Layer by Layer: Ocean Sediment Reveals Earth's Past Climates

LESSON SUMMARY

First, students will use a self-created map of important events in a year of their own life as an analogy to understand that ocean sediment cores record important climate changes throughout Earth's history. Then, students will analyze and interpret data of climate proxy variables that show a pattern of climate warming and cooling. Finally, students will hypothesize why climate has had a pattern of warming and cooling in the past.

SCIENTIFIC OCEAN DRILLING

Standards and Dimensions

NGSS: HS-ESS2-2

Science Engineering Practices: Analyzing and Interpreting Data, Developing and Using Models

Cross-Cutting Concepts: Stability and Change, Cause and Effect

Disciplinary Core Ideas: ESS2.A Earth Materials and Systems, ESS2.D Weather and Climate, ESS3.D Global Climate Change

Connections to 2050 Science Framework

Strategic Objectives: Earth's Climate System, Feedbacks In The Earth System and Global Cycles of Energy and Matter

Flagship Initiatives: Ground Truthing Future Climate Change

Enabling Elements: Broader Impacts and Outreach

Ocean Literacy Principle(s)

OLP 3: The Ocean is a major influence weather and climate. (3C, F)

Suggested Time

90-120 minutes

Preparation of Materials

For the Teacher:

- A way to collect student summaries of each graph (google doc, slide or poster paper).
- A way to collect whole class discussion of what the variables support (google slide/poster paper).
- Any extension materials prepared.

Per student:

- Map for Year in Your Life
- Copy of each graph/data table for each climate variable for each student (in a packet) to write/annotate on.
- Copy of background info connected to each climate variable for each student (in a packet) for each student to write/annotate on.
- Annotation materials (sticky notes, pens/pencils, highlighters)

Acknowledgments

Authors: Melisa Dettbarn and Lindsay Mossa, based on "Inquiry into High-Resolution Ice Core and Marine Sediment Records" by Kristen St. John and Mark Leckie.

Scientific Acknowledgment:

Expedition: Leg 198 was conducted for the purpose of sampling in the Atlantic Ocean to collect stratigraphic data to understand climate change patterns.

Data Source: Shipboard Scientific Party, 2001. Extreme Warmth in the Cretaceous and Paleogene: A Depth Transect on Shatsky Rise, Central Pacific. **http://www-odp.tamu.edu/publications/prelim/198_prel/198PREL.PDF**

Developed in collaboration with the American Geosciences Institute

BACKGROUND FOR THE INSTRUCTOR

Milankovitch cycles refer to the long-term changes in Earth's climate that are driven by variations in its orbit around the Sun. Named after the Serbian scientist Milutin Milankovitch, these cycles include three main components: eccentricity, axial tilt, and precession. Eccentricity describes the shape of Earth's orbit, which varies from more circular to more elliptical over a cycle of about 100,000 years. Axial tilt, or obliquity, refers to the angle of Earth's axis relative to its orbit, which changes over a 41,000-year cycle. Precession, the wobble in Earth's rotational axis, occurs over a 26,000-year cycle. Together, these cycles influence the amount and distribution of solar energy Earth receives, leading to periodic shifts in climate, including the advance and retreat of ice ages.

Ocean sediment cores provide valuable evidence to support Milankovitch cycles by preserving records of past climates. As sediments accumulate on the ocean floor, they trap microfossils, isotopes, and other materials that reflect the environmental conditions at the time of deposition. By analyzing the composition of these cores, scientists can identify patterns that correspond to the timing of Milankovitch cycles. For example, variations in the ratio of oxygen isotopes, color of the sediment in the cores, percent light reflectance, and bulk density of the sediments can indicate changes in global ice volume, which is directly related to the cyclical changes in Earth's orbit. Thus, ocean sediment cores serve as a crucial tool for understanding how Milankovitch cycles have influenced Earth's climate over millions of years.

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

Teachers/Students will need to have background information/learning on:

- **Milankovitch Cycles**
- **Ice rafted debris (IRD)**
- **Paleoclimatology: How Can We Infer Past Climates?**
- **Paleoclimatology: the Oxygen Balance**
- **Colors of sedimentary rock**

Initial Inquiry

1. Mapping a year of your life.

    a. Start in January and go to December. Label 4 events that happen over the year for you. Ex: end of school year, start of summer, start of a sport, big vacation, birthday, start of school, holidays.

