The Impression of Impact Craters

LESSON SUMMARY

In this lesson, students investigate meteorite impact craters and analyze evidence for the K/Pg (formerly known as K/T) boundary impact event and its relationship to the extinction of the dinosaurs. In Part A they will engage using a hands-on model to simulate meteorite impact structures. In Part B students will explore cenote locations of the Yucatan peninsula to visualize the hidden Chicxulub impact structure. In Part C students will analyze *JOIDES Resolution* core data before composing a scientific explanation.

This series can be part of an Earth History Unit and/or included with other topics such as landscapes, astronomy, or rocks and minerals.

Standards and Dimensions

NGSS: MS-ESS1-4, **MS-ESS2-3**, **HS-ESS1-1**, **HS-ESS1-6**
Science Engineering Practices: Asking questions and defining problems, Planning and carrying out investigations, Analyzing and interpreting data, Engaging in argument from evidence
Cross-Cutting Concepts: Patterns, Cause and Effect: Mechanism and Explanation, Energy and Matter: Flows, Cycles, and Conservation, Stability and Change
Disciplinary Core Ideas: ESS1.C: The History of Planet Earth, ESS2.A: Earth's Materials and Systems, PS4.B: Electromagnetic Radiation

Connections to 2050 Science Framework

Strategic Objectives: Habitability and Life on Earth
Flagship Initiatives: Ground Truthing Future Climate Change
Enabling Elements: Terrestrial to Extraterrestrial

Ocean Literacy Principle(s)

OLP 7: The ocean is the largest unexplored place on Earth. (7a)

Suggested Time

2 hours

Preparation of Materials

Per group:

- **Part A Surface Model for Meteorite Impacts**
  - flour
  - cocoa powder
  - pie tins or baking pans
  - marbles or balls of different sizes
  - rulers
  - spray bottle filled with water
  - drop cloth or newspaper (to cover work surface)

> **Teacher Note:** You may want to prepare the model before class. In clean, dry baking tins, add about 6 cm of flour in an even layer. Dust a thin layer of cocoa powder over the entire surface of the flour. Mist the cocoa evenly with a small amount of water.

- **Part B The Ring of Cenotes**
  - observations from Part A
  - map of the Ring of Cenotes in the Yucatan peninsula
  - student handout
  - computer with internet access
  - online simulator: **Meteorite Launcher**
  - copy of student handout

- **Part C Expedition 364 Core Data and Explanation**
  - observations and data from Parts A and B
  - copy of station handouts
  - computer with internet access
  - chart paper and markers (optional)

Developed in collaboration with the American Geosciences Institute

Acknowledgments

Authors: Arthur Funk, based on "Impact Craters and the K-Pg Boundary" by Dr. Beth Christensen and Catherine Wiltsey. Edited by Lindsay Mossa.

Scientific Acknowledgment

Expedition: Leg 171B was conducted for the purpose of sampling in the western North Atlantic Ocean to test the geochemistry and mineralogy of the Cretaceous/Tertiary Boundary.

Data Source: IODP Expedition 364 Scientists (2017): Physical properties (MSCL) of IODP Hole 364-M0077A, Related to: Gulick, SPS; Morgan, J; Mellett, C (2016): Expedition 364 Scientific Prospectus: Chicxulub: drilling the X-Pg impact crater. International Ocean Discovery Program Scientific Prospectus, International Ocean Discovery Program.

BACKGROUND FOR THE INSTRUCTOR

The Cretaceous-Tertiary (K-Pg) boundary marks a pivotal moment in Earth's history, about 65.5 million years ago, when a 10 km meteorite hit the planet causing catastrophic environmental changes. Shocked quartz is a type of quartz that has been deformed by intense pressure and heat generated by an impact event. Therefore, the presence of shocked quartz microstructures found at extreme depth within a core provides excellent evidence of a massive meteorite impact. The impact left a crater 180 km (110 mi) across, sending debris into the atmosphere and blocking incoming sunlight for an extended time. The current working theory for is that this meteorite impact and its after-effects led to a mass extinction event.

A positive iridium anomaly is evident in the peak-ring sequence of the Chicxulub impact structure. This anomaly was found in drill core retrieved by IODP-ICDP Expedition 364 at Site M0077 (21.45°N, 89.95°W) is located offshore of the Yucatán Peninsula. It has been shown that this iridium layer has a near global distribution. Globally, the K-Pg mass extinction is identifiable by elevated levels of iridium, an element normally found in trace amounts on Earth, but it is common when meteorites bit the Earth. Large-scale structural evidence can be observed by examining maps of cenote (sinkhole) locations within the Yucatan peninsula. Hundreds of these unique formations can be found in a circular pattern around the Chicxulub crater. Within a few decades following the impact, the Chicxulub impact basin returned to a depositional environment with relatively low energy. As a result, the recovery of life during the succeeding millennia is recorded in exceptional detail.

