Cycles and Sediments
The Layers in Ocean Sediment Cores Reveal Earth's Climate History

LESSON SUMMARY

This lesson has students analyze sediment in ocean cores from the Ross Sea to interpret as evidence of environmental changes. Emphasis is on observing patterns of sediment deposition to understand past regionaland global climate changes. Before doing this lesson, students should understand glacial erosion and deposition during glacial expansion and retreat.

SCIENTIFIC OCEAN DRILLING

Standards and Dimensions

NGSS: MS-ESS2-1, **HS-ESS2-2**

Science Engineering Practices: Analyzing and Interpreting Data

Cross-Cutting Concepts: Patterns; Stability and Change

Disciplinary Core Ideas: ESS2.A: Earth's Materials and Systems; ESS2.D: Weather and Climate

Connections to 2050 Science Framework

Strategic Objectives: Earth's Climate System.

Enabling Elements: Land to Sea.

Ocean Literacy Principle(s)

OLP 1: Earth has one big ocean with many features. (1C)

OLP 3: The ocean is a major influence on weather and climate. (3G)

Suggested Time

45 minutes per part (135 minutes total)

Preparation of Materials

Per Group:

- computer with internet access
- copy of Figures 2–5 (as needed)

Per Student:

- copy of Figure 6

For Teacher Demonstration:

- plastic bin (17" x 11" x 6")
- ice block and cubes (see preparation note)
- sand
- gravel, silt, small rocks
- water
- spray bottle with warm water
- hair dryer (optional)

Teacher Note: Freeze a large block of ice and a few ice cubes with sand/gravel inside them. The blockneeds a large surface area, andyou may want to freeze it in a shallow container layer by layer, alternating ice with sediment types that "tell a story" of its formation.

Build a model ocean in a clear plastic bin with a thin layer of sand on the bottom. Add more sand to one end of the container to make "land". Carefully add water to the "ocean" until it covers the "beach" enough for students to see that the land slopes down into the water.

Acknowledgments

Lesson Contributors: Lindsay Mossa (AGI), based on "Interpreting Antarctic Sediment Cores: A Record of Dynamic Neogene Climate" by Kristen St John, R Mark Leckie, Kate Pound, Megan Jones and Lawrence Krissek.

Scientific Acknowledgment

Expedition: Leg 374 was conducted for the purpose of collecting ocean sediment cores that contain evidence of changes in ice cover in the Antarctic during the Neogene and Quaternary Periods.

Data source: McKay, R.M., De Santis, L., Kulhanek, D.K., and the Expedition 374 Scientists, 2018. *Expedition 374 Preliminary Report: Ross Sea West Antarctic Ice Sheet History*. International Ocean Discovery Program, 374.

https://doi.org/10.14379/iodp.pr.374.2018

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BACKGROUND FOR THE INSTRUCTOR

Understanding the types of sediment found on the ocean floor is crucial for piecing together the story of Earth's climate history. Sediments can vary significantly, and their composition can reveal much about past environmental conditions. For instance, layers rich in microfossils, such as diatoms and foraminifera, often indicate colder climates. These tiny organisms thrive in frigid waters, and their presence in sediment cores suggests that the ocean was once much colder than it is today. By examining the abundance and types of microfossils in various sediment layers, scientists can infer shifts in ocean temperatures and ice cover over time, providing a clear picture of past cold periods.

In contrast, the presence of larger terrigenous sediments—composed of particles eroded from land—can indicate warmer climates. These sediments often result from increased weathering and erosion of landmasses when temperatures rise. During warmer periods, ice sheets melt and river flows increase, carrying more sediments into the ocean. By analyzing the ratios and types of sediments, researchers can identify warmer climate intervals and correlate them with global events such as greenhouse gas concentrations or volcanic activity. Together, these sediment types serve as valuable records of Earth's climatic changes, helping scientists understand the complex interactions between the atmosphere, oceans, and land over geological timescales. The International Discovery Program conducted Expedition 374 to sample sediment on the floor of the Ross Sea to study how ice cover has changed over the last 25 million 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

- **Expedition 374**, IODP
- **Marine sediments as climate archives**, Zurich Edumedia
- **Sea-Floor Sediments**, Physical Geology by Steven Earle
- **Depositional Environments**, Geosciences Libre Textbook