- **b.** For each of these 4 changes, describe how someone would be able to tell this change happened to you. Did the clothes you wear change? Did your schedule change? Did your activities change? Did you do something special to mark the event? Add these descriptions alongside your timeline where you marked the location of these changes as annotations.

- **c.** Make a connection to how core data can show important events in the history of the earth such as warming/cooling.

2. Connect this activity to the idea that Earth has also changed over its history. Introduce that ocean sediment cores are a place to look for data about past climate changes.

ANNOTATED STUDENT ACTIVITY

Objective(s)/Outcome(s)

Students will be able to:

1. analyze and interpret data taken from core samples of the sea floor to identify patterns.
2. draw conclusions from the patterns in the data about changes in climate periods where the data was sourced.
3. postulate the cause of the climate changes as evidenced from the patterns in the data.

Materials

- copies of each handout to annotate
- computer with internet access

Background

Ocean core sediment data offer a fascinating glimpse into Earth's climate history, revealing how the planet's climate has shifted over time. Foraminifera fossils, tiny marine organisms found in these sediments, are key indicators of past ocean temperatures and ice volume. By analyzing the oxygen isotopes in these fossils, scientists can reconstruct past climate conditions. When glaciers and ice sheets melt, they release freshwater into the oceans, which carries with it terrestrial sediment that deposits on the ocean floor and provides evidence of past climates.

Ice rafted debris, which consists of rocks and sediments carried by floating ice, further enhances our understanding of past climates. When large ice sheets break apart, they release debris that settles into ocean sediments. By studying these layers, scientists can track periods of intense ice activity and correlate them with Milankovitch cycles—long-term changes in Earth's orbit and axial tilt that influence climate patterns. These cycles, in combination with sediment data, help us understand significant climate events such as glaciations and interglacial periods, giving insight into how Earth's climate system responds to both natural and potentially human-induced changes.

Activity

1. Read about **Milankovitch Cycles**, and annotate Figure 1 to describe the factors that contribute to these cycles.

2. Make observations of the Milankovitch Cycle Data Graph. This figure shows how variations in Earth's orbit affect the amount of solar energy reaching the Earth at high latitudes and the observed glacial cycles that have resulted.

   a. Revisit your summary of each variable on the graph (from step 1). The first four variables (precession, obliquity, eccentricity, and solar forcing) on the graph are thought to contribute to the last line, showing periods of glaciation on Earth.

   b. Explain the trend in each of the first four variables. It may help to use a ruler to line up data on each of the graphs. (Note: solar forcing data was determined for 65 °N latitude, which crosses through Northern Canada/Alaska, Southern Greenland, and Northern Europe and Russia, including Siberia. This latitude receives approximately 22 hours of sunlight in summer and 3 ½ hours during winter).

c. How do the trends of the first four variables appear to relate (compare) to the trend of glaciation events? (Note: the gray rectangles denote recognized interglacial periods.)

Teacher Note: It may be helpful to have a class discussion on question 1 before students proceed. If students have not yet been introduced to ocean sediment cores, it may be helpful to discuss how they are collected and the types of sediment common within them.

3. Make observations of the core taken from Expedition 198, which collected sediment cores from the Central Pacific Ocean. This core is Pleistocene in age, which corresponds the data in the graph used in step 1.

    a. Make observations of each graph individually.

    b. Read the following passage about sediment color and how it relates to percent reflectance:

    - The lighter layers of sediment and rocks tend to be dolomites, which are made up of a high percentage of calcareous microfossils. Microfossils tend to be deposited directly from the water column to the seafloor beneath where the organisms lived; significant death of these organisms occurs during times of lower productivity. Darker layers tend to contain more organic material derived from terrestrial environments. As terrestrial glaciers and ice sheets melt, there is increased runoff from the land, leading to an influx of organic sediment into the ocean. This typically correlates with times of higher productivity and less deposition of calcareous microfossils.

    - How does this information change or add to your interpretation of the trends in the data?

    c. Compare each graph to the core.

    d. Finally, compare each graph to each other.

Analysis

1. According to the Milankovitch Cycle Data Graph, what is the cycle of glacial periods (how often do they occur)?

    a. Summarize the trends of the other factors on the graph, relating their trends to the occurrence of glacial periods. How does each factor potentially contribute to the onset of a glacial period?

    b. Do any of the factors seem to have a greater influence than the others on when glacial periods occur? Use evidence from the graph to explain your answer.