In this lesson, students will have the opportunity to simulate and analyze impact structures using a physical model. By recreating the impact process, students will gain a better understanding of how these structures form and the types of features and materials that are associated with them. Through collaboration and documentation of their observations, students will develop critical thinking and communication skills while deepening their understanding of this fascinating geological phenomenon.

Supplemental Resources*

Oceanic Drilling

- **Introducing the International Ocean Discovery Program**
- **Holes in the Bottom of the Sea: History, Revolutions, and Future Opportunities**
- **Highlights of IODP Discoveries**

Lesson specific

- **Chicxulub Impact Event**
- **Earth's history: What happens after a meteorite impact?**
- **364: Chicxulub K-Pg Impact Crater**
- **Ring of Cenotes**
- **Meteor Impact Site | National Geographic video**
- **Crater Explorer**
- **Meteorite Launcher**

Initial Inquiry

1. Show images of craters on Earth and the Moon. Ask students to identify the characteristics they observe about the craters. Ask students how these impact events might have affected life. Have students document questions before starting the simulation.

Suggested Response: Sample student-generated questions:
- What is the process by which impact craters are formed?
- How do the characteristics of the impact object and the target surface affect the size and shape of the impact crater?
- What impact craters have been discovered, and what can we learn from them?
- What evidence supports the theory that a massive impact caused the extinction of the dinosaurs?

2. Ask students: *How would we know if a catastrophic (extinction-level) meteorite or asteroid impact event happened in the past? What evidence would we expect to find?*

Suggested Response: Have students explain the evidence that they suggest. Variation in responses is expected, but will likely include: a large impact crater, widespread debris from the impact, a large number of fossils of the same age as the impact, fewer and new types of fossils in slightly younger layers (since the extinction resulted in fewer organisms, and then also may have changed the environment enough that new organisms evolved or moved into areas).

ANNOTATED STUDENT ACTIVITY

Objective(s)/Outcome(s)

Students will be able to:

1. simulate and analyze impact structures using a physical model to collaborate and document observations.
2. apply observations their model to identify possible impact structure evidence preserved in the Yucatan peninsula landforms and use a digital model to make inferences about the magnitude of the Chicxulub impact event.
3. analyze and synthesize core data with initial model observations to compose a scientific explanation (justification) that supports the claim that the K-Pg Boundary is a result of the Chicxulub meteorite impact event.

Part A – Surface Model for Simulating Meteorite Impacts

Materials

- flour
- cocoa powder
- deep pie tins or baking pans
- marbles (or similar) of different sizes
- rulers
- spray bottle filled with water

Background A

The Earth has experienced numerous impacts from meteorites throughout its history, leaving behind impact structures that range in size from small craters to vast basins. These impacts have had a significant impact on the geological and biological evolution of our planet, including the extinction of the dinosaurs 66 million years ago. To better understand these events, scientists use models and simulations to recreate the impact process and analyze the resulting structures and materials. Evidence of impact events can not only be seen near where the meteorite struck the Earth but can also be found globally due to debris from the impact being carried through the atmosphere and eventually settling back to the ground.

Activity A

> **Teacher Note:** It is recommended that students work in groups of 3–4. Provide each group with a prepared baking pan model or have them create it. Once each group has completed at least three impacts, discuss as a class what the observations can tell us about meteorite impacts and the resulting impact structures.

1. Drop the marble onto the model and observe the resulting impact structures.

2. Design a data table to record measurements and observations.

Teacher Note: After students have generated ideas about what should be in the data table, you may want to discuss this as a class so that all groups record the same data points. A sample data table may look like Table TE-1 but with more rows to accommodate the number of tests students conduct. Observations can be of the object dropped as well as of the craters.

Table TE-1. Sample Data Table

Mass of Object Dropped (g)	Drop Height (cm)	Crater Diameter (cm)	Crater Depth (cm)	Observations & Notes

3. Record observations of the shape of the impact, as well as other changes that may have occurred.
4. Carefully remove the marble, and measure and record the diameter and depth of the resulting craters.
5. Once all your observations are recorded, gently shake the baking tray to smooth out the surface of the sediment.
6. Use the spray bottle to evenly mist the surface of the sediment.
7. Repeat steps 1–3 two more times with marbles of different sizes.
8. Journal questions that could guide research about real impact structures.

