AMERICAN MUSEUM of NATURAL HISTORY

EDUCATOR'S GUIDE

ARTHUR ROSS HALL OF METEORITES

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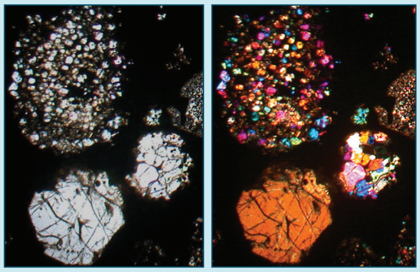
amnh.org/meteorites-educators

ESSENTIAL Questions

What are meteorites?

Meteorites are **rocks** from space that survive a violent passage through our atmosphere to land on Earth. All meteorites come from inside our solar system. Most are fragments of **asteroids** that have orbited the Sun between Mars and Jupiter for billions of years. A small number are pieces of rock from the surfaces of other planetary bodies, including the Moon. Other than Moon rocks brought back by the Apollo astronauts, meteorites are our only samples of these other worlds.

What do meteorites tell us about the birth of the solar system?



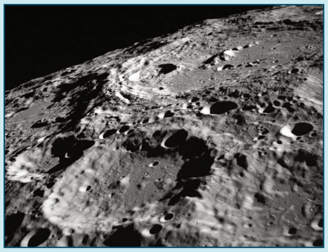
Seen under a microscope, the Allende chondrite meteorite can be viewed in ordinary light (left) or in cross-polarized light (right), which helps scientists identify different minerals. Rounded chondrules are embedded in a dark "matrix" made of tiny mineral grains, or "dust."

Some primitive meteorites, called chondrites, are like time capsules. They have remained essentially unchanged since the solar system formed, and scientists who study them can infer the age, composition, and conditions of the early solar system. Small white objects inside these meteorites are rich in calcium and aluminum. These calcium-, aluminum-rich **inclusions**, or CAIs, are the oldest objects formed in our solar system. Scientists have used **radiometric dating** to determine the age of CAIs, and inferred that the solar system is at least 4.568 billion years old. Chondrites contain tiny near-spherical objects called chondrules, which likely formed when clumps of dust grains drifting in the solar nebula melted and then solidified rapidly.

What do meteorites tell us about planets and asteroids?

As the material in the inner solar system cooled, vapor condensed into solids. Small bodies **accreted** into larger ones. These bodies collided with each other, and meteorite fragments record this dramatic history. The largest bodies **differentiated** into cores and **mantles**. Meteorites that were formed by differentiation are called achondrites. Their chemistry is evidence that differentiation occurred widely and on a large scale to form the planets of the inner solar system. Crystal-chemical patterns within iron achondrites reveal the rate at which the metal cooled. Since larger objects cool more slowly than small ones, scientists can use this information to estimate the size of each meteorite's parent body.

What do craters tell us?



Taken by an *Apollo 10* astronaut, this photo shows a few of the impact craters that record the Moon's history of asteroid bombardment.

Since Earth's formation some 4.6 billion years ago, countless meteorites have crashed into the planet. Some caused dramatic changes, including at least one mass extinction. Because of dynamic Earth processes, only about 200 impact **craters** have been found so far on Earth's current surface. Most craters have been erased by **plate tectonics**, while others have been hidden beneath lava, ice, or oceans, or weathered away by wind and water. The structure of craters tells us about the energy of their impact. Being so close to Earth, the Moon has also been exposed to asteroid bombardment. Unlike Earth's surface, the Moon's inactive surface shows traces of impacts that are billions of years old, making it the definitive record of that history.

