



National Aeronautics and Space Administration

WORLD BOOK @ NASA



Print This



Close Window

Moon is Earth's only natural satellite and the only astronomical body other than Earth ever visited by human beings. The moon is the brightest object in the night sky but gives off no light of its own. Instead, it reflects light from the sun. Like Earth and the rest of the solar system, the moon is about 4.6 billion years old.

The moon is much smaller than Earth. The moon's average radius (distance from its center to its surface) is 1,079.6 miles (1,737.4 kilometers), about 27 percent of the radius of Earth.

The moon is also much less massive than Earth. The moon has a mass (amount of matter) of 8.10×10^{19} tons (7.35×10^{19} metric tons). Its mass in metric tons would be written out as 735 followed by 17 zeroes. Earth is about 81 times that massive. The moon's density (mass divided by volume) is about 3.34 grams per cubic centimeter, roughly 60 percent of Earth's density.

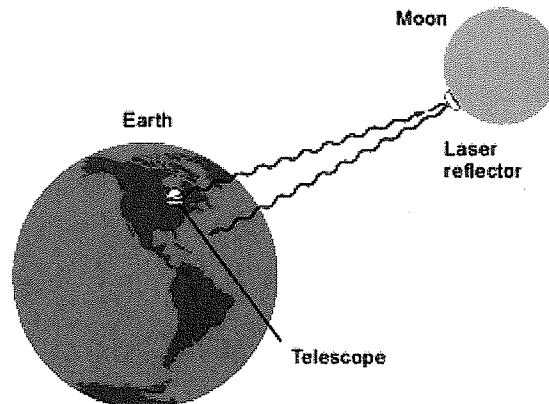
Because the moon has less mass than Earth, the force due to gravity at the lunar surface is only about 1/6 of that on Earth. Thus, a person standing on the moon would feel as if his or her weight had decreased by 5/6. And if that person dropped a rock, the rock would fall to the surface much more slowly than the same rock would fall to Earth.

Despite the moon's relatively weak gravitational force, the moon is close enough to Earth to produce tides in Earth's waters. The average distance from the center of Earth to the center of the moon is 238,897 miles (384,467 kilometers). That distance is growing -- but extremely slowly. The moon is moving away from Earth at a speed of about 1 1/2 inches (3.8 centimeters) per year.

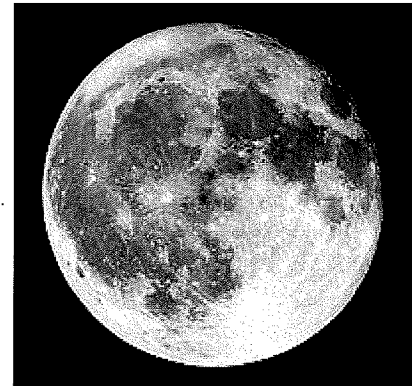
The temperature at the lunar equator ranges from extremely low to extremely high -- from about -280 degrees F (-173 degrees C) at night to +260 degrees F (+127 degrees C) in the daytime. In some deep craters near the moon's poles, the temperature is always near -400 degrees F (-240 degrees C).

The moon has no life of any kind. Compared with Earth, it has changed little over billions of years. On the moon, the sky is black -- even during the day -- and the stars are always visible.

A person on Earth looking at the moon with the unaided eye can see light and dark areas on the lunar surface. The light areas are rugged, cratered highlands known as terrae (TEHR ee). The word terrae is Latin for lands. The highlands are the original crust of the moon, shattered and fragmented by the impact of meteoroids, asteroids, and comets. Many craters in the terrae exceed 25 miles (40 kilometers) in diameter. The largest is the South Pole-Aitken Basin, which is 1,550 miles (2,500 kilometers) in diameter.



The distance to the moon is measured to an accuracy of 5 centimeters by a laser beam sent from Earth. The beam bounces off a laser reflector placed on the moon by astronauts, and returns to Earth. Image credit: World Book diagram by Bensen Studios



The moon's surface shows striking contrasts of light and dark. The light areas are rugged highlands. The dark zones were partly flooded by lava when volcanoes erupted billions of years ago. The lava froze to form smooth rock. Image credit: Lunar and Planetary Institute

The dark areas on the moon are known as maria (MAHR ee uh). The word maria is Latin for seas; its singular is mare (MAHR ee). The term comes from the smoothness of the dark areas and their resemblance to bodies of water. The maria are cratered landscapes that were partly flooded by lava when volcanoes erupted. The lava then froze, forming rock. Since that time, meteoroid impacts have created craters in the maria.

