Lesson 06

Geology of Earth's Moon

The **Moon** is the only natural satellite of Earth.

Satellite is any object (natural or manmade) that orbits a planet. Moons are **natural satellites** of planets. Spaceships and other craft are **artificial satellites**.

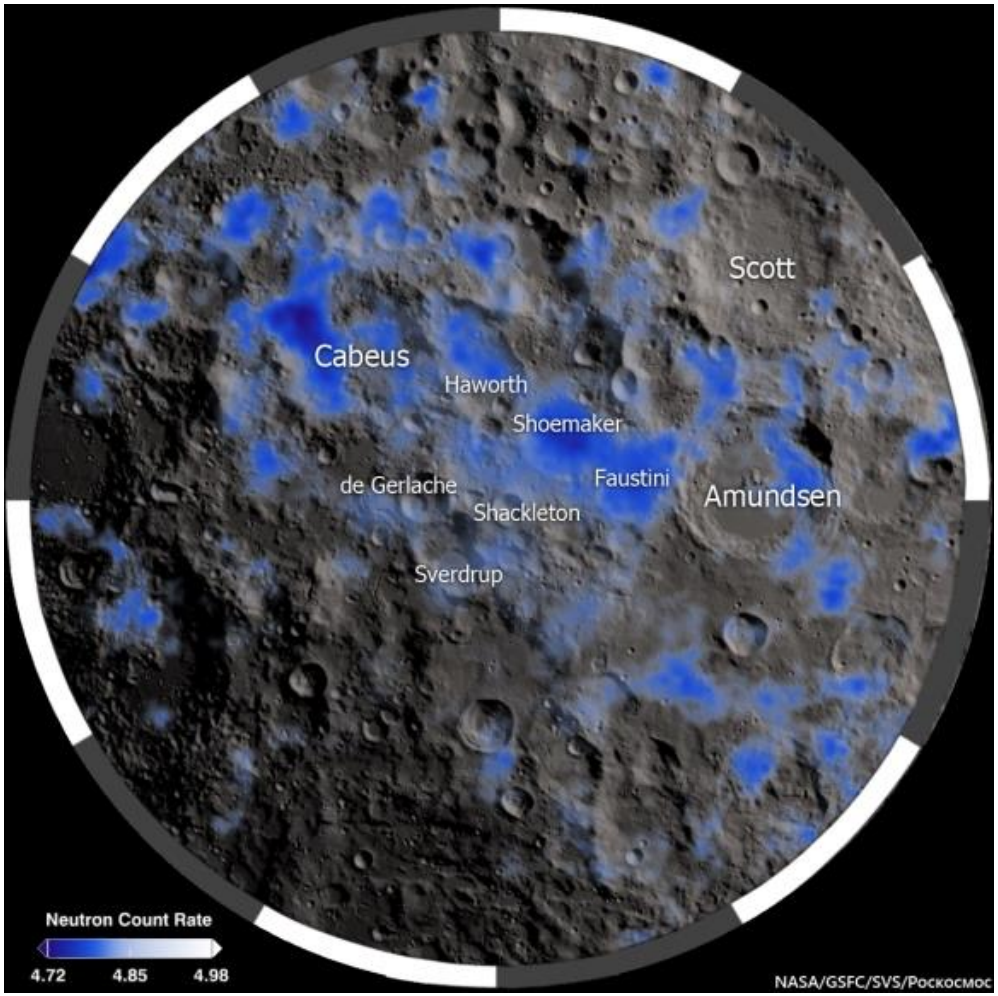
Facts about Earth's Moon

- Name: **Luna** (Roman goddess of night)
- Equatorial diameter: 3470 km
- Mass: 7.35×10^{22} kg
- Bulk density: 3.34 g/cm^3
- Atmosphere: none
- Surface gravity: 1.62 m/s^2

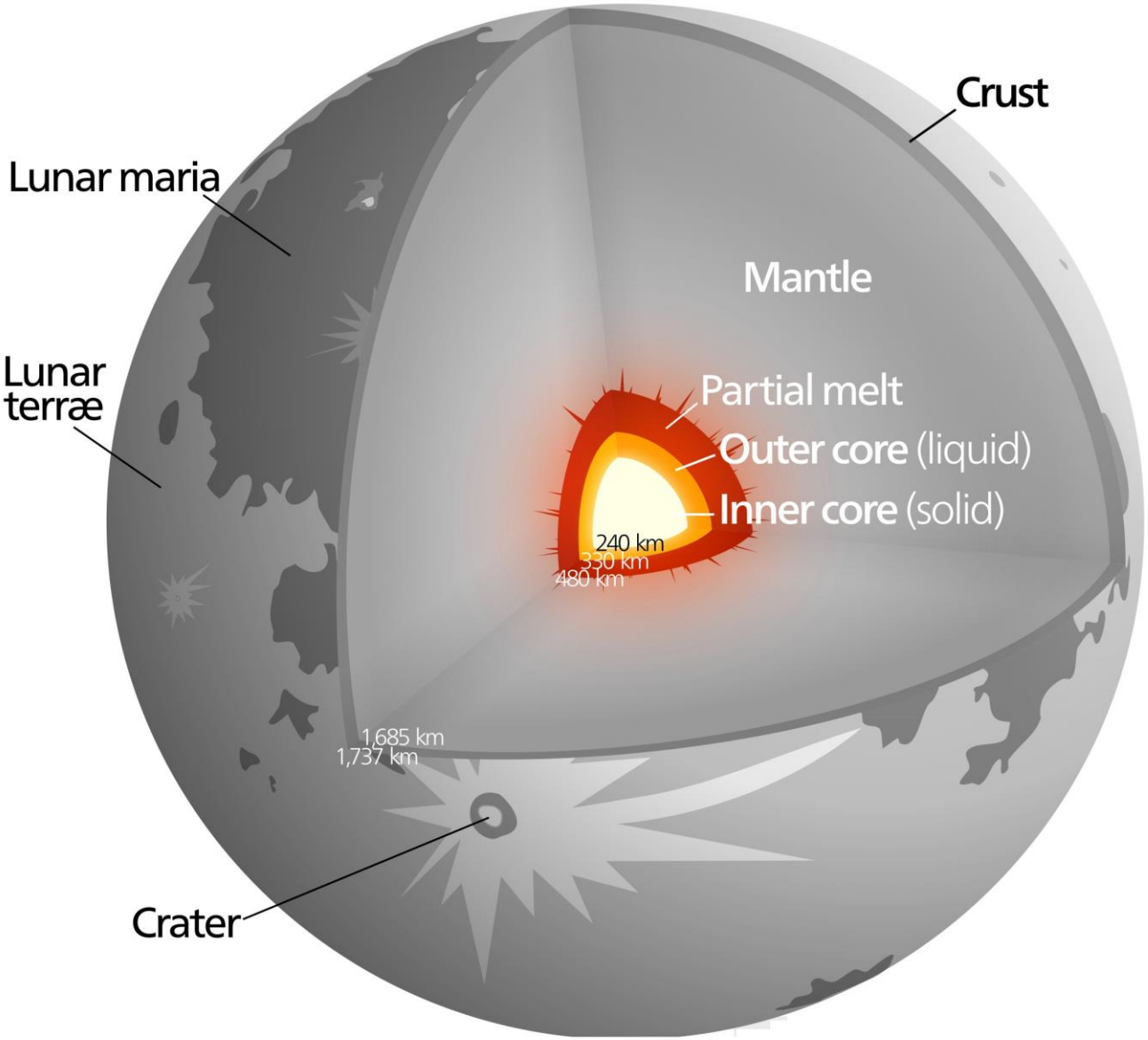
The moon's surface gravity 1.62 m/s^2 is much weaker than Earth's gravity field of 9.81 m/s^2. The moon has a much lower mass and bulk density than the Earth. Astronauts feel only 1/6 of their weight on the moon.