Analysis A

1. Use observations of your experiment to describe what happens to Earth's surface during an impact event.
2. How does the size / mass of the meteorite affect the resulting crater? Use your data to support your claim.
3. What kind of evidence do you think scientists look for when studying past meteorite impacts?
4. What kind of short and long term effects do you think a meteorite impact can have on the environment and life on Earth?

Suggested Response: A meteorite leaves an impact crater on Earth's surface. Rock, sediment, and other objects located where the impact occurs will be ejected, possibly quite far from the impact site (e.g., dust). Within the crater, older layers of sediment and rock will be exposed due to the ejection of material above it. Some students may mention that because meteorites burn when they hit the atmosphere, that impact events may also cause fires on the surface. Students should reference specific data points to describe that the larger the diameter or mass of the meteorite, the larger the crater it will form. Scientists look for impact craters, ejecta (layers of dust near the impact site or globally, depending on the size of the meteorite), and elements or molecules tha are typically found in meteorites (e.g, radioactive potassium, thorium, or uranium), especially if they are rare on Earth. Short-term effects of an impact could be the death of organisms living in the area, fires, waves or tsunamis if the impact is near/in water, earthquakes/shock waves, and settling of ejecta. Long-term impacts could be a change in climate depending on the amount of ejecta (e.g, cooling due to ejecta blocking the sun, or more rain as ejecta acts as condensation nuclei for clouds) and a disruption of the food chain and subsequent extinctions (either local or widespread).

Synthesis A

1. What evidence of a meteorite impact might we look for in the real world?
2. How might the impact structures you made relate to the impact associated with the extinction of the dinosaurs and the post-impact environmental changes?

Suggested Response: These questions are to get students thinking about real-world impact events. Student responses will vary but accept any that they are able to justify and later refine, after completing Parts B and C of the lesson.

Extensions A

1. Have students research and present on a relatively recent meteorite impact event. Encourage them to include information about the impact site, the resulting impact structure, and the environmental effects of the impact.

Part B – The Ring of Cenotes

Materials B

- observations from Part A
- map of the Ring of Cenotes in the Yucatan peninsula
- computer with internet access
- copy of student handout

Background B

The Yucatan peninsula in Mexico is home to one of the most well-known impact structures on Earth, known as the Chicxulub crater. This structure was formed 66 million years ago when a massive meteorite collided with Earth, causing widespread destruction and contributing to the extinction of the dinosaurs. Despite being largely buried by sediment and vegetation, the Chicxulub impact structure is still visible in the form of various geological features, such as the circular ring of cenotes and the Chicxulub peak ring.

Activity B

Teacher Note: Introduce the lesson by explaining that impact events are obvious on the Moon but they are less obvious on Earth due to tectonics, weathering and erosion. It may also help for students to watch **this video** before starting, or after step 1.

1. Make observations and look for patterns using **maps showing the ring of cenotes** found on the Yucatan Peninsula.

2. Measure and record the size of the crater rim formed by the impact as evident in the ring of cenotes.

3. Using a computer, access the **Meteorite Launcher**, the online meteorite impact simulator.

   a. Modify the parameters of composition, diameter, speed, and impact angle to launch a meteorite in the simulation.

   b. Try out a few combinations of parameters to see how the impact site is affected.

   c. Then, try to recreate the Chicxulub impact by modifying and documenting parameters.

Teacher Note: Students should discover that although the model will simulate extremely devastating impact events, the model will not simulate an impact quite as large as Chicxulub. Conclude this part of the lesson by having students reflect on what they learned and how it can be applied to other impact events and Earth systems. Be sure to have students reflect on the importance of impact events in Earth's history.

Analysis B

1. What patterns do you notice in the distribution of impact structures between the Surface Model for Meteorite Impacts activity and the Ring of Cenotes map? What might this tell us about the process of impact crater formation?

Suggested Response: The exact location of a meteorite impact appears as a depression, but there is evidence of areas outside of this impact site that are also affected. The ring of cenotes was formed due to the meteorite impact causing cracks in the limestone in the area, which then filled in with water that further wore away the limestone, leading to sinkholes (the cenotes). The Surface Model for Meteorite Impacts should have also shown a pattern of features around each impact event, especially larger ones. The debris from the impact should be noticeable around the impact site, showing that the effects of a meteorite are not limited to the exact site of impact.

