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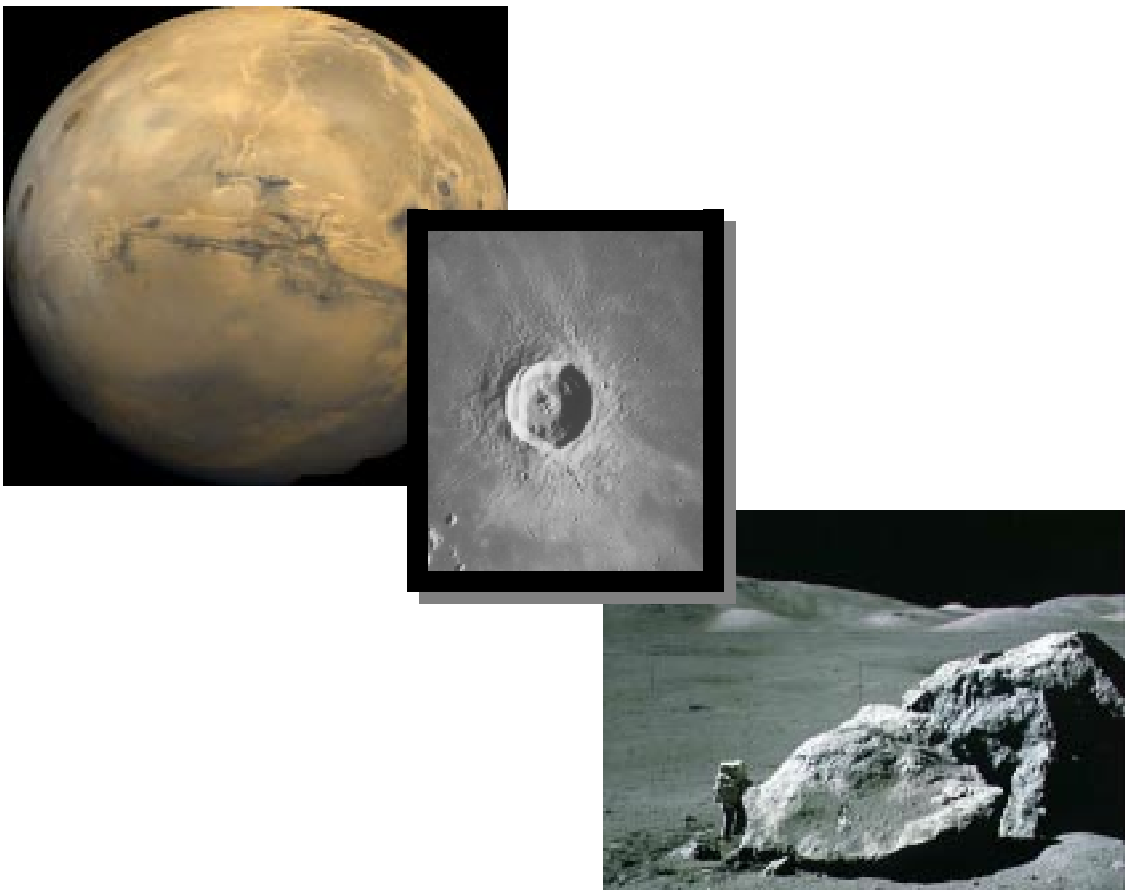
Astrogeology Research Program

USGS Educational Outreach



Impact Craters Module

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IMPACT CRATERS

The solar system formed 4.5 billion years ago. As the rotating **solar nebula** collapsed in on itself the sun formed. Material further out in the cloud collected (accreted) to create the planets, asteroids, and comets that presently inhabit our solar system. About 3.8 billion years ago, after the planets had finished forming, there was still a lot of leftover debris in our solar system. This material often crossed the orbits of the newly formed planets resulting in a tremendous number of impact craters.

Asteroid Ida with it's moon, Dactyl.

