Climate Data from Arctic Coring

LESSON SUMMARY

These short activities reveal that data on past climates can be obtained from ice and sediment cores. A subset of research results are investigated to address the question of why more cores should be obtained from the Arctic Ocean and to demonstrate that science is an evolving process. This activity could be used within a unit on climate change, geologic time, or plate tectonics.

SCIENTIFIC OCEAN DRILLING

Standards and Dimensions

NGSS: MS-ESS1-4, **MS-ESS2-3**

Science Engineering Practices: Constructing Explanations and Designing Solutions; Analyzing and Interpreting Data

Cross-Cutting Concepts: Scale, Proportion, and Quantity; Patterns

Disciplinary Core Ideas: ESS1.C: The History of Planet Earth; ESS2.B: Plate Tectonics and Large-Scale System Interactions

Connections to 2050 Science Framework

Strategic Objectives: The Oceanic Life Cycle of Tectonic Plates, Earth's Climate System.

Flagship Initiatives: Ground Truthing Future Climate Change.

Enabling Elements: Broader Impacts and Outreach.

Ocean Literacy Principle(s)

OLP 1: Earth has one big ocean with many features. (1B, 1D)

OLP 7: The ocean is largely unexplored. (7D, 7F)

Suggested Time

60–75 minutes

Preparation of Materials

Per student:

- copy of analysis and synthesis questions
- handout for Part 2 (2A–2E, recommended that each group do one part)
- highlighters or markers

Teacher demonstration:

- **model ice core instructions**
- 3 Pringles cans
- water
- food coloring or instant coffee
- leaf litter
- sand
- graduated cylinder
- plastic insects (optional)
- freezer access

Acknowledgments

Authors: Lindsay Mossa, based on an original lesson, "Window on Arctic Coring," by Mark Leckie and Kristen St. John. Edited by Lauren Brase.

Scientific Acknowledgment

Expedition: Leg 302 was conducted with the purpose of sampling the Arctic Ocean to collect data on the palaeoceanographic history of the shelves that were formed during the early Paleogene Period.

Data Source: Backman, J., Moran, K., & Evans, D. (2004). Integrated Ocean Drilling Program Expedition 302 Scientific Prospectus, ACEX Arctic Coring Expedition, Paleoceanographic and tectonic evolution of the central Arctic Ocean. IODP. **https://bit.ly/Leg302.**

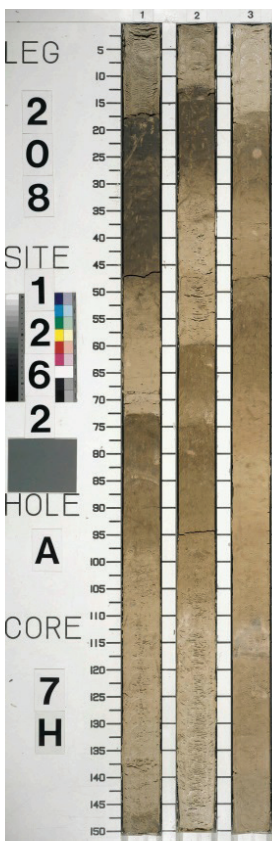
AGI Developed in collaboration with the American Geosciences Institute

BACKGROUND FOR THE INSTRUCTOR

Evidence for past climate change on Earth can be found in ice cores taken from glaciers and from sediment cores taken from the ocean almost anywhere on Earth. Many more cores have been taken from Arctic glaciers than from ocean sediment, however, glaciers undergo many melting periods and therefore any evidence of specific climate conditions captured within the melted layers has been lost. Glaciers are also much thinner than sediment that accumulates on oceanic crust.

Given that most ice on Earth forms at the poles, collecting evidence from the Arctic Ocean and Southern Ocean may reveal more information about ice ages or other cooling events compared to evidence from other oceans. Very few oceanic drilling expeditions have occurred in these oceans, which provides the perfect opportunity to explore data and make a case for doing so. Figure A shows a sample of a core from Expedition 208. Cores can be studied by looking at the color, as abrupt changes often correlate with a change in climate. The sediment's chemical composition can be analyzed to look at concentration of oxygen and carbon isotopes, which are also known to change depending on climate conditions. The specific microfossil content can also indicate the climates that existed as each layer formed, since specific microfossils have preferred environments.

Figure TE-1. Sediment core from site 1262, which was taken from the southern Atlantic Ocean.



Credit: IODP, **http://www-odp.tamu.edu/publications/208_IR/VOLUME/CHAPTERS/IR208_03.PDF**

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**
- **How Do You Measure a Core?**

Lesson specific

- **Arctic coring during Expedition 302**
- **Deepwater drilling in the Arctic Ocean's permanent sea ice**
- **Ice Coring (with Videos)**
- **Creating Classroom Ice Cores**
- **Geologic Time Scale**

Initial Inquiry

1. Show **an image** comparing the arctic during the last ice age versus today. How has the north polar region changed in the last 12,000 years? Why do you think this is?

Suggested Response: There was more ice during the ice age. Students may offer explanations such as: temperatures were colder then, or continents may have been closer to the poles, so more ice was able to accumulate on the continents.

2. Show students **an image of an ice core** taken from the west Antarctic Ice Sheet, then show two model ice cores that have been constructed ahead of time. It is best if the two models are viewed right next to each other.

   a. What do you notice? Make observations of the core image and models.

   b. Suggested Response: Will vary but may include there are distinct layers; the layers are different colors and thicknesses; sediment and other debris are visible in some layers.

   c. Why do you think there are layers?

Suggested Response: The ice was not all deposited at the same time. The layers are from different time intervals.

   d. How might we learn more information from the cores?