2. Based on the data collected in this activity, what can we infer about the size and scale of the Chicxulub impact event and its effects on the Yucatan Peninsula?

> **Suggested Response:** The meteorite must have been very large, as it is difficult to simulate the exact effects of it on the Meteorite Launcher due to limits in the model, especially the size of the meteor. The Chicxulub impact crater is about 110 miles wide, and the largest impact that can be simulated on the model creates a crater ~80 miles wide.

Synthesis B

1. How do the observations and data collected in this activity support the hypothesis that the Chicxulub impact event was a major contributing factor to the mass extinction event at the Cretaceous-Paleogene boundary?

> **Suggested Response:** The data should show that larger meteorites have a proportional effect on the environment, with more ejecta that could lead to widespread and long-term effects. The ejecta could be enough to block the sun's rays, leading to reduced photosynthesis, and therefore less food at the bottom of the food chain. The ejecta could also have led to significant cooling, which would affect the survival of many organisms, in addition to there being less food.

2. What other information would you want to know about the Chicxulub impact event to determine why it had such a profound and far-reaching effects across the Earth?

> **Suggested Response:** Will vary but will likely include: How large was the meteor? At what angle did it hit the Earth? What was the temperature of the metoer when it made imapct? Did it hit a terrestrial or aquatic environment? What type of rocks were in the area? Did it cause fires, and, if so, how long did they last? How far was the ejecta from the impact spread? How long did it take the ejecta to settle?

Extensions B

1. Explore the geoheritage of the Ring of Cenotes in the Yucatan Peninsula. Research the history and cultural significance of the sinkholes and caves, in addition to their geological formation. Why do you think the Ring of Cenotes should be preserved and protected as a geoheritage site?

2. What makes the Ring of Cenotes unique from features left at other impact sites? What impact has it had on the local ecosystem?

3. Explore the feedback loops that result from an impact event. Research how the release of energy during the impact can affect the Earth's atmosphere, hydrosphere, and biosphere.

Part C – Expedition 364 Core Data and Explanation

Materials C

- copy of station sandouts
- Oobservations and data from Parts A and B
- computer with internet access
- chart paper and markers (optional)

Background C

The Chicxulub impact is widely believed to have contributed to the Cretaceous-Paleogene (K/Pg) extinction event, which occurred approximately 66 million years ago and marked the end of the Cretaceous period and the beginning of the Paleogene period. One of the key pieces of evidence supporting this hypothesis comes from the analysis of the 364 *JOIDES Resolution* core data.

In 2016, the International Ocean Discovery Program (IODP) conducted a drilling expedition called Expedition 364 aboard the *JOIDES Resolution* research vessel. The goal of the expedition was to collect rock samples from the Chicxulub Crater, which lies partly on land and partly beneath the Gulf of Mexico. The samples were obtained by drilling deep into the seafloor to collect core samples, which were then brought to the surface and analyzed by scientists. The 364 *JOIDES Resolution* core data provides a wealth of information about the impact event and its aftermath. The cores contain layers of sediment that were deposited in the aftermath of the impact, including a layer of ash and debris that was blasted into the atmosphere and eventually settled back down to Earth.

Activity C Workstations

> **Teacher Note:** Review Parts A and B, then discuss the importance of understanding the K-Pg Boundary and the Chicxulub impact event. Explain to students that at each station, they are to identify any evidence that supports the claim that the K-Pg Boundary is a result of the Chicxulub meteorite impact event. Encourage students to discuss their findings and collaborate with their peers to compose a scientific explanation. It may be beneficial to complete station 1 as a class.

1. Station 1: Chicxulub Core Poster

   a. Read over the **Blast from the Past poster** as well as the **flyer on core 40R-1** (automatic pdf download), to study the timeline of the Chicxulub impact event and specific layers of the core.

> **Teacher Note:** There is a core replica available to borrow. For more information, see the page on the **Cretaceous Impact Kit**.

   b. Summarize information that supports the claim that the K-Pg Boundary is a result of the Chicxulub meteorite impact event.

   c. Identify any discrepancies or inconsistencies between their model and the *JOIDES Resolution* core data.

