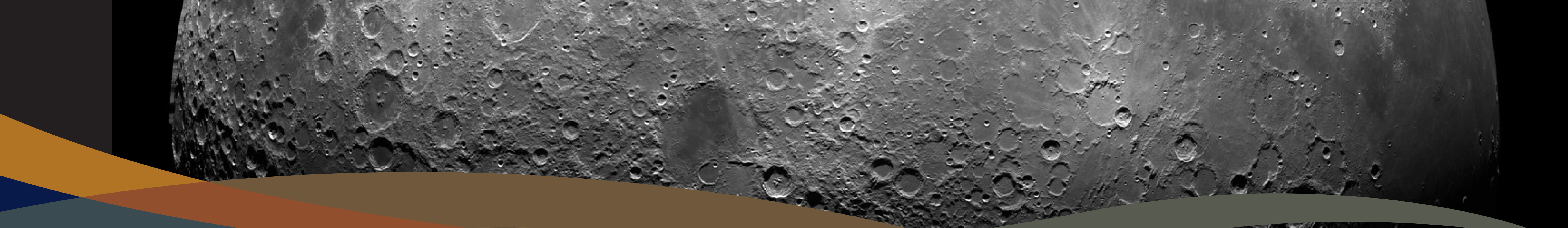


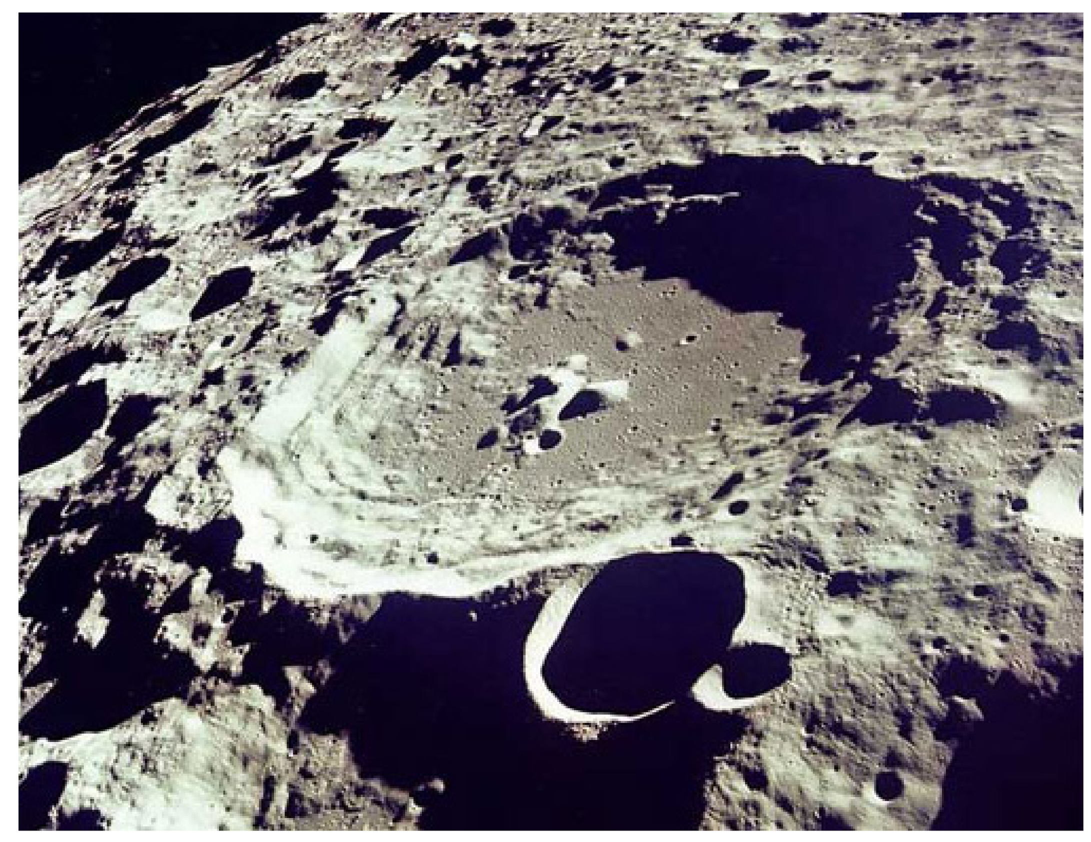
MOON FORMATION — 4.5 BILLION YEARS AGO

Moon spawned from Earth

Scientists believe that the Moon formed when an object the size of Mars crashed into Earth roughly 4.5 billion years ago. The debris from the collision ended up in orbit around Earth, coalescing through accretion to form our Moon. This theory is the most widely accepted, primarily because Moon rocks are younger than Earth's formation by millions of years, and their composition mimics the composition of Earth's crust.

