Credit: https://www.lpi.usra.edu/education/explore/planetary-defense/space_rocks/

Explore! Planetary Defenders

Space Rocks!
A Meteorite Board Game

Overview

Players assume the roles of meteorites and play a giant board game to learn about meteors, meteoroids, and meteorites. They compete to get to Antarctica, where they have the chance to be found and studies by scientists! The game can be played as a whole group activity, in teams, or by individuals.

Ages: 3rd grade and up

Duration: 15 – 45 minutes

What's the Point?

Participants will:

- Learn about meteorites and how we discover them.
- Discover that the odds of a meteorite landing on Earth and being discovered are low.
- Have fun!

Materials

- Space Rocks game board (one per each group of players)
- Game Pieces (use pebbles or game pieces from other games)
- Game Cards (or powerpoint questions, computer, and projector)
- Information about Space Rocks for facilitator (below)
- Background Information about Planetary Defense

- Background Information about Planetary Defense
- Dice
- Optional Supporting Videos:
    - History Channel – The Secrets of Meteorites. http://www.history.com/shows/how-the-earth-was-made/videos/the-secrets-of-meteorites
    - PBS NOVA – Hunting for Meteorites. http://www.pbs.org/wgbh/nova/space/matson-meteorite.html
- Optional Supporting Websites
    - NASA's Solar System Exploration – Meteors and Meteorites. https://solarsystem.nasa.gov/asteroids-comets-and-meteors
    - Killer Asteroids. http://www.killerasteroids.org
    - NASA Goddard Scientific Visualization Studio – Asteroids. http://svs.gsfc.nasa.gov/search/Keyword/Asteroid.html

Preparation

- Print the Space Rocks game board; if possible, laminate or glue to poster board
- Determine whether you will project the questions from a computer or use physical cards. If using cards, print and cut apart the Space Rocks! Game Cards. (Laminating the cards will increase their durability)

Activity

1. Welcome and introduce the topic. Ask participants what they know about meteorites. After participants have shared and compared their thoughts, share some background:

- Meteorites are blown off the surface of their parent body by an impact and eventually land on the surface of another moon or planet.
- Most meteorites come from asteroids, such as the large asteroid Vesta.
- While they are moving through space, these rocks are known as meteoroids.
- While they pass through the Earth's atmosphere, they create a streak of light called a meteor.
- Most meteoroids are small and burn up in Earth's atmosphere.
- Many meteorites land in the ocean or other locations where they are never discovered.
- On Earth, we have found meteorites from the Moon, Mars, and asteroids.

Describe the game: they will be playing individually or in teams to move their rock from a parent body (the Moon, Mars, Vesta, or Bennu) to Earth; their goal is to land their rock on Antarctica where it has a larger chance of being discovered.

2. Set up the game. Place the game board in the center of each group of players and place the cards (question-side down) nearby. If more than 4 participants are playing, either conduct multiple games or invite them to play as teams. Invite each player or team to select their "meteoroid" game piece to move about the game board, starting from one of the four corners (parent bodies): Moon, Mars, Vesta, or Bennu.

3. Rules of the game. Make sure that everyone understands the game and their role in it before proceeding to play. Reassure them that they can ask for your help in the process, if needed, as the game is played.

- The players or teams will move from their parent body (Moon, Mars, Vesta, or Bennu) in toward the Earth. The first player or team to land in Antarctica and correctly answer a final question **wins**.
- Whether they can move forward depends on both what they roll on the dice and whether they can answer a card question correctly. If they don't roll the correct number or answer the question correctly, they need to stay in the same spot until it's their turn again.
- If a group is playing together as a single team, then all can help to answer the questions.
- More information about the correct answers is available on a cheat sheet that the facilitator can use to explain the answers, or that the players can review after the game.

4. Game Instructions.

- Roll a die to determine which player or team will go first. The player or team with the highest number will begin the game. Play always passes to the player on the left. The rules for their play **depends** on which zone their piece is in.

Leaving the Parent Body (Moon, Mars, Vesta, or Bennu)

- The first player or team rolls a die. If they roll an odd number, their turn ends. If the player rolls an even number, then an impact has occurred, which may blow your rock into space to become a meteoroid. Another player picks a card and reads the question aloud for the active player to answer. If they answer correctly, they can move forward to the Meteoroid Zone before their turn ends.
- The die passes to the player or team on the left; again, they need to roll an even number and then answer a card question correctly to move forward to the next zone. If player answers the question incorrectly, they will remain in their current position and pass the die.
- Continue passing the die to the left.

The Meteoroid Zone: Once in the meteoroid zone, a player needs to roll a 5 or a 6 to approach Earth. If they roll 1 -4, their turn ends. If the player *rolls a 5 or a 6*, then their space rock is approaching Earth. Another player picks a card and reads the question aloud for the active player to answer. If they answer correctly, they can move forward to the Meteor Zone before their turn ends.

The Meteor Zone: Once in the meteor zone, a player needs to roll an odd number to land on Earth. If they roll an even number, their turn ends. If the player *rolls an odd number*, and answers a question correctly, they can move forward to the Meteorite Zone before their turn

ends.

The Meteorite Zone: Once in the meteorite zone, a player needs to roll a 1 to determine whether they landed in Antarctica, where they are more likely to be discovered by scientists. If they roll 2-6, their turn ends. If the player *rolls a 1*, and answers a question correctly, they land in Antarctica and win.

Conclusion

Discuss how unlikely it is for a rock to be blown off another object and land somewhere on Earth where it can be found and studied. And yet hundreds or thousands are found each year!

Background Information

Additional details and background information about the questions for the game facilitator.

What is a meteor/ what is a meteorite / What is a shooting star/ What is a meteoroid?
Meteoroids are often small particles — often no bigger than a grain of sand — that orbit our Sun. When meteoroids enter Earth's atmosphere, they produce brilliant streaks of light that can be seen in our sky. These brief streaks of light (often called "shooting stars") are meteors. Meteorites are rocks from space that have landed on Earth's — or another planet's — surface.

Why does a meteor glow? Which object does not have meteors?
A meteor is the streak of light we see in the sky as a meteoroid passes through our atmosphere; however, most of the meteoroids are very small—the size of a grain of sand. We

don't actually see the meteoroid. Instead, we are seeing the air itself glowing as it is ionized from the heat of the meteoroid speeding through it.

Since meteors are the glowing gases as a meteoroid passes through an atmosphere, objects without an atmosphere (like the Moon) do not have meteors. However, meteors may have occurred on Moon about 3.5 billion years ago, when it was surrounded by a temporary atmosphere.

How fast does a meteoroid move in our atmosphere?
Meteoroids are moving incredibly fast (around 50 thousand miles per hour) as they orbit the Sun; our Earth runs into them.

What are the different types of meteorites? What do most meteorites look like?
Most meteorites found on Earth are pebble to fist size, but some are larger than a building. Meteorites may look very much like Earth rocks, or they may have a burned exterior. Some may have depressioned (thumbprint-like), roughened, or smooth exteriors. This fusion crust is formed as the meteorite is melted by friction as it passes through the atmosphere.

Scientists classify meteorites into three groups: stony meteorites, iron meteorites, and stony iron meteorites. Stony meteorites make up about 95% of the meteorites reaching Earth. Iron meteorites make up about 5% of the meteorites found on Earth; these come from the cores of shattered planetary bodies (often from a shattered asteroid). These have high amounts of iron and nickel. Stony-iron meteorites are in between the other two types of meteorites. These are rare — only about 1% of the meteorite finds on Earth are stony iron meteorites.

What causes meteor showers/ Which is a meteor shower?
Meteor showers occur when Earth passes through the trail of dust and gas left by a comet along its elliptical orbit. The particles enter Earth's atmosphere and most burn up. Some meteor showers, such as the Perseids in August and the Geminids in December, occur annually when Earth's orbit takes it through the debris path left along the comet's orbit. Comet Halley's trails are responsible for the Orionids meteor shower.

What is an asteroid? Which is not an asteroid? Asteroid features.
Asteroids are rocky bodies ranging from 620 miles (1000 km) wide down to dozens of meters, which orbit our Sun or another asteroid. Ceres is the largest of the asteroids, and Vesta is the second largest. Bennu is an asteroid that the OSIRIS-REx mission is studying.

Most asteroids are irregularly shaped and all have craters from impacts with other asteroids. However, the largest asteroid, Ceres, has sufficient gravity to become nearly spherical, so it is also classified as a dwarf planet! Vesta, another large asteroid, has evidence of ancient lava flows on its surface. Asteroids usually have extensive cratering on the surface. Some asteroids, such as Ceres, have large amounts of ice. Asteroids are too small to have an atmosphere, so they cannot have storms.

What are the types of asteroids?
Asteroids are classified by their composition. Most of the known asteroids (over 75%) are C-type (carbon-rich) asteroids, located in the outer region of the main asteroid belt. These asteroids are usually composed of organic compounds and hydrated minerals. Stony or silicate-rich (S-type) asteroids dominate the inner part of the asteroid belt, closest to the Sun. These asteroids are composed of rocky materials and small amounts of metallic iron. M-type (metallic) asteroids are predominantly metallic iron and nickel.

Where do most meteorites come from?
Meteorites are ejected from a rocky body by an impact by an asteroid or comet. More than 50,000 meteorites have been found on Earth. Most come from asteroids; in particular, several different types of meteorites appear to be from the asteroid Vesta. A few meteorites originate from the Moon and Mars. Meteorites also fall on other solar system bodies. The Mars Exploration Rover, Opportunity, has discovered six meteorites during its travels on Mars.

What makes an impact crater?
Craters are roughly circular, excavated holes made by impact events. When an asteroid or comet strikes the solid surface of a planet, a shock wave spreads out from the impact, creating a crater much bigger than the asteroid or comet. The asteroid or comet is shattered into small pieces and may melt or vaporize.

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How long have asteroids been hitting the planets? Do large or small asteroids hit the Earth more frequently?
Early in the formation of the solar system (4.5 billion years ago), frequent and large impacts were common for all of the planets and moons. Impacts still occur across our solar system, but at a reduced rate. Scientists estimate that Earth and the other terrestrial planets are struck by, on average, five asteroids less than 2 kilometers (a little over 1 mile) across every million years. Larger impacts also still occur, but are more rare.

Which is hit by the smallest particles from asteroids and comets?
The Moon does not have an atmosphere to shield the surface from small particles; Earth, Venus, and Mars have atmospheres that burn up the smallest particles from asteroids and comets.

