# Science & Literacy Activity

**GRADES 9-12**

## OVERVIEW

This activity, which is aligned to the Common Core State Standards (CCSS) for English Language Arts, introduces students to scientific knowledge and language related to meteorites. Students will read content-rich texts, visit the Arthur Ross Hall of Meteorites, and use what they have learned to complete a CCSS-aligned writing task, creating an illustrated text about meteorites.

**Materials in this activity include:**

- Teacher instructions for:
  - o Pre-visit student reading
  - o Visit to the Ross Hall of Meteorites and student worksheet
  - o Post-visit writing task
- Text for student reading "New Meteorite Suggests That Asteroid Surfaces More Complex Than Previously Thought"
- Student Worksheet for the Ross Hall of Meteorites
- Student Writing Guidelines
- Teacher rubric for writing assessment

**Common Core State Standards:**
WHST.9-12.2, WHST.9-12.8, WHST.9-12.9
RST.1, RST.9-12.2, RST.9-12.4, RST.9-12.7, RST.9-12.10

**New York State Science Core Curriculum:**
PS 1.2c

**Next Generation Science Standards:**
PE HS-ESS1-6
DCI ESS1.C: The History of Planet Earth
Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.

**SUPPORTS FOR DIVERSE LEARNERS: An Overview**
This resource has been designed to engage all learners with the principles of Universal Design for Learning in mind. It represents information in multiple ways and offers multiple ways for your students to engage with content as they read about, discuss, view, and write about scientific concepts. Different parts of the experience (e.g. reading texts, or locating information in the exhibit) may challenge individual students. However, the arc of learning is designed to offer varied opportunities to learn. We suggest that all learners experience each activity, even if challenging. We have provided ways to adapt each step of the activities for students with different skill-levels. If any students have an Individualized Education Program (IEP), consult it for additional accommodations or modifications.

## 1. BEFORE YOUR VISIT

This part of the activity engages students in reading a non-fiction text about meteorites. The reading will prepare students for their visit by introducing them to the topic and framing their investigation.

**Student Reading**
Have students read "New Meteorite Suggests That Asteroid Surfaces More Complex Than Previously Thought." Have them write notes in the large right-hand margin. For example, they could underline key passages, paraphrase important information, or write down questions that they have.

Discussion Questions:

Ask:

- What are meteorites? *(A: Meteorites are space rocks that have fallen to Earth. Many meteorites are pieces of large space rocks, called asteroids.)*
- How can scientists use meteorites to learn about the solar system? *(A: Meteorites are samples of the early solar system. They contain information about stages in the formation and evolution of the solar system. Most meteorites are parts of distant objects, like asteroids, that scientists have not been able to visit directly.)*
- What questions are the scientists trying to answer in this article? *(A: The scientists in this article are trying to learn the answers to many "unsolved questions" such as the origins of life on Earth, the history of the solar system, and the nature of asteroids.)*

- What are the tools and techniques that scientists use to study meteorites? *(A: Scientists in this article detect meteorites even before they land on Earth, studying the speed and direction of objects that enter the atmosphere using devices like Doppler radar. Once meteorites land, scientists recover and study them further using instruments like CT scanners — powerful X-ray machines that can look inside of objects.)*

Students can work in pairs, small groups, or as a class. During discussion, remind them to use evidence from the text to explain their thinking, and to use specific examples, such as specific methods used by scientists to study newly discovered meteorites.

**SUPPORTS FOR DIVERSE LEARNERS: Student Reading**

- "Chunking" the reading can help keep them from becoming overwhelmed by the length of the text. Present them with only a few sentences or a single paragraph to read and discuss before moving on to the next "chunk."
- Provide "wait-time" for students after you ask a question. This will allow time for students to search for textual evidence or to more clearly formulate their thinking before they speak.

## 2. DURING YOUR VISIT

This part of the activity engages students in exploring the hall.

**Museum Visit & Student Worksheet**

Explain to students that they will be focusing on the formation and evolution of the solar system, and using worksheets to gather all the necessary information about specific meteorites. Tell the that back in the classroom they will refer to these notes when completing the writing assignment.