Initial Inquiry

1. Place the large block of ice you made onto the land are of your ocean model (if you made one end thinner, place the ice so the thinner end is nearer the ocean). The ice should be sloping toward the water.

   a. Allow students to observe the model. Discuss how the ice likely formed and how sediment becomes trapped within it.

b. Have students make predictions about what will happen over time. Students will likely discuss that the ice will melt.

c. Have students make observations as you spray the ice with water to simulate precipitation and warming. It is best to use warm water, although you may choose to withhold this detail from students. You could also use a hair dryer to speed the process, though you will still want to use water to wash the glacial sediment into the ocean.

d. As students start noticing sediment wash into the ocean, stop spraying/heating the ice and discuss what types of sediments they observe and where they expect different types of sediment to end up. Lead the discussion to talk about how smaller particles will travel farther from the land.

e. Continue to spray/heat the ice for as long as you want students to make observations and discuss what they are observing. You may also want to spray around the sides of the ice to show students how melting along the bottom of the glacier can also wash sediment into the ocean.

f. Have students watch a **video on sediment from glaciers**. Discuss how the size and weight of glaciers contributes to the formation of various types of rocks and sediment.

g. Discuss that the model represents a period of warming, which can also result in large chunks of ice breaking off the glaciers to form icebergs. Add the small pieces of ice you made to the model.

h. Ask students: *How will the icebergs change how far particles can travel from land?* Discuss with students that large pieces of rock within icebergs will drop much farther from land than if they came from the glacier. These are called dropstones or Ice Rafted Debris (IRD).

i. You may want to use the hair dryer to speed the melting of the ice cubes for students to observe dropstones.

j. Stop heating the glacier. Ask students: *Does all sediment deposited on the ocean floor come from land? Are there other types of sediments on the ocean floor that come from the ocean itself?* Discuss shelled microorganisms and how when they die and are deposited, this forms layers of ocean-derived sediment that are carbonate or silica rich depending on the types of microfossils in the water.

Teacher Note: Links to Expedition and Site summaries within this lesson all go to documents. You will need to locate the indicated Figures within each summary.

k. Show students images (from **Site U1521 of Expedition 374**) of sediment (Site U1521, Figure F6) and microfossils (Site U1521, Figures F13–18) found within ocean sediment cores. Discuss what these lines of evidence might suggest about the environment in which the core formed and how it changed over time. The focus of this discussion should be on making observations.

l. Ask students: *If you found more ocean-derived sediment than land-derived sediment at a location on the seafloor, what might that indicate about the climate at the time?* Use observations of the model to support your response.

ANNOTATED STUDENT ACTIVITY

Objective(s)/Outcome(s)

Students will be able to explain how the types of sediment on the seafloor are evidence of how ice cover changes in polar regions as a result of climate change.

Materials

Per Group:

- computer with internet access
- copies of Figures 2–5 (as needed)

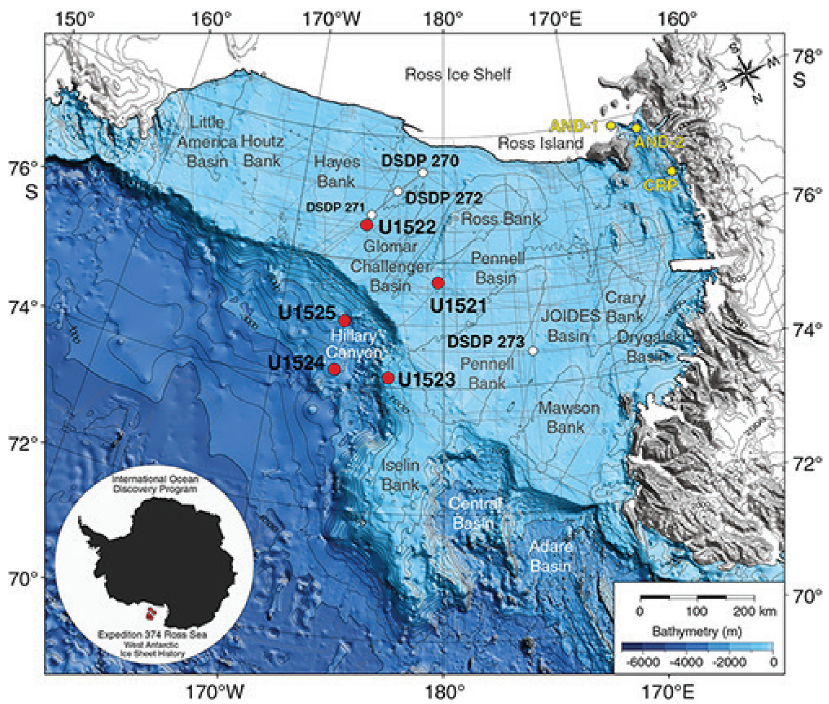
Per Student:

- copy of Figure 6

Background

In the icy waters of Antarctica's Ross Sea, scientists aboard the research vessel *JOIDES Resolution* explored deep beneath the ocean surface during IODP Expedition 374. They drilled into the seafloor to uncover sediment cores that hold secrets about Earth's climate history. These cores contain preserved layers of mud and sand that formed over thousands (or hundreds of thousands!) of years. Different sediment types, such as fine clay, coarse sand, large rocks, and remnants of shelled microorganisms indicate changes in ocean currents and temperatures over time that can help scientists determine ice cover at different time periods.

FIGURE 1. EXPEDITION 374 DRILLING MAP.



Credit: McKay et al., 2018

Activity

1. Study the map of drill sites for Expedition 374 in Figure 1.
   a. Predict which drilling site(s) you think will have more land-derived (terrigenous) sediment.
   b. What types of terrigenous sediment would you expect to find at each site (sand or clay), and why?
   c. Study a map (**Expedition 374 Summary, Figure F5**) that shows more detail about the depth of each drilling site (bathymetry) and the water circulation patterns in the Ross Sea. Does this figure cause you to revise your answers to questions 1 a and b? If so, revise your answers and use evidence from Figure F5 to explain your changes. If not, explain the evidence from Figure F5 to add support to your answers.

Teacher Note: This lesson looks at four of the five cores collected during Expedition 374. It may be helpful to demonstrate the analysis of one of the cores before having students observe the other three. A full analysis of core U1521A is below step 2. Print the Lithostratigraphic Summaries (Figures 2–5 on the handouts at the end of this lesson) for students to annotate as they learn more about each sediment core. You may also want to have different student groups focus on making observations of one core, then share their observations (either through presentations or jig sawing) to be able to compare the cores. Figure 6 can be printed as a handout for students to use as they compare the cores from all 4 drilling sites.

2. Watch a video (**Expedition 374: Birth of the West Antarctic Ice Sheet**) that introduces how data was collected from sediment cores to explain how Earth's climate has changed and affected the Antarctic Ice Sheet. Pay particular attention to 1:36–2:00 and 2:25–3:00 for information on how sediments and lithology are studied.

3. For each drill site you are assigned, complete the following steps:
   a. Locate and study the Lithostratigraphic Summary (F6 for Site **U1521A**, F5 for **U1522** and **U1523**, F4 for **U1524A/C**). Annotate the printout of the Lithostratigraphic Summary with evidence that can help you describe how the environment changed to cause the formation of the layers within the core.
   b. Use **Tulane University's summary of Sedimentary Rocks** to find information about each sediment and rock type in the key of the Lithostratigraphic Summary. For **Diamictite**, see the Geoscience LibreText.
   c. Locate and study the Lithology and Sedimentary Structures (F9 for Site U1521A, F8 for U1522 and U1523, F7 for U1524A/C). Add more notes to the Annotate the printout of the Lithostratigraphic Summary with evidence that can help you describe how the environment changed to cause the formation of the layers within the core.
   d. Locate and study the Micropaleontology Summary (F11 for Site U1521A, F10 for U1522 and U1523, F8 for U1524A/C). Add more notes to the Annotate the printout of the Lithostratigraphic Summary with evidence that can help you describe how the environment changed to cause the formation of the layers within the core.
   e. Locate the Shipboard Age Model (F12 for Site U1521A, F15 for U1522, F11 for U1523, F10 for U1524A/C). Use the graph to describe the relative sedimentation rates (e.g., fast, moderate, slow) during different time intervals. Add this information to your annotations.