Which does an asteroid hit the fastest?
Asteroids orbit the Sun at high speeds. When asteroids approach a massive planet, the gravity of that planet pulls them faster. Asteroids hit Earth at a faster speed because the Earth's gravity is greater than the Moon's or Mars'.

Where did an impact cause a mass extinction?
An asteroid or comet caused a mass extinction on Earth about 66 million years ago, extinguishing dinosaurs and most other life. None of the other planets are known to have any life.

Which hits the Earth most frequently?
Asteroids hit Earth more frequently. Most asteroids follow simple orbits between the planets Mars and Jupiter, in planes close to Earth's (the ecliptic). Comets follow highly elongated orbits around the Sun, which carry them high above and below Earth's orbit, making them less likely to impact Earth.

Which asteroid is the OSIRIS REx mission orbiting?
In 2020, this mission continues to orbit the small asteroid Bennu; it will collect a sample of the asteroid to return to Earth for study.

On Earth, where and when do meteorites fall?
Meteorites fall everywhere on Earth, all the time. They are easier to find in areas with less vegetation like deserts. Scientists travel to Antarctica annually to collect meteorites from bases of mountain ranges where glaciers deposit them.

Names of meteorites:
Meteorites can be named after the places where they are found. For instance, the largest carbonaceous chondrite ever found on Earth, Allende is named after a village in northern Mexico called Pueblito de Allende, where it fell in 1969. Meteorites found in Northwest Africa start with NWA in their names followed by a specific number for each meteorite. Shergotty is a meteorite that was found in Shergotty, India. Later this was identified as a type of Mars meteorite, and the related group of meteorites were named Shergottites.

Mars meteorites:
Are ejected from the surface during an impact on Mars, if they are thrown faster than 3 miles per second. They have gases embedded in the meteorites that match the composition of the Martian atmosphere. By 2019, scientists had identified 224 meteorites from Mars. The oldest Mars meteorites were formed on the surface of Mars over 4 billion years ago, but spend much less time in space before landing on Earth; for instance, Dhofar 019 spent 20 million years in space.

Lunar meteorites:
Meteorites from the Moon can also be called Lunaites. These are ejected from the surface during an impact on the Moon (on all sides of the Moon), if they are thrown faster than 1.5 miles per second. Scientists first identified a meteorite as from the Moon in 1981; by 2019, scientists had identified about 400 meteorites from the Moon that had landed on Earth. None of the lunar meteorites was seen falling as a meteor, and none have been found in North America.

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Space Exploration

Explore! Warding our World: Planetary Defense

About Planetary Defense

The asteroid Gaspra as seen by the Galileo spacecraft en route to Jupiter. Credit: NASA.

NASA scientists and engineers are studying asteroids and comets, and the effects of impacts on planets and moons. NASA's Planetary Defense Coordination Office is researching technologies and techniques for deflecting asteroids away from Earth, and coordinating with other government agencies to develop a plan to address these issues.

Collisions are one of the most important processes throughout our solar system. Today, Earth encounters many bits of ice and rock—asteroids, comets, and meteoroids. Most meteoroids burn up in the atmosphere as meteors. Some chunks make it to Earth's surface as meteorites. Larger rocks capable of damage to people or cities are rare. Currently, no known asteroids are predicted to collide with our world.

Early in the formation of the solar system, frequent and large impacts were common. These impacts left scars – gouges and craters. Many of the objects in the solar system bear those ancient scars to this day. Our Earth-Moon system formed after the impact of the early proto-Earth with another planet half of Earth's width. The huge northern lowlands of Mars may be the result of impacts – or possibly one incredibly large impact!

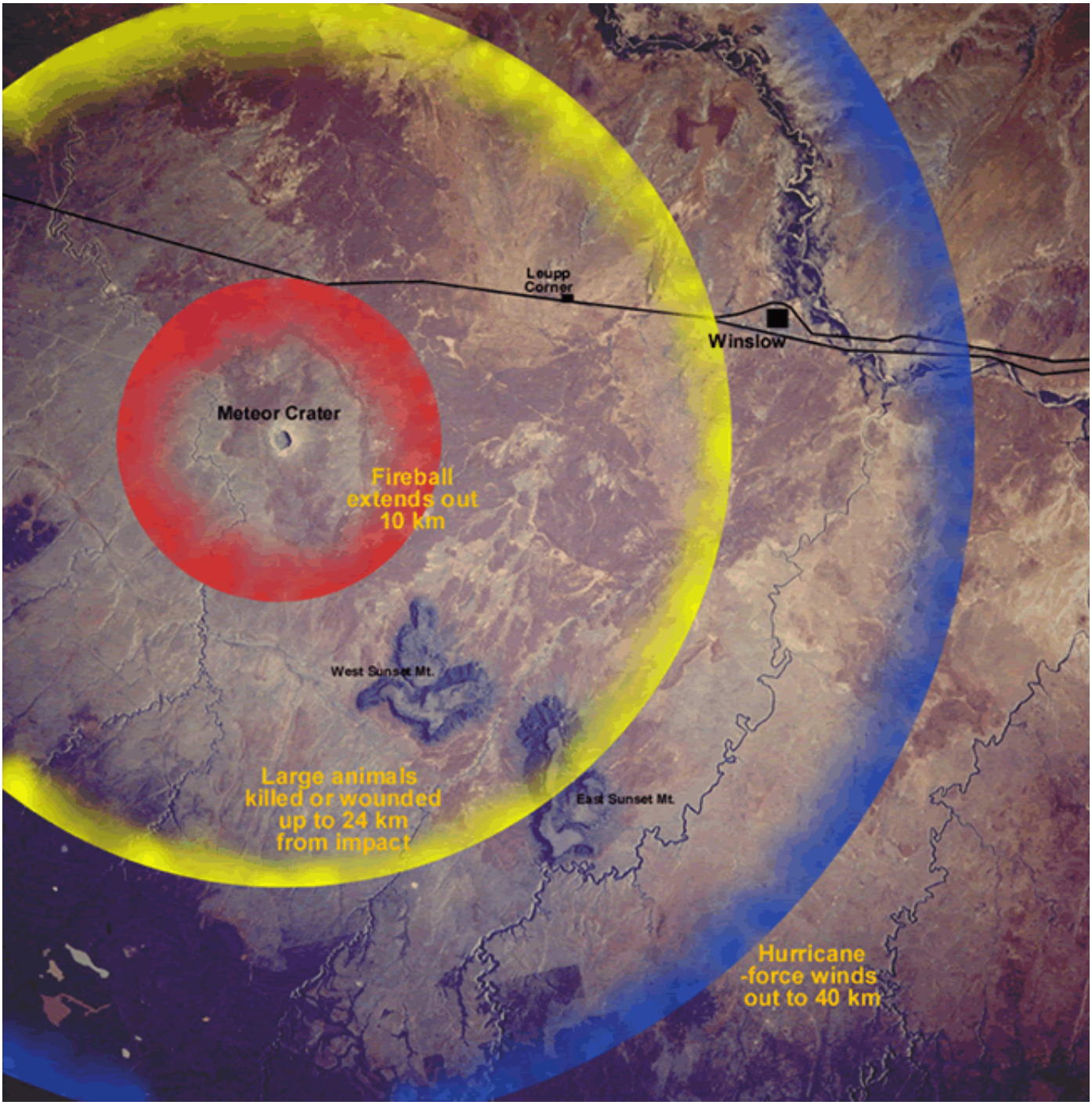
This "heavy bombardment" period ended around 3.9 billion years ago. However, impacts still occur, at a reduced rate, and Earth continues to be a target. Scientists estimate that Earth and the other terrestrial planets are struck every million years by an average of five small asteroids (less than 2 kilometers wide). Larger impacts occur less frequently.

NASA is searching for and examining potentially hazardous asteroids and comets. Near-Earth Objects (NEOs) are those whose orbits bring them close to Earth. Large NEOs with orbits that cross Earth's are considered potentially hazardous objects. The space near Earth is dominated by asteroids: scientists think millions of near-Earth asteroids may exist, but only about 20,000 have been discovered so far, and just a hundred near-Earth comets have been found.

Earth Impacts

Although many of the craters on Earth are no longer visible, it has actually been rocked by 13 to 20 times more impacts than our Moon!

Fifty thousand years ago, an iron asteroid struck what is today Arizona. The resulting impact crater, called Barringer (or Meteor) Crater, is still visible today. The relatively small 30 meter-wide (100 foot) asteroid that created this crater erased the vegetation over an area of the size of Los Angeles or Houston! Impacts this size occur once every few thousand years on Earth.



The environmental effects of the impact of the iron asteroid that formed Meteor Crater. Credit: University of Arizona/ LPL/David A. Kring

An asteroid impact with Earth's surface can cause significant damage:

- A fireball would extend up to 6 miles (10 km) from the impact site (red circle)
- The impact shock wave would injure or kill animals up to 15 miles (24 km) (yellow circle)
- Hurricane-force winds would be felt as far away as 25 miles (40 km) (blue circle)

Asteroids and comets can also explode in the air. More common than impacts, airbursts can strike once every hundred years or so. The explosions generate shockwaves with energies greater than World War II-era atomic bombs. Such an airburst leveled 800 square miles of forest in Siberia in 1908. A smaller airburst exploded above Chelyabinsk, Russia on February 15, 2013, knocking people off their feet, crumbling walls, and shattering windows.

Planetary Defense

Scientists are examining asteroids' characteristics and searching for those whose orbits may eventually intersect Earth. Radio observatories like the Arecibo Observatory in Puerto Rico use radio waves (radar) to determine an asteroid's distance from Earth, its orbit, size, and how quickly it spins. Planetary scientists study impact craters on Earth and other bodies, and meteoritic samples of near-Earth asteroids that have fallen to Earth.

Planetary missions are analyzing the damage produced by impact cratering on asteroids themselves, and comparing the types and compositions asteroids. Impacts can alter the structure of an asteroid; some are solid throughout while others are loose collections of rubble. Understanding the structure of asteroids will help scientists and engineers create solutions to remove potential, future threats of impact.

Planetary defense research is critical to our assessment of future impact hazards and for developing spacecraft missions that will assist us in protecting our home.