The moon is a very dry place. There is *no liquid water* on the moon's surface. However, in the late 2000's, water ice was discovered in the soils contained inside craters near the moon's south pole. The craters are permanently shadowed where sunlight cannot evaporate the ice.

Many different satellites made light measurements and radiometric measurements to determine that hydrogen and oxygen compounds are in the craters. Water is H_2O, two hydrogens and one oxygen, which gives off a specific light absorbance and reflection.

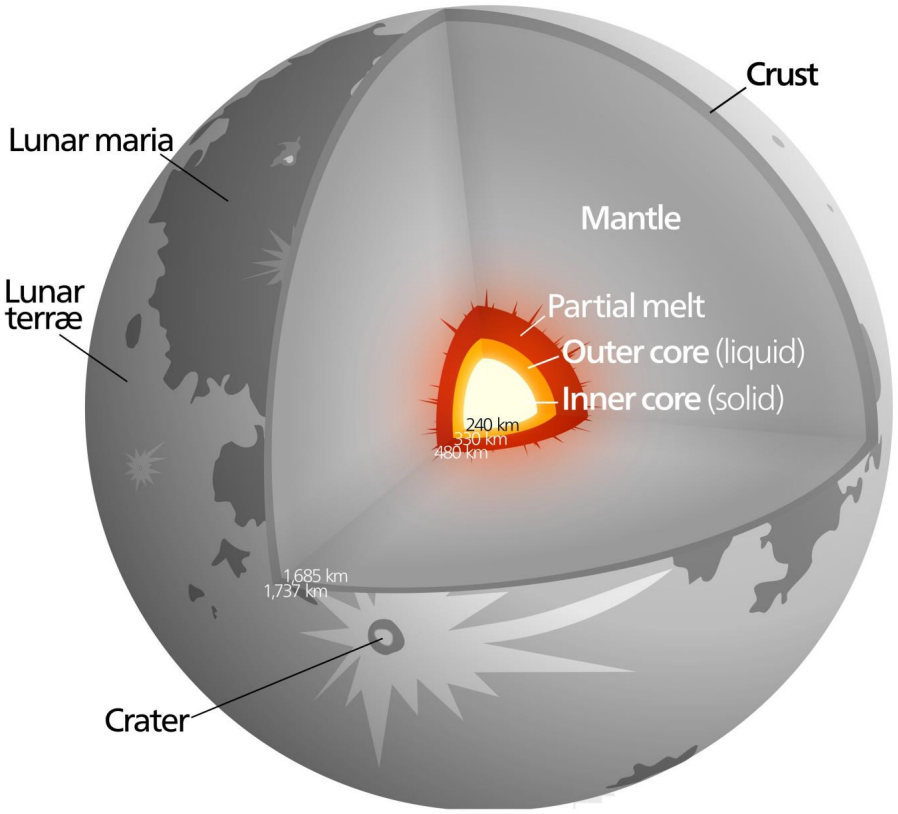


A geologic cross-section of the moon's interior.



Just like the Earth, the moon's interior is different layers.

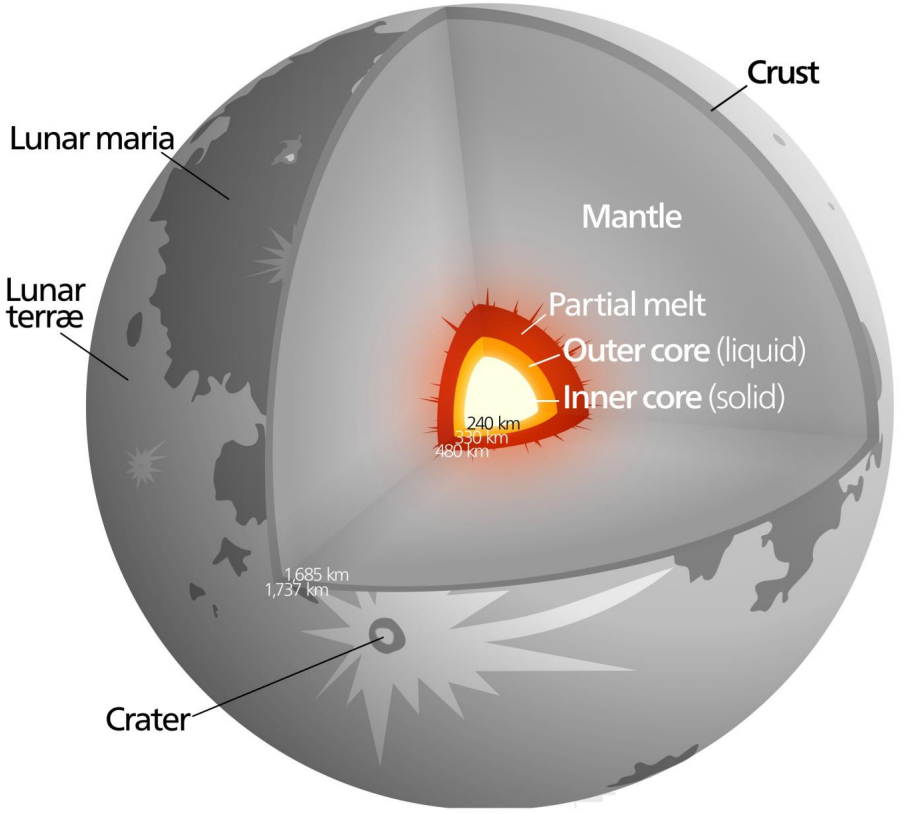
- The inner core is a solid sphere of iron and nickel metals.
- The outer core is a molten one of iron and nickel metals.
- The mantle is made of dense silicate rocks.
- The thin crust is made of lesser dense silicate rocks.



There are also many differences between the moon's layers compared to the Earth's layers.

The inner core and outer core of the moon are very small. The moon by % mass composition has much less iron and nickel. The mass of the mantle is > 75% of the total mass of the moon. The moon's bulk density is very low at only 3.34 $g/cm^{3.}$

In contrast, the Earth has a greater bulk density of 5.57 g/cm^3. The Earth's inner and outer core occupy a greater bulk percentage of the Earth's total mass.



The small size of the moon means that the moon's interior had cooled off very quickly over geologic time. Smaller mass and smaller size yields faster rate of cooling in the core—not enough insulation to keep the heat inside longer.

Most of the moon's outer core has cooled and solidified, or has turned to a partial melted metal mush. The slow rotation of the moon plus very little molten metal moving in the outer core makes a very, very weak magnetic field.

The lack of internal heat from the moon's core has stopped plate tectonics. There is not enough heat from the outer core to make mantle convection. There is no recent plate tectonics or volcanism on the moon's surface over the past 1-2 billion years.

The lunar surface is clearly visible from Earth without magnification. Ancient peoples until the invention of the telescope (1608) thought that the moon's surface geography was similar to Earth's—covered with oceans and continents.

The dark areas were called **maria** (plural for **mare**), Latin for oceans.

The lighter areas were called **terrae** (plural for **terra**), Latin for land or continents.

The **lunar highlands** (terrae) are the lighter-colored portions of the lunar crust. The lunar highlands tend to be mountainous and heavily cratered.

The millions of overlapping craters were formed by impacting asteroids and meteorites over a 4 billion-year period.