Suggested Response: Will vary but may include cutting the cores in half or into sections (especially where layers meet) to see inside; using a hand lens or microscope to see the ice core contents magnified; melting the ice to collect the sediment or fossils within the core; testing the chemistry of the ice.

   e. The two models represent ice cores taken from different locations. What conditions could have caused the layers and the ice cores to be different?

Suggested Response: Temperature changes could cause more or less ice to form in a particular timeframe. The amount of precipitation also affects how much ice forms. Other environmental conditions, such as erosion or the exact location of where the ice forms could affect what gets trapped inside it (sediment and/or fossils). For example, the dark band at the bottom of the Antarctic Ice core image is volcanic ash from an eruption that took place elsewhere on Earth.

f. What similarities do the two ice cores share?

Suggested Response: They contain the same layers, but in different places. Students may want to shift one of the cores up or down to get the layers to line up and may notice that the patterns now match.

g. How do you think cores retrieved from glaciers could be used to make inferences about past climate?

Suggested Response: Students will likely describe that past environments can be inferred from sediments and organisms trapped or preserved within the ice, showing a record over time. Students might also say they don't exactly know how the cores can help but that they probably could be used to tell scientists something about how cold it was or how much ice there was at different times in the past. Introduce students to the concept that the chemistry of the sediments can help tell us about the atmosphere at the time the sediment was deposited.

h. Ice coring is done by researchers from organizations such as the **International Partnership in Ice Core Science** and the **United States Antarctic Program**. The International Ocean Discovery Program takes sediment cores from the ocean floor. Show a **sediment core taken from Expedition 151**, which sampled sediment on oceanic crust within the Greenland Sea, off the east coast of Greenland. Could cores from the ocean floor also be used to infer past climate? Why or why not?

Suggested Response: Cores taken from the ocean floor contain layers of sediment deposited at different time periods, much like the layers in ice. The layers of sediment from an ocean core can also show change over time by looking at the minerals, microfossils, and chemical composition of the sediment to infer what the climate was like.

ANNOTATED STUDENT ACTIVITY

Objective(s)/Outcome(s)

Students will be able to use data to describe patterns about regional climate change and make an argument for the need to collect more data from the Arctic.

Materials

- highlighters or markers

Background

Earth's climate is warming at a very fast rate, which we know from data that has been collected about past climate change. We see temperatures are rising much faster now than they have at any other time in Earth's history. Much of this data comes from the analysis of sediment cores taken from the oceans. However, very few drilling sites have been chosen in the Arctic Ocean compared to other oceans.

Most ice on Earth forms at the poles because of the extreme climate conditions. Sediment cores taken from the Arctic may give us new insights into Earth's climate history. The change in the size of glaciers over time is of special interest to scientists. Keep this in mind as you proceed through this lesson, in which you will propose specific drilling sites within the Arctic.