Additional information about impact craters.
Additional information about asteroids, comets, and meteoroids

Other sites:

NASA's Planetary Defense Website

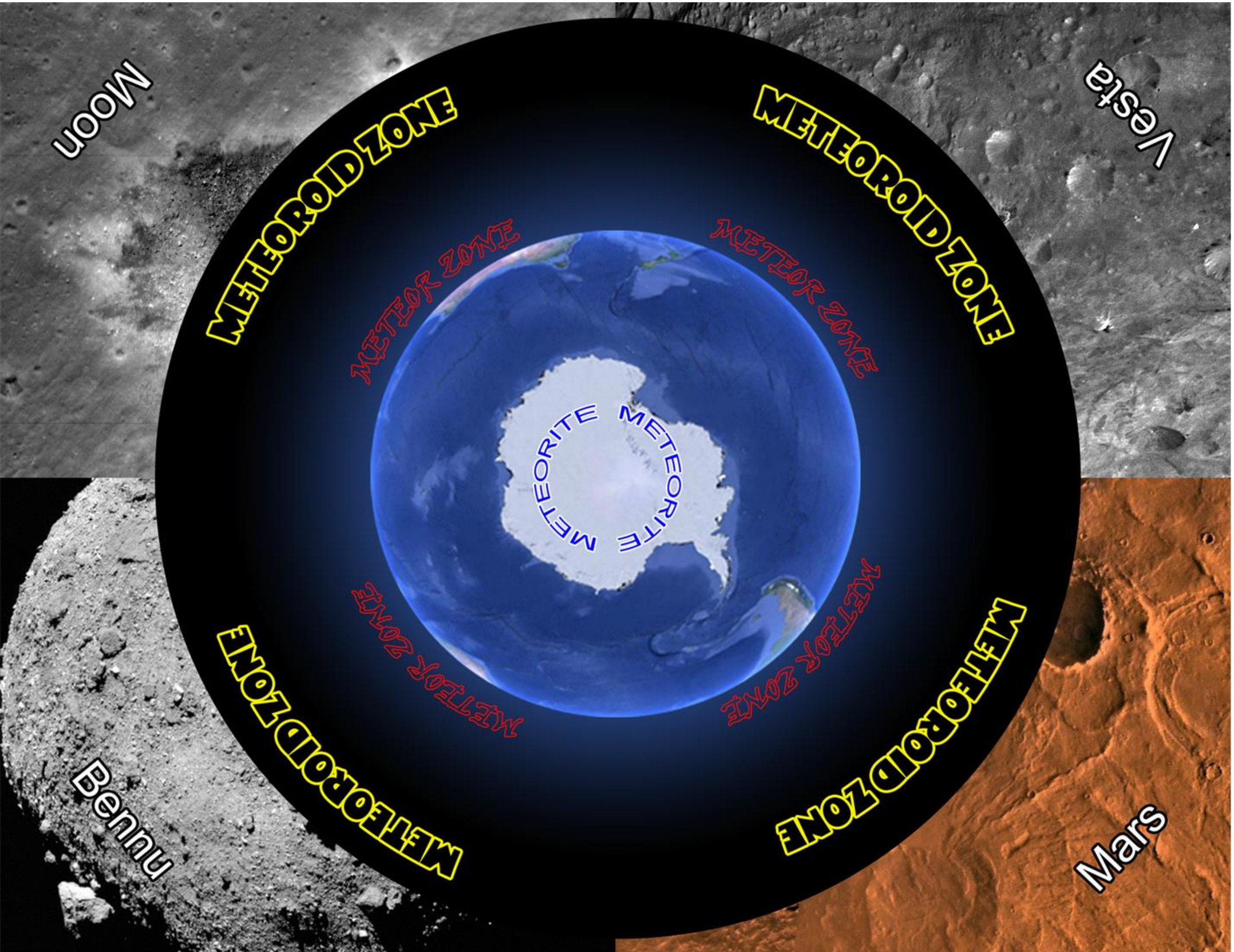
Killer Asteroids

Solar System Exploration: Asteroids

Center for Lunar Science and Exploration:

- Traveling Exhibits:
- Illustrations: Asteroids and Comets

Terrestrial Impact Craters and their Environmental Effects



Space Rocks!
Game Instructions

Roll a die to determine which player or team will go first. Play always passes to the player on the left. The rules for play depends on which zone their piece is in.

Leaving the Parent Body (Moon, Mars, Vesta, or Bennu)
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The Meteoroid Zone: Once in the meteoroid zone, a player needs to roll a 5 or a 6 to approach Earth. If they roll 1 -4, their turn ends. If the player *rolls a 5 or a 6*, then their space rock is approaching Earth. Another player picks a card and reads the question aloud for the active player to answer. If they answer correctly, they can move forward to the Meteor Zone before their turn ends.

The Meteor Zone: Once in the meteor zone, a player needs to roll an odd number to land on Earth. If they roll an even number, their turn ends. If the player *rolls an odd number*, and answers a question correctly, they can move forward to the Meteorite Zone before their turn ends.

The Meteorite Zone: Once in the meteorite zone, a player needs to roll a 1 to determine whether they landed in Antarctica, where they are more likely to be discovered by scientists. If they roll 2-6, their turn ends. If the player r*olls a 1*, and answers a question correctly, they land in Antarctica and win.

Space Rocks! Rules

The rules for their play depends on which zone their piece is in.

Leaving the Parent Body Roll an even number and answer a question correctly to move to the Meteoroid Zone.

The Meteoroid Zone: Roll a 5 or a 6, and answer a question correctly to move to the Meteor Zone.

The Meteor Zone: Roll an odd number, and answer a question correctly to move to the Meteorite Zone,

The Meteorite Zone: Roll a 1 and answer a question correctly to land in Antarctica and win.

Which is hit the most by the smallest particles from asteroids and comets?

A. Earth

B. The Moon

C. Mars

Answer: B

Which does an asteroid hit the fastest?

A. Earth

B. The Moon

C. Mars

Answer: A

Where did an impact cause a mass extinction?

A. Earth

B. The Moon

C. Mars

Answer: A

How long have asteroids been hitting the planets?

A. 10 thousands years

B. 5 million years

C. 4.5 billion years

Answer: C

Which hits the Earth most frequently?

A. Comets

B. Asteroids

C. Both hit the Earth at the same rate.

Answer: B

We have not found meteorites on Earth from

A. The Moon

B. Mars

C. Venus

Answer: C

Which does not have meteors?

A. The Moon

B. Mars

C. Earth

Answer: A

On Earth, where do meteorites fall?

A. North America

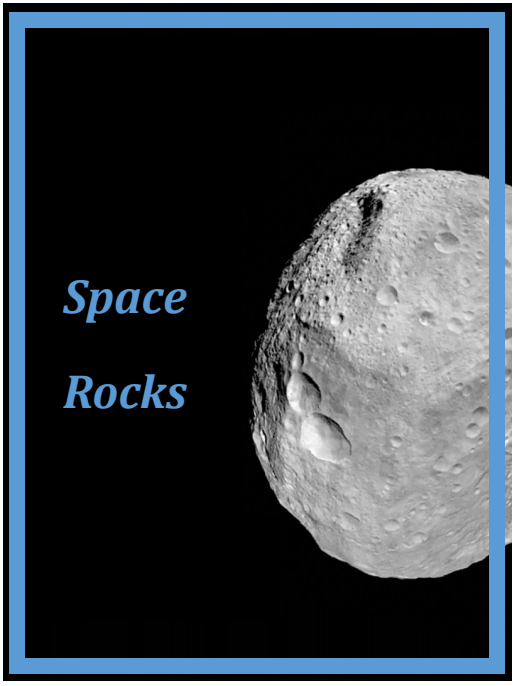
B. Antarctica

C. Everywhere

Answer: C

Space

Rocks



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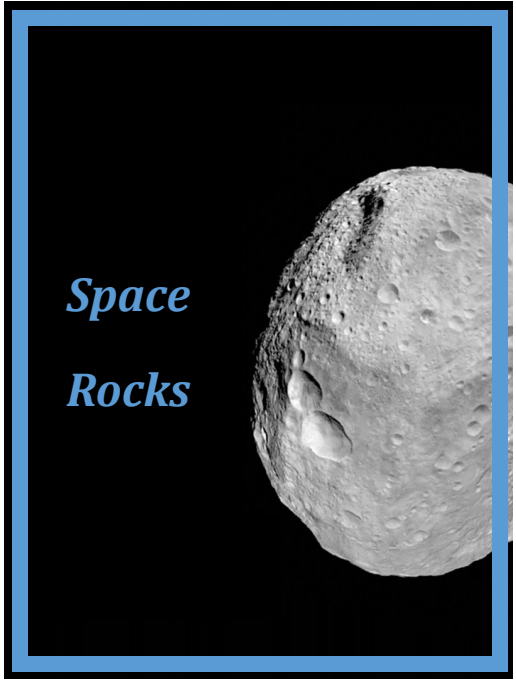

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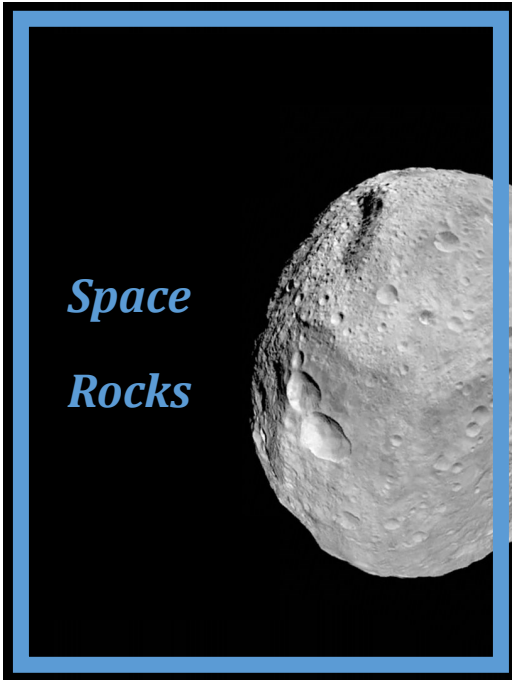

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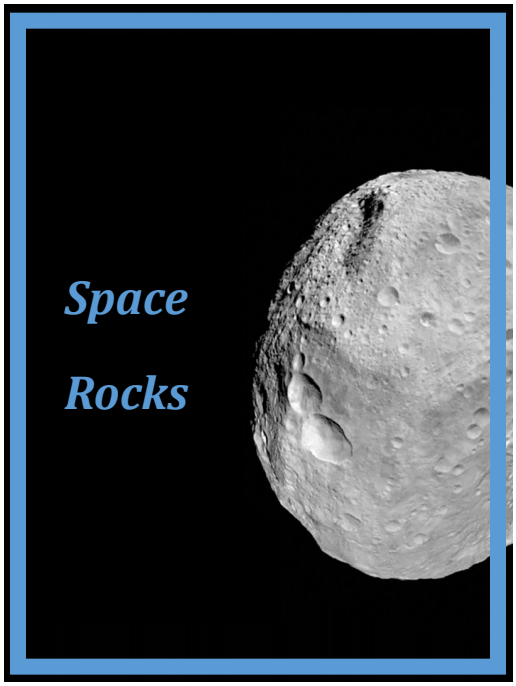