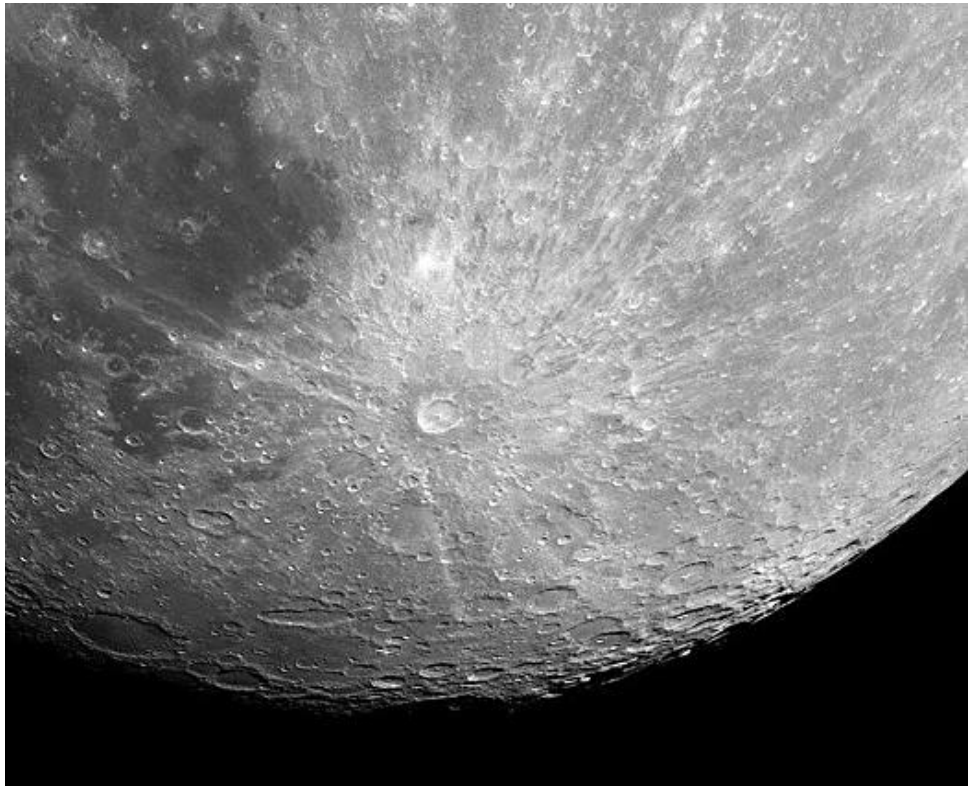
The **lunar highlands** (**terrae**) are geologically older than the lava flows that make the **maria**. The age of rocks in the **terrae** tend to be 3.9-4.0 billion years old. The rocks are made with the mineral called anorthosite, which is the primary mineral that makes up Earth's mantle rock.

A **crater** is a circular or bowl-shaped depression in the crust that forms from the impact of an asteroid or meteorite. In most circumstances, the impactor is completely vaporized by the impact and explosion, as well as some of the crust rock at the point of impact.

Ejecta ("ejected rock") is blasted away from the explosion by the extreme force and energy of the impact. The result is the depression.

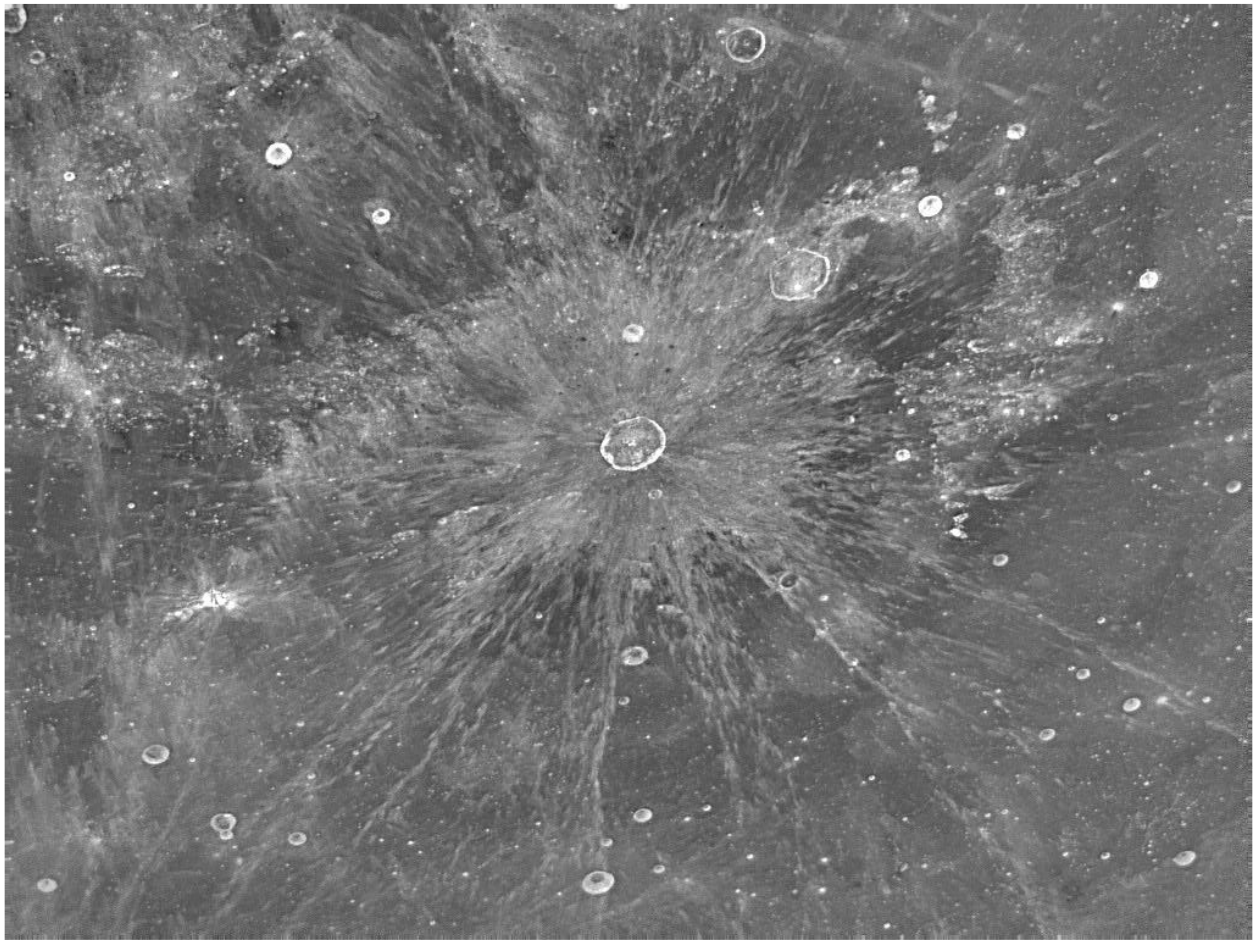
The moon's craters are named after past and present astronomers, scientists, and philosophers.

Copernicus impact crater is a noteworthy crater. *Copernicus* is named after Nicolaus Copernicus, the Polish astronomer credited with the heliocentric model of the solar system.