The moon has no substantial atmosphere, but small amounts of certain gases are present above the lunar surface. People sometimes refer to those gases as the lunar atmosphere. This "atmosphere" can also be called an exosphere, defined as a tenuous (low-density) zone of particles surrounding an airless body. Mercury and some asteroids also have an exosphere.

In 1959, scientists began to explore the moon with robot spacecraft. In that year, the Soviet Union sent a spacecraft called Luna 3 around the side of the moon that faces away from Earth. Luna 3 took the first photographs of that side of the moon. The word luna is Latin for moon.

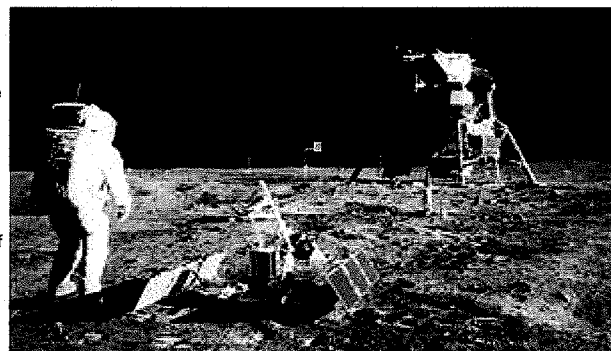
On July 20, 1969, the U.S. Apollo 11 lunar module landed on the moon in the first of six Apollo landings. Astronaut Neil A. Armstrong became the first human being to set foot on the moon.

In the 1990's, two U.S. robot space probes, Clementine and Lunar Prospector, detected evidence of frozen water at both of the moon's poles. The ice came from comets that hit the moon over the last 2 billion to 3 billion years. The ice apparently has lasted in areas that are always in the shadows of crater rims. Because the ice is in the shade, where the temperature is about -400 degrees F (-240 degrees C), it has not melted and evaporated.

This article discusses Moon (The movements of the moon) (Origin and evolution of the moon) (The exosphere of the moon) (Surface features of the moon) (The interior of the moon) (History of moon study).

The movements of the moon

The moon moves in a variety of ways. For example, it rotates on its axis, an imaginary line that



The first people on the moon were U.S. astronauts Neil A. Armstrong, who took

connects its poles. The moon also orbits Earth. Different amounts of the moon's lighted side become visible in phases because of the moon's orbit around Earth. During events called eclipses, the moon is positioned in line with Earth and the sun. A slight motion called libration enables us to see about 59 percent of the moon's surface at different times.

this picture, and Buzz Aldrin, who is pictured next to a seismograph. A television camera and a United States flag are in the background. Their lunar module, Eagle, stands at the right. Image credit: NASA

Rotation and orbit

The moon rotates on its axis once every 29 1/2 days. That is the period from one sunrise to the next, as seen from the lunar surface, and so it is known as a lunar day. By contrast, Earth takes only 24 hours for one rotation.

The moon's axis of rotation, like that of Earth, is tilted. Astronomers measure axial tilt relative to a line perpendicular to the ecliptic plane, an imaginary surface through Earth's orbit around the sun. The tilt of Earth's axis is about 23.5 degrees from the perpendicular and accounts for the seasons on Earth. But the tilt of the moon's axis is only about 1.5 degrees, so the moon has no seasons.

Another result of the smallness of the moon's tilt is that certain large peaks near the poles are always in sunlight. In addition, the floors of some craters -- particularly near the south pole -- are always in shadow.

The moon completes one orbit of Earth with respect to the stars about every 27 1/3 days, a period known as a sidereal month. But the moon revolves around Earth once with respect to the sun in about 29 1/2 days, a period known as a synodic month. A sidereal month is slightly shorter than a synodic month because, as the moon revolves around Earth, Earth is revolving around the sun. The moon needs some extra time to "catch up" with Earth. If the moon started on its orbit from a spot between Earth and the sun, it would return to almost the same place in about 29 1/2 days.

A synodic month equals a lunar day. As a result, the moon shows the same hemisphere -- the near side -- to Earth at all times. The other hemisphere -- the far side -- is always turned away from Earth.

People sometimes mistakenly use the term dark side to refer to the far side. The moon does have a dark side -- it is the hemisphere that is turned away from the sun. The location of the dark side changes constantly, moving with the terminator, the dividing line between sunlight and dark.

The lunar orbit, like the orbit of Earth, is shaped like a slightly flattened circle. The distance between the center of Earth and the moon's center varies throughout each orbit. At perigee (PEHR uh jee), when the moon is closest to Earth, that distance is 225,740 miles (363,300 kilometers). At apogee (AP uh jee), the farthest position, the distance is 251,970 miles (405,500 kilometers). The moon's orbit is elliptical (oval-shaped).