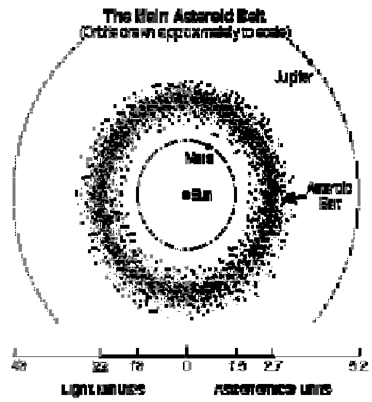


Diagram of Main Asteroid Belt.

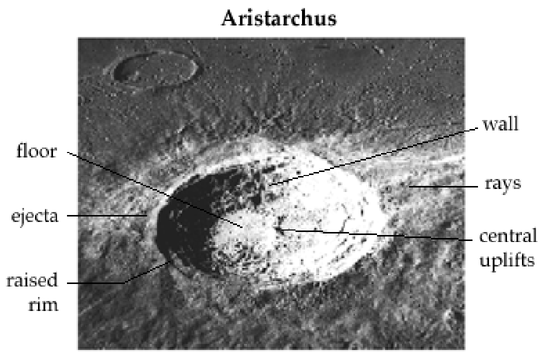
There are still many objects in space besides planets, including asteroids and comets. **Asteroids** come in many shapes and sizes and are leftover debris that was never incorporated into a planet. Many asteroids orbit around the sun in the main asteroid belt, located between Mars and Jupiter. **Comets** are lumps of frozen gas and rock similar to dirty snowballs. They formed at the same time as the planets and the sun and reside in the Oort Cloud, the Kuiper-belt, the trans-Neptune belt, and in isolated clouds. They orbit the sun just like the planets but their orbits are very elliptical. **Meteor showers** occur when the Earth passes through the orbital path of a comet. Dust particles associated with the comet are swept into the atmosphere and vaporized appearing as shooting stars. **Meteors** are parts of asteroids or comets that have entered a planets atmosphere. **Meteorites** are rocks from space that have survived their passage through the atmosphere to land on Earth's surface.

A meteor the size of a pea streaming through Earth's atmosphere.

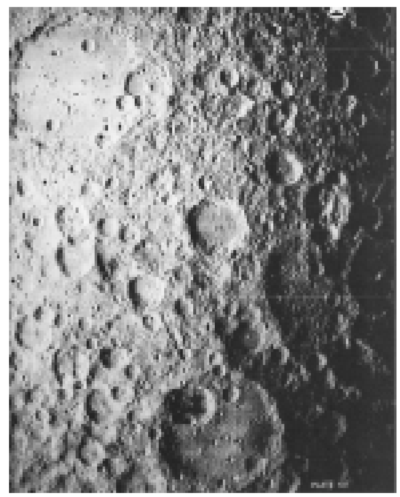
Comet Hale-Bop.

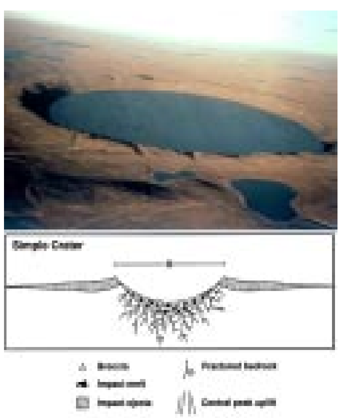
Impact craters are formed when a meteor collides with a planetary surface. We have learned from data sent back by spacecraft that all the rocky planets, Mercury, Venus, Earth, Mars, and Earth's Moon, have craters on their surfaces. We also know, thanks to the Shoemaker-Levy Nine comet collision with Jupiter, that asteroids and comets strike the giant gaseous planets, Jupiter, Saturn, Uranus, and Neptune, but we can't see their impact scars because of the thick atmospheres enveloping these planets. Many of the rocky moons orbiting these gas giants have heavily cratered surfaces, further suggesting that the outer planets have also been targeted.