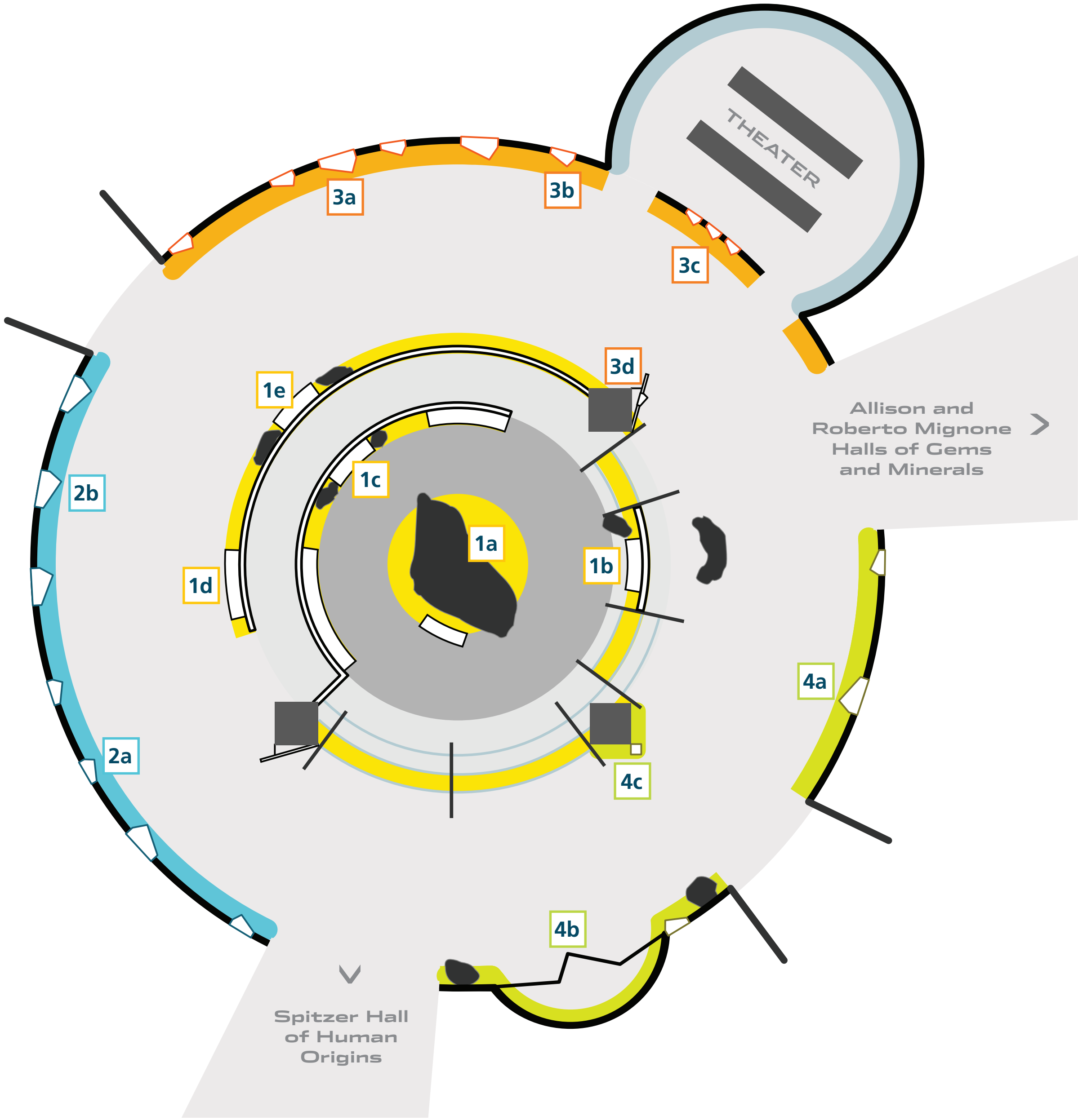
How do we collect and study meteorites?

Scientists search for meteorites by traversing and systematically scanning promising areas. Meteorites are easiest to find in deserts, whether cold ones like Antarctica or hot ones like those of Africa and Australia, where they can be easy to spot against sand or snow. Water causes meteorites to decay and rust, but they can survive a long time in dry conditions. Scientists also search where impacts have been discovered, both recently and long ago. Once specimens reach the lab, scientists cut them into thin slices to study under microscopes. They use CAT scans to determine three-dimensional structure and electron-beam instruments to analyze **mineral** composition. To establish the age of the samples, researchers measure the ratios of **isotopes** of certain elements that undergo radioactive decay at known rates.

Embedded in ice, transported by glaciers, and eventually exposed at the surface, meteorites accumulate in certain parts of Antarctica, where scientists have been collecting them for several decades.