**SUPPORTS FOR DIVERSE LEARNERS: Museum Visit**

- Review the Student Worksheet with students, clarifying what information they should collect during the visit.
- Have students explore the hall in pairs, with each student completing their own Student Worksheet.
- Encourage student pairs to ask you or their peers for help locating sources of information. Tell students they may not share answers with other pairs, but they may point each other to places in the hall where answers may be found.

## 3. BACK IN THE CLASSROOM

This part of the activity is to engage students in an informational writing task that draws on the pre-visit reading and on observations made at the Museum.

**Writing Task**

Distribute the Student Writing Guidelines handout, which includes the following prompt for the writing task:

> Based on the article "New Meteorite Suggests That Asteroid Surfaces More Complex Than Previously Thought," your visit to the Arthur Ross Hall of Meteorites, and your discussions, write an essay in which you:
>
> - define the word "meteorite"
> - explain how meteorites tell the story of the formation and evolution of the solar system
> - include at least three labeled illustrations of meteorites
>
> Support your discussion with evidence from your reading and the Ross Hall of Meteorites.

Go over the handout with students. Tell them that they will use it while writing, and afterwards, to evaluate and revise their essays.

Before they begin to write, have students use the prompt and guidelines to frame a discussion around the information that they gathered in the Arthur Ross Hall of Meteorites, and compare their findings. They can work in pairs, small groups, or as a class. Referring to the writing prompt, have students underline or highlight all relevant passages and information from the reading, and their notes from the hall that can be used in their response to the prompt. Instruct each student to take notes on useful information that their peers gathered as they compare findings. Students should write their essays individually.

**SUPPORTS FOR DIVERSE LEARNERS: Writing Task**

- Re-read the "Before Your Visit" assignment with students. Ask what they saw in the hall that helps them understand meteorites.
- Allow time for students to read their essay drafts to a peer and receive feedback based on the Student Writing Guidelines.

## Student Reading

# December 20, 2012: New Meteorite Suggests That Asteroid Surfaces More Complex Than Previously Thought

### Scientists Around the World Work Together on Speedy Space Rock Analysis

A small asteroid — the name for a space rock larger than about 10 meters (33 feet) in diameter — entered the atmosphere over California and Nevada. This asteroid created a flash of light before shattering into many small pieces. The small pieces, called meteorites, fell to the ground where scientists were able to collect them. These meteorites — space rocks that have landed on Earth — are showing scientists just how complex an asteroid surface can be.

A new study published in *Science* this week by an international team of researchers describes the speedy recovery of the meteorites and reports that this space rock is an unusual example from a rare group known as carbonaceous chondrites, which contain some of the oldest material in the solar system. The study of these meteorites and others like them could hold answers to unsolved mysteries about the origin of life on Earth as they contain molecules such as water and amino acids.

"We found that this meteorite is a 'breccia,' a mixture of different rocks that accumulated at the surface of a larger asteroid, and those surfaces can be more diverse than we thought before," said co-author Denton Ebel, chair of the Division of Physical Sciences at the American Museum of Natural History.

About eight months ago, several Doppler weather radars detected a hail of rocks following a fireball traveling at a record-breaking 28.6 kilometers per second (about 64,000 miles per hour) over the Sierra Nevada in northern California. An immediate search-and-recover mission, led by NASA Ames Research Center, the SETI Institute, and the University of California, Davis, resulted in the retrieval of 77 meteorites. The fragments, which were in pristine shape despite entering the atmosphere at a speed twice as fast as a typical meteorite fall, were collectively called the Sutter's Mill meteorite after the nearby historical site that started the California Gold Rush.

"From the loud sonic boom, we quickly realized that this was an asteroid several meters in size, the biggest object to hit over land since the impact of asteroid 2008 TC3 in the north of Sudan in 2008," said lead author and meteor astronomer Peter Jenniskens of NASA Ames and SETI. "That asteroid proved to be a mixed bag of different types of meteorites, and we realized it would be very interesting to find out how diverse the Sutter's Mill meteorites were."