Impact craters come in many shapes and sizes (Lesson 1). Planetary controls on cratering include atmospheric density and composition of surface materials. Other controls are size of the meteor, velocity and angle of impact. The biggest control on cratering is the planet's gravity. Objects that form craters the size of Meteor Crater (1 km) don't even know there is an atmosphere and things that form craters the size of Chicxulub (150 km) are large enough that the top of the impactor is above the atmosphere while the bottom in already burrowing into a planet's surface. Furthermore, if a planet has a dense atmosphere a small meteor will most likely burn up before it hits the ground, whereas, a thin atmosphere allows penetration. How do you think the shape and size of a crater would vary if the meteor collided with a rocky surface as opposed to a water covered surface? Most impact craters are circular because of the direction of **shock waves** during impact. However, some craters, like Meteor Crater in Arizona, appear square due to preexisting weakness or jointing in the bedrock into which the meteor impacted.

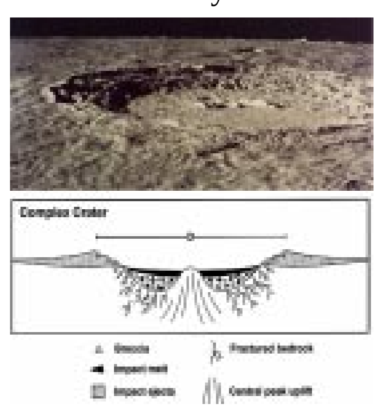


The parts of an impact crater.


Impact Craters on the farside of the Moon. Notice the large number of craters.


Simple crater.

Impact craters are grouped into three general categories based on diameter and morphology (Lesson 1). **Simple craters** are bowl-shaped and quite circular. They are small depressions, usually less than 5 km (3 miles) across. These craters are very common on all rocky planets and the moons of the gaseous planets. They are quite similar in form to craters formed by nuclear explosions. **Complex craters** are larger, between 5 and 50 km (3 to 31 miles) across. They have a central peak near the middle of the depression caused by elastic rebound of material after the shock waves traveled through the surface during impact. Some very large craters have a circular ring of mountains near the center of the crater floor instead of one central peak. The last type of crater is called a **multi-ring basin**. These craters are typically larger than 50 km (31 miles) across and contain more than one concentric ring of low ridges or hills protruding above the floor inside the crater's dominant rim. The transition between simple and complex craters is different on every body and is highly dependent on the gravitational pull of that body.


Simple crater.

A complex impact crater on the surface of Mars.

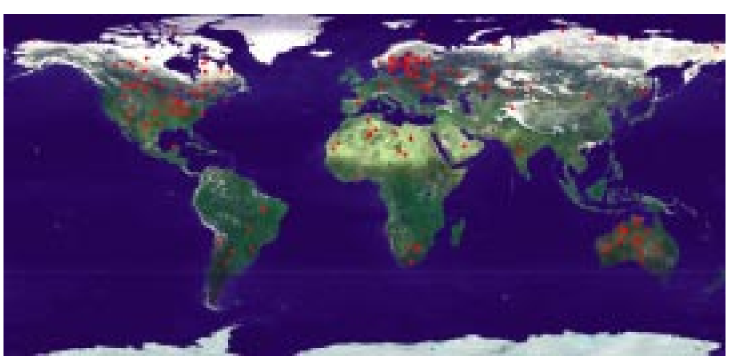
When meteors strike a surface and create an impact crater, large amounts of material are thrown up into the atmosphere. This is called **ejecta**. Ejecta is composed primarily of pulverized and melted bedrock, and meteorite fragments. As ejecta settles back to the surface it forms an **ejecta blanket** surrounding the impact site. Large fragments of rock also get thrown into the air creating chains of **secondary craters** as they return to strike the planets surface.

Meteor Crater, AZ.