Artist's depiction of what the early Moon would have looked like as it coalesced from debris excavated during a collision of a large planetesimal with Earth. NASA ©

Such a large amount of accretion would have produced a large amount of heat. Consequently, the Moon would have been almost entirely molten—imagine a giant magma ocean. Over its first few hundred million years, this magma ocean cooled, and crystals began to form. Less dense minerals, such as **anorthosite** (a feldspar), rose to the top, floating, and formed the **crust**. Thus, initially, Moon's surface would have been composed mostly of feldspar-rich igneous rocks called **anorthosites.** These rocks can be found today in the **lunar highlands**—the lighter-colored part of the Moon visible from Earth. Dense, iron-rich silicate minerals, such as **olivine** and **pyroxene**, sank to the bottom to form the Moon's **mantle**. (The Moon does have a tiny **core**, which is mostly iron and represents less than 1 percent of the Moon's mass).



This large impact basin is Crater 308. It spans about 30 km and was photographed by the Apollo 11 crew as they circled the Moon in 1969.The far side of the Moon is rough and filled with craters. By comparison, the near side of the Moon, the side we always see, is relatively smooth. Since the Moon's rotation is locked to always face the same side toward Earth, we have glimpsed the lunar farside only in the last century using satellites. NASA ©

The final liquids to crystallize would have been sandwiched between the crust and mantle. They would have contained a high abundance of elements that don't fit into the crystalline matrix of common minerals. These 'incompatible' elements include heat-producing radioactive elements, which later cause portions of the mantle to melt and erupt on the surface.

On Earth, the surface is eroded by the action of water and wind. The most important process for altering the surface of the Moon, however, is that of meteorites impacting upon and breaking up the surface. Since the Moon's surface is not constantly being eroded or recycled, like Earth's, the Moon's surface preserves the scars of the meteorite impacts of its past, especially those that occurred during the first few hundred million years of the heavy bombardment. A **breccia** forms when meteorites break up the surface and the pieces are welded together by the heat and pressure of the impact. The largest impacts produced large craters and may have stripped off large segments of 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.

The darker areas on the Moon are known as **mare**. Most of the mare formed about 4 billion to 3 billion years ago when the Moon's mantle melted after accumulating an excess of heat from the decay of radioactive elements trapped inside it. The melts rose to the surface most easily under the broken crust of the big impact craters. Over time the craters came to be filled with these iron-rich lava flows that cooled and solidified into **basalt**. Small eruptions may have continued until as recently as 1 billion years ago. Since then, only an occasional impact by an asteroid or comet has modified the surface.

However, 3 billion years of impacts of micrometeoroids have ground the surface rocks into a fine, dusty powder known as the **regolith**, which overlies bedrock on the Moon. The longer a rock is exposed at the surface, the thicker the regolith that forms on it.

Earth-Moon facts

The Moon during its first few million years was 322,000 km closer to Earth and larger in the sky. Earth spun faster—a day was 6 hours long. Tides were more extreme (higher highs and lower lows) both in the oceans and on land. The land tides caused Earth's crust to bulge as high as 61 m, twice a day, in places. As the Moon moved further away over time, the Earth's spin slowed. The retreat of the Moon continues today and has been measured at 3.8 cm/yr. The collision that led to the formation of the Moon also caused Earth's axial tilt and hence seasons.

The Moon is in synchronous rotation, meaning that it keeps nearly the same face turned towards the Earth at all times. It is the brightest object in the night sky but gives off no light of its own. Instead, it reflects light from the Sun. The Moon has no substantial atmosphere. Scientists study the Moon mostly through remote data collection via satellites and unmanned landers. They also have directly sampled rocks from the Moon both through manned space missions and by studying Moon meteorites (fragments of the Moon that are ejected during a Moon impact event and then land on our planet). Most of what scientists know about the interior of Earth and the Moon has been learned by studying seismic events. The data on moonquakes come from scientific equipment set up by Apollo astronauts from 1969 to 1972.

Lunar rocks

Small rock fragments from the Apollo 11 regolith. The image includes mare basalts, crystalline impact-melt breccias, regolith breccias, anorthosites, glass fragments, and spherules. The background grid spacing is 2 mm. Photo by Randy Korotev ©

Lunaite (lunar mare basalt; 253 grams). Collected on the Moon's surface by Alan Bean on 20 November 1969. CMNH public display (Cleveland Museum of Natural History, Cleveland, Ohio, USA) ©

Lunar Breccia (sample 60016 from the APOLLO 16 mission). Breccia are rocks composed of fragments of other rocks—this one formed from the welded-together remnants of a meteorite collision with the Moon.The white minerals visible in this image are 4.6-billion-year-old feldspars that were part of the Moon's first crust. Parts of this rock have been studied in about 15 labs throughout the world to determine composition and age of it and its components. Weight: 4.31 kg. Dimensions: 13 x 16 x 20 cm. NASA ©