Phases

As the moon orbits Earth, an observer on Earth can see the moon appear to change shape. It seems to change from a crescent to a circle and back again. The shape looks different from one day to the next because the observer sees different parts of the moon's sunlit surface as the moon orbits Earth. The different appearances are known as the phases of the moon. The moon goes through a complete cycle of phases in a synodic month.

The moon has four phases: (1) new moon, (2) first quarter, (3) full moon, and (4) last quarter. When the moon is between the sun and Earth, its sunlit side is turned away from Earth. Astronomers call this darkened phase a new moon.

The next night after a new moon, a thin crescent of light appears along the moon's eastern edge. The remaining portion of the moon that faces Earth is faintly visible because of earthshine, sunlight reflected from Earth to the moon. Each night, an observer on Earth can see more of the sunlit side as the terminator, the line between sunlight and dark, moves westward. After about seven days, the observer can see half a full moon, commonly called a half moon. This phase is known as the first quarter because it occurs one quarter of the way through the synodic month. About seven days later, the moon is on the side of Earth opposite the sun. The entire sunlit side of the moon is now visible. This phase is called a full moon.

About seven days after a full moon, the observer again sees a half moon. This phase is the last quarter, or third quarter. After another seven days, the moon is between Earth and the sun, and another new moon occurs.

As the moon changes from new moon to full moon, and more and more of it becomes visible, it is said to be waxing. As it changes from full moon to new moon, and less and less of it can be seen, it is waning. When the moon appears smaller than a half moon, it is called crescent. When it looks larger than a half moon, but is not yet a full moon, it is called gibbous (GIHB uhs).

Like the sun, the moon rises in the east and sets in the west. As the moon progresses through its phases, it rises and sets at different times. In the new moon phase, it rises with the sun and travels close to the sun across the sky. Each successive day, the moon rises an average of about 50 minutes later.

Eclipses occur when Earth, the sun, and the moon are in a straight line, or nearly so. A lunar eclipse occurs when Earth gets directly -- or almost directly -- between the sun and the moon, and Earth's shadow falls on the moon. A lunar eclipse can occur only during a full moon. A solar eclipse occurs when the moon gets directly -- or almost directly -- between the sun and Earth, and the moon's shadow falls on Earth. A solar eclipse can occur only during a new moon.

During one part of each lunar orbit, Earth is between the sun and the moon; and, during another part of the orbit, the moon is between the sun and Earth. But in most cases, the astronomical bodies are not aligned directly enough to cause an eclipse. Instead, Earth casts its shadow into space above or below the moon, or the moon casts its shadow into space above or below Earth. The shadows extend into space in that way because the moon's orbit is tilted about 5 degrees relative to Earth's orbit around the sun.

Libration

People on Earth can sometimes see a small part of the far side of the moon. That part is visible because of lunar libration, a slight rotation of the moon as viewed from Earth. There are three kinds of libration: (1) libration in longitude, (2) diurnal (daily) libration, and (3) libration in latitude. Over time, viewers can see more than 50 percent of the moon's surface. Because of libration, about 59 percent of the lunar surface is visible from Earth.

Libration in longitude occurs because the moon's orbit is elliptical. As the moon orbits Earth, its speed varies according to a law discovered in the 1600's by the German astronomer Johannes Kepler. When the moon is relatively close to Earth, the moon travels more rapidly than its average speed. When the moon is relatively far from Earth, the moon travels more slowly than average. But the moon always rotates about its own axis at the same rate. So when the moon is traveling more rapidly than average, its rotation is too slow to keep all of the near side facing Earth. And when the moon is traveling more slowly than average, its rotation is too rapid to keep all of the near side facing Earth.

Diurnal libration is caused by a daily change in the position of an observer on Earth relative to the moon. Consider an observer who is at Earth's equator when the moon is full. As Earth rotates from west to east, the observer first sees the moon when it rises at the eastern horizon and last sees it when it sets at the western horizon. During this time, the observer's viewpoint moves about 7,900 miles (12,700 kilometers) -- the diameter of Earth -- relative to the moon. As a result, the moon appears to rotate slightly to the west.

While the moon is rising in the east and climbing to its highest point in the sky, the observer can see around the western edge of the near side. As the moon descends to the western horizon, the observer can see around the eastern edge of the near side.

Libration in latitude occurs because the moon's axis of rotation is tilted about $6\frac{1}{2}$ degrees relative to a line perpendicular to the moon's orbit around Earth. Thus, during each lunar orbit, the moon's north pole tilts first toward Earth, then away from Earth. When the lunar north pole is tilted toward Earth, people on Earth can see farther than normal along the top of the moon. When that pole is tilted away from Earth, people on Earth can see farther than normal along the bottom of the moon.