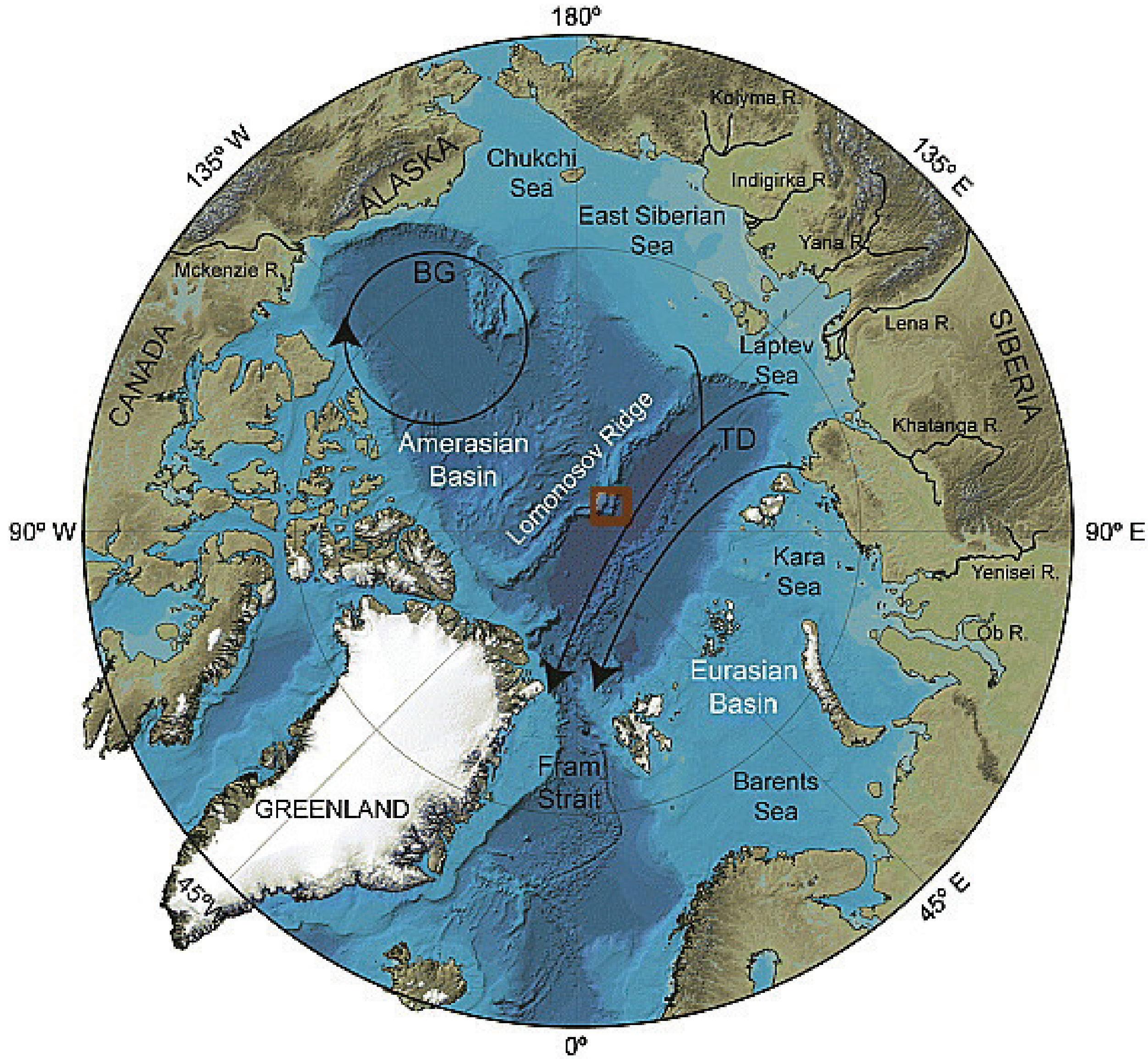
Activity

> Teacher notes: This activity asks students to analyze 5 different types of data in Part 2 (labeled 2A–2E), which increases in difficulty from A to E. It is recommended that students work in groups and that each group analyze one set of data in Part 2. Groups will then present their findings to the whole group before moving on to Part 3. Alternatively, have all groups complete all Part 2 sections (2A–2E).

Part 1

1. Figure 1 is a map of the Arctic Ocean. Observe and discuss with your group the different attributes of the map, such as the different colors/shades, arrows, and labels on the map.

FIGURE 1. A VIEW OF EARTH FROM ABOVE THE ARCTIC OCEAN.



Credit: Martinez et al., 2009, **https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2007PA001567**

Teacher Note: A whole-class discussion may be beneficial if students are not as familiar with reading maps. The numbers along the outside are the coordinates to be able to locate specific sites on the map. This is a bathymetric map (**original** with key and no markings), where different shades of blue indicate water depth. As depth increases, the shade of blue gets darker. Brown areas are land, and white areas are continental glaciers. The arrows represent the direction of flow of two ocean currents. The entire ocean can be considered a basin, but some specific low points are labeled as basins on the map. Ridges are mountains and volcanoes that form high points on the ocean floor.

2. There are hundreds of sites in the Arctic Ocean where sediment cores have been taken. Cores can give insight into past climates. Examine the view of Earth from above the Arctic Ocean (Figure 1) and discuss with your group where you would want to take samples from and why. Mark a few locations on the map with a marker.

Analysis

1. What factors shown on the map did you consider when choosing a drilling site? Why did these affect your decision?

> Responses will vary but may include, water depth, distance to shore, and ocean currents.

2. Did you consider other factors that were not shown on the map? If so, which ones? If not, list a couple factors that you might now consider.

> Responses will vary but may include, weather conditions/time of year, how much ice is present in the water, and distance between the proposed drill sites and areas that have already been sampled.

Part 2

1. Complete the Part 2 handout(s) you were assigned, recording data as you work.

2. Complete the Analysis questions associated with your data.

> **Teacher Note:** If each group is completing one section (2A–2E), give instructions on how they will be presenting their findings to the other groups. It may be helpful for students to construct a data table to organize their data and the findings they want to present, such as the one suggested here. It includes examples of some of the findings students might share:

Group	Description of Data	Recommendation based on Data Analysis
2A	Video from the crew and scientists who take ice cores, discussing the challenges that occur during expeditions.	Factors to take into consideration: weather conditions (cold, wind, storms), the amount of sea ice, the difficulty of cutting through the ice (especially deeper cores), cost, time, keeping the cores frozen on the ship/plane and in storage facilities as well as when they are sent to institutions for analysis. The benefits of collecting ice cores include collecting data on temperature records (from analyzing water molecules frozen within the ice) and changes in atmospheric gas concentrations over time. Volcanic ash layers are also well-preserved in glaciers, and these layers can be compared between cores from different sites.
2B As group 2B shares their data, it may be helpful to have group 2E also share what they observed in terms of color changes within the cores.	Image of a sediment core taken from the Arctic. Thick layers of tan versus gray occur throughout the core, and most layers contain slightly darker bands within them. One small section of gray sediment has very large rocks within it.	The color or shade of the sediment indicates changes in climate when the sediment was deposited (although this group may not be able to draw exact conclusions about what the shades mean). Ice Raft Debris (IRD) are large pieces of sediment or rocks dropped from melting glaciers or icebergs. Their presence in a core indicates a period of warming, as the IRD was dropped by melting glaciers.

2C	Images of the Lomonosov Ridge. One image is a 3D view of the ridge. The second image is of the sediment layers on the ridge that shows possible drill sites.	Students will likely conclude that site 4 is the best core to take, since it is the deepest. This would provide the greatest number of layers and therefore the most data on past climates.
2D After this group presents, revisit the image from group 2C and ask students to estimate the time period of the oldest sediment from the bottom of the Lomonosov Ridge, given that it is ~450 m deep.	Graph of sedimentation rate. The steeper the line, the faster sedimentation occurred, forming a thicker layer.	Taking cores from many areas can allow for comparison of sedimentation rate from different areas of the seafloor. Conclusions can be drawn about what can cause changes in sedimentation rate and the thickness of sediment layers. Provide students **this geologic time scale** to use when estimating the age of 450 m deep sediment. Students should estimate that sediment from 450 m down would be older than those shown on the graph, which goes to the Paleocene Epoch (between 56 and 66 Ma). On the graph, "Maa" is the Maastichtian Age, and "Campan" is the Campanian Age, both part of the late Cretaceous Epoch. Depending on sedimentation rate, the 450 m deep sediments could be these ages (66–83.6 Ma).
2E After this group presents, have students use the information to determine the time period during which the most rapid climate change occurred.	Images of sediment cores taken from the Arctic were lined up with a graph showing changes in carbon content over time. Higher levels of carbon correlate with lighter sediment color.	Analysis of sediment colors can reveal changes in temperatures over time. The more cores that are collected, the more these color changes can be correlated with each other to show how widespread climate events were. More cores are needed from the Arctic to show if the poles were affected to the same extent and in the same way as other areas when there were changes in Earth's climate.