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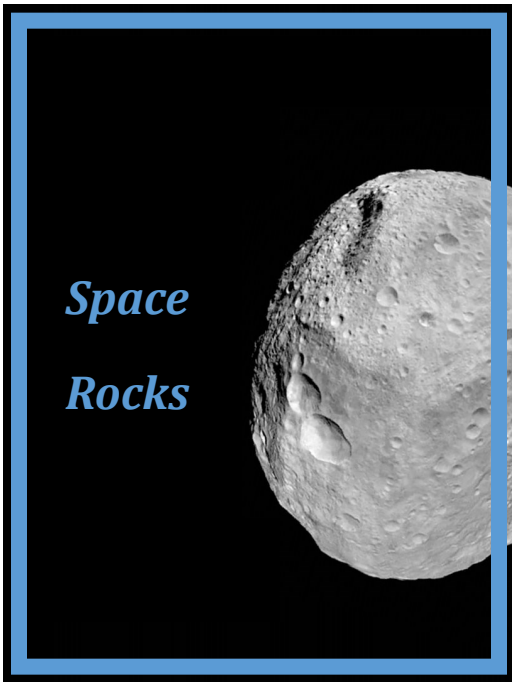

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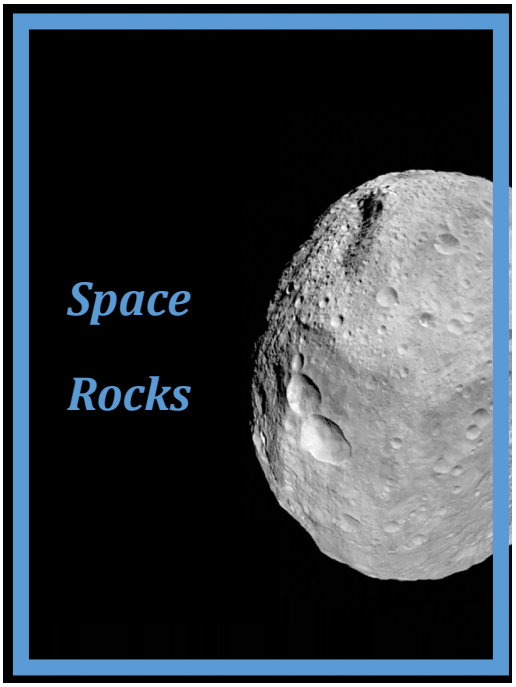

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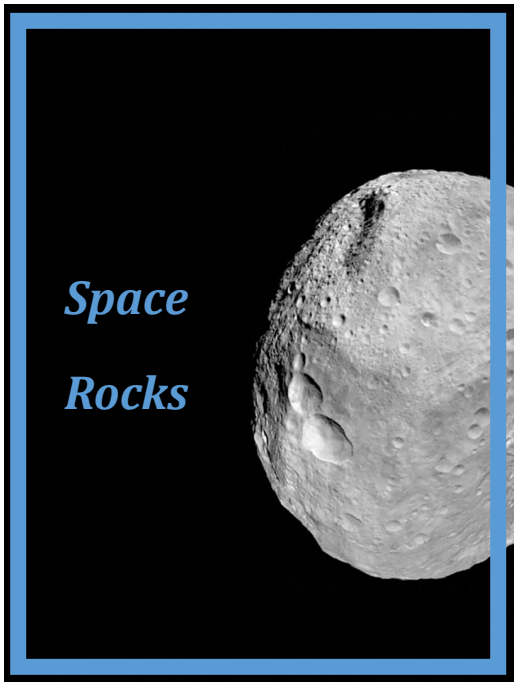

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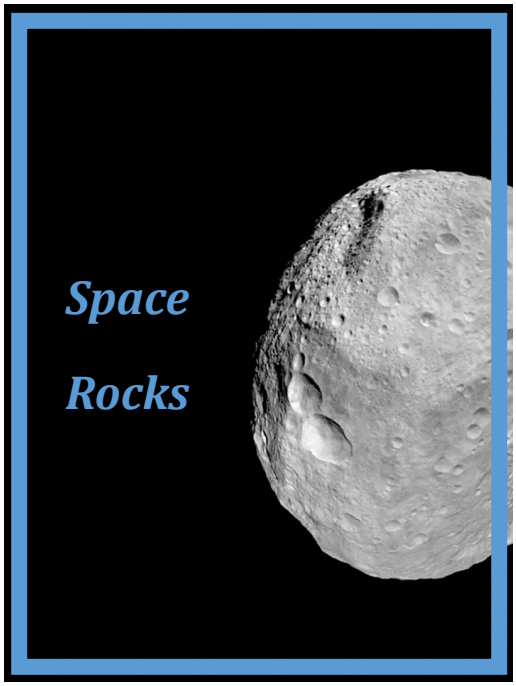

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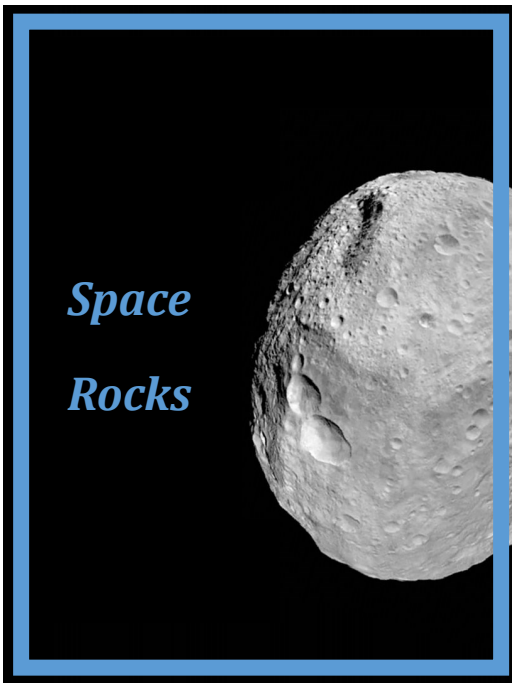


On Earth, when do meteorites fall?

A. At night

B. During the day

C. All the time

Answer: C

What is a meteor?

A. A rock from space

B. A streak of light in the sky

C. A star that explodes

Answer: B

What is a meteorite?

A. A rock from space that has landed on Earth

B. A rock on another planet

C. A small asteroid

Answer: A

What is a shooting star?

A. A star that explodes

B. Another name for a meteor

C. A piece of a star

Answer: B

What is a meteoroid?

A. A rock that has landed on Earth

B. Another name of a meteor

C. A particle or rock in space

Answer: C

Why does a meteor glow?

A. Meteoroids glow white-hot in our atmosphere

B. Meteoroids ignite our atmosphere

C. The air around the meteoroid is ionized

Answer: C

How fast does a meteoroid move in our atmosphere?

A. Around 50 thousand miles per hour

B. About 30 miles per hour

C. Approximately 100 miles per hour

Answer: A

What is an asteroid?

A. A rocky body less than a thousand km wide

B. A type of star

C. A rock that has landed on Earth

Answer: A

Which of these is not an asteroid?

A. Ceres

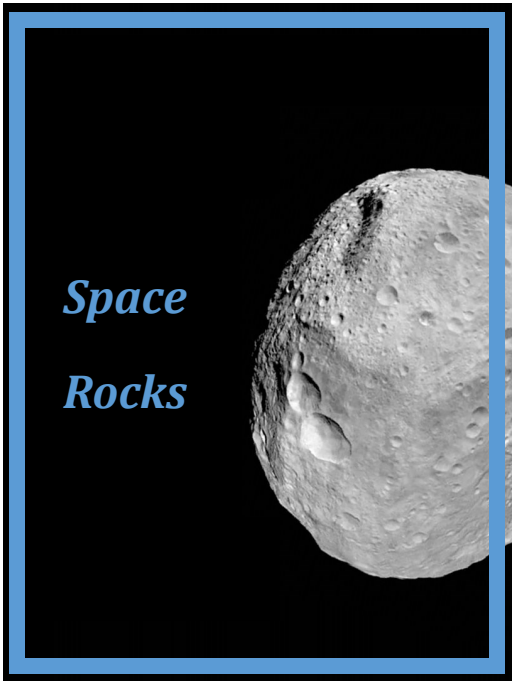
B. Mars

C. Vesta

Answer: B

Space

Rocks



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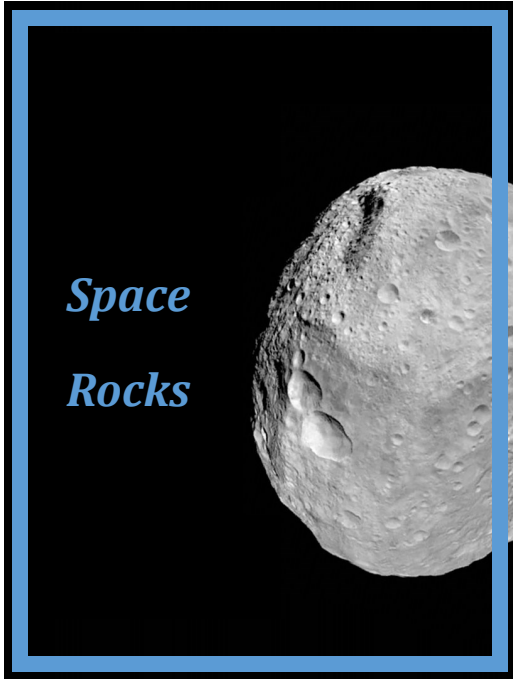

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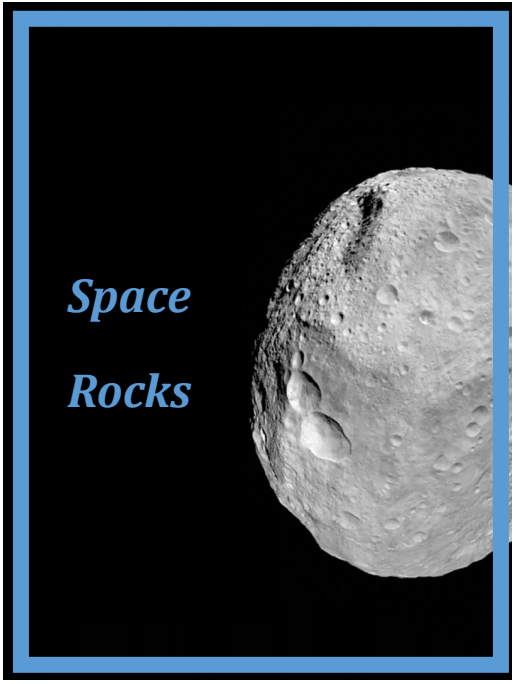

