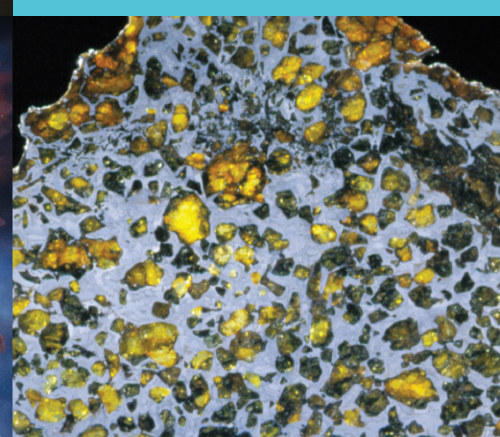
American Museum of Natural History

Educator's Guide

Arthur Ross Hall of Meteorites

Inside:



amnh.org/meteorites/educators

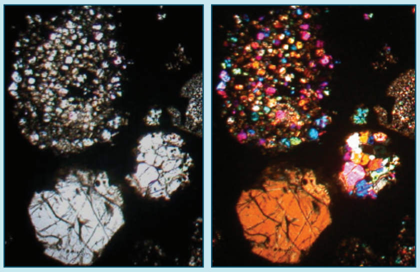
ESSENTIAL Questions

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 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 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?

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 **inclusions**, or CAIs, are the oldest objects formed in our solar system. Scientists have used **radiometric dating** to determine the age of CAIs, and in turn inferred that the solar system is at least 4.567 billion years old. Chondrites contain tiny spherical objects called chondrules, which likely formed when clumps of dust grains drifting in the solar nebula melted and then solidified rapidly.



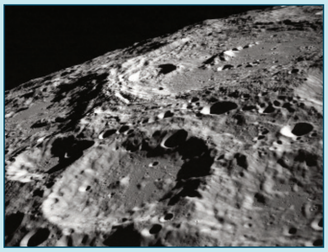
Seen under a microscope, the Allende meteorite can be viewed in ordinary light (left) or in cross-polarized light (right), which helps scientists identify different minerals. Rounded chondrules are embedded in a dark "matrix" made of mineral dust particles.

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 this process 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 patterns within 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 the meteorite's parent body.

What do craters tell us?

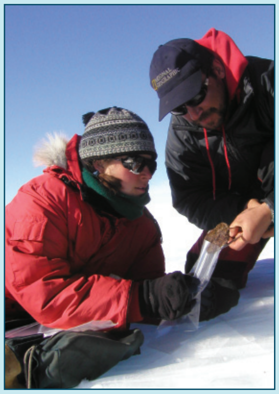
Since Earth's formation some 4.6-billion-years ago, countless meteorites have crashed into the planet. Some caused dramatic changes, including at least one mass extinction. Because of dynamic Earth processes, only about 200 impact **craters** have been found so far on Earth's current surface. Most craters 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 the impact. Being so close to Earth, the Moon has been exposed to about the same amount of 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.



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

How do we collect and study meteorites?

Scientists search for meteorites by walking across 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 reported, both recently and long ago. Once specimens reach the lab, scientists cut them into thin slices to study under a microscope. They use CAT scans to determine three-dimensional structure and electron-beam instruments to analyze **mineral** composition. To establish the age of the material, 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 for over twenty years.

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 impact of an extraterrestrial body from above or by a volcanic eruption from below

differentiation: the process of forming layers of different compostion, usually by sinking of dense material and floating of light material

inclusion: a fragment of one rock enclosed in another rock

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 meteorites 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.

Read the Essential Questions in this guide to see how themes in the Arthur Ross Hall of Meteorites connect to your curriculum. Identify the key points that you'd like your students to learn.

Review the Teaching in the Exhibition section of this guide, 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 Arthur Ross Hall of Meteorites.

