crossing Asteroids, whose orbits bring them closer to the Sun than the Earth's orbit. Astronomers estimate that there are, in this sub-class, between 1000 and 4000 asteroids larger than one kilometer (0.6 miles) across (asteroids smaller than that can cause severe local damage where they hit but do not threaten the global ecosystem). Of these, only about 150 have been identified by astronomers.

In recent years, astronomers have undertaken studies aimed at discovering more asteroids. They look in photographs for faint specks of light that move with respect to the background stars. By the late 1990s, they were finding four or more new asteroids each month.

Will future impact occur?

Yes! Scientists base this conclusion studying the population of asteroids and comets and their orbits, as well as studying the age and distribution of craters on the Earth and other planetary objects.

Today, many asteroids are now known; their orbits pass through the inner solar system and cross Earth's orbit. Some of these could potentially hit Earth in the future.

Also, more asteroids are constantly being deflected from the asteroid belt onto orbits among the inner planets, including Earth. And added to this shoot gallery are Comets, which can appear from out of nowhere because their orbits are highly elliptical and originate from the outer reaches of our Solar System.

Based on the record of craters on other planets and moons, and an idea of the numbers and orbits of earth-crossing asteroids, scientists estimate that asteroids big enough to wipe out many species (>1 kilometer across), like in the case of the dinosaurs, occur only every 100 Million years or so. So it is unlikely that we or even our great-great-grandchildren will see one. Smaller rocks, between about 90 meters (300 feet) and one kilometer in diameter, hit the Earth, on average, once every 300 years or so. These types of impacts cause atomic bomb sized explosions. The last one was the Siberian explosion of 1908, where a small asteroid roughly 90 meters (300 feet) across is thought to have exploded about 20 kilometers (12 miles) above the ground in a desolate valley of the Tunguska River in central Siberia. The blast, with a force of 12 million tons of TNT, 800 times more powerful than the atomic bomb dropped on Hiroshima, destroyed a forest the size of Rhode Island and booted a man off a chair at a trading post 112 kilometers (70 miles) away.

Because most of the Earth is covered with water, most will land there, with little effect on humans or other life. A 1978 explosion in the South Pacific, once though to be a nuclear test, is now thought to have been a small asteroid hit in the water.

Astronomers have also discovered some recent cosmic close-calls. On March 23, 1989, an asteroid about a half- mile wide crossed the Earth's orbit about 640,000 kilometers (400,000 miles) from Earth. The Earth had been in that same spot a mere six hours earlier. The closest approach recorded was an asteroid, called 1991BA, about nine meters (30 feet) across, which passed within 170,000 kilometers (106,000 miles) of Earth, less than half the distance to the Moon, on January 17, 1991.

It is possible that by the year 2100, or sooner, we may have the capability to deflect any approaching asteroid before it hits.

Lesson

Although this exercise simulates the impact process, it must be noted that the physical variables do not scale in a simple way to compare with full-size crater formation. In other words, this exercise is a good approximation but not the real thing. Impact craters form when objects from space, such as asteroids, impact the surface of a planet or moon. The size of the crater formed depends on the amount of kinetic energy possessed by the impacting object. Kinetic energy (energy in motion) is defined as: $KE = ½(mv^2)$, in which m = mass and v = velocity. Weight is related to the mass of an object. During impact the kinetic energy of the object is transferred to the target surface. The impact velocity of the due to the slingshot is only ~70 m/sec, while the velocity of an asteroid or meteorite is 10,000 to 20,000 m/sec. So for the same sized object, the asteroid will release 4 orders of magnitude more energy.

This exercise demonstrates the mechanics of impact cratering and introduces the concept of kinetic energy (energy of motion): KE = 1/2 (mv2), where m = mass and v = velocity. The effects of the velocity, mass, and size of the impacting projectile on the size of the resultant crater are explored. By the conclusion of the exercise, the student should understand the concept of kinetic energy, and know that the velocity of the impactor has the greatest effect on crater size [$KE = 1/2 (mv2)$].

Use of a slingshot to fire projectiles is required in this exercise. It is the instructor’s decision whether this exercise should be done as a demonstration or by the student. Students should be supervised carefully at all times during the firing of the projectiles and everyone should wear protective goggles. Place the tray on a sheet of plastic or drop cloth; this will make cleanup easier. Fill the tray completely with sand, then scrape the top with the ruler to produce a smooth surface. The dyed sand is best sprinkled on the surface through a fine screen, or a flour sifter.

This exercise requires the calculation of kinetic energies. All of the velocities necessary for these calculations have been provided in the student’s charts. Calculation of velocity for dropped objects is simple using the formula:
$v = (2ay).5$ where v is the velocity, a is the acceleration due to gravity (9.8 m/s2), and y is the distance dropped

Calculation of the velocity for objects launched by a slingshot is a time consuming procedure for values used in only two entries in the exercise; however, it is an excellent introduction to the physics of motion and can be done in a class period before performing this exercise. The procedure for calibrating the slingshot and for calculating velocities of objects launched by the slingshot follows the answer key (where it may be copied for student use).

Advanced students and upper classes can answer the optional starred (*) questions, which apply their observations to more complex situations.