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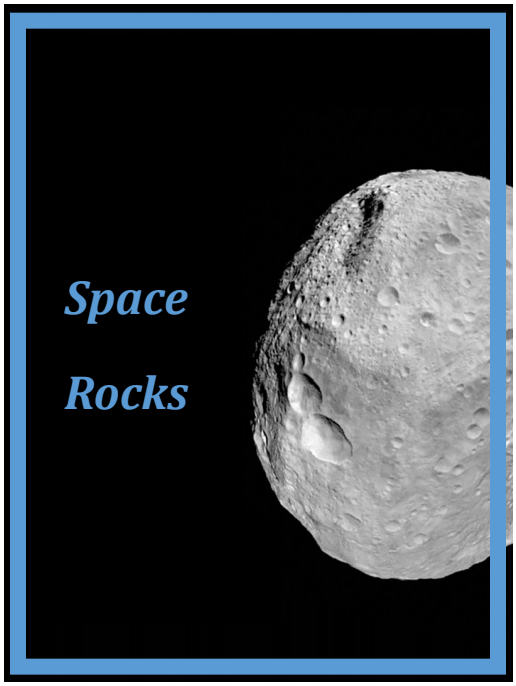

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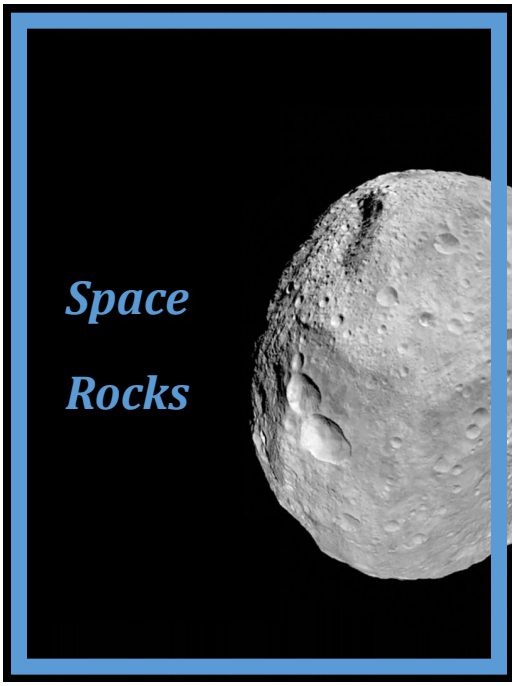

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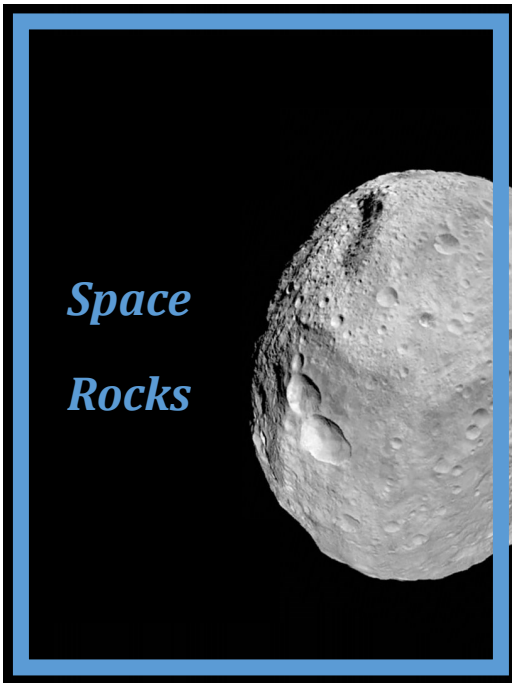

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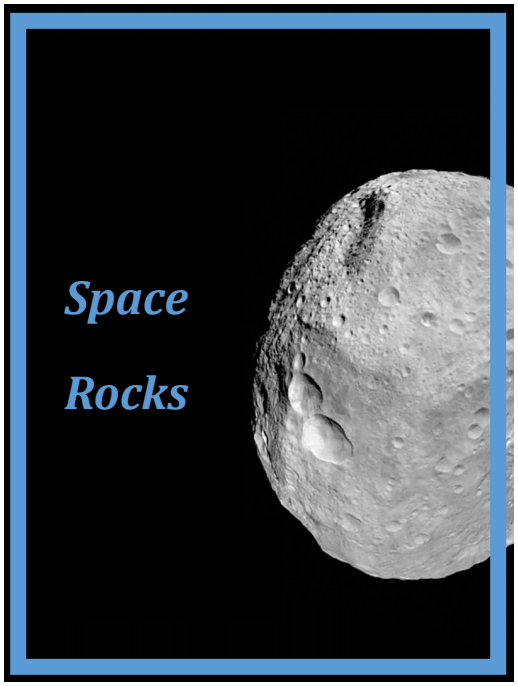

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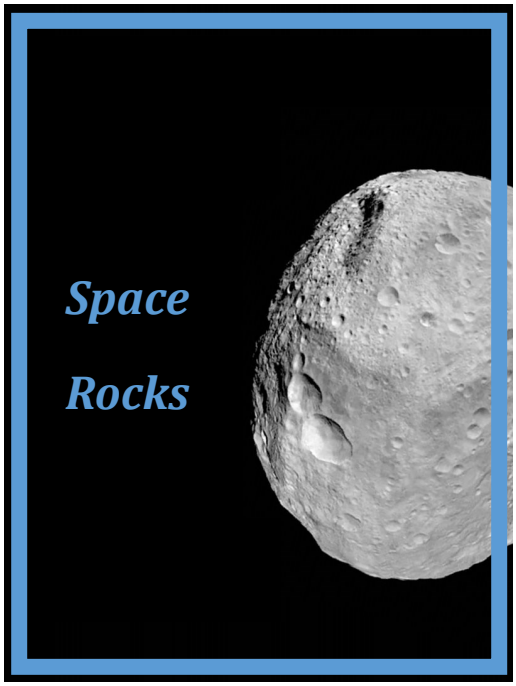

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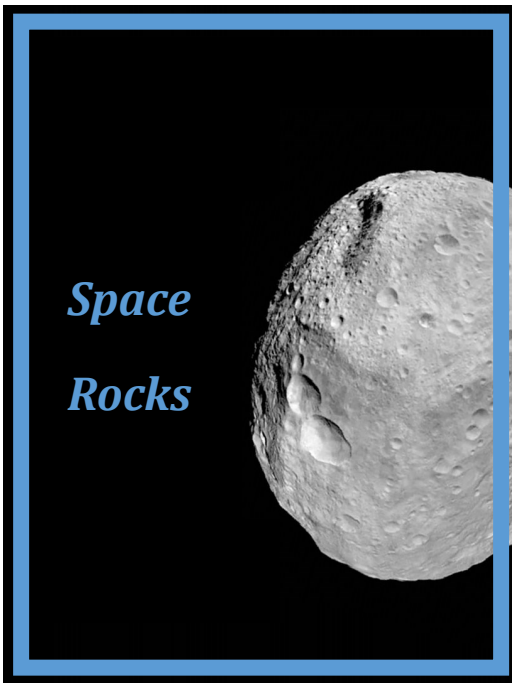


Do large or small asteroids hit the Earth more frequently?

A. Large asteroids strike more frequently.

B. Small asteroids strike more frequently.

C. All asteroids hit the Earth at the same rate.

Answer: B

What causes meteor showers?

A. Earth passes through a trail of comet dust

B. Asteroids explode above our atmosphere

C. Rain forms due to an asteroid impact

Answer: A

What are the different types of meteorites?

A. Fast and slow

B. Icy, rocky, and iron

C. Stony, iron, and stony-iron

Answer: C

What do most meteorites look like?

A. Silver and round

B. Dark crust and irregular-shaped

C. Black and shiny

Answer: B

Which is a meteor shower?

A. The Perseids

B. The Katydids

C. The Lemonids

Answer: A

What makes an impact crater?

A. A comet or asteroid exploding on the surface

B. A meteorite melting the surface

C. An asteroid bouncing off the surface

Answer: A

What are the types of asteroids?

A. Round, Oblate, and Irregular

B. Carbon-rich, Stony, and Metallic

C. Icy, Sandy, and Rocky

Answer: B

Asteroids cannot have _____ .

A. Craters

B. Storms

C. Ice

Answer: B

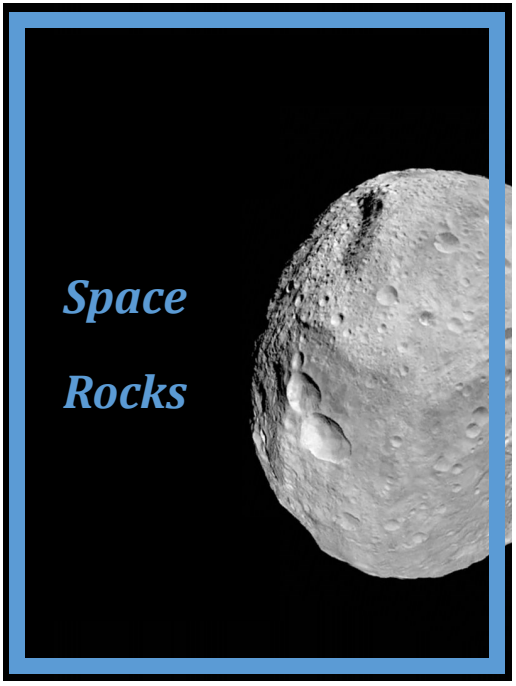
Where do most meteorites come from?