- You and your chaperones can facilitate the visit using the **Teaching in the Exhibition** section.
- Students can use the student **worksheets** to explore the exhibition 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

Teaching in the EXHIBITION

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), and "**Meteorite Impacts**" (dynamics of the solar system). Numbers correspond to stops on the map.

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, Ahnighito is much heavier than it looks. Have students 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.)* Help students understand 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)*.

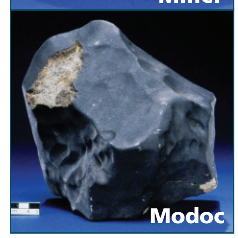
The Woman, the Dog, and Ahnighito (in rear).

1b. Fragments of Cape York: Tell students that 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). Have students watch the video to learn how they reached the Museum.

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. Have students compare the polished surface of Estacado (stony) and Ahnighito (iron) and describe their differences. *(Stone has different-sized grains. Iron has a regular pattern.)*

Bring magnets or compasses with you. Students can see how these tools react to the iron-nickel alloy meteorites.

1d. What Does a Meteorite Look Like?: During a meteorite's fall through the atmosphere, it heats up and melts on the outside. Its appearance depends on what it's made of, how it came through the atmosphere, and what happened after impact. Have students compare the meteorites' external appearances to explore the effects of their high-speed journeys. *(For example, 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 hitting the ground.)*



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

ORIGIN

OVERVIEW: Because Earth is dynamic, all the material on its surface has changed 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 type 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. Have students 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. Have students investigate how scientists determine the age of mineral inclusions, and why that information is significant.

- **Matrix:** Dust from the early solar system has been preserved as matrix, a dark, fine-grained material surrounding chondrules and CAIs. Ask students why some meteorites, such as Murchison, are black like tar and others are much lighter in color. *(The matrix of darker meteorites is rich in carbon compounds; the other is not.)* Be sure to draw their attention to 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:

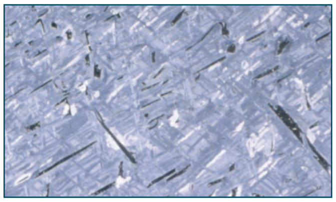
- **Parent Bodies:** By analyzing their composition, scientists can determine if meteorites came from the same source. Have students find three meteorites (Kunashak, Kyushu, Suizhou) and explore why they may have belonged to the same parent body. *(Even though they fell to Earth at different times and places, their composition is identical.)*
- **Solar System:** The chemical makeup of meteorites and the planets in our solar system relates to distance from the Sun. Have students compare the chemistry and origin 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. Have students 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 in 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, so meteorites from objects that were broken up after differentiation help us understand the process. Have students compare the specimens in the Crust, Mantle, and Core cases to understand the relationship between how meteorites look and where they originated. Next, have students examine meteorites in the Iron Crystals case that display the characteristic criss-crossing known as the Widmanstatten pattern. Have them explore how this pattern forms, and how scientists know that it's found only in meteorites.



Widmanstatten pattern

3b. Vesta: View specimens from Vesta, an asteroid that "lives" in the asteroid belt. What does comparing the three types of HED meteorites tell us about the processes that shaped Vesta? *(Molten rock flowed from Vesta's interior onto its surface, and also hardened beneath the surface. Impacts mixed these materials together.)*

3c: Mars: Scientists figured out these meteorites 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. Have students explore these samples and the evidence they contain.

3d. Theater: Students can watch a 7-minute film that provides an overview of the themes in this hall.

IMPACTS

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

GUIDED EXPLORATIONS

4a. Earth Impact: Invite students to explore this area and consider the various factors — such as the size of the object, its speed and trajectory, and where it lands — that determine how catastrophic an impact could be.

4b. Meteor Crater: Scientists determined that the 1,200-meter-wide Barringer crater in Arizona was caused by a meteorite, not a volcano. Have students 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 Moon's shared history of asteroid bombardment.

CONTINUE Your Journey

AT THE MUSEUM

Willamette meteorite

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.

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."