Suggested Response: Glacial periods occur approximately every 100,000 years. Note the troughs, although more recent glacial periods have been colder than older ones. For precession, times of glaciation tend to correspond with taller and more consistent intervals between peaks. Because precession is Earth's wobble, this affects the Earth's tilt, which determines solar radiation. More tilt means less direction radiation, means cooling and glaciation events. Relatedly, obliquity is the angle at which the Earth is tilted. Obliquity has the least variation of all the factors, but periods of glaciation seem to have slightly higher peaks in obliquity. Times of greater eccentricity means that as Earth travels its path around the sun, it is slightly farther away and so would get less radiation, which could contribute to cooling and glaciation events. This corresponds with the fact that peaks in eccentricity correlate to glacial periods. All these factors determine the amount of radiation reaching Earth and correlate with the solar forcing data. A higher precession and eccentricity seem to be most directly related to an increase in solar forcing, which occurs during interglacial periods. So, decreases in these factors correlate more with glacial stages than does obliquity.

2. How does the data taken from the core (both visual and numeric) relate to the Milankovitch Cycle data? Do the trends in the core data seem to correlate or contradict the Milankovitch Cycle data?

Suggested Response: The core shows alternating patterns of dark and light. The percent reflectance of the sediment core shows that the lighter the sediment in the core is, the higher the reflectance. Lighter layers have less organic materials in them, as they were formed during colder and less productive periods. These times alternate, much like glacial cycles. When the sediment is darker, it is less reflective, and there is more organic material in it, which means there was more productivity, which is typically associated with warmer times. So the more reflective the sediment, the colder the environment of deposition. These two periods alternate, as occurs in Milankovitch Cycles. The bulk density data is pretty consistent with the color and reflectance; darker sediment has lower reflectance and lower density. This also shows cycles which could support Milankovitch Cycles.

Synthesis

1. Use what you learned from this investigation to summarize why Earth's climate changes in a cyclic manner.

Suggested Response: Because factors like eccentricity and precession/wobble, there are varying amounts of sunlight reaching and being absorbed on Earth. The less energy that reaches Earth, the cooler Earth will be, which can lead to glacial periods. But then the eccentricity and wobble change again, which then increases the solar energy reaching Earth, leading to another warming period. These continue to alternate.

2. The data in this lesson was collected from or interpreted for specific areas (e.g., solar forcing was at 65 °N latitude, and data from one core from the Pacific Ocean). Consider this as you answer the following questions:

   a. How are we limited by data or data collection?

   b. What could impact our abilities to collect data?

   c. What limits our analysis or interpretation of data?

   d. How could we overcome the constraints or limitations of data and data collection?

Suggested Response: While general conclusions can be drawn from data taken from one or a few locations, it may not apply to everywhere on Earth. For example, there are some climate events that occur locally, which means that the changes that occur in some places do not occur everywhere. Data may not be collected from everywhere on Earth due to accessibility, cost, time, and the ability to process large amounts of data. The more data scientists collect, the more sure they can be about their conclusions, especially when making general statements about large areas or Earth as a whole. New technologies may allow us to collect more data or to be able to remotely take data without having to take as many physical samples. This would allow for a wider range of data without as many constraints.