Part 3

1. Share your findings with other groups.

> **Teacher Note:** If groups completed one section, each group should share their section with the class. Alternatively, students could share with other groups in a jigsaw arrangement. If groups completed more than one section, go over each section as a class, having individual students share their findings to discuss options for recommendations for where to drill in the Arctic.

2. Consider each of the data sources and findings in Part 2. What types of data were analyzed? How might the findings influence the types of locations where you would want to drill?

3. Revisit Figure 1. Use a different color marker to indicate if there are any new locations of where you would take core samples. Use a pen to put an X through any locations where you have no longer decided to take core samples. Be sure to have reasoning for your changes.

Synthesis

1. What is the benefit of taking cores from many locations around the Arctic?

Suggested Response: Different areas will vary in their sediment content and thickness. This can provide information on local environmental changes. There will also be consistency in layers that were caused by regional or global changes, showing how different areas were affected by large events that caused a change in sedimentation rate or type over a wide area; these layers can be correlated.

2. Determine the top three locations your group would choose as drilling sites to obtain sediment cores from the Arctic Ocean and identify them on the map. Compile all the evidence from this activity to write an argument as to the importance of drilling at these sites and what information you would hope to obtain by doing so.

Extensions

1. Read the following research abstract from the peer-reviewed scientific journal Nature on the Arctic record of the Paleocene/Eocene Thermal Maximum (PETM).

Subtropical Arctic Ocean temperatures during the Palaeocene/Eocene thermal maximum.

The Palaeocene/Eocene thermal maximum, 55 million years ago, was a brief period of widespread, extreme climatic warming that was associated with massive atmospheric greenhouse gas input. Although aspects of the resulting environmental changes are well documented at low latitudes, no data were available to quantify simultaneous changes in the Arctic region. Here we identify the Palaeocene/Eocene thermal maximum in a marine sedimentary sequence obtained during the Arctic Coring Expedition. We show that sea surface temperatures near the North Pole increased from 18°C to over 23°C during this event. Such warm values imply the absence of ice and thus exclude the influence of ice-albedo feedbacks on this Arctic warming. At the same time, sea level rose while anoxic and euxinic conditions developed in the ocean's bottom waters and photic zone, respectively. Increasing temperature and sea level match expectations based on palaeoclimate model simulations, but the absolute polar temperatures that we derive before, during and after the event are more than 10°C warmer than those models predicted. This suggests that higher-than-modern greenhouse gas concentrations must have operated in conjunction with other feedback mechanisms—perhaps polar stratospheric clouds or hurricane-induced ocean mixing—to amplify early Palaeogene polar temperatures.

From: Sluijs et al., (1 June 2006). Nature 441, 610-613 doi:10.1038/nature04668

a. Highlight any words in the passage that are new to you. Determine their meaning from context, if possible. Underline words that are still unclear and discuss possible meanings with your group.

Teacher Note: If time allows, discuss the abstract and vocabulary with students. It may also be helpful to provide students with a **sea surface temperature map.**

b. List two observations (data) used in this research study.

Suggested Response: Sea surface temperatures, sea level, and the amount of dissolved oxygen in the water (anoxic and euxinic conditions).

c. List two interpretations (hypotheses) made in this research study.

Suggested Response: 1. Warming occurred during the Paleocene/Eocene thermal maximum due to an increase in the concentration of greenhouse gases in the atmosphere.

2. Based on data, the initial hypothesis was revised to: Atmospheric greenhouse gases are not enough to explain the extreme temperature changes, so other factors, such as storms, ocean mixing, etc., contributed to the PETM.

d. How were the surface water temperatures of the Arctic Ocean different during the PETM?

Suggested Response: They were 18 to 23oC warmer than expected (based on averages over time).

e. Where do you think you would find ocean waters of this temperature today?

Suggested Response: Near the equator, which gets more direct sunlight that causes the atmosphere, water, and land to be warmer than at the poles.

2. While the primary objective of the Arctic coring expedition was to recover cores to reconstruct a paleoceanographic history of the central Arctic Ocean, a secondary objective was to sample the bedrock under the sediment cover to decipher the tectonic history of the Lomonosov Ridge, which is a divergent plate boundary. What types of rocks would you expect to find within the bedrock of the Lomonosov Ridge since it is a divergent plate boundary?

Suggested Response: Divergent boundaries are where new crust forms as material from the mantle rises as magma at the ridge between two plates. This magma solidifies into igneous rock. Given that the Lomonosov Ridge is forming new oceanic crust, the igneous rocks forming are likely mafic or ultramafic, including basalt and gabbro.

HANDOUTS

Part 2A

1. Drilling a long core into the sea floor of the Arctic Ocean poses some unique challenges but also has many benefits. Learn what these are and more by watching the video on the National Ice Core Facility: **http://bit.ly/3LoVjyi**. Write down some notes about what was discussed in the video and any terms with which you are unfamiliar.

2. Discuss with your group the challenges to coring in the Arctic (either ice coring or oceanic coring).

> **Suggested Response:** Will vary but will likely include extreme weather conditions and/or ice blocking the ship's passage into the Arctic. Keeping the cores frozen and in-tact until they get them to the repository may also pose a challenge.

Analysis

1. Consider data/evidence of past climate change that scientists can get from ice cores. How might this data be applied to understand current changes in global temperature and atmospheric conditions?

> **Suggested Response:** The rate of change today can be measured and studied in real time, but data from the cores can tell us the rate of past change so we can make comparisons and determine that the changes occurring today are much faster than at any other time in Earth's history.

2. What do you think two of the most challenging issues scientists and the crew of the coring ship may face when trying to drill sediment cores near the poles? What might scientists and/or the Expedition team do to address these challenges?