A. The Moon

B. Asteroids

C. Andromeda

Answer: B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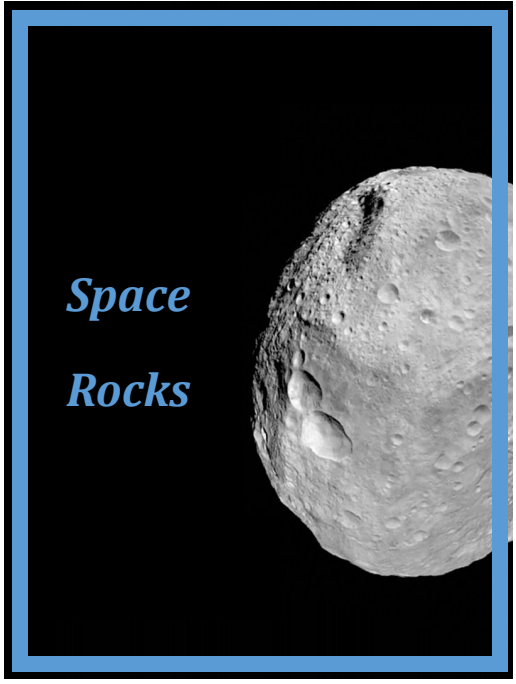
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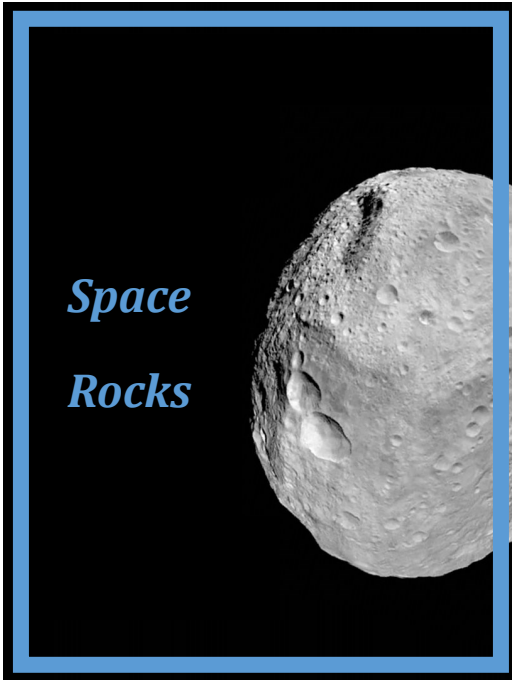
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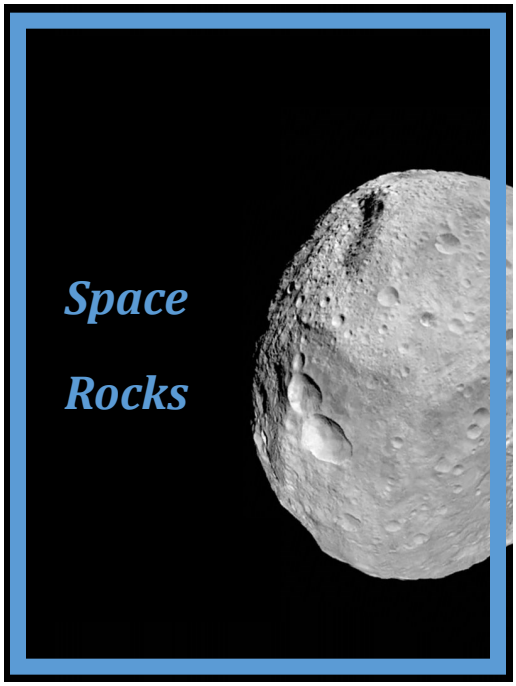
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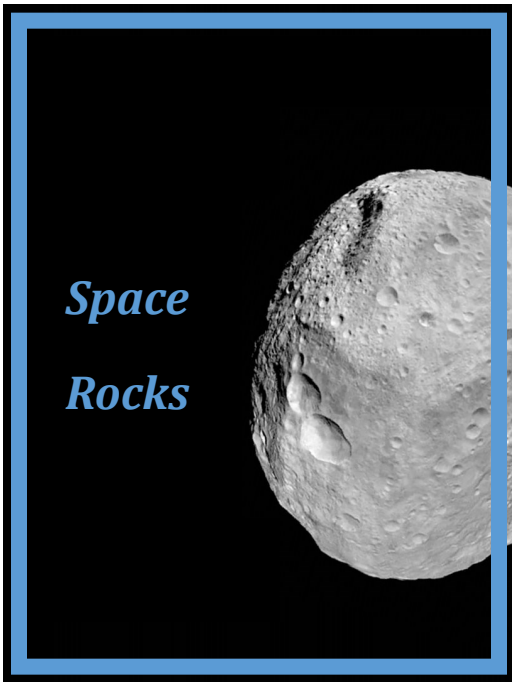
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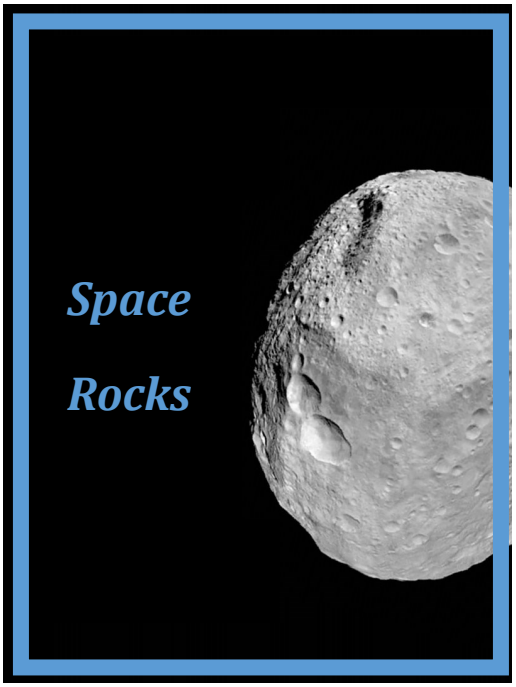
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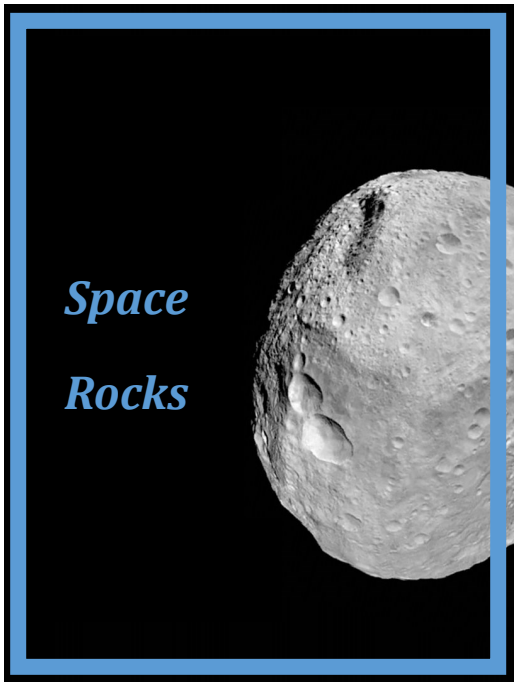
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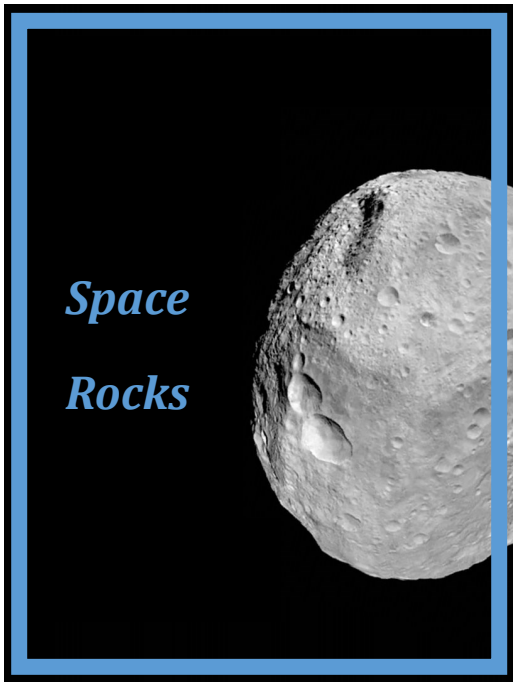
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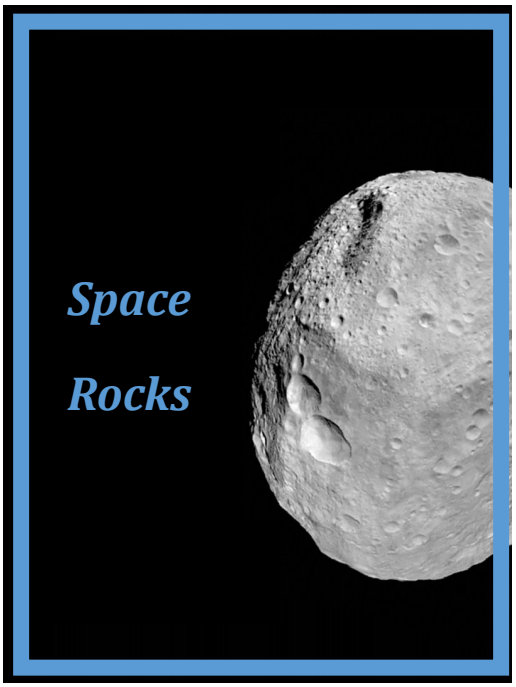
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What is another name for a lunar meteorite?

A. Brie

B. Moonite

C. Lunaite

Answer: C

How fast does a rock need to go to escape from the Moon's gravity?

A. about 1.5 miles per second

B. about 15 miles per second

C. about 150 miles per second

Answer: A

How many meteorites have we found from the Moon?

A. about 4

B. about 400

C. about 40,000

Answer: B

Where on the Moon do lunar meteorites come from?

A. the Maria

B. the Highlands

C. all over the Moon

Answer: C

How many lunar meteorites were seen falling as a meteor?

A. 0

B. 10

C. 15

Answer: A

A lunar meteorite has never been found on which continent?

A. Antarctica

B. Africa

C. North America

Answer: C

In what year was the first identified lunar meteorite found?

A. 1701

B. 1981

C. 2019

Answer: B

How fast does a rock need to go to escape from the gravity of Mars?

A. 3 miles per second

B. 30 miles per second

C. 300 miles per second

Answer: A

How many meteorites have we found from Mars?