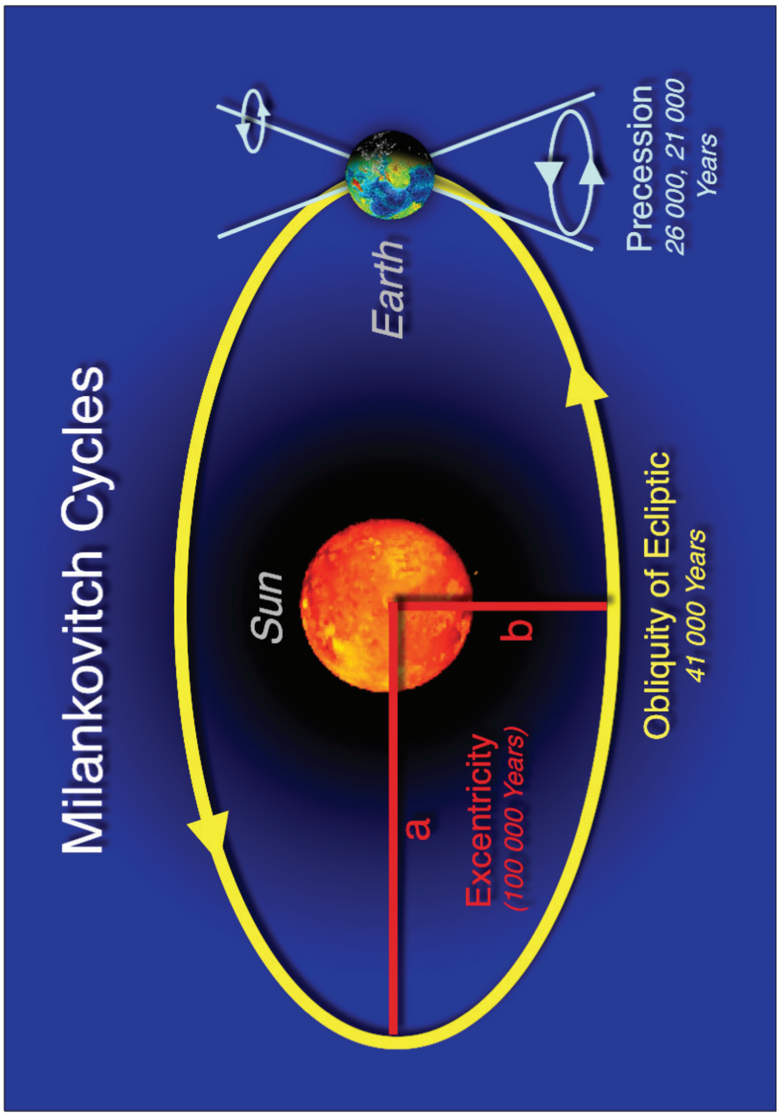
Extensions

1. Research how Milankovitch cyclicity relates to Heinrich events, and together, how they describe significant shifts in climate over Earth's history.

2. The core in this investigation was taken from the Central Pacific Ocean. Where else would you want to collect data from to show that the climate changes indicated in this core were widespread? Explain your reasoning.