> **Suggested Response:** Will vary but could include navigating around icebergs, cold and weather conditions, having enough supplies for crew to handle rough conditions, equipment needed for drilling is large/tough to transport, and others.

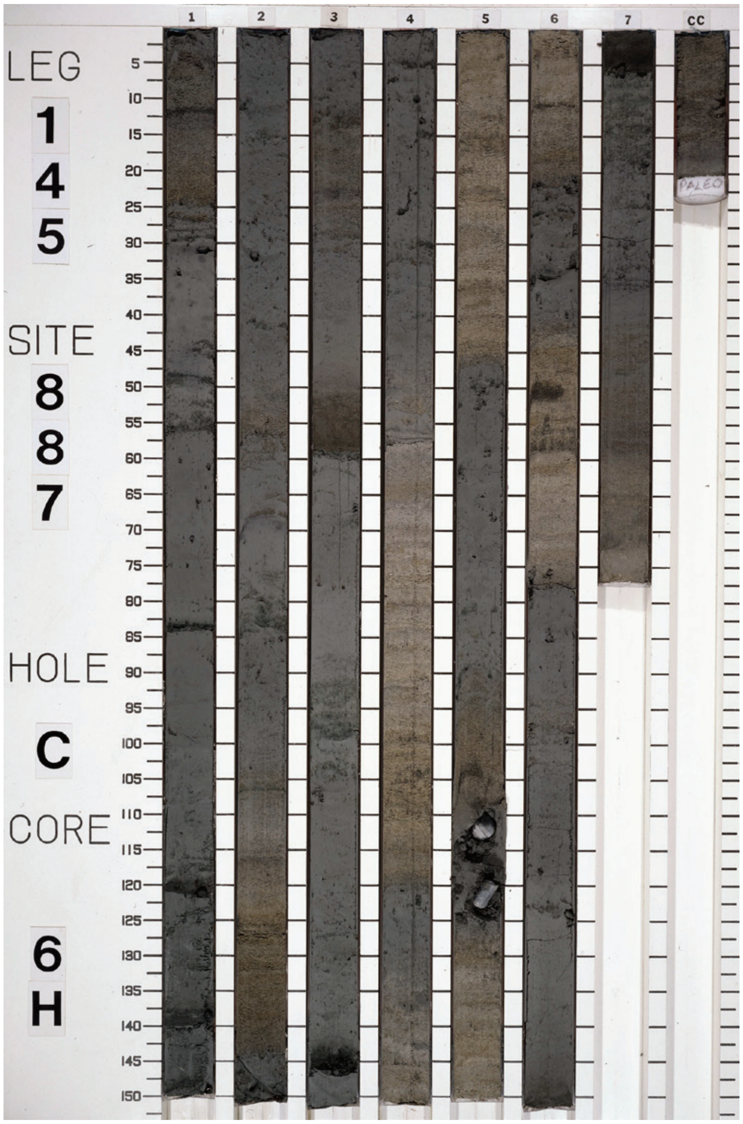
3. During what time of year would you plan an Expedition near the poles? Why?

> **Suggested Response:** Will vary. Some may argue that warmer times of the year would pose fewer challenges in terms of weather conditions and amount of sea ice, but others may argue that more data might be obtained as more ice is formed during colder months.

Part 2B

1. Examine the sediment core in Figure 2 and consider what the different colors and thicknesses may represent.

FIGURE 2. CORE 6H FROM SITE 887 OF EXPEDITION 145, TAKEN FROM THE ARCTIC OCEAN.



Credit: Rea et al., 1993.

2. One of the pieces of evidence used to infer the existence of past glaciers is rock fragments, pebbles, unexpectedly coarse mineral grains, and even sand grains in marine sediments. Such rock fragments and mineral grains are the products of weathering and erosion on land but are too large or heavy to have been transported to the sea by wind. Their location on ridges also rules out the possibility that these were transported offshore by river systems and related underwater debris flows. By process of elimination, these large sediments are interpretated to have fallen off ice rafts floating in the ocean and are known as Ice Rafted Debris (IRD).

a. Examine Figure 2. Identify and circle the rock fragments, pebbles, and other debris present in the Arctic core. How many meters under the surface was the IRD discovered?

> **Suggested Response:** The rock debris is found within the between 110 cm and 125 cm mark of the 5th segment of the core. The total depth of this IRD is approximately 710–725 cm (7.10–7.25 m).

b. Discuss with your group how the presence of rock fragments might provide insight on climate conditions at the time the fragments were deposited.

> **Suggested Response:** Student hypotheses will vary. It is likely that more rock debris would be found in times of global warming, as glaciers break, forming more ice rafts, which, as they melt, will drop their large sediments into the water.

c. Which color (light tan or dark gray) do you think represents deposition during a warmer climate and which during a colder climate? Why do you think so?

> **Suggested Response:** The sediment is within a darker color in the core (dark gray), and if more IRD occurs in time of warming, a darker color likely occurs when there are higher temperatures.

Analysis

1. Would you expect to find IRD in sediment cores taken in the Atlantic, Pacific, Southern, and/or Indian oceans? Why or why not?

> **Suggested Response:** IRD will be most common in oceans where glaciers and icebergs exist, meaning the Southern and Arctic Oceans. Due to expansion of glaciers during past ice ages, as well as plate movement, however, it is possible to find IRD in the sediment of other oceans, though it is much less likely.

