

Exploring the Moon in BIG SKY Country

Rocks in the Mountains of
Montana Tell a Story
of the Moon's History

The Beartooth Mountain Range near Bozeman, Montana contains a special type of rock — anorthosite. The Moon's oldest crust is made of this very same type of rock. Scientists travel from all over the world to visit Montana and study its anorthosite to help them learn more about our Moon's story of formation.

Rocks in the Beartooth Mountain Range near Bozeman contain layers of anorthosite, a light-colored rock made of crystals that formed from slowly cooled magma. Ninety to 100% of anorthosite is composed of a single mineral — plagioclase feldspar.

Rocks in the Beartooth Mountains are like a sliver of the Moon in miniature.

The mountains of Montana contain rocks that are like those we find on the Moon

Anorthosite is not common on Earth, but it is very common in the Moon's oldest crust. The Apollo astronauts brought back samples of anorthosite from the Moon. These samples are important in helping scientists understand the geology and history of our near neighbor. However, the small number of samples is not enough to answer all the questions, and scientists cannot easily visit the Moon to study its rocks in more detail. Scientists can, however, visit Montana's Beartooth Mountain Range to study the anorthosite rocks found there. Their studies of anorthosites in Montana help them understand how the Moon's anorthosite crust formed.

The story of Montana's Moon-like rocks



Anorthosite layers in the Stillwater Complex.

The anorthosite in the Beartooth Mountains is part of a group of rocks called the Stillwater Complex. The Stillwater Complex rocks formed about 2.7 billion years ago, when the magma in a giant chamber under Earth's surface began to slowly cool. As the magma cooled, mineral crystals grew. The denser (heavier) minerals sank to the bottom of the chamber, cooling and forming a layer of rock. Because scientists can study the details of the Stillwater Complex, they know the story has many parts. New magma was added to the chamber, hot currents mixed the magma, and new crystals formed and sank. Layer upon layer of rock formed. Sometimes the magma lost the more dense materials and low-density (lighter) plagioclase feldspar minerals crystallized and created a layer of anorthosite. Eventually, all the magma in the chamber cooled and became solid. Over the billions of years that followed, the land around the Stillwater Complex changed — it was eroded, new materials were deposited on top, and the land was broken by faults and crumpled into mountains. With time, the Stillwater Complex was exposed at the surface for scientists to study.

The rocks of the Stillwater Complex are like a Moon in miniature. They help scientists understand how anorthosite forms. Scientists use this information to piece together the story of the Moon's formation and how it has changed over time.

As the Moon cooled, the outer crust of anorthosite solidified, creating the bright lunar highlands.

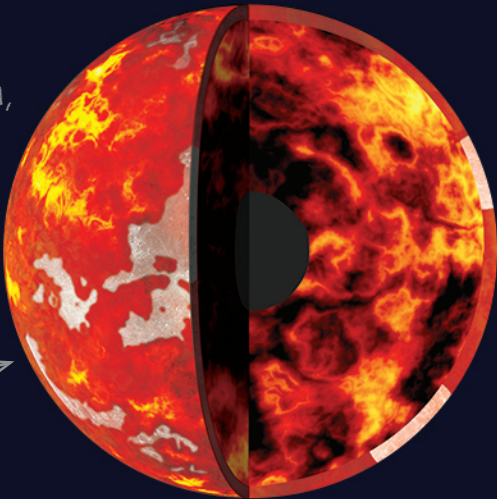


Anorthosite rocks tell the story of the Moon's history

Our Moon's most ancient crust is made of anorthosite. Creating anorthosite requires magma that is mostly plagioclase feldspar. However, scientists know from studies of Earth that magmas usually contain the materials for lots of different minerals. A magma containing only one mineral happens only under special circumstances. Knowing these circumstances, learned in part from studies of rocks like those in the Beartooth Mountains, helps scientists understand the story of our Moon's early history.

The magma that formed the Moon's crust must have differentiated — the different materials in the magma separated — just like they did in the formation of the Stillwater Complex rocks. Because the *entire* Moon was covered with an anorthosite crust, whatever happened must have been BIG!

When the Moon first formed, its surface (or maybe more!) was covered by an ocean of magma. Inside the early Moon, iron separated from the other materials and sank to the center to form its small core.