ARTHUR ROSS HALL OF METEORITES

MAP



CENTER AREA

- 1a Thirty-Four Tons of Iron
- 1b Fragments of Cape York
- 1c Stone and Iron from Space
- 1d What Does a Meteorite Look Like?
- 1e Looking Inside Meteorites

ORIGIN

- 2a Chondrules, CAIs, Matrix
- 2b Parent Bodies, Solar System, Planetesimals

PLANETS

- 3a Crust, Mantle, Core, Iron Crystals
- 3b Vesta
- 3c Mars
- 3d Missions

IMPACTS

- 4a Earth Impacts
- 4b Meteor Crater
- 4c On the Moon

Teaching in the Hall

This hall uses specimens to investigate the origins of meteorites, their journey through space and fall to Earth, and the wealth of information they contain. The hall is laid out in a circle, with an overview in the **center** and three areas on an outer ring: **"Origin of the Solar System"** (primitive, or pre-planetary meteorites), **"Building Planets"** (material from planetary bodies, including sample return missions), and **"Meteorite Impacts"** (dynamics of the solar system). Numbers correspond to stops on the map.

THEATER: An eight-minute video gives an overview of the hall, exploring what meteorites are and what they tell us about the solar system. Topics include: what we can infer about Earth's core from meteorites; the hazards of meteorites and how we can stop them from hitting Earth; and how Museum scientists study meteorite and extraterrestrial samples.

CENTER AREA

OVERVIEW: The centerpiece of this hall is Ahnighito, one of the three Cape York meteorites on display here. Touchable specimens and text panels explain the characteristics of stony, stony-iron, and iron meteorites, and the history of meteorite science.

GUIDED EXPLORATIONS

1a. Thirty-Four Tons of Iron: Because it's made of iron-nickel alloy, the Ahnighito meteorite is much heavier than it looks. Students can touch it and describe what they feel and see. (Tip: Look for the two polished spots; the criss-crossing pattern shows how the crystals grew.) Students can then read about the difference between a meteor (an object that enters Earth's atmosphere, usually disintegrating) and a meteorite (material that survives the intense heat and pressure to land on Earth's surface).

The Woman, the Dog, and Ahnighito (in rear).

1b. Fragments of Cape York: Along with Ahnighito, these two meteorites, known as the Woman and the Dog, are fragments of a much larger meteorite that landed in Greenland thousands of years ago (see insert). Students can watch the video to learn how they reached the Museum and read text to learn about Arctic explorer Matthew Henson, the first African American to explore Greenland.

1c. Stone and Iron from Space: The most common type, stony meteorites are made of minerals that are similar to those in rocks on Earth. Iron meteorites are more than 98% metal. Stony-irons are a mixture of metal and rock. Students can compare the polished surface of Estacado (stony; different-sized grains) and Ahnighito (iron; regular pattern).

1d. What Does a Meteorite Look Like?: During a meteorite's fall through the atmosphere, it heats up and melts on the outside. Its ultimate appearance depends on what it's made of, how it came through the atmosphere, and what happened after impact. Students can compare the external appearances of several meteorites to explore the effects of their high-speed journeys.

One side of Miller stayed oriented towards Earth as it passed through the atmosphere. It eroded into an aerodynamic "nose cone" shape, and molten rock formed flow lines from front to back. Modoc's broken surface highlights its dark fusion crust, a thin, glassy coating that formed as its molten surface solidified before the meteorite hit the ground.

1e. Looking Inside Meteorites: Scientists often cut meteorites into thin petrographic sections to study their internal structure. Students can examine the slices and read about what they reveal.

ORIGIN

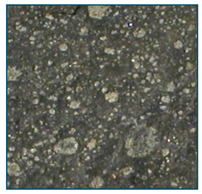
OVERVIEW: Because Earth is dynamic, it has changed dramatically since the planet formed some 4.6 billion years ago. Some meteorites, on the other hand, have remained unchanged as they travel through the vacuum of space, so they contain important information about physical and chemical processes at work in the early solar system. The chondrite meteorites in this section are the most common types collected on Earth.

GUIDED EXPLORATIONS

2a. These three cases "take apart" primitive meteorites into three components:

- **Chondrules:** Under a microscope, these glassy beads are revealed in the thin section of Allende. Students can read about what the chemical composition of primitive meteorites tells us about the solar system.
- **CAIs:** Calcium-aluminum inclusions are the oldest rocks that formed in our solar system. Students can investigate how scientists determine the age of mineral inclusions, and why that information is significant.

- **Matrix:** Mineral dust from the early solar system has been preserved as matrix, a dark, fine-grained material surrounding chondrules and CAIs. Students can explore why some meteorites, such as Murchison, are black like tar and others are much lighter in color. They can also examine the presolar grains extracted from the Allende meteorite.