Teacher Note: Analysis of core U1521A: From **Figure F6**, we can see that from 280 m down, all sediment is terrigenous (there is some chert from 280–380 m, but from Figure F9, we can see it is not biogenic, so it is terrigenous also). Figure 9 also shows that the terrigenous sediment from ~515 m and down is coarser, as it is sandstone rather than mudstone, which means more terrestrial erosion occurred at this time. From 280–210 m, there is the introduction of diatom-rich sediment, which shows a shift toward more ocean-derived sediment, which continues up to 85 m, where there is no coarse terrigenous sediment, meaning that this likely represents a time of colder climate and more ice cover. At 85–35 m, there is only coarse terrigenous sediment. At 35–0 m to present, there is a shift back to a mix of ocean and terrigenous sediment.

This evidence is further supported by Figure F11, which shows that all microfossil types are rare or non-existent from 280 m down (except for 440–480 m, where some diatoms were common though not enough to be marked as diatom-rich sediment), as terrigenous sediment washed into the ocean by glacial erosion was predominant. This likely represents a warm period with less ice cover. Above 280 m, many microfossils became common, meaning there was an increase in ocean sedimentation, likely representing a colder time period than 280 m and below.

Figure F12 shows a relatively low sedimentation rate from the mid-Miocene through recent times, which explains the thin sediment layers. There was a rapid increase in sedimentation rate through the mid-Miocene, seen as an accumulation of diamictite. Then there is a sudden shift to another low rate or possible unconformity at 85 m, shifting to more oceanic sediment, which accumulated at a fast rate into the early Miocene and persisted even when terrigenous sediment dominated at 280 m and below.

4. Follow your teachers' instructions for sharing your observations with your classmates.

Analysis

1. Compare the lines of evidence for the cores at each drill site. Note major differences and similarities on Figure 6.

Suggested Response: Core 1521 has very little sediment that is Pleistocene or Pliocene age (very thin layers). In sediments that are marked as being Pleistocene age, there are similarities between cores 1521, 1522, and 1524, with a low level of ocean derived sediment mixed with small terrigenous sediment. For Core 1524, the sediment is only fine-grained mud. Core 1523 has more ocean derived sediment and mostly fine-grained terrigenous sediment. For sediment that is Pliocene age, the cores are similar to the Pleistocene age sediment except in core 1524 there is an increase in the amount of ocean derived sediment. As you go down into Miocene age sediment, core 1521 is different than the rest in that it has exclusively terrigenous sediment. Core 1522 has some ocean-derived sediment, 1523 has more, and 1524 has the most. Core 1522 has almost exclusively diamictite as the terrigenous sediment type (almost no mudstone). Core 1523 has a majority mudstone as its terrigenous sediment, and Core 1524 has exclusively mudstone as its terrigenous sediment until 320 m.

In terms of microfossils, Core 1521 has almost none below 280 m, then above that, diatoms, dinocysts, and forams become common. Core 1522 has little microfossils below 400 m, then a period where microfossils are common until 200 m, where they become sparse again. Most microfossil types are common throughout core 1523 with the exception of dinocysts above 60 m. Diatoms and radiolarians are common throughout core 1524.

2. Describe how the sedimentation rates differed at each site. What might cause sedimentation rates to change? Reference data from one of the graphs to support your answer.

Suggested Response: the sedimentation rate during the Pleistocene was very low at sites 1521, 1522, and 1523. The sedimentation rate during the same age at site 1524 was moderate to high. The sedimentation rate during the Pliocene was very low at site 1521, moderate to high at site 1522 and very high at sites 1523 and 1524. The sedimentation rate during the Miocene was very high at site 1521. At site 1522 the rate was unknown for some time but then was moderate through the rest of the Miocene. For sites 1523 and 1524, the rate of sedimentation between the Pliocene and Miocene was very low but then was moderate to high throughout the Miocene. Sedimentation rate is based on many factors. When the earth's climate is warmer, there is more ice melting and changes in weather patterns can cause greater precipitation, both of which contribute to more terrigenous sediment coming from the land, which increases sedimentation rate in the ocean. The rate of sedimentation of ocean derived sediment can increase when there are more organisms dying off and settling to the sea floor.