Several fragments were sent to laboratories around the world for simultaneous analysis of the meteorite's mineralogy and structure. The Sutter's Mill meteorite was classified as a CM chondrite, C standing for carbonaceous — high in carbon content — and M standing for the group's type specimen, the Mighei meteorite that fell in Ukraine in the late 1800s.

Ebel received five Sutter's Mill meteorites to study using x-ray computed tomography (CT), an imaging technique that takes pictures of the inside of a specimen without destroying it. The Museum's scanner takes more than 1,000 x-ray images of the object as it rotates inside of the machine. The data collected from these x-rays are then converted by computers to form a 3-D image of the specimen's interior, one slice at a time, to understand the components of the meteorite.

"In the same way that medical tomography, called CAT scanning, is used to image the interior of the human body, CT scanning in a research laboratory allows us to obtain images of the interiors of solid objects, but with a much higher resolution," Ebel said. "This is a fundamentally important tool not just for looking at rocks but for curating them and figuring out whether anything interesting is inside."

CT scans at the Museum, and at the University of California, Davis in an effort led by cosmochemist Qing-Zhu Yin, revealed that no two Sutter's Mill meteorites are the same. The meteorites contained angular pieces of different composition and density. They showed diversity on millimeter scale.

"This was the first time that a CM chondrite was found to be clearly a breccia," Yin said. "The rocky fragments came together following impacts on the parent asteroid, which implies that this meteorite originated from near its surface." Analyses performed using different techniques at other institutions were in agreement: the mineralogy and other geochemical features of these fragments are unexpectedly diverse and complex. This suggests that the surface of the asteroid that spawned the CM chondrites, their "parent body," is more complex than previously thought.

"This meteorite is special because it records many collisional processes and mixing that we, oddly, don't see very often," Ebel said. "Maybe the real question is 'why don't we see more of this?' It could be that most of the samples we've worked with in the past didn't hold up very well as they entered the atmosphere. Or that we're just seeing a small segment of what's really out there because we don't have meteorite records of what fell to Earth thousands or millions of years ago. We still have a lot of work to do to figure out what's really going on in the asteroid belt."

# Student Worksheet

Meteorites tell the story of the formation and evolution of the solar system. As you explore the Arthur Ross Hall of Meteorites, you will follow and record this story, which begins at the front of the hall, and continues clockwise along the outside wall. At each stop, you will be asked to read text and record information.

**Stop 1: Meteorites**

• Read the label that starts with "For thousands of years…"
• What is a meteorite? Why are meteorites useful to scientists?

**Stop 2: Origins of the Solar System**

• Read the label that starts with "The blue-white fireball streaked across the dark skies…"
• Record the Allende meteorite in your data table.
• What does Allende tells us about the early solar system? Why is it so important?

**Stop 3: Chondrules: Drops of Fiery Rain**

• Read the label that starts with "When our solar system began to take shape…"
• What is a chondrite?

• What is a chondrule?

**Stop 4: CAIs: The Oldest Rocks**

• Read the label that starts with "A solar system such as our own begins when…"
• How did the early solar system change over time?

• What is a CAI?

• Look at the meteorite sample of Allende. Describe the CAIs that you find.

**Stop 5: Parent Bodies: A Meteorite Family Tree**

- Read the label that starts with "In just a few thousand years..."
- What does it mean to say that meteorites come from "parent bodies?"

- Continue reading "Meet the parents" found inside the plastic display case.
- How do scientists tell meteorites apart? What kinds of things do they measure?

**Stop 6: Planetesimals: Building Blocks of the Solar System**

- Read the label that starts with "The small particles..."
- How did giant planets grow from tiny dust particles?

- Find the meteorite called Paragould and record it in your data table.
- What evidence of impacts does this meteorite contain?

**Stop 7: Building Planets**

- Read the label that starts with "The farmland near..."
- How is the Brenham meteorite different from all the others you have seen so far?

- Record the Brenham meteorite in your data table.

**Stop 8: Crust**

- Read the label that starts with "As the solar system formed..."
- What kinds of solar system bodies developed a crust? Describe how a large solar system body separates into a core, mantle, and crust.