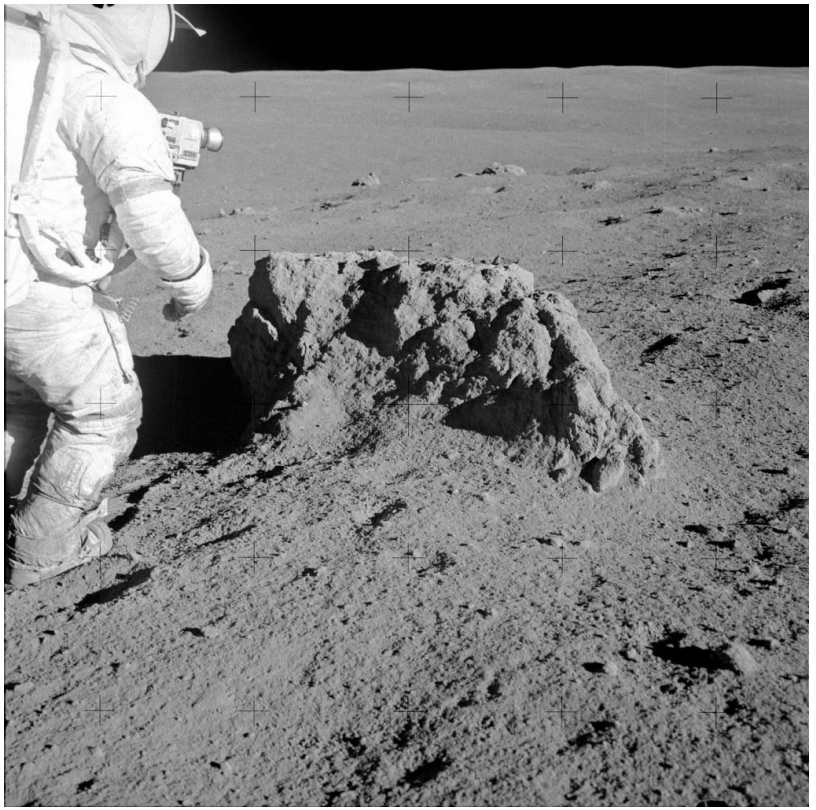


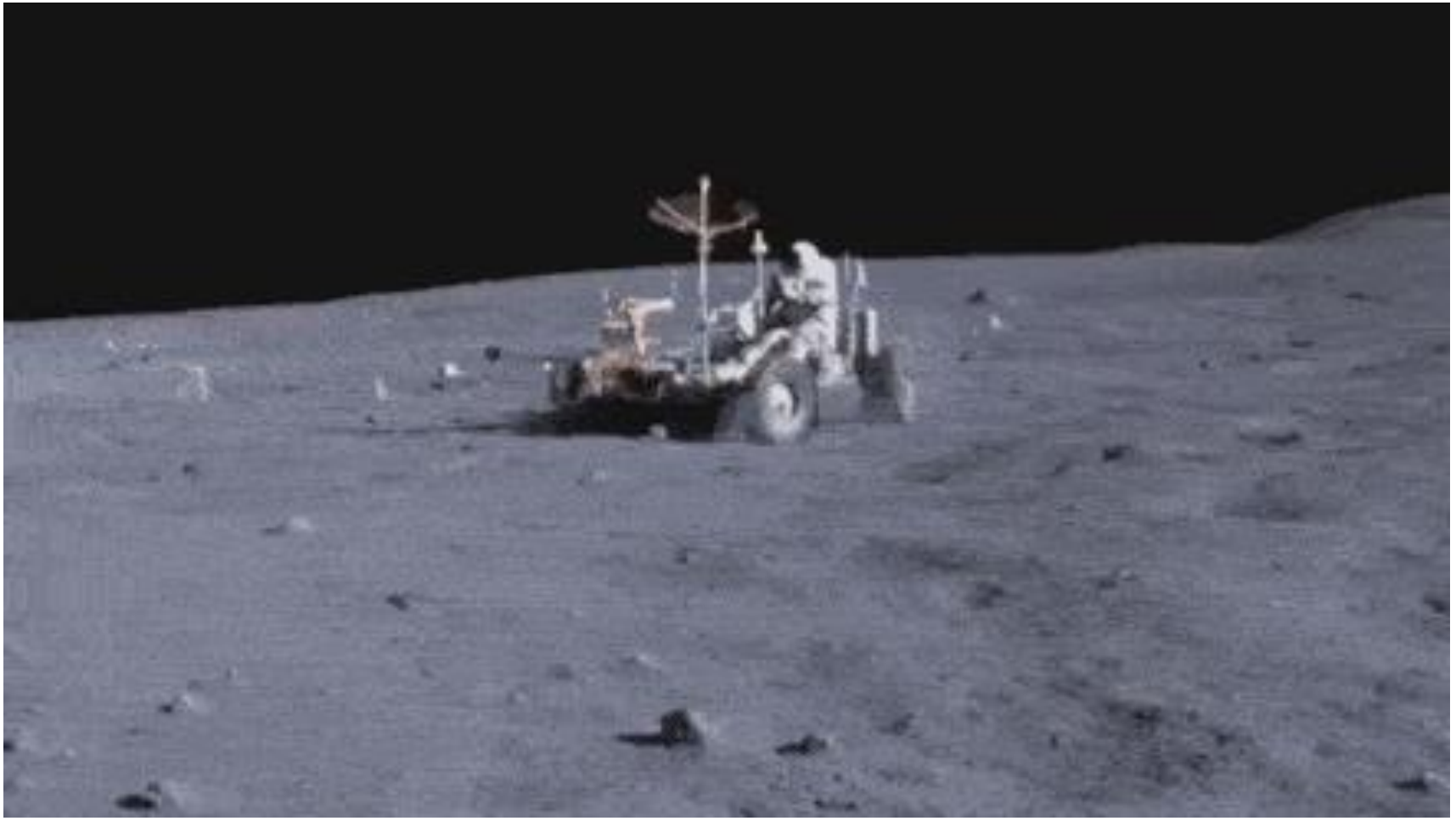
Tycho impact crater is the most noteworthy and visible of the moon's millions of impact craters. *Tycho* is named after Tycho Brahe, the Danish astronomer. *Tycho* is located near the moon's south pole.

Some impact craters are surrounded by **rays**. **Rays** are the whitish or light-colored streaks of regolith (pulverized rock), breccia (crushed angular gravel and pebbles), and other rock debris that was blasted out of the crust during the impact.



The surface of the moon's crust is covered in meters-deep thick regolith, also called "**moon dust**". **Regolith** is a fine, powdery soil that forms when asteroids and meteorites impact the surface and pulverize the moon's crustal rock.