Synthesis

1. Consider the depth of each site, as well as their distance from land. How can each of these factors help explain the types of sediment found at each location?

Suggested Response: Sites 1521 and 1522 are shallower and closer to land, which explains the fact that more diamictite are found at these locations. Because diamictite is made up of coarser grained terrigenous sediment that cannot travel too far into the ocean, it makes more sense that this coarser sediment washed from the land is deposited at these sites. Site 1523 is a bit deeper but is on a part of the ocean floor that is sloping down, so it makes sense that more mudstone has accumulated here as well as more ocean sediment given that the column of water above it is deeper than it cites 1521 and 1522. Site 1524 is farthest away from land and also at a deeper part of the sea, which explains why it has almost exclusively mudstone and ocean derived sediment. Mudstone is made of a very fine grain sediment which can travel far into the ocean before it settles to the sea floor. Also a deeper water column explains more ocean derived sediment being at this site.

2. Summarize evidence from the cores that indicates what the climate of the area around the Ross Sea was like at different times. What evidence indicates warmer times? What evidence indicates periods of greater ice cover? Reference specific depths in the cores that show evidence of climate change.

Suggested Response: more terrigenous sediments, especially being deposited at high sedimentation rates, can indicate a warmer climate. Warmer climates cause more glacial melting and more frequent precipitation which can contribute to sand, mud, gravel, and other terrigenous sediments being washed into the ocean which then settles to the sea floor. One example could be at site 1521A, when there is a sudden shift from diamictite (relatively coarse terrigenous sediment) to mudstone and ocean derived sediment; this shift occurred around 85 m, but then shifted back to diamictite around 205 m. This period of more ocean derived sediment and finer terrigenous sediment could indicate a colder time with more ice cover and less erosion of land. There was also a shift in the rate of sedimentation which can indicate a changing environment. A similar shift in rate is seen in core 1524 between the late Miocene and Pliocene (~320 m), when there is also a change from more terrigenous sediment to more ocean derived sediment.

3. Rewatch :30–:45 of the video from step 2 (**Expedition 374: Birth of the West Antarctic Ice Sheet**), pausing as needed to see the extent of ice cover in Antarctica from 10–15 Ma and 5 Ma (Note: Ma means millions of years ago. Correlate each of these times) with the layers in the cores. Does the evidence from the cores match the proposed ice cover for each time period? Use evidence to explain your answer.

Suggested Response: Students may acknowledge that the first time shown in the video is between 35 to 30 million years ago, which is older than any of the sediment that was collected from the cores in expedition 374. The next time shows 10 to 15 Ma (mid-Miocene) which shows Antarctica covered with widespread ice. During this time, evidence from core 1521 shows a shift to more fine-grained sediment which means there was less land erosion which correlates with a colder climate. The other three cores show more ocean derived sediment which also correlates with a colder climate. The next time shown in the video is about 5,000,000 years ago which is in the early Pliocene. Compared to the warmer time period shown in the video from 35 to 30 Ma, around 5 Ma, there was still more ice cover even though it was warming. This is consistent with the low sedimentation rate shown at all 4 sites, which is known to happen as the climate is shifting from cold to warmer, or vice versa. Students may try to explain data that correlates with today, however, there has not been enough time for evidence to collect on the seafloor to describe such recent times

4. How might a study of the types of microorganisms found in the sediment layers provide further evidence of climate conditions recorded within the core?