Here in Flagstaff, we are fortunate to have an impact crater nearby. **Meteor Crater** is roughly 40 miles east of town (Lesson 6). It is a simple crater that formed approximately 49,000 years ago when a meteor about 30 meters (100 feet) across struck, forming a bowl-shaped depression about 180 meters (600 feet) deep and 1.2 km (3/4 mile) in diameter. Gene Shoemaker of the U.S. Geological Survey was the first scientist to demonstrate scientifically that Meteor Crater was created by the impact of extraterrestrial material, or a meteor, hence the name Meteor Crater. Much of Shoemaker's understanding of Meteor Crater was derived from looking at large scale explosions. He compared the structure of craters formed by nuclear explosions to Meteor Crater and observed similar characteristics. Up until that time many scientists believed that the crater was the result of volcanic activity. Shoemaker's field studies revealed meteor fragments and geologic evidence proving an impact theory to be true. Shoemaker went on to become one of the world's premier impact crater scientists.

Simple impact craters are similar in form to nuclear explosion craters.

Impact craters are very important tools for planetary geologists in the study of our solar system. They provide much information about the surface of a planet, such as its age and it's volcanic and erosional history (Lesson 2). Scientists often use "**crater counting**" to determine relative ages of planetary surface areas or units. Simply put, an unmodified unit that has more craters is older than an unmodified unit or surface area with fewer craters. To understand this concept, compare the surface of the Moon with the surface of the Earth. The Moon has many more craters than the Earth. Using this observation, we can predict that the surface of the Moon is older than the surface of the Earth. And this is true but why? Not because the moon has been hit more often than the Earth, but because craters on the Earth have been erased through erosional,

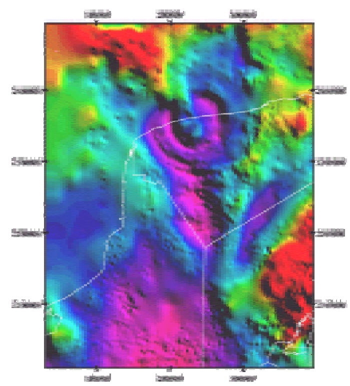


Locations of all discovered terrestrial impact craters.

depositional, and similar geologic processes. **Plate tectonics** is an active process on the Earth, providing a means to continually recycle crustal material. Old crust is destroyed in subduction zones while new crust is formed at mid-ocean spreading ridges and by volcanic activity. Therefore, the oldest crust on the surface of the Earth is relatively young even though the Earth is 4.5 billion years old, the same age as the moon. However, plate tectonics is not an active process on the moon, so much more of its impact history is preserved.

Craters can also provide actual rock samples of other planets. Pieces of both the Moon and Mars have arrived on Earth after being thrown out of craters there during an impact event.

Approximately 140 craters have been identified on our planet with ages ranging from very recent to nearly 2 billion years old. It is now believed that the demise of the dinosaurs was a result of a meteor impact on Earth approximately 65 million years ago, represented in geological time by the Cretaceous/Tertiary boundary. It is widely accepted that the meteor landed just off the Yucatan Peninsula in Central America resulting in the crater now named **Chicxulub** (Lessons 3, 4 and 5).



Gravity map of the Chicxulub impact basin off the Yucatan peninsula in Central America.

The meteor was about 10 km (6 miles) across leaving a crater 150-200 or more km (93-125 miles) wide and a few km (~1.8 miles) deep. The result of such an impact would annihilate nearly all life on the planet and vaporize all animal and plant life to a distance of 500-1000 kilometers (300-600 miles) as well cause dramatic changes to Earths climate. A primary effect would be blocking out the sun's light. It might have been too dark to see for 1-6 months and too dark for photosynthesis for 2 months to a year. The energy released from such an impact would have been 6 million times that of the 1980 Mt. St. Helen's volcanic eruption.

Effects of an impactor comparable to that of Meteor Crater.

Even though we have yet to witness a sizable meteor impact on Earth in our lifetime, scientists predict that an event like the one that created Meteor Crater will happen again. Large impacts like these occur about every 50,000 years. Astronomers are currently searching for and identifying potential Earth-crossing asteroids with hopes of increasing our awareness of potential asteroid hazards.

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