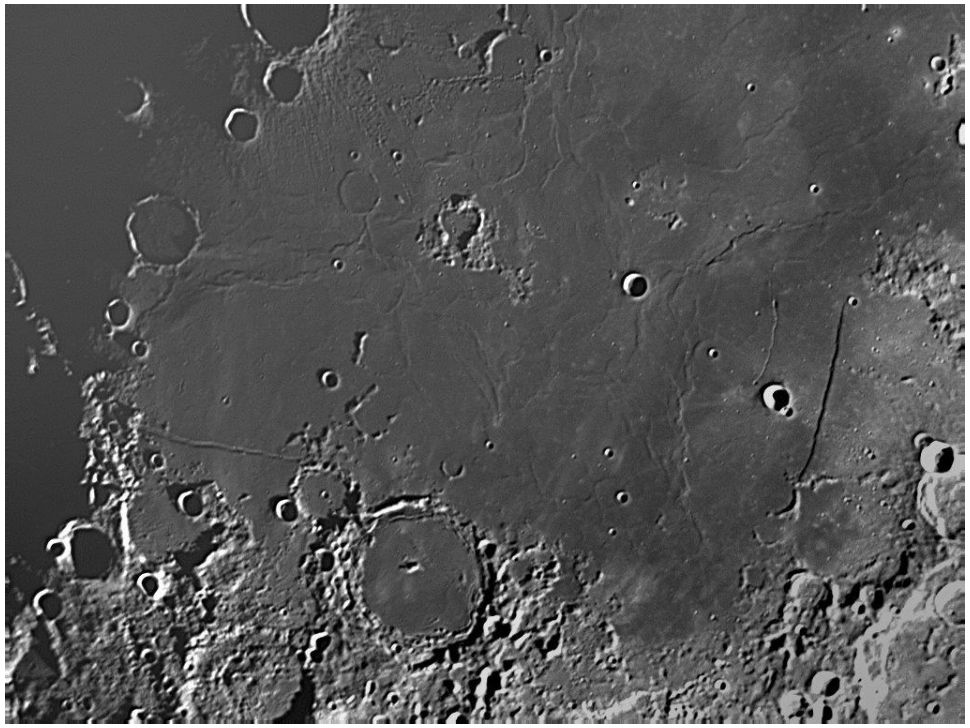


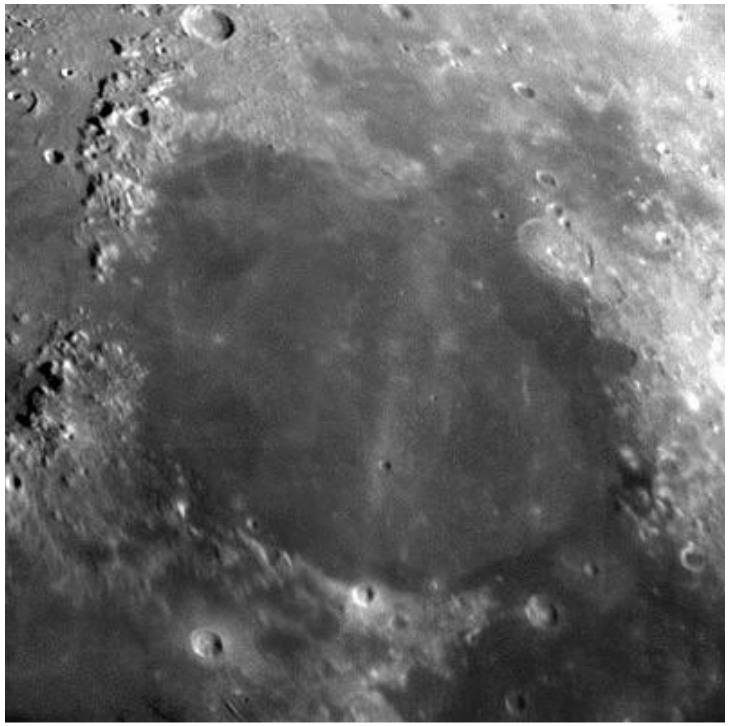
Lunar roving vehicle (the “moon buggy”) rolling over regolith covered terrae in July 1971.

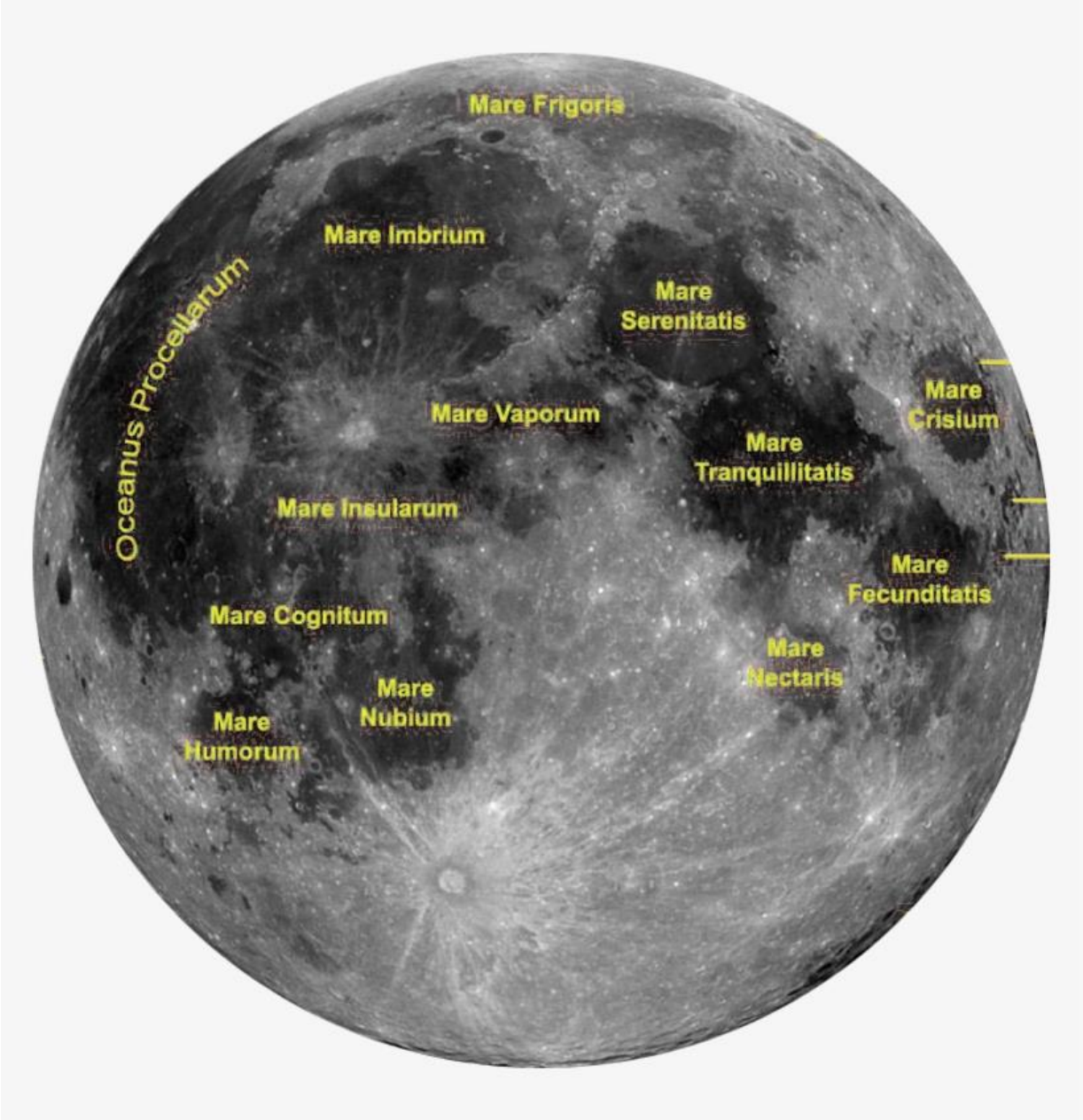
Neil Armstrong's footprint in regolith on the moon's surface. The footprint will remain unaltered on the moon's surface because there is no weather, no wind, no real atmosphere, no flowing water, and no geologic activity.

The moon system lacks all of the normal geological processes like erosion and plate tectonics. The footprint *could be* erased by a future asteroid impact.

Mare (Maria) “seas” are the smoother darker plains on the lunar surfaces. Maria are very large basins that are filled with basaltic lava created by ancient volcanic eruptions or by lava flowing out of fractures in the lunar crust after very large asteroid impacts.