2. Station 2: Entire Core Overview
   a. View the **image of the entire core**.
   b. Repeat steps 1b–1c to analyze the image.
3. Station 3: Core Descriptions
   a. View the **core description** scientists on board the *JOIDES Resolution* created for Core 40R (page 40). Compare this to other sections of the core taken from above (505–616 mbsf) and below (619–1335).
   b. Repeat steps 1b–1c to analyze the image.
4. Station 4: Profile of Iridium Core 40R-1
   a. Study the profile of iridium on the Data Handout.
   b. Repeat steps 1b–1c to analyze the image.
5. Station 5: Core 40R-1
   a. Study how each piece of data relates by viewing the series of images on the Core Handout.
   b. Repeat steps 1b–1c to analyze the image.

Synthesis C

1. Compose a Scientific Explanation: Use your findings from the workstations, as well as from Parts A and B, to compose a scientific explanation that supports the claim that the K-Pg Boundary is a result of the Chicxulub meteorite impact event.

Teacher Note: Provide chart paper and markers for students to create a visual representation of their scientific explanation. Encourage students to use scientific language and to cite evidence from their observations and data. If time allows, have each group present their scientific explanation and visual representation to the class. Encourage students to provide feedback and ask questions to further develop their understanding of the K-Pg Boundary and the Chicxulub impact event. A sample scientific explanation of the evidence is below:

The cores obtained during Expedition 364 contain a layer of sediment that marks the boundary between the Cretaceous and Paleogene periods, known as the K-Pg boundary or simply the KT boundary. This layer is characterized by a sharp increase in the abundance of the element iridium, which is rare on Earth's surface but abundant in certain types of meteorites and comets.

The iridium layer found in the core samples is consistent with the hypothesis that the Chicxulub impact was caused by a large meteorite or comet. The impact would have released a huge amount of energy, creating a massive explosion and ejecting a huge amount of material into the atmosphere. This material would have traveled around the world, causing wildfires and blocking out the sun, resulting in a global cooling event and widespread extinction of many species, including the dinosaurs.

In addition to the iridium layer, the 364 *JOIDES Resolution* core data also contains evidence of shocked quartz—a type of mineral that has undergone intense pressure and deformation as a result of a high-energy impact event. When a meteorite or meteorite collides with the Earth's surface, it can create a shock wave that travels through the rock, generating high pressure and temperatures that cause the quartz to undergo a unique transformation. The quartz crystals are deformed and fractured in a distinct way and the resulting structure is characterized by planar deformation features, such as tiny parallel lines or wrinkles, that are not found in quartz that has been formed under normal conditions. These changes are consistent with the hypothesis that the Chicxulub impact was a major driver of the K-Pg extinction event at the K-Pg boundary.

Microfossils also can provide evidence of a mass extinction event The K-Pg boundary is characterized by a sharp decrease in the abundance and diversity of many types of microfossils, including foraminifera, dinoflagellates, and radiolarian The impact site show a sharp decline in diversity and abundance across the K-Pg boundary. This pattern is consistent with a major disruption to marine ecosystems that occurred at the time of the impact.

Extensions C

1. Have students investigate the causes of other extinction events, such as the Permian-Triassic extinction, which is sometimes referred to as the "Great Dying" and is considered the largest mass extinction event in Earth's history. Encourage them to explore the evidence for different hypotheses about the causes of this event, such as massive volcanic eruptions, a meteorite impact, or some combination of factors.

HANDOUT B

RING OF CENOTES

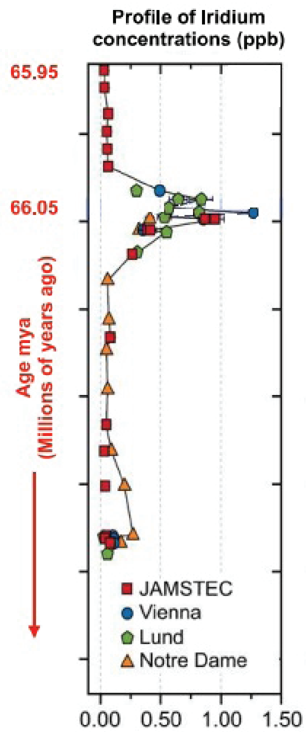
Patterns and Observations of Chicxulub Crater	
Size of Chicxulub Crater (km)	
Similarities of simulated craters to Chicxulub Crater	
Differences between simulated craters and Chicxulub Crater	