A. 12

B. 224

C. 4,048

Answer: B

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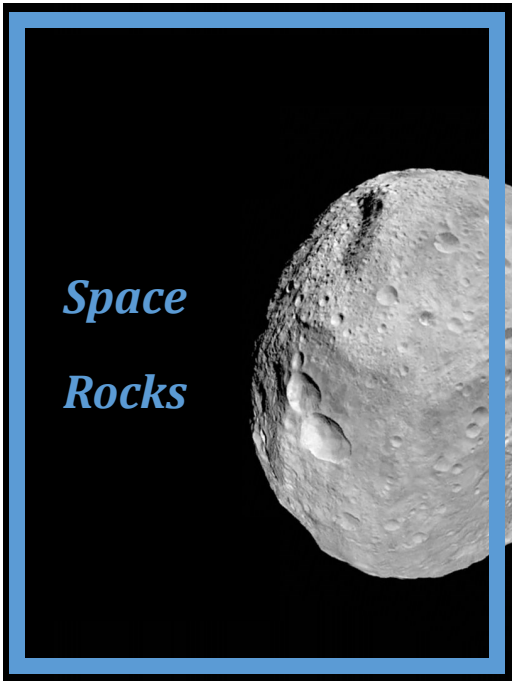

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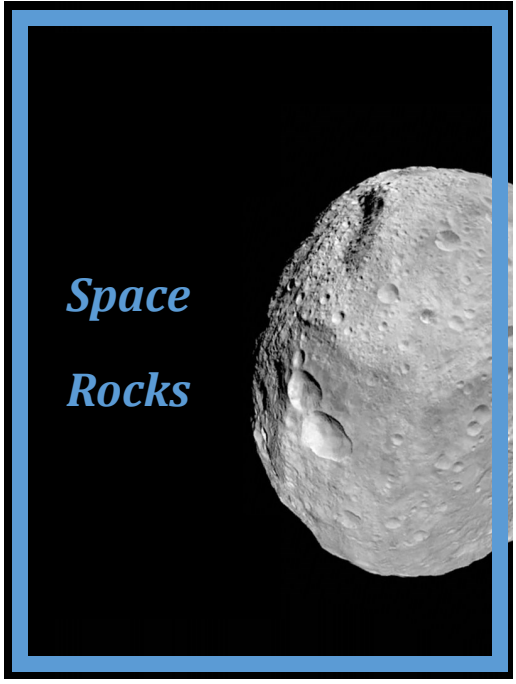

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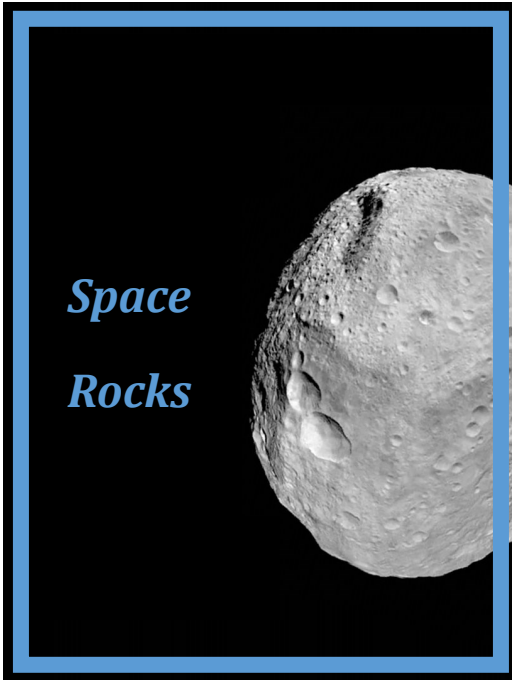

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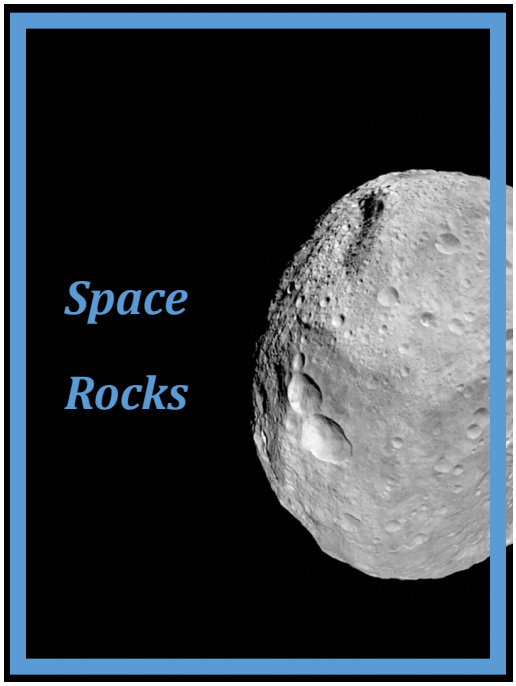

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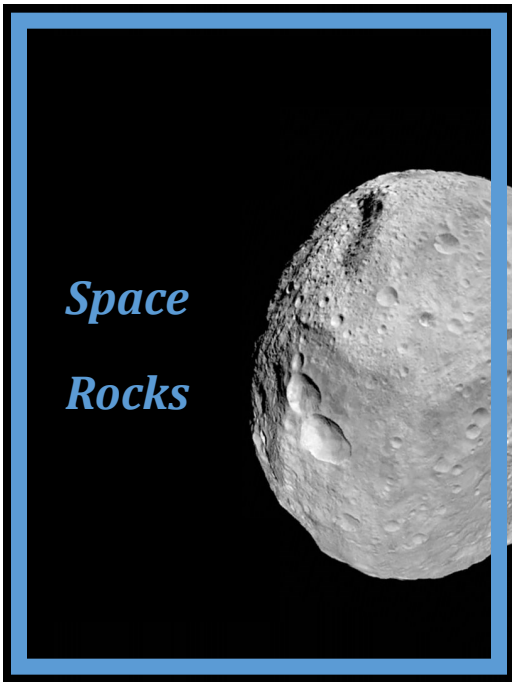

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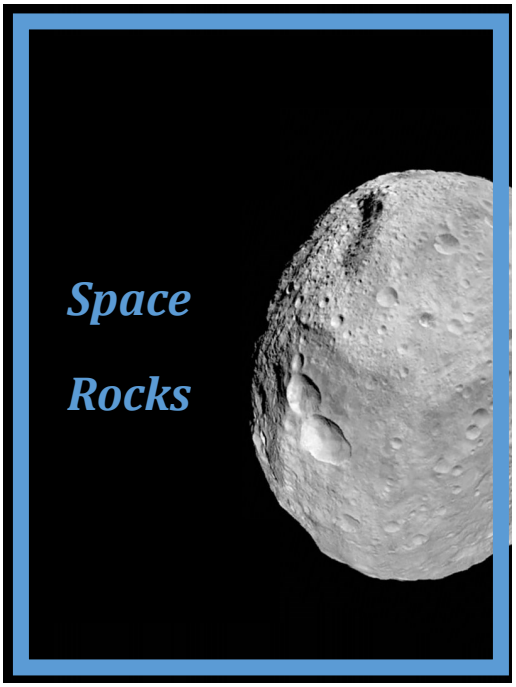

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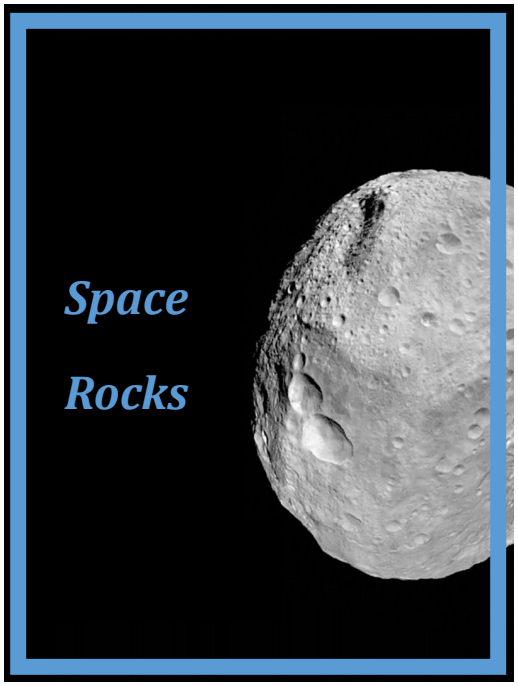

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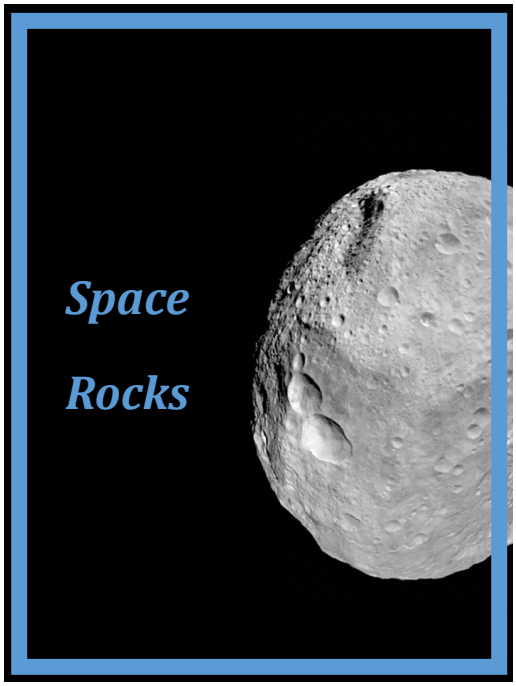

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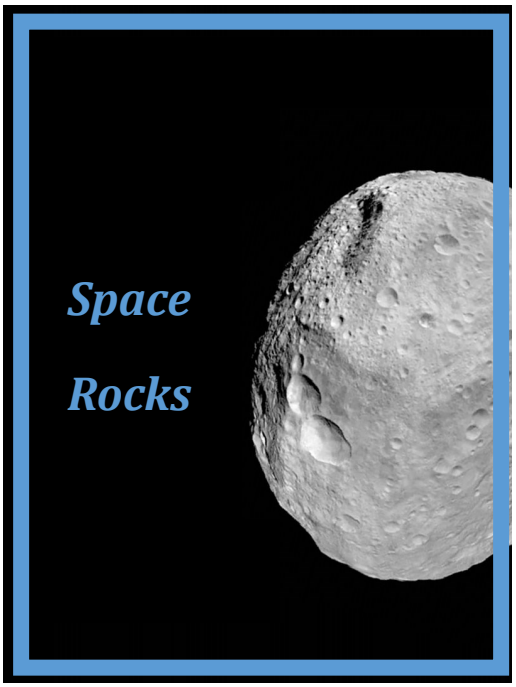


Which type of Mars meteorite was found in Shergotty, India?

A. A Nakhlite

B. A Chassignite

C. A Shergottite

Answer: C

Which asteroid is the OSIRIS REx mission orbiting?

A. Vesta

B. Ceres

C. Bennu

Answer: C

Which of these asteroids has been identified as the source for many meteorites?