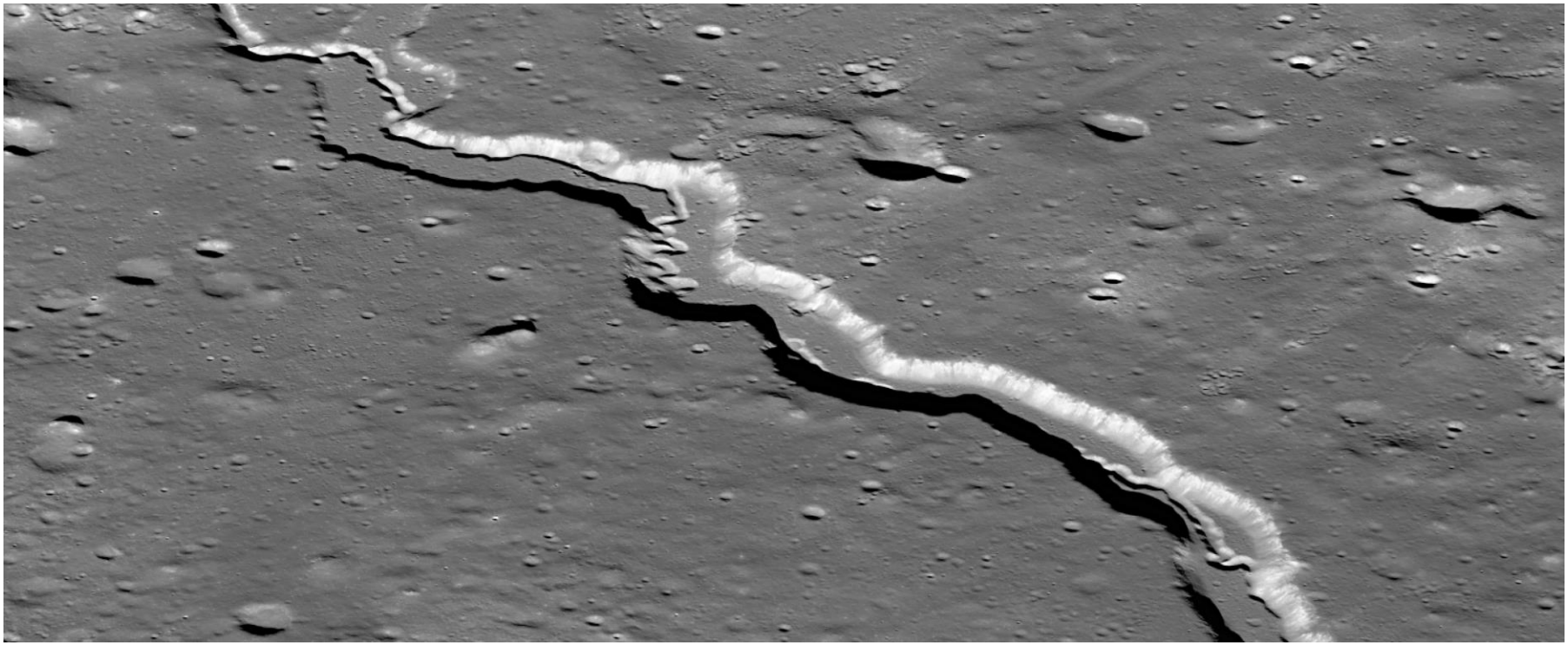


There are 14 named maria. The basalt rock of the maria is geologically younger than the lunar highlands, probably 3.9-3.0 billion years old.

Mare (Maria) lack great numbers of impact craters. They tend to have very few craters compared to the millions in the lunar highlands.

Maria would be younger than lunar highlands. The lava flows making the maria covered over and filled in the older impact craters. The volcanic episodes happened long after most of the asteroid and meteorite impacts already happened.

Rilles (grooves): Long, deep canyons or trenches, most are in maria.. Some are sinuous (very curvy) and some are straighter. Sinuous rilles are thought to be collapsed lava tunnels beneath the maria crust. Straighter rilles are thought to be caused by parallel faults causing the crust to drop.



Moonquakes are the moon's equivalent to earthquakes on Earth. **Moonquakes** can be stronger shaking events, but most are much weaker than typical earthquakes. Moonquakes can last for 10-30 consecutive minutes. Unlike the earth, there are no liquid water oceans on the lunar surface and no molten outer core that dampen (weaken) the earthquake waves.

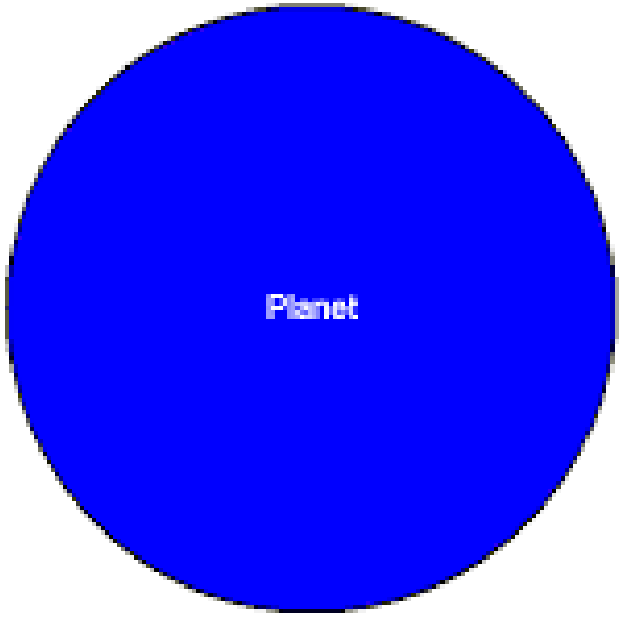
NASA catalogued hundreds moonquake events from 1969-1977 from seismographs left on the moon between 1969 and 1972.

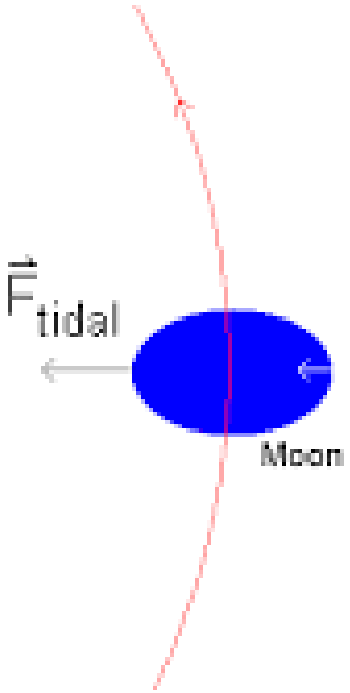
Moonquakes are thought to be caused by factors other than plate tectonics like on Earth. The theories for moonquake occurrences are:

The moon's size is contracting over geologic time because the outer core is slowly solidifying as it cools. The reduction of heat in the moon's interior means the rock and metals in the interior thermally shrink. This cracks the rigid crust causing quakes.

The moon rotates once every 28 Earth days. The daytime side of the moon absorbs a lot of sunlight and heat while the nighttime side freezes. The crust expands in the prolonged sunlight while the crust contracts in the freezing nighttime side. The expansion and contraction causes quakes.

Some of the moonquakes are thought to be caused by **tidal deformation.** **Tidal deformation** happens by **tidal forces**. The gravity between the planet (larger object) and the moon (smaller object) causes the moon to slightly stretch and contract in shape. The friction that happens as the moon's rock stretches and contracts and rubs against each other, causing the moonquake.