METEORITE LAUNCHER

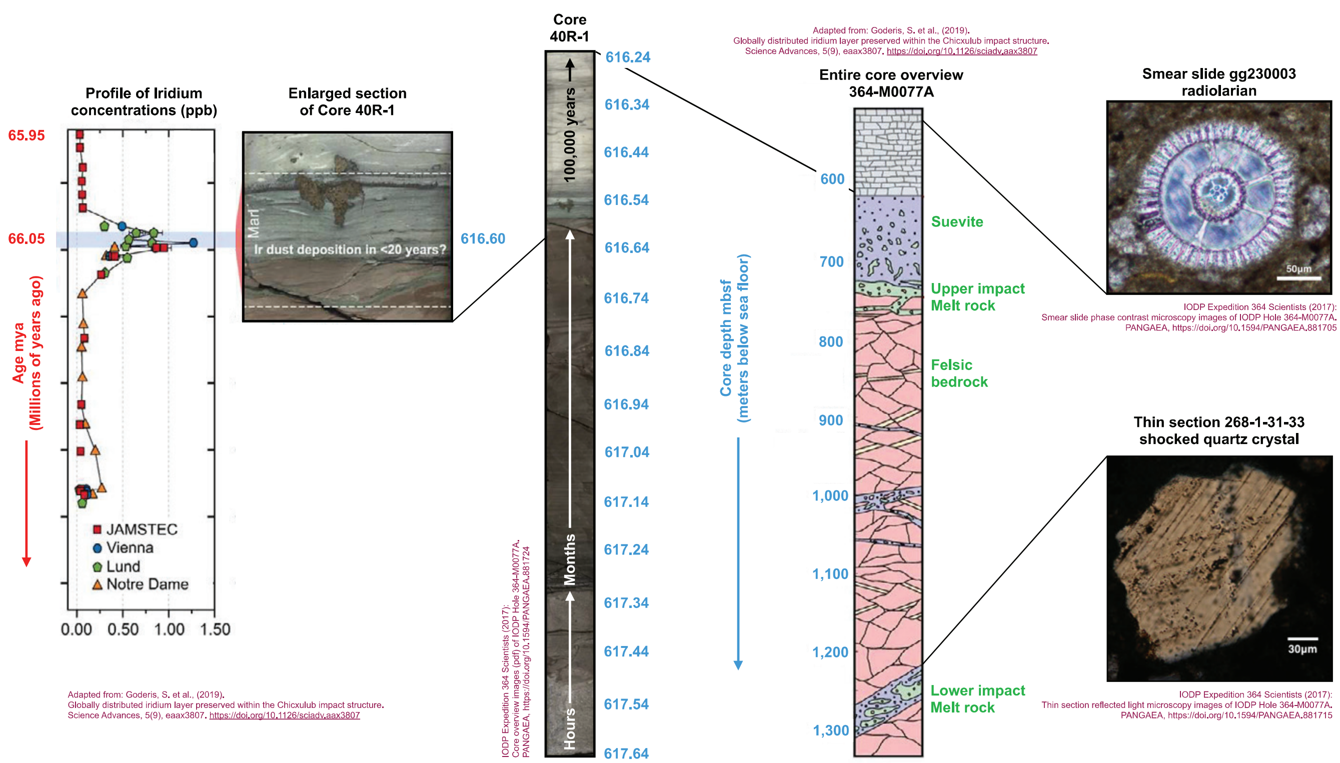
Composition	Diameter	Speed	Impact Angle	Frequency and Observations

HANDOUTS C

STATION 4:



STATION 5: CORE HANDOUT



WORKSTATIONS

Evidence	Supports the claim. What did you see? What are the relevant observations or data that support the claim? (Use some specific examples and data points)	
Claim	Answers the question. What claim can be made based on the evidence? Does the evidence support your prediction?	
Science Concepts	The science topics that have informed you. What scientific concepts are connected to the evidence and help explain the claim?	
Scientific Reasoning	Logic statements. How do the evidence and scientific concepts link to support the claim?	

When writing your final scientific explanation, consider using some of the following sentence starters:

- The evidence I use to support _____________ is _____________.
- For example, you can see that ______.
- When looking at _______, you can tell that _______.
- If you measure _______, you will find that _______, which shows _______.
- The data regarding _______, shows _____________.
- When observing _______, you can clearly see that _______.

CLOSURE

1. Exit ticket: Where else might you collect data from to see the extent of the impact that formed the Chicxulub Crater? What evidence would you look for to support the claim that a mass extinction event occurred following this impact event?

2. This lesson could be followed up with lessons on causes of other mass extinctions.

References

Goderis, S. et al., (2019). Globally distributed iridium layer preserved within the Chicxulub impact structure. Science Advances, 5(9), eaax3807. **https://doi.org/10.1126/sciadv.aax3807**

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