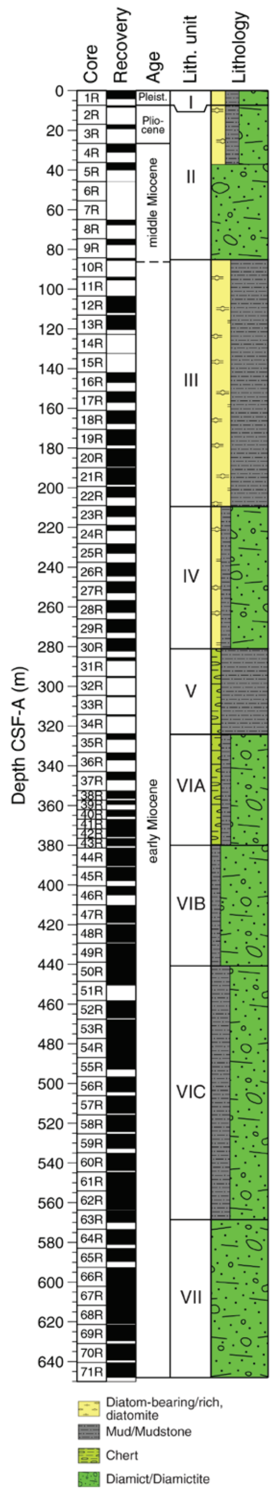
Suggested Response: Just like with macrofossils, microfossils are records of organisms that live in specific climates and environmental conditions. The specific species accumulating at certain times indicate what the area was like and can tell about the climate conditions given that scientists know what types of environment different species prefer. When a specific species starts to disappear from the area, that can indicate climate change. In general, the more species of microfossils there are in the area, the more “productive” the area is considered, which typically indicates a colder climate.

Extensions

1. **Watch a video** showing some of the scientists and crew involved in Expedition 374. Summarize some of the work done to collect and analyze cores. What did you find most interesting or surprising about this work or life on board a research vessel?