Murchison

2b. To learn more about the early formation of the solar system, students can explore these three cases:

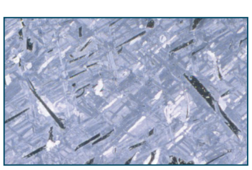
- **Parent Bodies:** By analyzing the composition of meteorites, scientists can determine whether they came from the same source. Students can explore evidence that three meteorites (Kunashak, Kyushu, Suizhou) may have belonged to the same parent body.
- **Solar System:** The chemical makeup of meteorites and the planets in our solar system relates to their distance from the Sun. Students can compare the chemistry and origins of three different meteorites (Eagle, Farmington, Banten).
- **Planetesimals:** Meteorites record the processes—such as heating, melting, and pulverizing—that occured when objects in the early solar system collided. Students can examine the specimens and explore the processes.

BUILDING PLANETS

OVERVIEW: As the solar system was forming, countless small objects smashed into each other, gradually forming larger and larger bodies such as asteroids and planets. The meteorites in this section illustrate this process of accretion. Relatively rare, they are important for understanding the formation of planets, including Earth.

GUIDED EXPLORATIONS

3a. Crust, Mantle, Core, and Iron Crystals: As a planet forms, it melts and differentiates into layers. (The densest materials, like iron, sink to the center, while the lightest, like stones, float to the surface.) We can't go deep inside planets, even our own, but meteorites from objects that were broken up after differentiation help us understand the process. Students can compare the specimens in the Crust, Mantle, and Core cases to understand the relationship between how meteorites look and where they originated. Students can also examine meteorites in the Iron Crystals case that display the characteristic cross-hatching intergrowth known as the Widmanstatten pattern, and find out how this pattern forms and how scientists know that rocks found on Earth's surface displaying this pattern must be meteorites.



Widmanstatten pattern

3b. Vesta: Students can view specimens from Vesta, a differentiated asteroid that "lives" in the asteroid belt. They can find out what the three types of HED (howardite-eucrite-diogenite) meteorites tell us about the processes that shaped Vesta.

3c: Mars: Scientists figured out the meteorites in this case came from a large planet that had water and volcanic activity. Mars fit the bill. But it wasn't until NASA's Viking probes landed in the 1970s and measured the composition of the Martian atmosphere that we had conclusive evidence: gases trapped inside these rocks were a perfect match. Students can explore these samples and the evidence they contain.

3d. Missions: Meteorites were once our only samples of worlds outside our own, but their brutal journey to Earth changed them. Students can play a game and read about missions to asteroids Bennu and Ryugu and comet Wild-2 to collect pristine samples from extraterrestrial objects unaffected by the rigors of passing through Earth's atmosphere and weathering once here.

IMPACTS

OVERVIEW: This section explores what we can learn from meteorite impacts, the probability of future impacts, plans to deflect incoming asteroids, and what craters tell us about the dynamic history of the solar system and the histories of planets.

GUIDED EXPLORATIONS

4a. Earth Impacts: Students can explore the panels to find out how past impacts affected the surface of Earth and other planetary bodies and what can be done to deflect objects heading our way. By engaging with the interactive, students can visit the history of some notable impacts and investigate different types of objects in space.

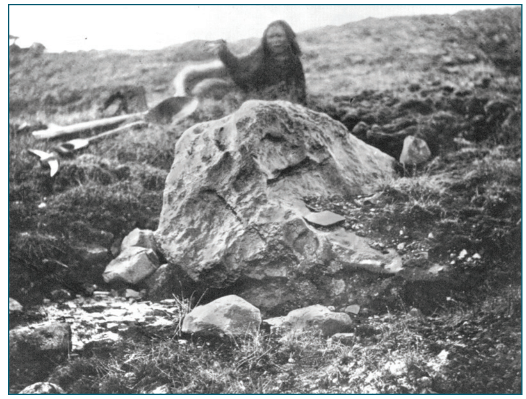
4b. Meteor Crater: Scientists determined that the 1,200-meter-wide Barringer crater in Arizona was caused by a meteorite, not a volcano. Students can explore the mini diorama and the evidence (deposition of specific rock layers around the rim; undisturbed rock underneath).

4c. On the Moon: Unlike Earth, the Moon is a "dead" planetary body—it has no life, no atmosphere, and almost no water or geologic activity—so it has remained largely unaltered for most of its history. Students can explore how lunar craters allow scientists to piece together Earth and the Moon's shared history of asteroid bombardment, as well as how the Moon formed. They can look closely at three Moon rocks and consider what they reveal about the Moon's formation.