A. Vesta

B. Ceres

C. Bennu

Answer: A

About how old are the oldest Mars meteorites?

A. Under 4 thousand years old

B. About 4 million years old

C. Over 4 billion years old

Answer: C

Mars meterorites with “NWA” in their names were found in _____ .

A. Northwest Africa

B. Northwest America

C. Northwest Antarctica

Answer: A

After leaving Mars, how long did meteorite Dhofar 019 spend in space?

A. 3 years

B. 20 million years

C. 4 billion years

Answer: B

Which helps identify meteorites from Mars?

A. Their weight is lighter.

B. The color is redder.

C. The gas composition matches Mars’.

Answer: C

Many meteorites on Earth formed when Vesta _____ .

A. Was hit by another asteroid a billion years ago.

B. Had an enormous volcanic eruption.

C. Exploded.

Answer: A

Iron meteorites come from _____.

A. The cores of shattered planetary bodies.

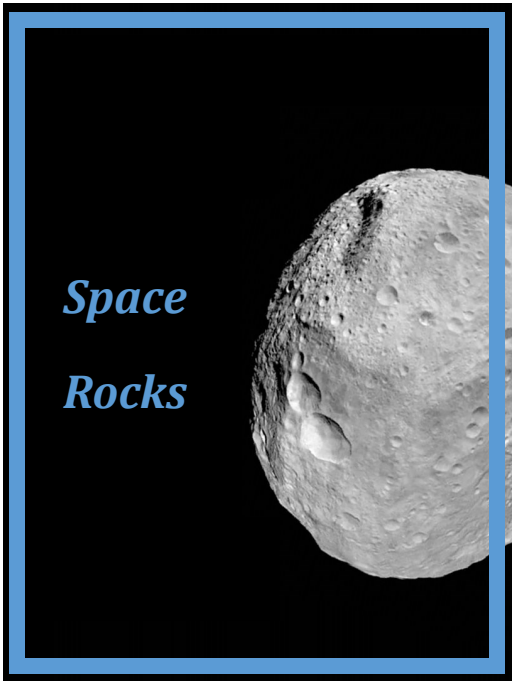
B. Iron asteroids.

C. Mars.

Answer: A.

Space

Rocks



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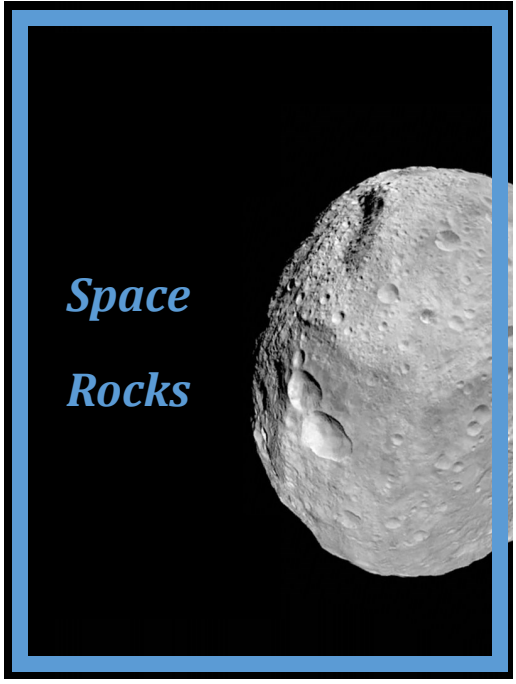

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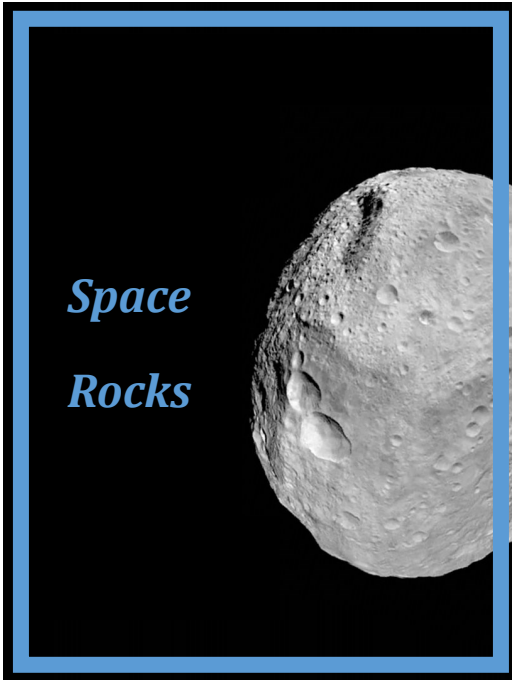

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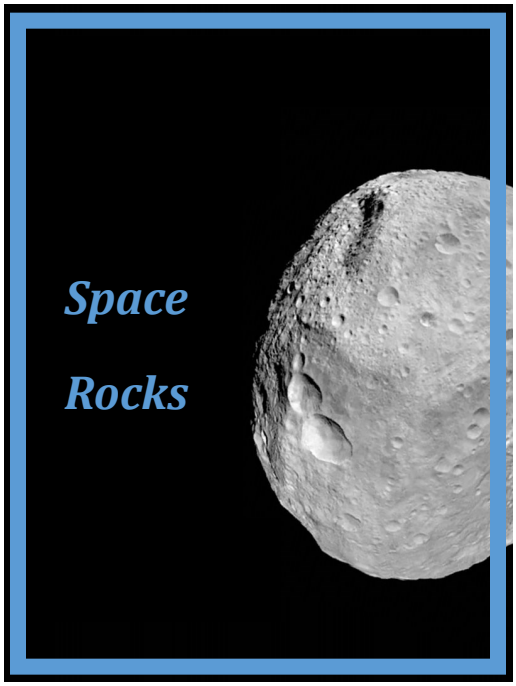

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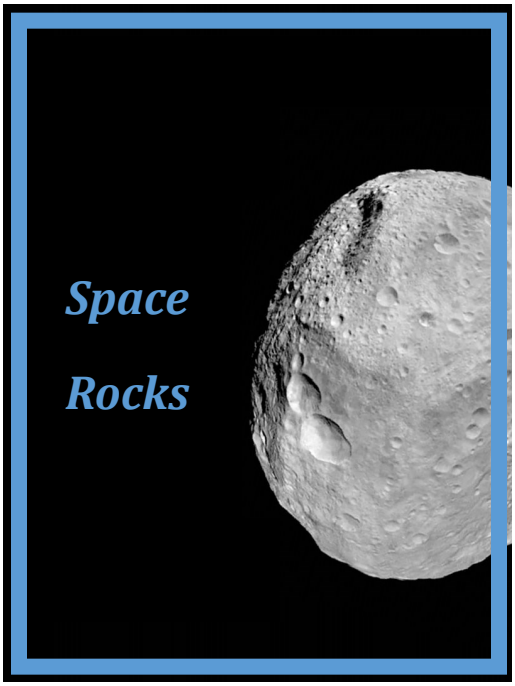

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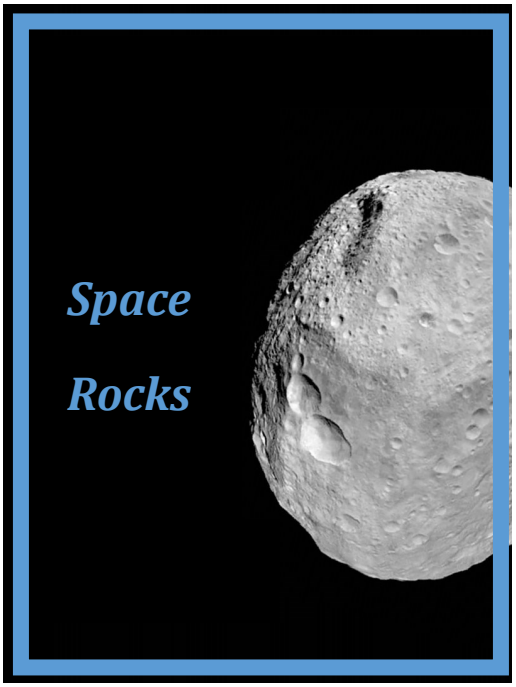

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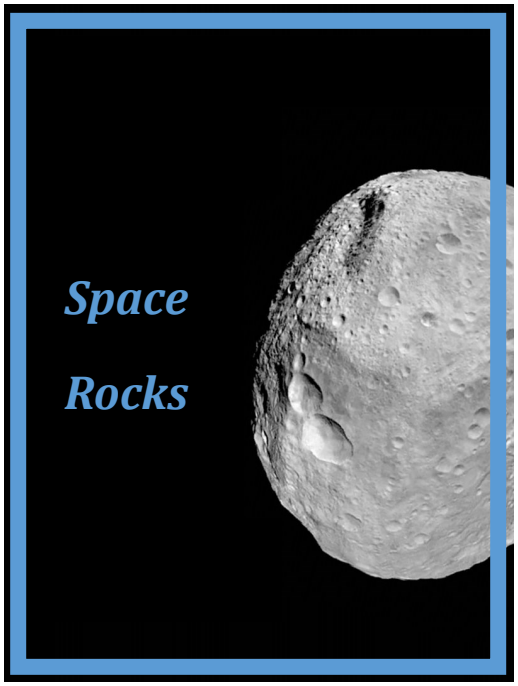

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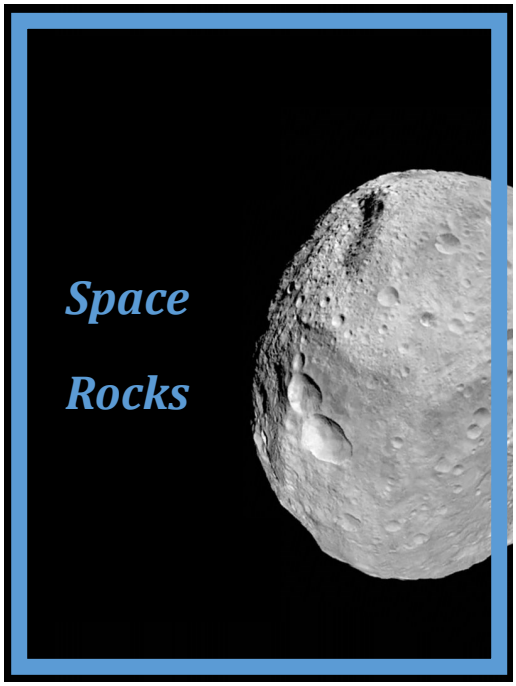

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