AstroBulletins
sciencebulletins.amnh.org

Videos, essays, and data visualizations about current scientific research. Browse the Astrobulletins (list on left) for astrophysics news and stories.

NASA: Solar System Exploration
solarsystem.nasa.gov/planets

Click "meteors and meteorites" on the left-hand menu of NASA's Solar System Exploration site for an overview, photo gallery, lesson plans, and news.

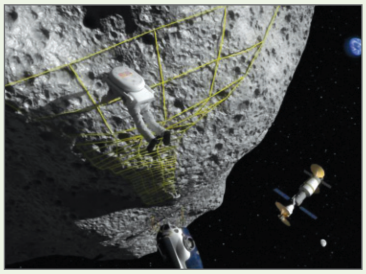
Fun Facts

"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 around 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 identical 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.



artist's rendering

CREDITS

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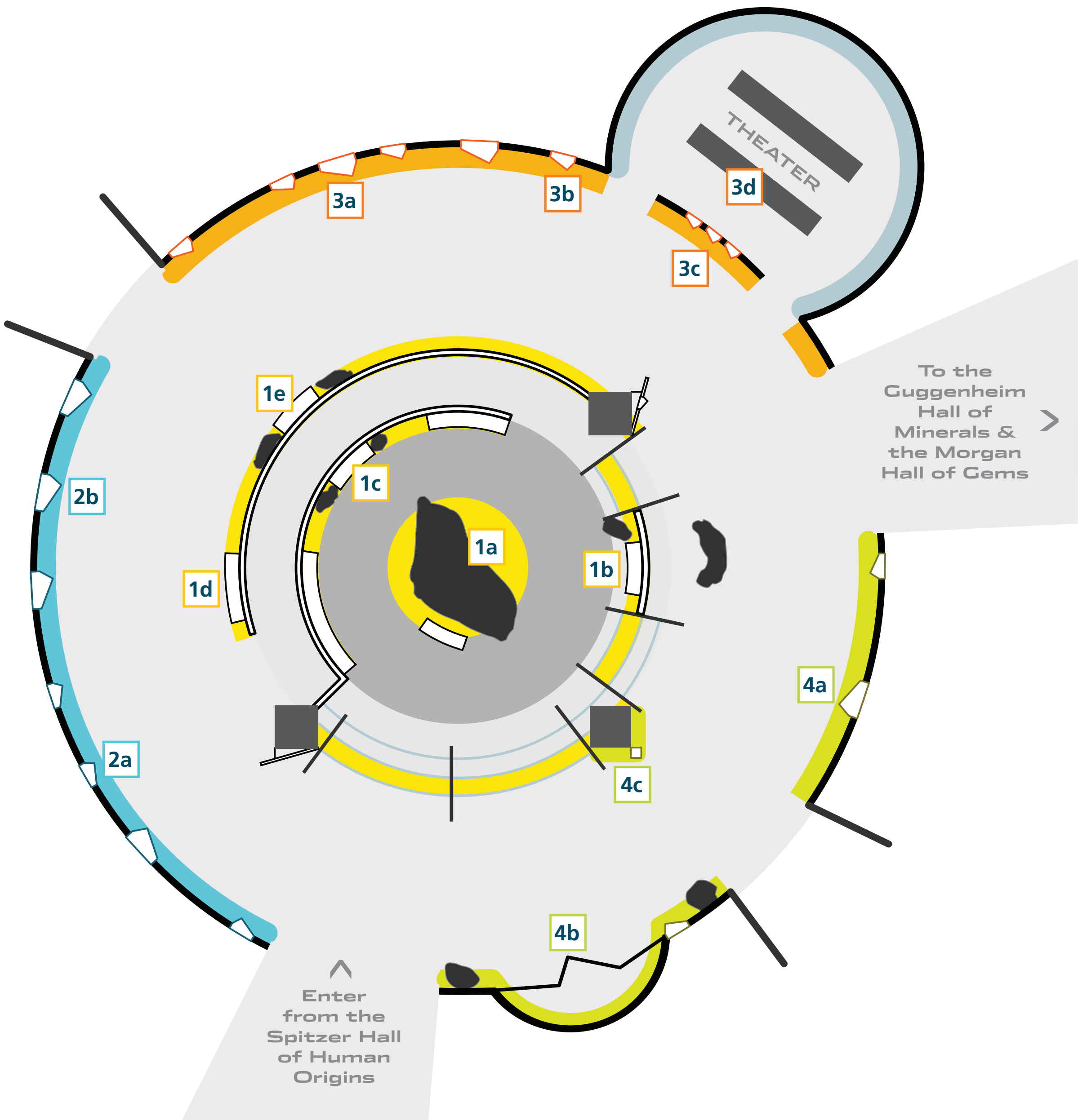
ARTHUR ROSS HALL OF METEORITES