- Find the Johnstown meteorite and record it in your data table.

**Stop 9: Mantle: Jewels from Space**

- Read the label inside the plastic display case that starts with "When newly formed..."
- What part of a planetary body is the mantle?

- Find the Esquel meteorite and record it in your data table.

**Stop 10: Core: Iron from Asteroids**

- Read the label in the plastic display case that starts with "Most iron meteorites..."
- What part of a parent body do metallic meteorites come from?

- Find the Bella Roca meteorite and record it in your data table.

**Stop 11: Cape York**

- At the center of the hall there is a large piece of the Cape York meteorite. This piece is sometimes called Ahnighito. Record this meteorite in your data table.
- What type of material is this meteorite made from?

- What does the composition of this meteorite tell scientists about its parent body?

- Could this meteorite have formed in the very early solar system? Explain:

# Data Table

| Name of meteorite | Date and location recovered | Sketch of meteorite | Useful information |
|---|---|---|---|
| Allende | | | |
| Paragould | | | |
| Brenham | | | |
| Johnstown | | | |
| Esquel | | | |
| Bella Roca | | | |
| Cape York (Ahnighito) | | | |

# ANSWER KEY

# Student Worksheet

Meteorites tell the story of the formation and evolution of the solar system. As you explore the Arthur Ross Hall of Meteorites, you will follow and record this story, which begins at the front of the hall, and continues clockwise along the outside wall. At each stop, you will be asked to read text and record information.

**Stop 1: Meteorites**
• Read the label that starts with "For thousands of years..."
• What is a meteorite? Why are meteorites useful to scientists?

*(Meteorites are rocks from space that have landed on Earth. Scientists use meteorites to learn about the formation and evolution of the solar system.)*

**Stop 2: Origins of the Solar System**
• Read the label that starts with "The blue-white fireball streaked across the dark skies..."
• Record the Allende meteorite in your data table.
• What does Allende tells us about the early solar system? Why is it so important?

*(Allende is one of the oldest meteorites ever recovered. It tells scientists that the solar system is about 4.57 billion years old. Allende also tells scientists about the chemical makeup of the early solar system.)*

**Stop 3: Chondrules: Drops of Fiery Rain**
• Read the label that starts with "When our solar system began to take shape..."
• What is a chondrite?

*(Chondrites are extremely old meteorites that have not changed much since the early solar system.)*

• What is a chondrule?

*(Chondrules are small pieces of partially melted rock that are found inside of some chondrites.)*

**Stop 4: CAIs: The Oldest Rocks**
• Read the label that starts with "A solar system such as our own begins when..."
• How did the early solar system change over time?

*(The early solar system was full of debris left over from the pre-solar nebula, a collection of gas and dust. This debris formed a disk around the young Sun, and most of these particles were small. Today, there is much less debris in orbit around the Sun, and eight large planets and several other large bodies contain most of the mass that is not in the Sun.)*

• What is a CAI?
*(CAIs are Calcium-Aluminum Inclusions. These are small particles that formed 4.567 billion years ago in the very early solar system. They tell us that a meteorite is extremely old.)*

• Look at the meteorite sample of Allende. Describe the CAIs that you find.

*(Allende has several CAIs inside of it, including a large round one. These CAIs are grey in color.)*

# ANSWER KEY

**Stop 5: Parent Bodies: A Meteorite Family Tree**

• Read the label that starts with "In just a few thousand years…"
• What does it mean to say that meteorites come from "parent bodies?"

*(A parent body is a larger object. When it is shattered in a collision, it releases many smaller objects into space. Meteorites that formed together in a larger "parent body" share unique properties.)*

• Continue reading "Meet the parents" found inside the plastic display case.
• How do scientists tell meteorites apart? What kinds of things do they measure?