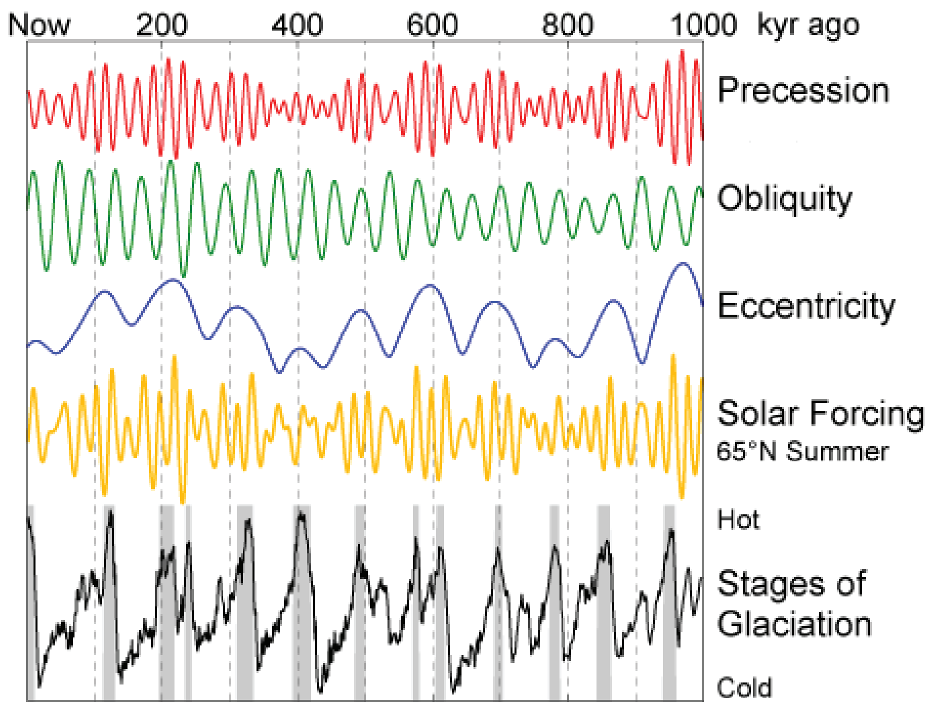
HANDOUTS

MILANKOVITCH CYCLES



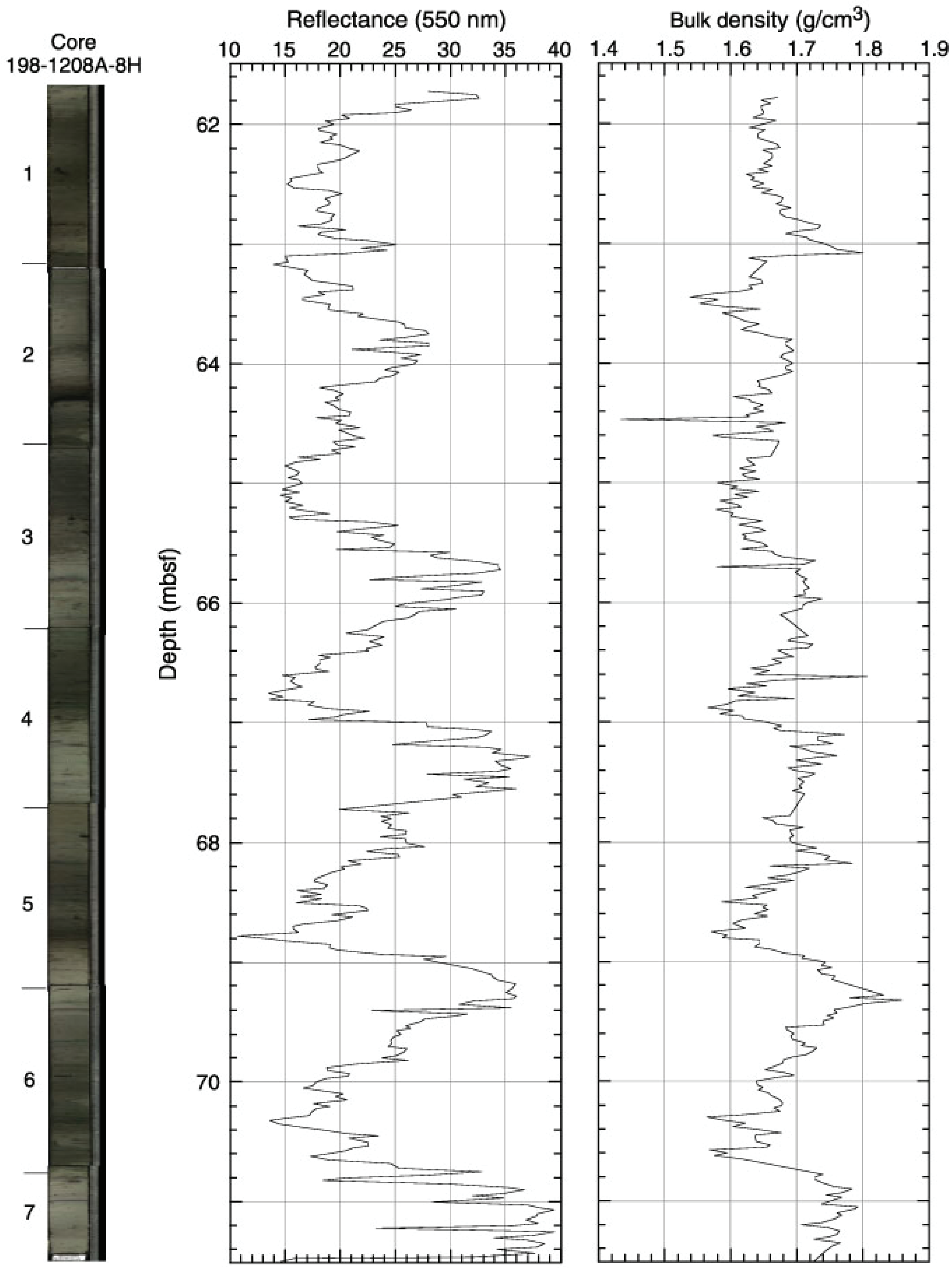
Credit: Hannes Grobe.

MILANKOVITCH CYCLE DATA



Credit: Robert A. Rhodes, Creative Commons Attribution-Share Alike 3.0 Unported.

OCEAN SEDIMENT CORE DATA



Credit: Shipboard Scientific Party, 2002.

CLOSURE

1. Exit Ticket:

   a. Students to complete an exit ticket with the following questions:

      - How can we use data to show evidence of climate changes?
      - What questions do you still have about the topic we studied today?

2. Follow-up lessons:

   a. Other data used to show climate change during past events compared to those occurring today.

References

Hannes Grobe, Alfred Wegener Institute for Polar and Marine Research, CC BY-SA 2.5 <https://creativecommons.org/licenses/by-sa/2.5>, via Wikimedia Commons.

Shipboard Scientific Party, 2002. Site 1208. In Bralower, T.J., Premoli Silva, I., Malone, M.J., et al., Proc. ODP, Init. Repts., 198: College Station, TX (Ocean Drilling Program), 1–93.