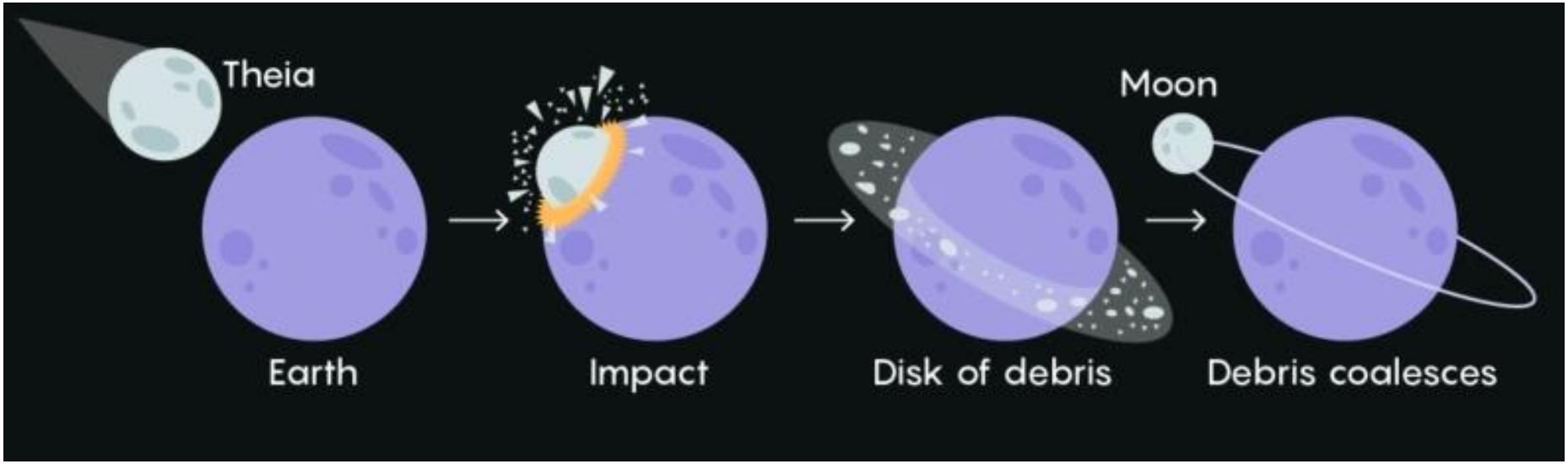


Formation of the Moon

The excepted modern theory of how Earth's moon formed is the **Giant Impact Theory** (sometimes also called the **Collision-ejection Theory**).

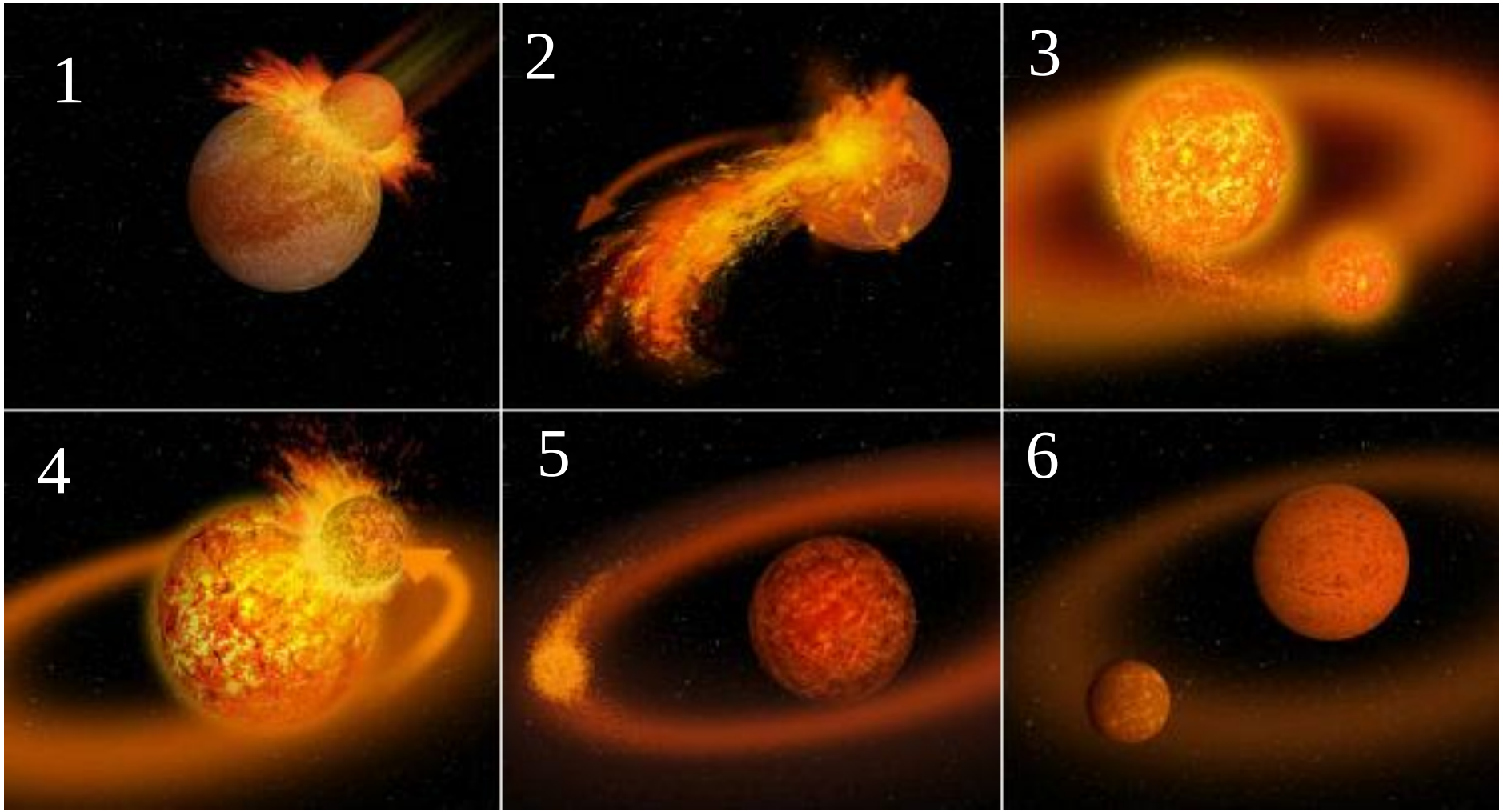
The **Giant Impact Theory** says that when the Earth and other planets were forming in their orbits 4.5 billion years ago, a Mars-sized **protoplanet** (young, forming planet) collided with the young, forming Earth. The material blasted out by the massive collision collected in a debris ring around the Earth. Over thousands of years, gravity pulled the debris in the ring together to form the moon.