Origin and evolution of the moon

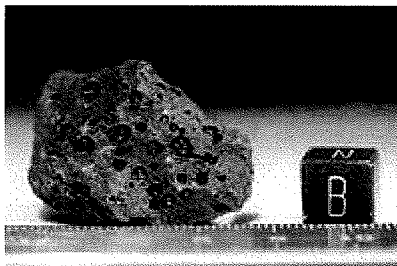
Scientists believe that the moon formed as a result of a collision known as the Giant Impact or the "Big Whack." According to this idea, Earth collided with a planet-sized object 4.6 billion years ago. As a result of the impact, a cloud of vaporized rock shot off Earth's surface and went into orbit around Earth. The cloud cooled and condensed into a ring of small, solid bodies, which then gathered together, forming the moon.

The rapid joining together of the small bodies released much energy as heat. Consequently, the moon melted, creating an "ocean" of magma (melted rock).

The magma ocean slowly cooled and solidified. As it cooled, dense, iron-rich materials sank deep into the moon. Those materials also cooled and solidified, forming the mantle, the layer of rock beneath the crust.

As the crust formed, asteroids bombarded it heavily, shattering and churning it. The largest impacts may have stripped off the entire crust. Some collisions were so powerful that they almost split the moon into pieces. One such collision created the South Pole-Aitken Basin, one of the largest known impact craters in the solar system.

About 4 billion to 3 billion years ago, melting occurred in the mantle, probably caused by radioactive elements deep in the moon's interior. The resulting magma erupted as dark, iron-rich lava, partly flooding the heavily cratered surface. The lava cooled and solidified into rocks known as basalts (buh SAWLTS).



Small eruptions may have continued until as recently as 1 billion years ago. Since that time, only an occasional impact by an asteroid or comet has modified the surface. Because the moon has no atmosphere to burn up meteoroids, the bombardment continues to this day. However, it has become much less intense.

Impacts of large objects can create craters. Impacts of micrometeoroids (tiny meteoroids) grind the surface rocks into a fine, dusty powder known as the regolith (REHG uh lith). Regolith overlies all the bedrock on the moon. Because regolith forms as a result of exposure to space, the longer a rock is exposed, the thicker the regolith that forms on it.

A basalt rock that astronauts brought to Earth from the moon formed from lava that erupted from a lunar volcano. Escaping gases created the holes before the lava solidified into rock. Image credit: Lunar and Planetary Institute

The exosphere of the moon

The lunar exosphere -- that is, the materials surrounding the moon that make up the lunar "atmosphere" -- consists mainly of gases that arrive as the solar wind. The solar wind is a continuous flow of gases from the sun -- mostly hydrogen and helium, along with some neon and argon.

The remainder of the gases in the exosphere form on the moon. A continual "rain" of micrometeoroids heats lunar rocks, melting and vaporizing their surface. The most common atoms in the vapor are atoms of sodium and potassium. Those elements are present in tiny amounts -- only a few hundred atoms of each per cubic centimeter of exosphere. In addition to vapors produced by impacts, the moon also releases some gases from its interior.

Most gases of the exosphere concentrate about halfway between the equator and the poles, and they are most plentiful just before sunrise. The solar wind continuously sweeps vapor into space, but the vapor is continuously replaced.

During the night, the pressure of gases at the lunar surface is about 3.9×10^{-14} pound per square inch (2.7×10^{-10} pascal). That is a stronger vacuum than laboratories on Earth can usually achieve. The exosphere is so tenuous -- that is, so low in density -- that the rocket exhaust released during each Apollo landing temporarily doubled the total mass of the entire exosphere.

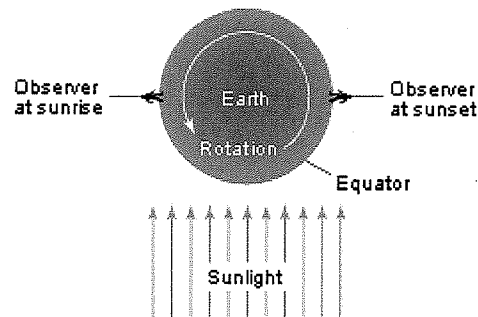
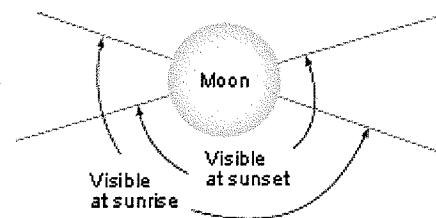
The surface of the moon is covered with bowl-shaped holes called craters, shallow depressions called basins, and broad, flat plains known as maria. A powdery dust called the regolith overlies much of the surface of the moon.