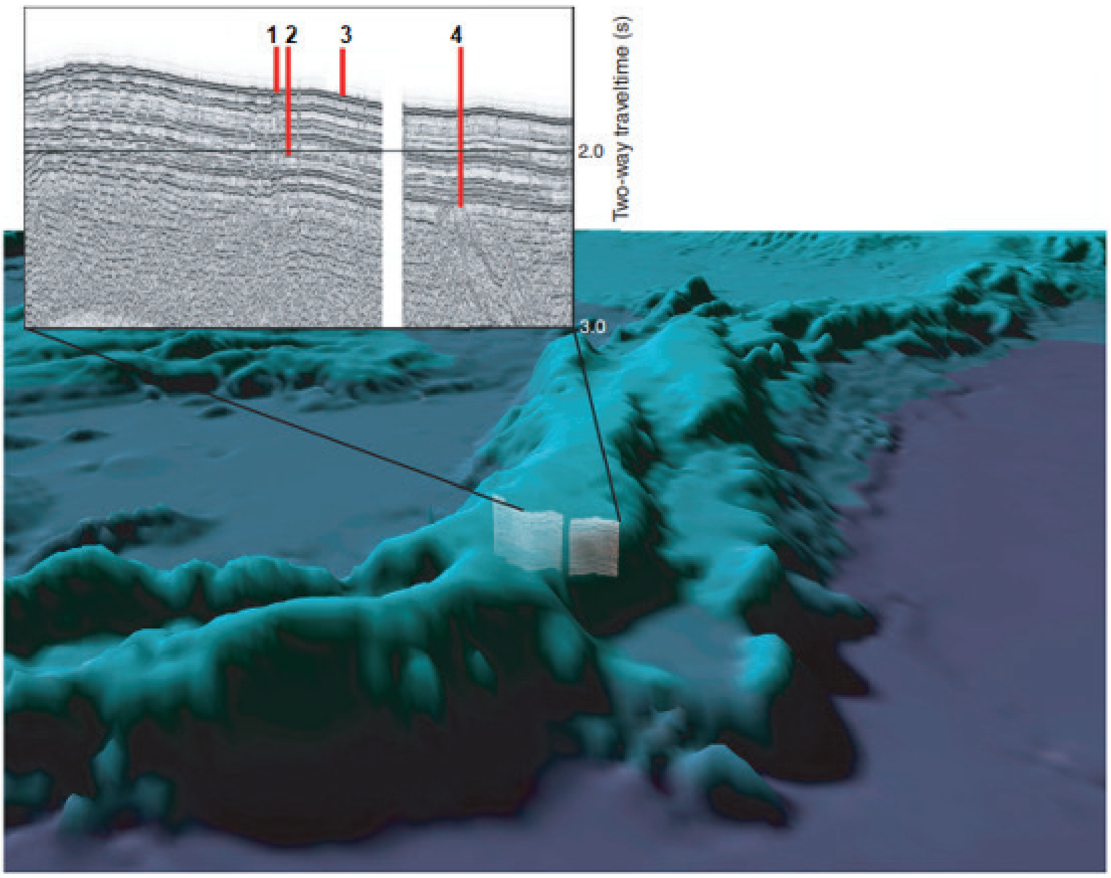
2. What does the discovery of IRD tell us about past climates? Consider if IRD would be more common during an ice age or during a period when ice is melting.

> **Suggested Response:** As ice melts, it will drop its IRD, which will then be deposited in the sediment at the bottom of the ocean. IRD can reveal times of warming temperatures.

Part 2C

In March 2002, a team of scientists led by Jan Backman from Stockholm University proposed to drill five sites along the ridge crest of the Lomonosov Ridge in the central Arctic Ocean (red square on Figure 1). Some information that helped this team select these particular sites were estimates that suggested sediments along this part of the ridge were ~450 m thick on top of harder basement rock (thick, metamorphic or igneous rocks that are directly above the mantle). One of those profiles is shown in Figure 4 with drill site locations and depths indicated.

FIGURE 3: SEISMIC SURVEY SHOWS SEDIMENT LAYERS ON OCEAN FLOOR.



Credit: Modified from **http://publications.iodp.org/proceedings/302/EXP_REPT/CHAPTERS/302_102.PDF.**

1. Identify the basement rock in the black and white profile. How did you determine this?

> **Suggested Response:** The basement layer is where the distinct black and white layers end and there is a change over to more consistent gray layers. Each gray layer likely represents the regular deposition of magma forming new crust. The sediment layers, however, are different colors due to different sediment types and different thicknesses due to differing sedimentation rates over time.

2. Discuss with your group if you think this Expedition would provide useful information on past climates.

> **Suggested Response:** Students will likely respond that this expedition will help understand past climates, as there are many layers of sediment on the ridge that have not yet been studied.

3. Discuss which of the four drill sites on Figure 4 you would be in favor of and why.

Suggested Response: Will vary, but groups should consider the depth when making an argument for drill sites. Two of the four drill sites are relatively shallow; deeper cores are likely to provide more information on past climates.

Analysis

1. Describe a benefit and one potential drawback of drilling on the Lomonosov Ridge versus choosing one of the ocean basins (such as the Amerasian Basin).

Suggested Response: Ridges are high points in the ocean floor (mountains or volcanoes). These sites may be easier to drill, as they are not as deep. It may also be easier to drill a deeper core. Drawbacks include the fact that sediment collects more easily at low points (basins), so there may not be as much sediment on the ridge, or it may be a different composition that in surrounding basins, since coarser sediment may not be found at high points. Also, ridges also indicate areas of change, such as those surrounding divergent plate boundaries, making it more likely that sediment on ridges may be interrupted or destroyed more often than in stagnant basins. Lastly, ridges being high points mean they may be more affected by ocean currents that can erode sediments off the ridge.

