Camden Fairview NASA Lunar Research Team PowerPoint

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Introduction to the Moon

The Moon is the only natural satellite of the Earth and was formed about the same time, over 4.5 billion years ago, but has not evolved in the same way. Lacking in atmosphere, water and life, and having cooled more rapidly due to its smaller size, much of the surface has not been changed significantly for billions of years.
Geologic Features Present On the Moon

- Craters
- Maria
- Basalt
- Valleys
Geologic Features Present On the Moon

- Volcanoes
- Rilles
- Ridges
- Mountains
Craters

What are craters?
Craters are large rimmed depressions that cover the lunar surface.

When did craters form?
Most of the craters on the Moon were formed during the Lunar Cataclysm.

Different sized craters are shaped differently.
Small craters have smooth sides and floors in a bowl shape.
Large craters have terraced walls and a flat floor.

Crater Formation
There are several theories that scientists have proposed to explain the formation of craters:

• Bursting gas bubbles in molten lunar crust
• Geyser-like fountains
• Mud volcanoes
• Collapse features
• Modified versions of terrestrial volcanoes
• High velocity impacts from outer space

After Moon exploration and study, we now know that they were formed by high velocity collisions with objects from outer space.
The Impact Process

The impact process is divided into three phases:

- **Compression Phase**
  During this phase, the impactor’s energy is transferred to the target surface. A high energy shock progresses into the target, fracturing and heating the material.

- **Excavation Phase**
  During this phase, the transient crater is formed by the cratering flow field. The field is deflected toward the surface by rarefactions from the surface. Thus streamlines in the flow field become concave upward toward the surface. Material flows along the streamlines.

- **Modification Phase**
  During this phase, the transient crater is modified into the final observed crater. Modification is driven by the rebound of the transient crater.
Simple Crater Formation

Contact/Compression stage
- Projectile
- Shock wave

End contact/compression stage
- Ejecta
- Rarfaction (release wave)
- Shock wave
- Material flow

Excavation stage
- Vapor
- Ejecta curtain
- Melt

End excavation stage
- Transient cavity

Modification stage
- Ejecta
- Fractured rock

Final crater
- Uplifted rim
- Melt-rich material
- Breccia lens
- Ejecta blanket

Simple Crater

- Breccia
- Impact melt
- Impact ejecta
- Fractured bedrock
- Central peak uplift
The Lunar Cataclysm

- An intense bombardment of meteorites hit the Moon.
- Occurred 3.9 billion years ago.
- Resulted in the formation of 1700 craters 100 km or larger.
- Resurfaced 80% of the Moon’s crust.
- Lasted less than 100 million years.

Proof of the Lunar Cataclysm:

- All the impact rocks in the Apollo collection were roughly the same age, 3.9 billion years.
- To strengthen the proof from the Apollo collection, scientist gathered four other meteorites that were not around the Apollo landing sites. Scientists proved they weren’t near the landing sites because the landing sites contained large amounts of potassium and phosphorous, but the meteorites had low concentrations of both. They made sure that these meteorites came from large impact craters by proving they contained “crystalline impact melts”, which is a characteristic of large impacts. The meteorites were then dated by Argon dating, and all proved to be 3.9 billion years old. This proved that the Moon took a severe beating from meteorites in a short period of time and that most of the craters are the same age.
Maria

Lunar maria is believed to be basaltic flood plains resulting from lava flows filling giant crater-like basins. It is thought to result from asteroids striking the surface of the Moon and subsequent volcanism. Some 31% of the near side surface area of the Moon is taken up by maria, while only 2.5% of the far side surface is covered by maria.

How did Maria form?
Large impacts fractured the Moon's lithosphere, allowing lava to fill the impact basins.

How old is Maria?
The age of lunar mare has been determined by both direct radiometric dating and by the technique of crater counting. The radiometric ages range from about 3.16 to 4.2 billion years old, whereas the youngest ages determined from crater counting are about 1.2 billion years old.
Basalt

Basalt is a dark-colored, fine-grained, igneous rock composed mainly of plagioclase and pyroxene minerals. It most commonly forms as an extrusive rock, such as lava flow, but can also form in small intrusive bodies, such as an igneous dike or thin sill.

How did Basalt form?
The rock basalt forms from the cooling and solidification of basaltic magma which is relatively high in iron and magnesium and relatively low in aluminum and silica when compared to andesitic and granitic magma.
A valley is an elongated depression between upland, hills, or mountains. These are abundant on the Moon. Therefore, many have yet to be discovered.

There are numerous valleys on the Moon’s surface.