Craters

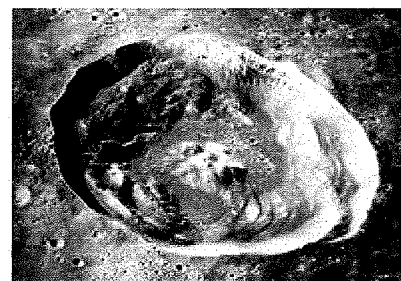
The vast majority of the moon's craters are formed by the impact of meteoroids, asteroids, and comets. Craters on the moon are named for famous scientists. For example, Copernicus Crater is named for Nicolaus Copernicus, a Polish astronomer who realized in the 1500's that the planets move about the sun. Archimedes Crater is named for the Greek mathematician Archimedes, who made many mathematical discoveries in the 200's B.C.

The shape of craters varies with their size. Small craters with diameters of less than 6 miles (10 kilometers) have relatively simple bowl shapes. Slightly larger craters cannot maintain a bowl shape because the crater wall is too steep. Material falls inward from the wall to the floor. As a result, the walls become scalloped and the floor becomes flat.

Still larger craters have terraced walls and central peaks. Terraces inside the rim descend like stairsteps to the floor. The same process that creates wall scalloping is responsible for terraces. The central peaks almost certainly form as did the central peaks of impact craters on Earth. Studies of the peaks on Earth show that they result from a deformation of the ground. The impact compresses the ground, which then rebounds, creating the peaks. Material in the central peaks of lunar



Diurnal libration enables an observer on Earth to see around one edge of the moon, then the other, during a single night. The libration occurs because Earth's rotation changes the observer's viewpoint by a distance equal to the diameter of Earth. Image credit: World Book illustration



Euler Crater has central peaks and slumped walls.

craters may come from depths as great as 12 miles (19 kilometers).

Surrounding the craters is rough, mountainous material -- crushed and broken rocks that were ripped out of the crater cavity by shock pressure. This material, called the crater ejecta blanket, can extend about 60 miles (100 kilometers) from the crater.

Farther out are patches of debris and, in many cases, irregular secondary craters, also known as secondaries. Those craters come in a range of shapes and sizes, and they are often clustered in groups or aligned in rows. Secondaries form when material thrown out of the primary (original) crater strikes the surface. This material consists of large blocks, clumps of loosely joined rocks, and fine sprays of ground-up rock. The material may travel thousands of miles or kilometers.

Crater rays are light, wispy deposits of powder that can extend thousands of miles or kilometers from the crater. Rays slowly vanish as micrometeoroid bombardment mixes the powder into the upper surface layer. Thus, craters that still have visible rays must be among the youngest craters on the moon.

Craters larger than about 120 miles (200 kilometers) across tend to have central mountains. Some of them also have inner rings of peaks, in addition to the central peak. The appearance of a ring signals the next major transition in crater shape -- from crater to basin.

Basins are craters that are 190 miles (300 kilometers) or more across. The smaller basins have only a single inner ring of peaks, but the larger ones typically have multiple rings. The rings are concentric -- that is, they all have the same center, like the rings of a dartboard. The spectacular, multiple-ringed basin called the Eastern Sea (Mare Orientale) is almost 600 miles (1,000 kilometers) across. Other basins can be more than 1,200 miles (2,000 kilometers) in diameter -- as large as the entire western United States.

Basins occur equally on the near side and far side. Most basins have little or no fill of basalt, particularly those on the far side. The difference in filling may be related to variations in the thickness of the crust. The far side has a thicker crust, so it is more difficult for molten rock to reach the surface there.

In the highlands, the overlying ejecta blankets of the basins make up most of the upper few miles or kilometers of material. Much of this material is a large, thick layer of shattered and crushed rock known as breccia (BREHCH ee uh). Scientists can learn about the original crust by studying tiny fragments of breccia.

Maria, the dark areas on the surface of the moon, make up about 16 percent of the surface area. Some maria are named in Latin for weather terms -- for example, Mare Imbrium (Sea of Rains) and Mare Nubium (Sea of Clouds). Others are named for states of mind, as in Mare Serenitatus (Sea of Serenity) and Mare Tranquillitatis (Sea of Tranquility).

Landforms on the maria tend to be smaller than those of the highlands. The small size of mare features relates to the scale of the processes that formed them -- volcanic eruptions and crustal deformation, rather than large impacts. The chief landforms on the maria include wrinkle ridges and rilles and other volcanic features.