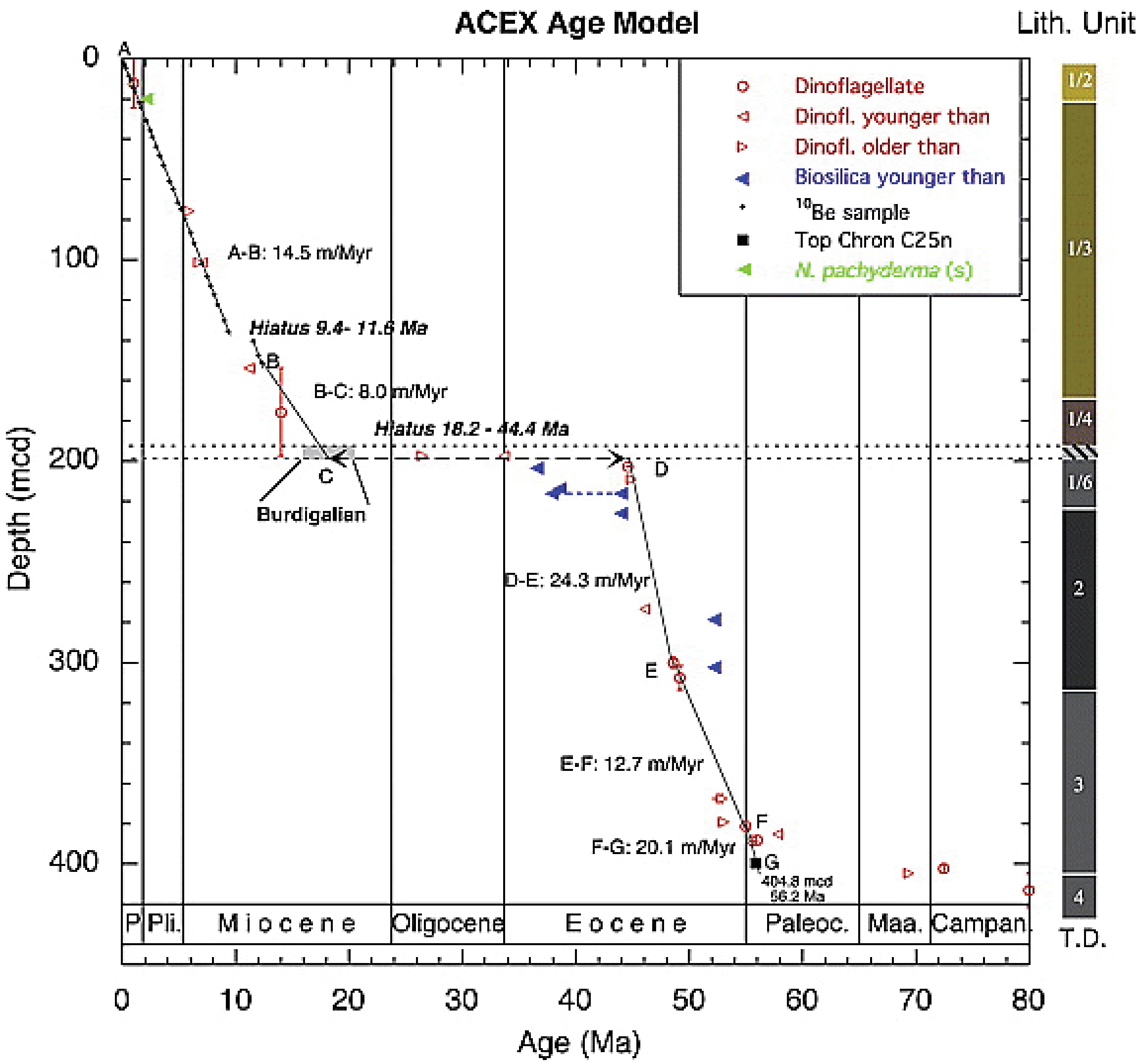
2. The oldest sediment cores taken from the Arctic date back to the Mid-Pleistocene. Use the geologic time scale (**http://bit.ly/40igN3J**) to determine the approximate age (in Ma).

Suggested Response: The mid-Pleistocene was approximately 1.8 million years ago.

Part 2D

1. The Arctic Coring Expedition (ACEX) was the first drilling expedition to recover deep cores from the high Arctic (near the North Pole). The ACEX team collected data on the sedimentation rate, which was used to construct Figure 3. This graph is a plot of depth in the core versus age of the sediment. It provides a useful record of sedimentation history in this area. The y-axis on Figure 3 represents core depth for the ACEX cores in meters composite depth (mcd). The x-axis is the age of the sediment labeled as the geologic time period when the sediment was deposited.

FIGURE 4. SEDIMENTATION RATE DURING DIFFERENT TIME PERIODS.



Credit: **https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2007PA001476**

a. Examine and compare lines A-G, which display data from different core sections. Discuss what you notice about the different lines with your group.

Suggested Response: The lines have different slopes.

b. One aspect you may notice is that the slopes of the lines are different. A steeper slope indicates a higher sedimentation rate. On the graph, identify the line (A-G) which has the highest sedimentation rate (steepest slope), and circle the corresponding time period on the x-axis.

Suggested Response: The line between D and E is the steepest, indicating the highest sedimentation rate. This occurred during the Eocene.

2. To the right of the figure is a stratigraphic column indicating the major boundaries between rock layers within the core.

   a. Put a star next to the thickest rock layer within the core.

   b. Put an X next to the thinnest layer.

Suggested Response: The second sediment layer (labeled 1/3) is the thickest. The layer between ¼ and 1/6 is the thinnest.

Analysis

1. How do the sedimentation rates correlate to the thickness of each layer?

Suggested Response: A higher sedimentation rate corresponds to thicker layers, since more sediment was deposited over time. The flat line at the middle of the graph (the longest hiatus) correlates with a very thin layer, since deposition was not occurring or was not fast enough to offset erosion that may have been occurring at this time.