COLLECTING a Meteorite

How Three Pieces of the Cape York Meteorite Traveled from Greenland to New York City

Inuit people had a long tradition of using tools and harpoons made of iron, but the metal's source was a puzzle to outsiders. Robert Peary and his party were the first non-indigenous Arctic explorers to find where it came from. Matthew Henson, the first African American to explore Greenland, accompanied Peary on seven of his voyages, over a period of more than two decades. Henson was fluent in Inuit languages and could use indigenous knowledge to train dogs and to build and repair sleds, making him essential to the success of the expeditions. In 1894, Peary convinced an Inuit guide, Aleqatsiag, to bring them the iron source: a total of three large meteorite fragments well preserved by the dry conditions, two on northern Greenland's Cape York and the third on an island nearby. Peary reported a local legend explaining that they represented a woman and her dog, sheltered by a tent, who had been cast from heaven by an evil spirit. Around the meteorites were scattered thousands of "hammerstones"—basalt stones hard enough to break iron brought to the site over the centuries from over 50 miles away.



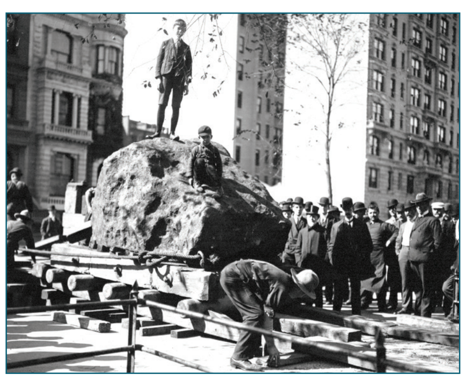
The massive meteorite was almost entirely buried in the ground.

Peary's team uses a bridge to load the Tent from the shore to the ship.

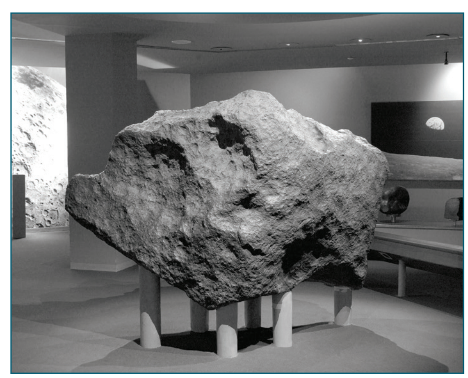
Working during the brief Arctic summers, Peary and his party took three years to collect the meteorites. In 1895, the Dog (900 pounds) and the Woman (3 tons) were transported to Peary's steamer, the Kite, on planks laid over a large ice floe. In 1896, Peary and his team returned for the Tent, the third and largest fragment (34 tons), which lay partly buried on an island just offshore. The party succeeded in moving the massive meteorite to the shore, but winter storms closed in. The explorers returned again in 1897, this time accompanied by Peary's wife and four-year-old daughter, who named the meteorite "Ahnighito," her middle name. Peary's team built Greenland's first and only (very short) railroad, greased the rails with soap tallow, and used powerful hydraulic jacks to move the meteorite the last few feet and aboard the *Hope*.

In 1904, it took 28 horses to haul Ahnighito on a massive custom-built cart from the Brooklyn Navy Yard to the American Museum of Natural History. To this day, Ahnighito remains the largest meteorite ever taken from where it fell, making it what scientists call "the largest meteorite in captivity."

Twenty-eight horses haul Ahnighito, the Tent, to the Museum.



Ahnighito arrives at the Museum.



Ahnighito is the largest meteorite "in captivity." The steel posts that support it extend all the way down to the bedrock underneath the building.

GLOSSARY

accretion: the accumulation of material, under the influence of gravity, to form a planet, moon, asteroid, or comet

alloy: a metal composed of more than one element

asteroids: small rocky or metallic bodies, most of which orbit the Sun between Mars and Jupiter

crater: a bowl-shaped depression on a planetary body caused by the explosive impact of an extraterrestrial body from above or by a volcanic eruption from below

differentiation: the process of forming layers of different composition, usually by sinking of dense material and floating of light material, in a large planetary body

inclusion: a fragment of one rock or mineral enclosed in another rock or mineral

isotope: elements having an identical number of protons in their nuclei but differing in their number of neutrons

mantle: the part of a rocky planetary body between the crust and the iron-rich core

meteors: often called "shooting stars," these are small pieces of asteroids or comets that enter Earth's atmosphere and usually disintegrate. Meteor showers occur when Earth passes through the trail of dust that follows a comet.