Wrinkle ridges are blisterlike humps that wind across the surface of almost all maria. The ridges are actually broad folds in the rocks, created by compression. Many wrinkle ridges are roughly circular, aligned with small peaks that stick up through the maria and outlining interior rings. Circular ridge systems also outline buried features, such as rims of craters that existed before the maria formed.

Rilles are snakelike depressions that wind across many areas of the maria. Scientists formerly thought the rilles might be ancient riverbeds. However, they now suspect that the rilles are channels formed by running lava. One piece of evidence favoring this view is the dryness of rock samples brought to Earth by Apollo astronauts; the samples have almost no water in their molecular structure. In addition, detailed photographs show that the rilles are shaped somewhat like channels created by flowing lava on Earth.

Volcanic features

Scattered throughout the maria are a variety of other features formed by volcanic eruptions. Within Mare Imbrium, scarps (lines of cliffs) wind their way across the surface. The scarps are lava flow fronts, places where lava solidified, enabling lava that was still molten to pile up behind them. The presence of the scarps is one piece of evidence indicating that the maria consist of solidified basaltic lava.

Small hills and domes with pits on top are probably little volcanoes. Both dome-shaped and cone-shaped volcanoes cluster together in many places, as on Earth. One of the largest concentrations of cones on the moon is the Marius Hills complex in Oceanus Procellarum (Ocean of Storms). Within this complex are numerous wrinkle ridges and rilles, and more than 50 volcanoes.

Large areas of maria and terrae are covered by dark material known as dark mantle deposits. Evidence collected by the Apollo missions confirmed that dark mantling is volcanic ash.

Much smaller dark mantles are associated with small craters that lie on the fractured floors of large craters. Those mantles may be cinder cones -- low, broad, cone-shaped hills formed by explosive volcanic eruptions.

The interior of the moon

The moon, like Earth, has three interior zones -- crust, mantle, and core. However, the composition, structure, and origin of the zones on the moon are much different from those on Earth.

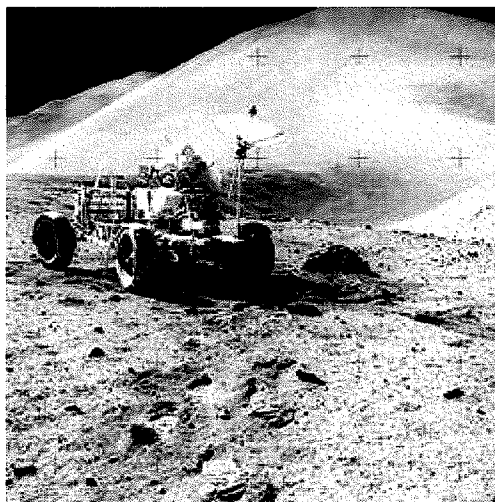
Most of what scientists know about the interior of Earth and the moon has been learned by studying seismic events -- earthquakes and moonquakes, respectively. The data on moonquakes come from scientific equipment set up by Apollo astronauts from 1969 to 1972.

Crust

The average thickness of the lunar crust is about 43 miles (70 kilometers), compared with about 6 miles (10 kilometers) for Earth's crust. The outermost part of the moon's crust is broken, fractured, and jumbled as a result of the large impacts it has endured. This shattered zone gives way to intact material below a depth of about 6 miles. The bottom of the crust is defined by an abrupt increase in rock density at a depth of about 37 miles (60 kilometers) on the near side and about 50 miles (80 kilometers) on the far side.

Mantle

The mantle of the moon consists of dense rocks that are rich in iron and magnesium. The mantle formed during the period of global melting. Low-density minerals floated to the outer layers of the moon, while dense minerals sank deeper into it.



A lunar rover is parked near the edge of Hadley Rille, a long channel probably formed by lava 4 billion to 3 billion years ago. The slopes in the background are part of a formation called the Swann Hills. This photo was taken during the Apollo 15 mission in 1971. Astronaut David R. Scott is reaching under a seat to get a camera. Image credit: NASA

Later, the mantle partly melted due to a build-up of heat in the deep interior. The source of the heat was probably the decay (breakup) of uranium and other radioactive elements. This melting produced basaltic magmas -- bodies of molten rock. The magmas later made their way to the surface and erupted as the mare lavas and ashes. Although mare volcanism occurred for more than 1 billion years -- from at least 4 billion years to fewer than 3 billion years ago -- much less than 1 percent of the volume of the mantle ever remelted.

Core

Data gathered by Lunar Prospector confirmed that the moon has a core and enabled scientists to estimate its size. The core has a radius of only about 250 miles (400 kilometers). By contrast, the radius of Earth's core is about 2,200 miles (3,500 kilometers).

The lunar core has less than 1 percent of the mass of the moon. Scientists suspect that the core consists mostly of iron, and it may also contain large amounts of sulfur and other elements.