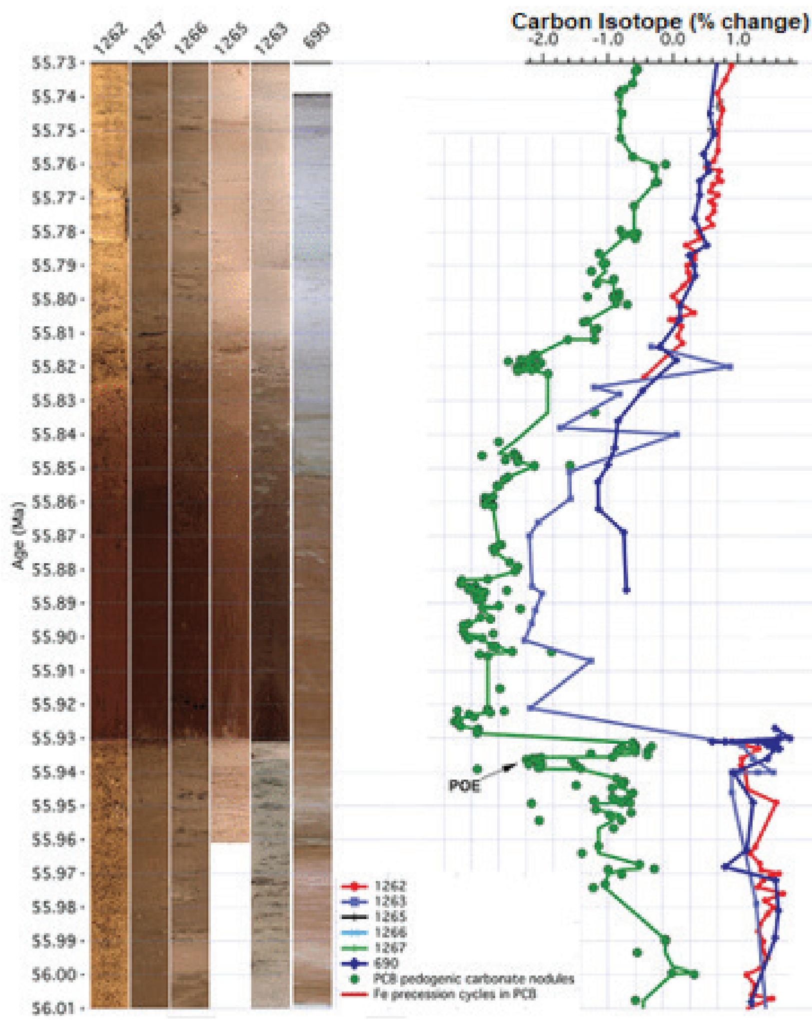
2. A hiatus (unconformity) in a sedimentary sequence can be caused by several factors but always results in "missing" data. Consider the location, water depth, and other factors to propose a hypothesis for what may have caused the large hiatus identified in the ACEX cores. What evidence would you look for to support your hypothesis?

Suggested Response: May vary but could include the ocean currents over the ridge eroding the sediment layers or volcanic activity at the ridge destroying or covering the sediment layers. Evidence of erosion could be uneven layers; the currents would not have affected all areas equally, resulting in some areas with thicker sediment and other areas where erosion thinned some layers. Evidence of magma eruptions from the ridge could be layers of igneous rocks or igneous intrusions crossing through the sediment. Contact metamorphism could also have occurred in the sediments that were heated by magma.

Part 2E

Examine Figure 5 which shows images and data of five cores taken from the southern Atlantic Ocean (1262–1263 and 1265–1267) and one core taken from the Southern Ocean (690). Each of these cores was analyzed for its carbon content.

FIGURE 5. CORES 1262–1263 AND 1265–1267, TAKEN FROM THE SOUTHERN ATLANTIC OCEAN. CORE 690 WAS TAKEN FROM THE SOUTHERN OCEAN.



Credit: Modified from Westerhold et al. (2018)

1. Look at the color of the sediment cores. Describe what you see.

Suggested Response: Each core has three distinct sections. The bottom portions are light in color, and most are mottled/striped/spotted. At 55.93 Ma, there is a rapid change in color and the cores are darker; these areas seem to have less spots and striping. Then each layer fades back to a lighter sediment (although at different times); some go back to being mottled, while some are not as striped as they were before the shift to a darker sediment.

2. Look at the graph of the change in carbon. Describe the three distinct trends on the graph.

Suggested Response: Between 56.01 Ma and 55.93 Ma, there was a consistently positive change in the percent of carbon. At 55.93 Ma, there was a sharp drop in carbon. Carbon then started to steadily increase again between 55.92 Ma and 55.73 Ma.

Analysis

1. How do the changes in the color of the cores correlate with the trend in carbon content?

Suggested Response: Lighter shades of sediment line up with more carbon content (positive changes). Darker sediment correlates with periods of lower carbon content (negative change).

2. Higher levels of carbon in the sediment correspond to colder time periods.

   a. When was the coldest time period (give a range, in Ma)?

Suggested Response: 56.01 Ma to just before 55.93 Ma and 55.82 Ma to 55.72 Ma

   b. When was the warmest time period?

Suggested Response: 55.92 Ma to 55.87 Ma

   c. When was climate change most rapid on this graph? How can you tell?

Suggested Response: The fastest change occurred between 55.93 Ma and 55.92 Ma, when the slope of the line was steepest. This was the most change in carbon over the shortest period of time.

3. Use the geologic time scale (**http://bit.ly/40igN3J**) to name the Era, Period, Epoch, and Age in which the warmest time period shown on the graph occurred.

Suggested Response: Cenozoic Era, Paleogene Period, Eocene Epoch, Ypresian Age

CLOSURE

1. Exit Ticket: How did this activity model scientific practice?

2. Exit Ticket: Look at the map of IODP Expeditions. Where has most drilling taken place? Explain whether or not you think scientists should also look into more drilling locations near the Antarctic (Southern Ocean).

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