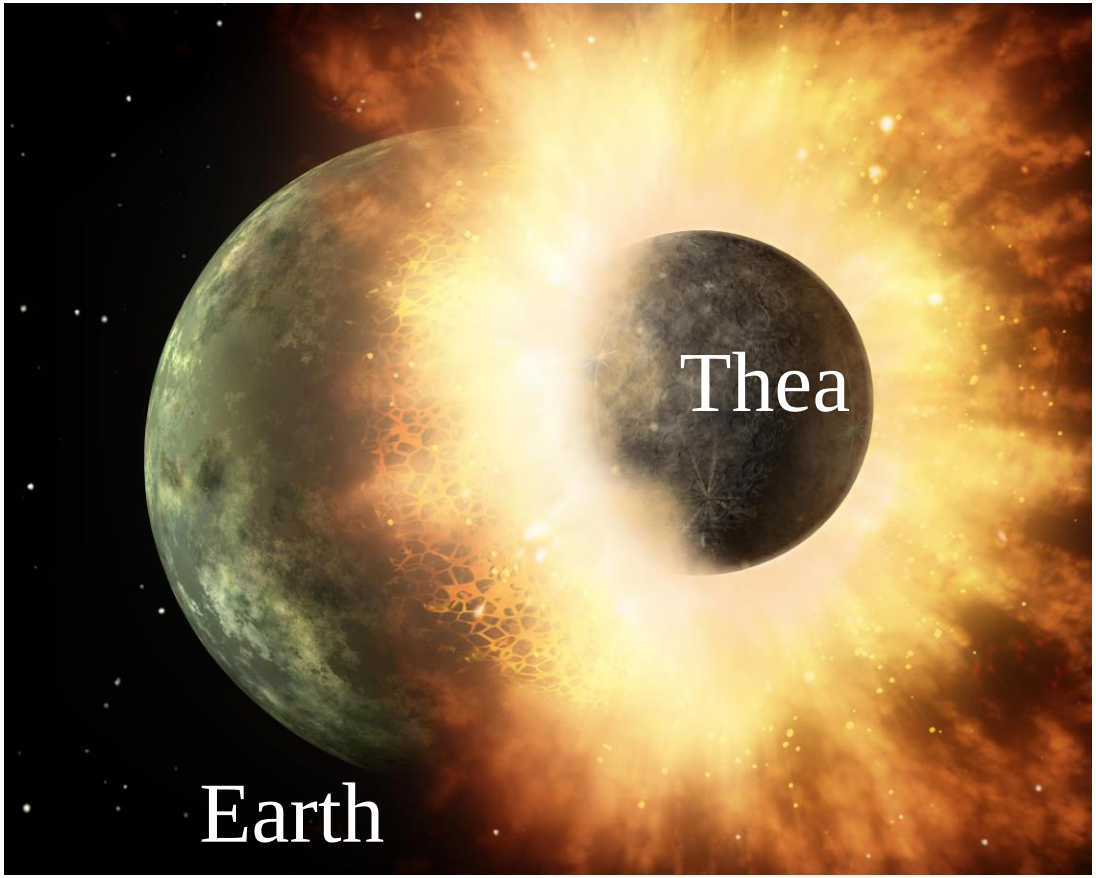
Simplified overview of the **Giant Impact Theory** (sometimes also called the **Collision-ejection Theory**).



Many computer simulations by university researchers and NASA have recreated the events.

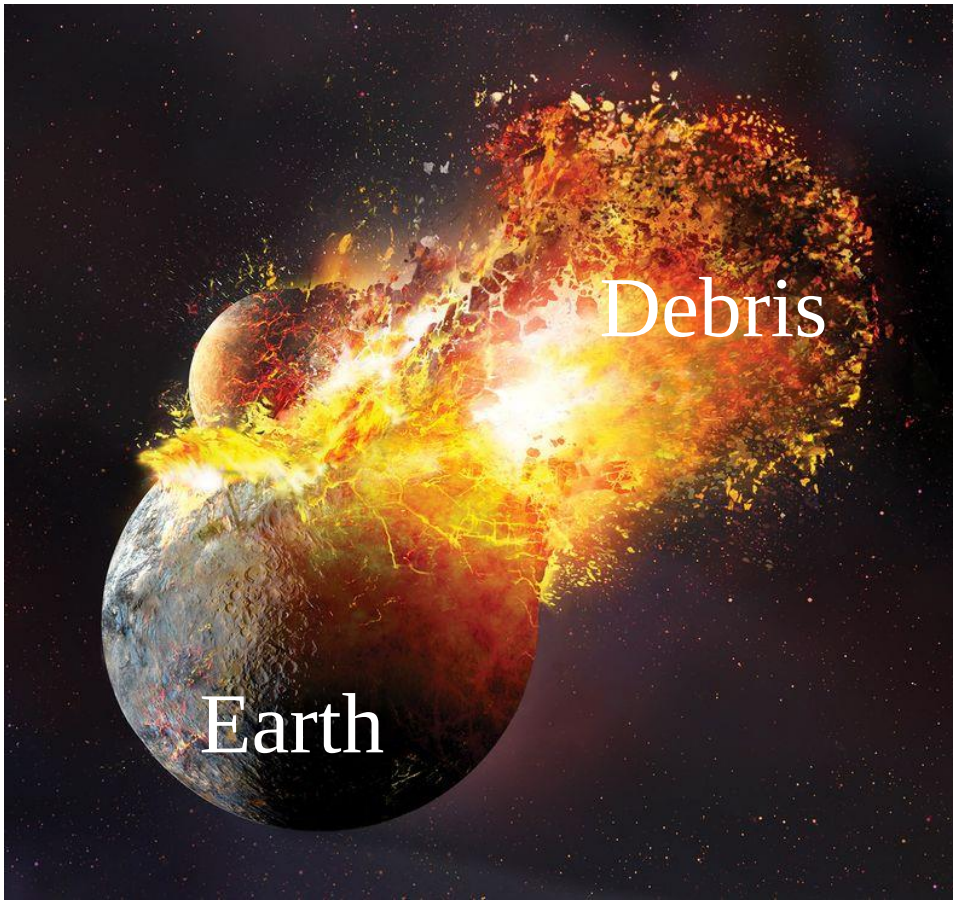
Another simplified overview of the **Giant Impact Theory** (sometimes also called the **Collision-ejection Theory**).





The smaller protoplanet in this Theory was called Thea.

According to the theory, Thea was forming at the same time and in approximately the same orbit as the Earth. Gravity pulled them together as they orbited the Sun. Thea crashed into the Earth at an indirect angle.



The force and energy of the impact completely melted the Earth and Thea as they collided. They mixed. Much of Earth's mantle and most of Thea's mass were blasted into space. The Earth was wrecked, but was not totally destroyed. It reformed into a planet again.

Over thousands of years, the hot rocky chunks of rock and metal in the debris ring orbited the Earth. Under gravity, the chunks clumped together to form a small moon. As the moon circled the Earth, it would collect more and more of the debris, eventually sweeping away all of the debris material. The moon was formed.

What is the evidence to support the Giant Impact Theory (Collision Ejection Theory)?

1. Moon rock, and the minerals in the moon rock, have very similar composition to Earth's mantle rocks.

Most of the rocks in the moon were formed from mantle rock blasted out of the Earth during impact.

2. The stable oxygen isotope ratio and zinc isotope ratio of moon rock is identical to the stable oxygen isotope and zinc isotope ratio of the Earth's crust rocks.

Most of the moon is made of Earth mantle rock.

What is the evidence to support the Giant Impact Theory (Collision Ejection Theory)?

3. The moon's crust rock was "superheated" beyond normal volcanic temperatures. The moon's rocks lack the lightest elements (called volatile elements) like sodium, potassium, nitrogen, and carbon.

The heat from the impact and the super high temperatures that followed after the blast vaporized all of the lightest elements out of the molten rock chunks in the debris ring.

What is the evidence to support the Giant Impact Theory (Collision Ejection Theory)?

4. The moon has pronounced **tidal bulge** that faces the Earth. The moon is stretched from spherical into a slight (egg shape).

As the new molten moon was forming, Earth's gravity pulled and stretched on the molten surface of the moon, slightly bulging the moon's surface toward the Earth.

5. The moon's orbit is offset from the Earth's equator by 19º.

Most moons that formed with their host planets have orbits that align with the planet's equator.

What is the evidence to support the Giant Impact Theory (Collision Ejection Theory)?

6. The Earth is tilted on its axis of rotation by 23.5º from upright.

The force of impact by Thea knocked the Earth over from upright in its orbit.

7. The moon is gradually moving outward and away from the Earth by approximately 3 cm per year. If time is rewound 4.5 billion years into the past to the time of the moon's formation (and formation of Earth), the distance that moon's orbit was from the Earth is too close for the moon's orbit to be stable.