Earth's core is made mostly of molten iron and nickel. This rapidly rotating molten core is responsible for Earth's magnetic field. A magnetic field is an influence that a magnetic object creates in the region around it. If the core of a planet or a satellite is molten, motion within the core caused by the rotation of the planet or satellite makes the core magnetic. But the small, partly molten core of the moon cannot generate a global magnetic field. However, small regions on the lunar surface are magnetic. Scientists are not sure how these regions acquired magnetism. Perhaps the moon once had a larger, more molten core.

There is evidence that the lunar interior formerly contained gas, and that some gas may still be there. Basalt from the moon contains holes called vesicles that are created during a volcanic eruption. On Earth, gas that is dissolved in magma comes out of solution during an eruption, much as carbon dioxide comes out of a carbonated beverage when you shake the drink container. The presence of vesicles in lunar basalt indicates that the deep interior contained gases, probably carbon monoxide or gaseous sulfur. The existence of volcanic ash is further evidence of interior gas; on Earth, volcanic eruptions are largely driven by gas.

History of moon study

Ancient ideas

Some ancient peoples believed that the moon was a rotating bowl of fire. Others thought it was a mirror that reflected Earth's lands and seas. But philosophers in ancient Greece understood that the moon is a sphere in orbit around Earth. They also knew that moonlight is reflected sunlight.

Some Greek philosophers believed that the moon was a world much like Earth. In about A.D. 100, Plutarch even suggested that people lived on the moon. The Greeks also apparently believed that the dark areas of the moon were seas, while the bright regions were land.

In about A.D. 150, Ptolemy, a Greek astronomer who lived in Alexandria, Egypt, said that the moon was Earth's nearest neighbor in space. He thought that both the moon and the sun orbited Earth. Ptolemy's views survived for more than 1,300 years. But by the early 1500's, the Polish astronomer Nicolaus Copernicus had developed the correct view -- Earth and the other planets revolve about the sun, and the moon orbits Earth.

Early observations with telescopes

The Italian astronomer and physicist Galileo wrote the first scientific description of the moon based on observations with a telescope. In 1609, Galileo described a rough, mountainous surface. This description was quite different from what was commonly believed -- that the moon was smooth. Galileo noted that the light regions were rough and hilly and the dark regions were smoother plains.

The presence of high mountains on the moon fascinated Galileo. His detailed description of a large crater in the central highlands -- probably Albategnius -- began 350 years of controversy and debate about the origin of the "holes" on the moon.

Other astronomers of the 1600's mapped and cataloged every surface feature they could see. Increasingly powerful telescopes led to more detailed records. In 1645, the Dutch engineer and astronomer Michael Florent van Langren, also known as Langrenus, published a map that gave names to the surface features of the moon, mostly its craters. A map drawn by the Bohemian-born Italian astronomer Anton M. S. de Rheita in 1645 correctly depicted the bright ray systems of the craters Tycho and Copernicus. Another effort, by the Polish astronomer Johannes Hevelius in 1647, included the moon's libration zones.

By 1651, two Jesuit scholars from Italy, the astronomer Giovanni Battista Riccioli and the mathematician and physicist Francesco M. Grimaldi, had completed a map of the moon. That map established the naming system for lunar features that is still in use.

Determining the origin of craters

Until the late 1800's, most astronomers thought that volcanism formed the craters of the moon. However, in the 1870's, the English astronomer Richard A. Proctor proposed correctly that the craters result from the collision of solid objects with the moon. But at first, few scientists accepted Proctor's proposal. Most astronomers thought that the moon's craters must be volcanic in origin because no one had yet described a crater on Earth as an impact crater, but scientists had found dozens of obviously volcanic craters.

In 1892, the American geologist Grove Karl Gilbert argued that most lunar craters were impact craters. He based his arguments on the large size of some of the craters. Those included the basins, which he was the first to recognize as huge craters. Gilbert also noted that lunar craters have only the most general resemblance to calderas (large volcanic craters) on Earth. Both lunar craters and calderas are large circular pits, but their structural details do not resemble each other in any way.

In addition, Gilbert created small craters experimentally. He studied what happened when he dropped clay balls and shot bullets into clay and sand targets.

Gilbert was the first to recognize that the circular Mare Imbrium was the site of a gigantic impact. By examining photographs, Gilbert also determined which nearby craters formed before and after that event. For example, a crater that is partially covered by ejecta from the Imbrium impact formed before the impact. A crater within the mare formed after the impact.