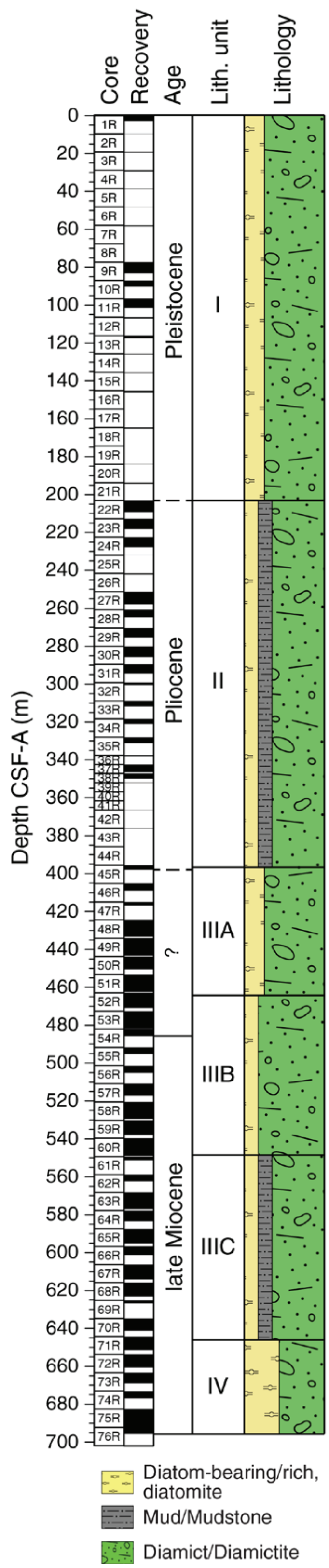
HANDOUTS

FIGURE 2. CORE FROM SITE U1521A



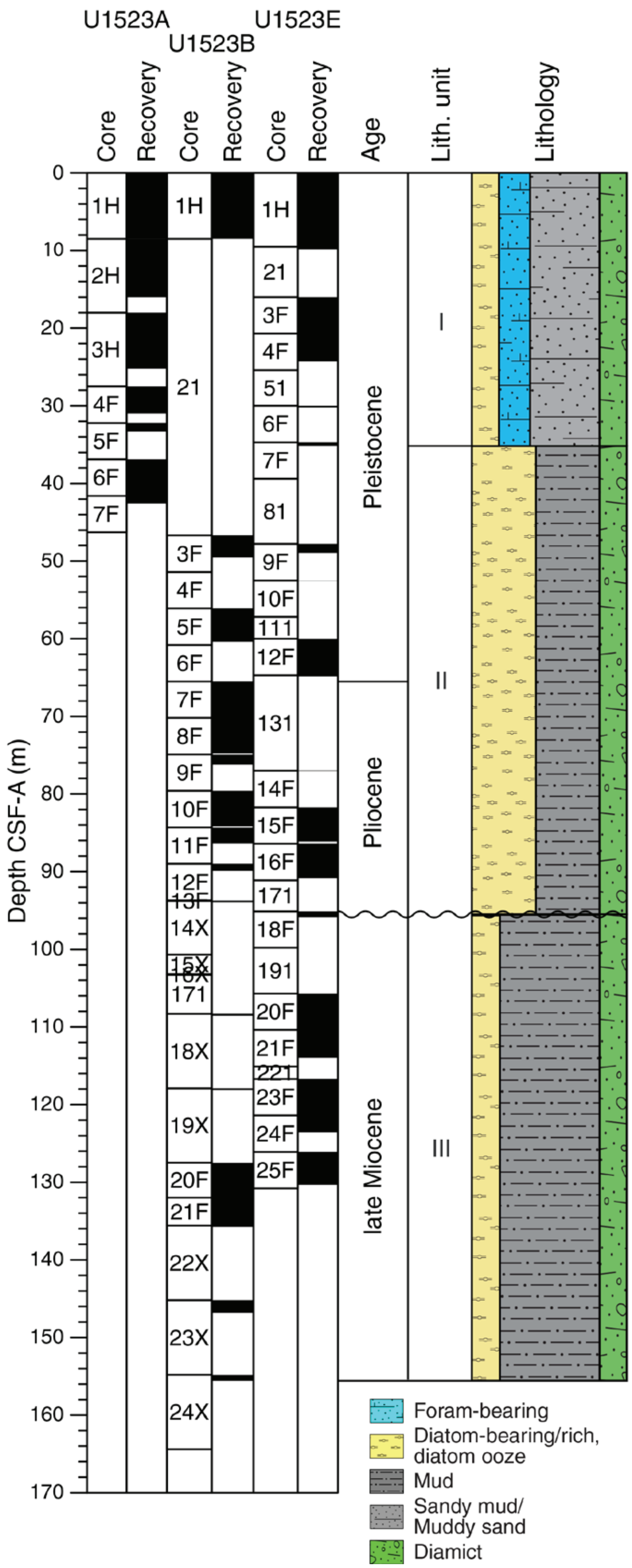
Credit: Modified from McKay et al, 2019.

FIGURE 3. CORE FROM SITE U1522



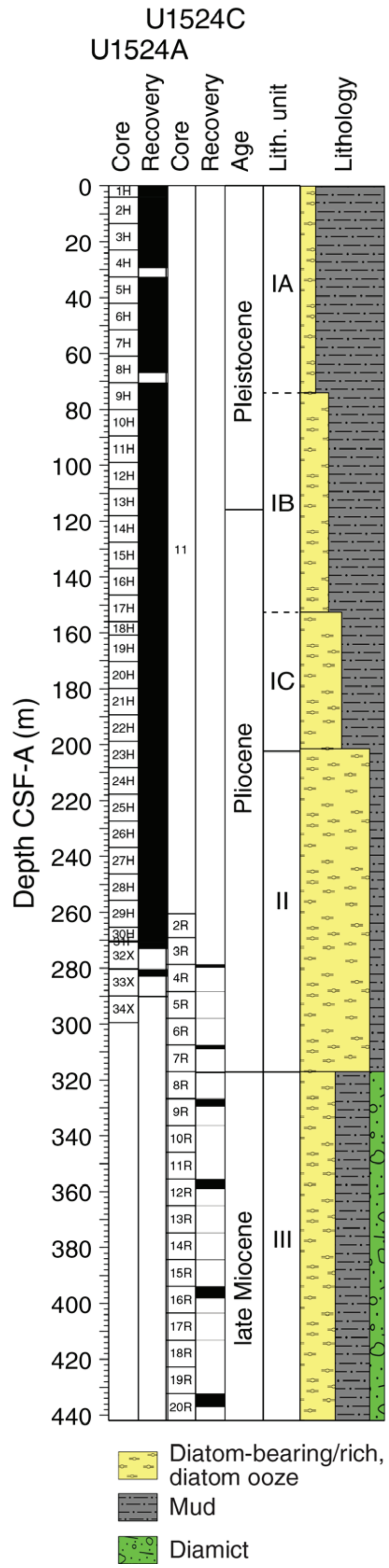
Credit: Modified from McKay et al, 2019.