meteorites: meteors that survive the trip through the atmosphere and reach Earth's surface

mineral: any naturally occurring, inorganic solid with a specific composition and an ordered crystalline structure

plate tectonics: a theory that describes the movement of the massive plates that make up Earth's outermost, rigid rocky layer

radiometric dating: a technique for calculating the age of geologic materials based on the decay of different naturally occurring radioactive isotopes

rock: a naturally occurring aggregate of one or more minerals

About the Arthur Ross Hall of Meteorites

This hall contains more than 130 remarkable specimens, among them the oldest and the most massive objects in the Museum. In 1900 J. P. Morgan purchased the extraordinary 12,300-specimen collection of Clarence S. Bement, a Philadelphia industrialist, and donated it to the Museum. Two railroad boxcars were required to transfer it, and the 580 meteorites it contained laid the foundation of the Museum's meteorite collection, one of the world's finest. Their scientific value has soared as advances in technology have revealed the information they contain. New additions include meteorites from Mars and the Moon.

COME PREPARED

- ☐ **Plan your visit.** For information about reservations, transportation, and lunchrooms, visit **amnh.org/plan-your-visit/field-trips**.
- ☐ **Read the Essential Questions** to see how themes in the hall connect to your curriculum. Identify the key points that you'd like your students to learn.
- ☐ **Review the Teaching in the Hall** section, which provides different ways to support your students as they explore the hall.
- ☐ **Download activities and student worksheets** at **amnh.org/meteorites-educators**. Designed for use before, during, and after your visit, these activities focus on themes that correlate to the standards.
- ☐ **Decide how your students will explore the hall.**
  - You and your chaperones can facilitate the visit using the **Teaching in the Hall** section.
  - Students can use the student **worksheets** to explore the hall on their own or in small groups.
  - Students, individually or in groups, can use copies of the **map** to choose their own paths.

CORRELATION TO THE FRAMEWORK FOR K–12 SCIENCE EDUCATION

Science Practices • Asking questions • Developing and using models • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Constructing explanations • Engaging in argument from evidence • Obtaining, evaluating, and communicating information

Crosscutting Concepts • Patterns • Cause and effect: mechanism and explanation • Scale, proportion, and quantity • Systems and system models • Structure and function • Stability and change

Core Ideas • PS1: Matter and Its Interactions • PS2: Motion and Stability: Forces and Interactions • ESS1: Earth's Place in the Universe • ESS2: Earth's Systems • ETS2: Links Among Engineering, Technology, Science, and Society

CONTINUE Your Journey

AT THE MUSEUM

Dorothy and Lewis B. Cullman Hall of the Universe

Lower Level

Visit the 15.5-ton Willamette meteorite, the largest ever found in the U.S. and the sixth-largest in the world. Unlike Ahnighito, which was well-preserved by the Arctic's dry climate, the Willamette was exposed to rainwater for thousands of years and its smooth surface corroded. The massive iron meteorite, found in Oregon, is sacred to the people of the local Clackamas tribe, who called it Tomanowos.

Willamette meteorite

ON THE WEB

Meteorites for Educators

amnh.org/meteorites-educators

Links to all the Museum's meteorite-related resources, including the educator's guide to the Arthur Ross Hall of Meteorites, and activities and articles such as "Launching and Recovering Meteorites" and "Crash Course."

Astronomy OLogy

amnh.org/ology/astronomy

OLogy is the Museum's science website for kids ages seven and up. Read an interview with a chondrite meteorite in "If Rocks Could Talk."

NASA: Solar System Exploration

solarsystem.nasa.gov/planets

Click "Asteroids, Comets, and Meteors" on the menu for overviews, photo galleries, and in-depth information.

Fun Facts

"Shooting stars" are actually meteors. People once thought they were stars falling from the sky. These tiny grains of dust glow brightly in Earth's atmosphere because they're travelling so fast that they release a tremendous amount of energy.

Meteorites can be huge or tiny. The biggest one ever found weighs over 60 tons, while others are the size of a grain of sand.

Small pieces of the Moon occasionally reach Earth as meteorites. We know where they come from because they're similar in composition to the lunar rocks collected by the *Apollo* astronauts.

Some asteroids could be rich sources of iridium, platinum, and other precious metals, making them potential targets for mining.

CREDITS

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Photo Credits

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