*(The chemical composition of a meteorite helps scientists better understand where it fits in and how it formed. Sometimes scientists look at the ratios between different elements to classify meteorites.)*

**Stop 6: Planetesimals: Building Blocks of the Solar System**

• Read the label that starts with "The small particles…"
• How did giant planets grow from tiny dust particles?
*(Frequent collisions in the early solar system helped smaller objects combine into larger objects. Once these objects grew large enough, their gravitational pull attracted material around them, greatly increasing their rate of growth.)*

• Find the meteorite called Paragould and record it in your data table.
• What evidence of impacts does this meteorite contain?
(*The meteorite Paragould contains fragments of rock that have been broken and cemented together by pressure and heat from impacts.)*

**Stop 7: Building Planets**

• Read the label that starts with "The farmland near…"
• How is the Brenham meteorite different from all the others you have seen so far?

*(This meteorite has a large amount of pure metal in it. The others were mostly stone.)*

• Record the Brenham meteorite in your data table.

**Stop 8: Crust**

• Read the label that starts with "As the solar system formed…"
• What kinds of solar system bodies developed a crust? Describe how a large solar system body separates into a core, mantle, and crust.

*(Only large parent bodies developed a crust, which formed when the lightest material floated towards the outside. When large solar system bodies were young, they were also extremely hot. This allowed dense materials to sink towards the center forming a dense core, and lighter rock to slowly move upwards forming the mantle and crust.)*

• Find the Johnstown meteorite and record it in your data table.

# ANSWER KEY

**Stop 9: Mantle: Jewels from Space**

• Read the label inside the plastic display case that starts with "When newly formed…"
• What part of a planetary body is the mantle?

*(The central part of a parent body is the mantle, which formed between the lightest and densest materials. It is a region of medium density.)*

• Find the Esquel meteorite and record it in your data table.

**Stop 10: Core: Iron from Asteroids**

• Read the label in the plastic display case that starts with "Most iron meteorites…"
• What part of a parent body do metallic meteorites come from?

*(Metallic meteorites come from the cores of large parent bodies that later shattered. Only a large, molten body with strong gravity could separate metals like iron and nickel from other lighter rocks.)*

• Find the Bella Roca meteorite and record it in your data table.

**Stop 11: Cape York**

• At the center of the hall there is a large piece of the Cape York meteorite. This piece is sometimes called Ahnighito. Record this meteorite in your data table.
• What type of material is this meteorite made from?
*(Cape York was formed in a large parent body because it is almost pure metal, and must have formed in an environment with a great deal of heat and gravity.)*

• What does the composition of this meteorite tell scientists about its parent body?
*(This is part of the core of a large object that shattered as a result of an impact, releasing many smaller pieces into space. Although the parent body is gone, scientists can still learn about it by recovering these pieces if they land on Earth.)*

• Could this meteorite have formed in the very early solar system? Explain:
*(This type of meteorite could not have formed in the very early solar system because it is the product of a great deal of processing over time.)*

ANSWER KEY

# Data Table

| Name of meteorite | Date and location recovered | Sketch of meteorite | Useful information |
|---|---|---|---|
| Allende | *(1969 Pueblito de Allende, Mexico)* | | *(Oldest meteorite known, gives chemical composition of the early solar system.)* |
| Paragould | *(1930 Greene County, Arkansas)* | | *(Contains rocks shattered and heated by impacts, these pieces were cemented together again by melted rock.)* |
| Brenham | *(1933 Brenham, Kansas)* | | *(A mix of metal and rock, this meteorite slice is partially transparent. This meteorite probably comes from the boundary between the core and mantle.)* |
| Johnstown | *(1924 Weld County, Colorado)* | | *(Large crystals inside this rocky meteorite, this is crust material from a large object, possibly the asteroid Vesta.)* |
| Esquel | *(1951 Chubut, Argentina)* | | *(This meteorite shows evidence of liquid metal moving among and between crystals of stone. This is also from the boundary between the core and mantle.)* |
| Bella Roca | *(1888 Durango, Mexico)* | | *(This all-metal meteorite contains many crystals. This meteorite comes from the core of a large solar system object. There is a nodule of sulfur that got pushed aside by growing crystals of iron.)* |
| Cape York (Ahnighito) | *(Greenland)* | | *(This is the largest meteorite on display in any museum. It weighs about 34 tons. This meteorite is almost all metal, mostly iron. This means it formed in the core of a large solar system body.)* |

# Student Writing Guidelines

Based on the article "New Meteorite Suggests That Asteroid Surfaces More Complex Than Previously Thought," your visit to the Arthur Ross Hall of Meteorites, and your discussions, write an essay in which you:

• define the word "meteorite"
• explain how meteorites tell the story of the formation and evolution of the solar system
• include at least three labeled illustrations of meteorites

Support your discussion with evidence from your reading and the Ross Hall of Meteorites.