The story of the Moon's anorthosites starts four-and-a-half billion years ago. Like all rocky moons and planets, our Moon was extremely hot when it formed. Temperatures on the Moon were hot enough — 3300° F (1800° C) — for the outer surface (or maybe all the Moon!) to be molten. To explain the anorthosite crust that covers the Moon, this ocean of magma must have covered all or most of the Moon.

As the Moon cooled, minerals began to form within the magma ocean. High-density (heavy) minerals, such as olivine and pyroxene, sank toward the middle of the Moon. Low-density (light) minerals, such as plagioclase, floated to the top.

Inside the cooling Moon, lighter minerals, such as plagioclase, floated to the surface to form the anorthosite crust. Heavier minerals such as olivine and pyroxene sank, forming the Moon's lower crust and mantle.

The plagioclase minerals crystallized into anorthosite rocks at and near the surface to form the outer crust of the Moon. These rocks make up the lunar highlands, the bright, lighter-colored areas we see on the Moon today. Below the surface, crystals of olivine and pyroxene settled toward the bottom of the magma ocean to form the Moon's lower crust and mantle.

Make a Model Moon!

You will need:

- One empty clear plastic water bottle with lid
- Enough clean aquarium gravel, sand, or marbles to fill the bottle about 1/5 full
- Enough beans, plastic beads, or drinking straws (cut into 1/4" pieces) to fill the bottle about 1/20 full
- Water or clear syrup to fill the bottle

- 1) Place the materials in the bottle. Put the lid on the bottle, and make sure it is tight.
- 2) Make a prediction: What will happen when you shake the bottle?
- 3) Shake the bottle so that the materials are mixed up.
- 4) Set the bottle down and observe what happens.



What happens to the materials in the bottle? Which sink? Which float? How is what you observe similar to how the Moon's crust formed?

You have just made a model of the Moon and observed how the materials differentiated (separated). The beans, beads, or straw pieces represent the less-dense (lighter) minerals of the Moon's anorthosite crust. The gravel, sand, or marbles represent the more-dense (heavier) materials in the Moon that sank to form the core. The water or syrup represents the Moon's middle layer — the mantle.



Anorthosite Highlands

You can see the anorthosite crust when you look at the Moon! Look for the brighter, light-colored, heavily cratered regions. These are the lunar highlands, and they are made of the oldest — 4.5 to 4.3 billion years old! — rocks on the Moon. They are made of anorthosite. The entire crust of the early Moon was made of this rock. Since its formation, the Moon has been bombarded by countless large and small asteroids and comets that have broken up the crust, creating large basins (big dark circles) and small craters on its surface.

New Spacecraft Are Helping Scientists Tell More of the Moon's Story



Why is the crust on the Moon's farside thicker than the crust on the nearside? This question has puzzled lunar scientists for many years. Finding an answer to this question requires a better understanding of the Moon below the crust. Data from the GRAIL mission will help scientists better understand the Moon's interior. Learn more about the GRAIL mission at <http://moon.mit.edu>.

A special camera onboard the Lunar Reconnaissance Orbiter (LRO) spacecraft is giving scientists views of the Moon never seen before! These pictures are helping scientists and engineers select landing sites for future missions. See these images at <http://www.lroc.asu.edu>.



The NASA Lunar Science Institute (NLSI) brings together research teams seeking answers to important questions about the history and future exploration of our Moon. Read more about NLSI at <http://lunarscience.arc.nasa.gov>.

Learn More About Our Moon

The Center for Lunar Science and Exploration (CLSE) is one of seven NLSI teams. CLSE is studying lunar rocks to better understand the history of asteroid impacts on the Moon.

Find out more about the CLSE team at <http://www.lpi.usra.edu/nlsi>.



Get Involved in Lunar Science and Exploration!

Moon Mappers puts you in the middle of the action! Help scientists in their quest to understand the history of the Moon by marking craters in images from LRO. Join Moon Mappers at <http://cosmoquest.org/mappers/moon>.

Join scientists, educators, and Moon enthusiasts from around the globe for one day each year to celebrate the Moon on International Observe the Moon Night! Visit <http://observethemoonnight.org> for more information and to find an event near you!