Describing lunar evolution

Gilbert suggested that scientists could determine the relative age of surface features by studying the ejecta of the Imbrium impact. That suggestion was the key to unraveling the history of the moon. Gilbert recognized that the moon is a complex body that was built up by innumerable impacts over a long period.

In his book *The Face of the Moon* (1949), the American astronomer and physicist Ralph B. Baldwin further described lunar evolution. He noted the similarity in form between craters on the moon and bomb craters created during World War II (1939-1945) and concluded that lunar craters form by impact.

Baldwin did not say that every lunar feature originated with an impact. He stated correctly that the maria are solidified flows of basalt lava, similar to flood lava plateaus on Earth. Finally, independently of Gilbert, he concluded that all circular maria are actually huge impact craters that later filled with lava.

In the 1950's, the American chemist Harold C. Urey offered a contrasting view of lunar history. Urey said that, because the moon appears to be cold and rigid, it has always been so. He then stated -- correctly -- that craters are of impact origin. However, he concluded falsely that the maria are blankets of debris scattered by the impacts that created the basins. And he was mistaken in concluding that the moon never melted to any significant extent. Urey had won the 1934 Nobel Prize in chemistry and had an outstanding scientific reputation, so many people took his views seriously. Urey strongly favored making the moon a focus of scientific study. Although some of his ideas were mistaken, his support of moon study was a major factor in making the moon an early goal of the U.S. space program.

In 1961, the U.S. geologist Eugene M. Shoemaker founded the Branch of Astrogeology of the U.S. Geological Survey (USGS). Astrogeology is the study of celestial objects other than Earth. Shoemaker showed that the moon's surface could be studied from a geological perspective by recognizing a sequence of relative ages of rock units near the crater Copernicus on the near side. Shoemaker also studied the Meteor Crater in Arizona and documented the impact origin of this feature. In preparation for the Apollo missions to the moon, the USGS began to map the geology of the moon using telescopes and pictures. This work gave scientists their basic understanding of lunar evolution.

Apollo missions

Beginning in 1959, the Soviet Union and the United States sent a series of robot spacecraft to examine the moon in detail. Their ultimate goal was to land people safely on the moon. The United States finally reached that goal in 1969 with the landing of the Apollo 11 lunar module. The United States conducted six more Apollo missions, including five landings. The last of those was Apollo 17, in December 1972.

The Apollo missions revolutionized the understanding of the moon. Much of the knowledge gained about the moon also applies to Earth and the other inner planets -- Mercury, Venus, and Mars. Scientists learned, for example, that impact is a fundamental geological process operating on the planets and their satellites.

After the Apollo missions, the Soviets sent four Luna robot craft to the moon. The last, Luna 24, returned samples of lunar soil to Earth in August 1976.

Recent exploration

No more spacecraft went to the moon until January 1994, when the United States sent the orbiter Clementine. From February to May of that year, Clementine's four cameras took more than 2 million pictures of the moon. A laser device measured the height and depth of mountains, craters, and other features. Radar signals that Clementine bounced off the moon provided evidence of a large deposit of frozen water. The ice appeared to be inside craters at the south pole.

The U.S. probe Lunar Prospector orbited the moon from January 1998 to July 1999. The craft mapped the concentrations of chemical elements in the moon, surveyed the moon's magnetic fields, and found strong evidence of ice at both poles. Small particles of ice are apparently part of the regolith at the poles.

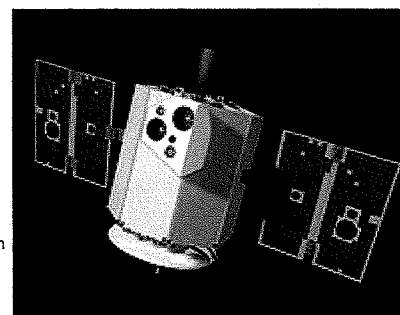
The SMART-1 spacecraft, launched by the European Space Agency in 2003, went into orbit around the moon in 2004. The craft's instruments were designed to investigate the moon's origin and conduct a detailed survey of the chemical elements on the lunar surface.

Contributor: Paul D. Spudis, Ph.D., Deputy Director and Staff Scientist, Lunar and Planetary Institute.

How to cite this article: To cite this article, World Book recommends the following format: Spudis, Paul D. "Moon." World Book Online Reference Center. 2004. World Book, Inc. (<http://www.worldbookonline.com/wb/Article?id=ar370060>.)

Find this article at:

http://www.nasa.gov/worldbook/moon_worldbook.html



The Clementine orbiter used radar signals to find evidence of a large deposit of frozen water on the moon. The orbiter sent radar signals to various target points on the lunar surface. The targets reflected some of the signals to Earth, where they were received by large antennas and analyzed. Image credit: Lunar and Planetary Institute