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 Theater

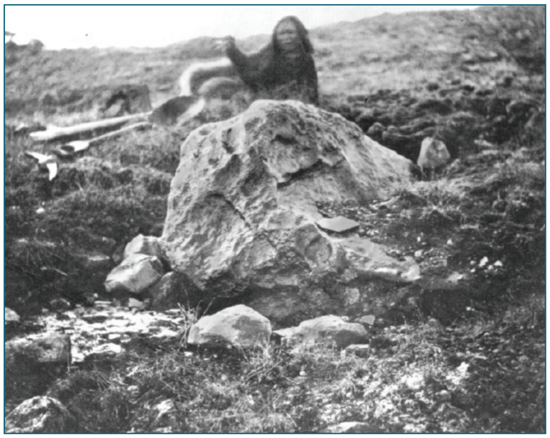
IMPACTS

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

COLLECTING a Meteorite

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

Robert Peary wasn't the first Arctic explorer to observe that the Inuit people were using tools and harpoons made of iron, but he was the one to find where the metal came from. In 1894 he convinced an Inuit guide to bring him to the "iron mountain" on northern Greenland's Cape York — a total of three large meteorite fragments well-preserved by the dry conditions. Peary was told of a local legend 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.



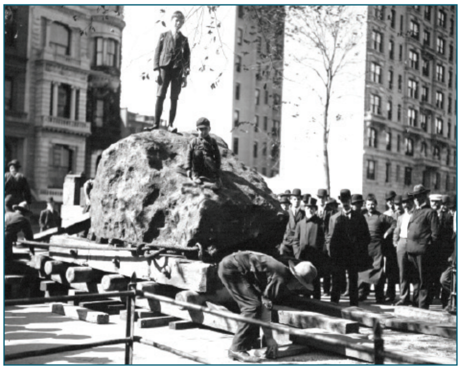
The massive meteorite was almost entirely buried in the ground.

Working during the brief Arctic summers, it took Peary three years to collect the meteorites. In 1895, the Dog (900 pounds) and the Woman (3 tons) were transported to his steamer, the *Kite*, on planks laid over a large ice floe. In 1896, Peary 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 explorer returned again in 1897, this time accompanied by his wife and four-year-old daughter, who christened 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*.

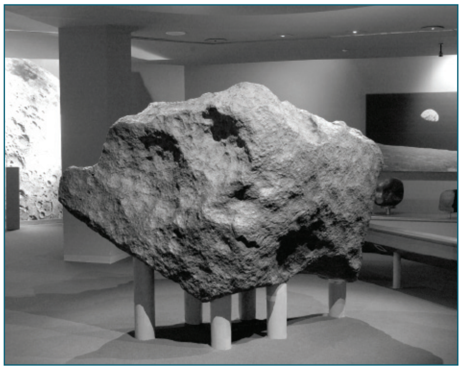
Peary's team uses a bridge to load the Tent from the shore to the ship.

Once the ship docked, it took twenty-eight 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.

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.