- **Official:**
  - Vallis Alpes
  - Vallis Baade
  - Vallis Bohr
  - Vallis Boucard
  - Vallis Capella
  - Vallis Inghirami
  - Vallis Palitzsch
  - Vallis Planck
  - Vallis Rheita
  - Vallis Schrddinger
  - Vallis Schroteri
  - Vallis Snellius

- **Unofficial:**
  - Vallis Abbe
  - Vallis Brianchon
  - Vallis Brisbane Z
  - Vallis Chapman D
  - Vallis Cleostratus
  - Vallis Cori
  - Vallis Ellerman
  - Vallis Eotvos
Volcanoes

Volcanic activity on the Moon was an important part of shaping its landscape.

Volcanic activity on the Moon began with its creation, when the surface of the Moon was still in a magma state, much like Earth when it first formed.

Main Types of Volcanic Features on the Moon.

- Highland terrae
- Lowland maria
- Dark mantling deposits
- Small volcanic cones & domes
- Sinuous rilles
Volcanoes

Types of Volcanoes Found on the Lunar Surface:

- **Lunar Domes** - (shield volcanoes) wide, rounded, circular features with a gentle slope rising in elevation a few hundred meters to the mid-point.
- **Lava Terraces** - “shorelines” left as lava withdrew back into a vent or lower basin.
- **Cinder Cones** - formed from lava bombs (“cinders”) erupted explosively from a central vent.
Highland Terrae were some of the first features on the Moon’s surface. The features were created when the magma surface of the Moon began to crystallize and solidify. The denser crystals and solid materials sank, while the less dense materials rose to the surface.

Lowland Maria are made up of basaltic lava flows that filled in large impact basins. As the Moon continued to cool and solidify, and its surface was being bombarded by large objects, basaltic lava flows originating from the still partially molten surface pooled into these huge impact basins.

Dark Mantling Deposits As the surface of the basaltic lava flows cooled and solidified, extremely hot and gaseous magma may have been trapped underneath. The pressure produced Small Volcanic Eruptions that deposited dark mantling material around small vents.

Sinuous Rilles mark the path taken by lava flows as the lava melted its way into the solidified rock much in the same way that flowing water erodes a river valley.
Mountains and Ridges

- Mountains are the most distinctive aspect of the Moon. The contrast between its light and dark zones are also distinct.
- Lighter surfaces are the lunar highlands, terrae, and the darker plains are called maria.
- Highlands are anorthositic in composition, while maria are basaltic.
- Maria are primarily found in the lowlands.
- Highlands are older and more newly cratered.

- Ridges are created by compressive tectonic forces within the maria.
- Ridges form from buckling of the surface across parts of the maria.
- Ridges may outline buried craters or other features beneath the maria.
  - Examples would be the crater Letronne

![Diagram of Anorthosite crust formation]
3 Major Types of Rilles:

- **Sinuous Rilles** - characterized by their meandering curves.

- **Arcuate Rilles** - smooth curvature.

- **Straight Rilles** - long and undeviating
Sinuous Rilles

- Found in lunar mare which is filled with basaltic rock.
- Characterized by their meandering curves.
- Typical dimensions = 30-40 km long x less than 1 km deep.
- Thought to be remnants of ancient lava flows.
- Much larger than their terrestrial equivalents. This is because of the lower amount of gravity, high melt temperature, low viscosity, and high extrusion rates.

Theories Explaining the Formation of Sinuous Rilles

1) Lava flowing through and modifying pre-existing tectonic graben.
2) Lava eroding a subsurface lava tube subject to subsequent collapse.
3) An open channel at the lunar surface.
4) Thermal Erosion
   - Thermal erosion is more efficient on the Moon than mechanical erosion (at a slope of ~3.5 degrees or less) and is said to be the cause of sinuous rilles.

- Apollo 15 confirmed the theory that sinuous rilles were analogous to lava channels and collapsed lava tubes.
Arcuate Rilles

- Have smooth curvature and are found on the edges of the dark lunar maria.
- They are believed to form when the lava flows that created a mare, cool, contract, and shrink.
- These are found all over the Moon, examples can be seen near the south-western border of Mare Tranquilitatis and on the south-eastern border of Mare Humorum.
Straight Rilles

- Some are thought to be similar to fault bounded troughs on Earth and may have originated when the central portion of the mare basin settled.
- Some are large enough to be seen on Earth based photographs.
- Named straight rilles because they are long and undeviating.
- Some of these trenches cut across surrounding plains, uplands, and craters. May record preferred directions of breakage of the lunar crust cause by internal stresses.
- Others ring crater floors and may be related to uplift of the floor caused by crustal re-adjustment after impact.
- A few contain low rimmed halo craters that are interpreted to be volcanic vents.
Relative Age

By studying the superposition of features on the lunar surface, we can begin to determine the ages of these features relative to each other. Here are some examples:

**Crater-Rille Relations**

**Mountain - Crater Relations**
KEY
RED = Complex Craters
YELLOW = Simple Craters

Apollo 11 Landing Site