**Use this checklist to ensure that you have included all of the required elements in your essay.**

- ☐ I introduced meteorites.
- ☐ I defined the word "meteorite."
- ☐ I clearly named at least three meteorite specimens and described how they help scientists understand the formation and evolution of the solar system.
- ☐ I included a labeled illustration of at least three meteorites.
- ☐ I only included relevant information about meteorites and the solar system.
- ☐ I used information from the "New Meteorite Suggests That Asteroid Surfaces More Complex Than Previously Thought" to explain meteorites and the formation and evolution of the solar system in detail.
- ☐ I used information from the Ross Hall of Meteorites to explain meteorites and the formation and evolution of the solar system in detail.
- ☐ I used academic, non-conversational tone and language.
- ☐ I included a conclusion at the end.
- ☐ I proofread my essay for grammar and spelling errors.

# Assessment Rubric

| | Scoring Elements | 1 Below Expectations | 2 Approaches Expectations | 3 Meets Expectations | 4 Exceeds Expectations |
|---|---|---|---|---|---|
| RESEARCH | **Reading** | Attempts to present information in response to the prompt, but lacks connections to the texts or relevance to the purpose of the prompt. | Presents information from the text relevant to the purpose of the prompt with minor lapses in accuracy or completeness. | Presents information from the text relevant to the prompt with accuracy and sufficient detail. | Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the text. |
| | **AMNH Exhibit** | Attempts to present information in response to the prompt, but lacks connections to the Museum exhibit content or relevance to the purpose of the prompt. | Presents information from the Museum exhibit relevant to the purpose of the prompt with minor lapses in accuracy or completeness. | Presents information from the Museum exhibit relevant to the prompt with accuracy and sufficient detail. | Accurately presents information relevant to all parts of the prompt with effective paraphrased details from the Museum exhibit. |
| WRITING | **Focus** | Attempts to address the prompt, but lacks focus or is off-task. | Addresses the prompt appropriately, but with a weak or uneven focus. | Addresses the prompt appropriately and maintains a clear, steady focus. | Addresses all aspects of the prompt appropriately and maintains a strongly developed focus. |
| | **Development** | Attempts to provide details in response to the prompt, including retelling, but lacks sufficient development or relevancy. | Presents appropriate details to support the focus and controlling idea. | Presents appropriate and sufficient details to support the focus and controlling idea. | Presents thorough and detailed information to strongly support the focus and controlling idea. |
| | **Conventions** | Attempts to demonstrate standard English conventions, but lacks cohesion and control of grammar, usage, and mechanics. | Demonstrates an uneven command of standard English conventions and cohesion. Uses language and tone with some inaccurate, inappropriate, or uneven features. | Demonstrates a command of standard English conventions and cohesion, with few errors. Response includes language and tone appropriate to the purpose and specific requirements of the prompt. | Demonstrates and maintains a well-developed command of standard English conventions and cohesion, with few errors. Response includes language and tone consistently appropriate to the purpose and specific requirements of the prompt. |
| SCIENCE | **Content Understanding** | Attempts to include science content in explanations, but understanding of the topic is weak; content is irrelevant, inappropriate, or inaccurate. | Briefly notes science content relevant to the prompt; shows basic or uneven understanding of the topic; minor errors in explanation. | Accurately presents science content relevant to the prompt with sufficient explanations that demonstrate understanding of the topic. | Integrates relevant and accurate science content with thorough explanations that demonstrate in-depth understanding of the topic. |