FIGURE 4. CORE FROM SITE U1523



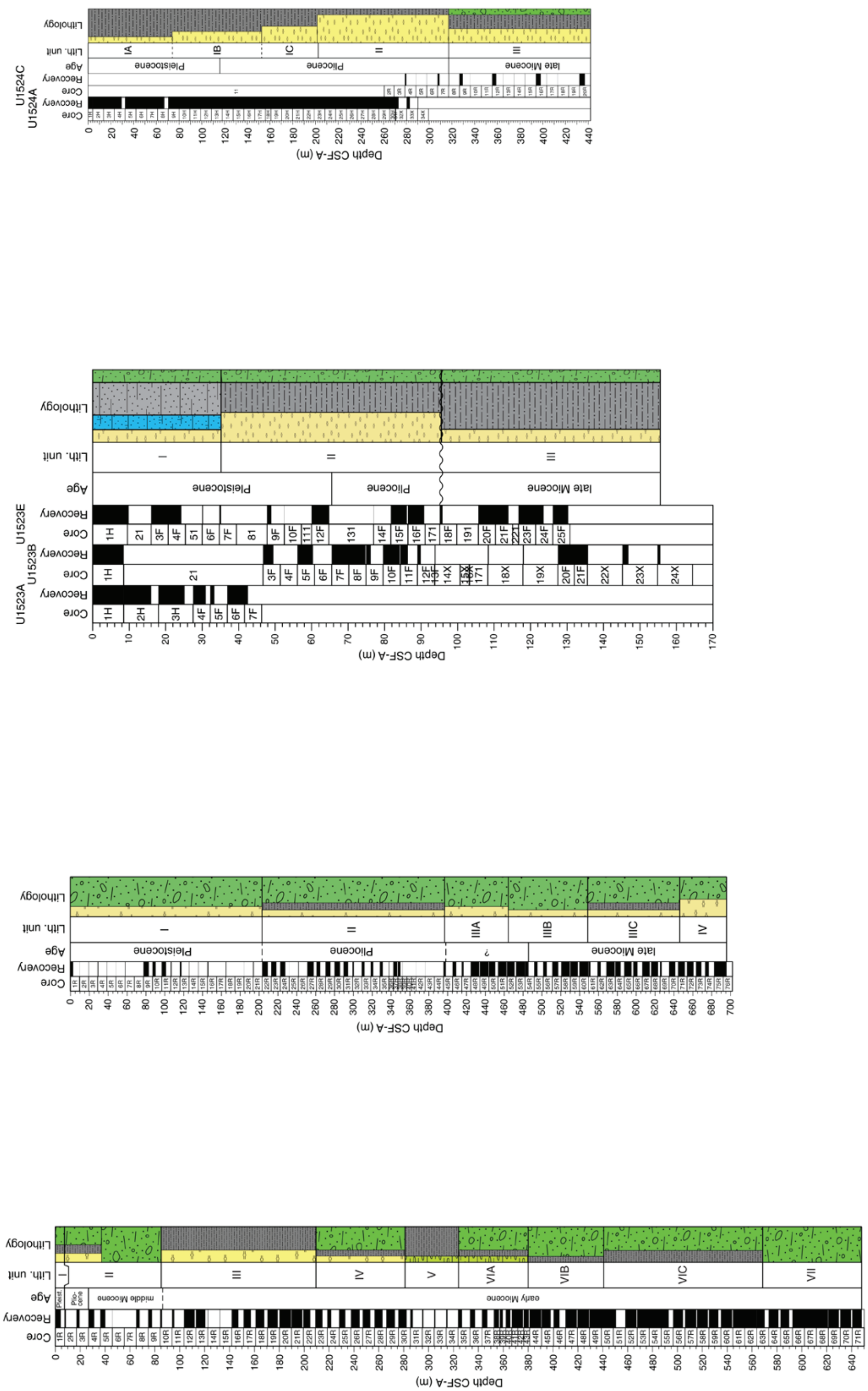
Credit: Modified from McKay et al, 2019.

FIGURE 5. CORE FROM SITE U1524A AND C



Credit: Modified from McKay et al, 2019.

FIGURE 6. CORES FROM FOUR DRILLING SITES FROM EXPEDITION 374.



Credit: Modified from McKay et al, 2019.

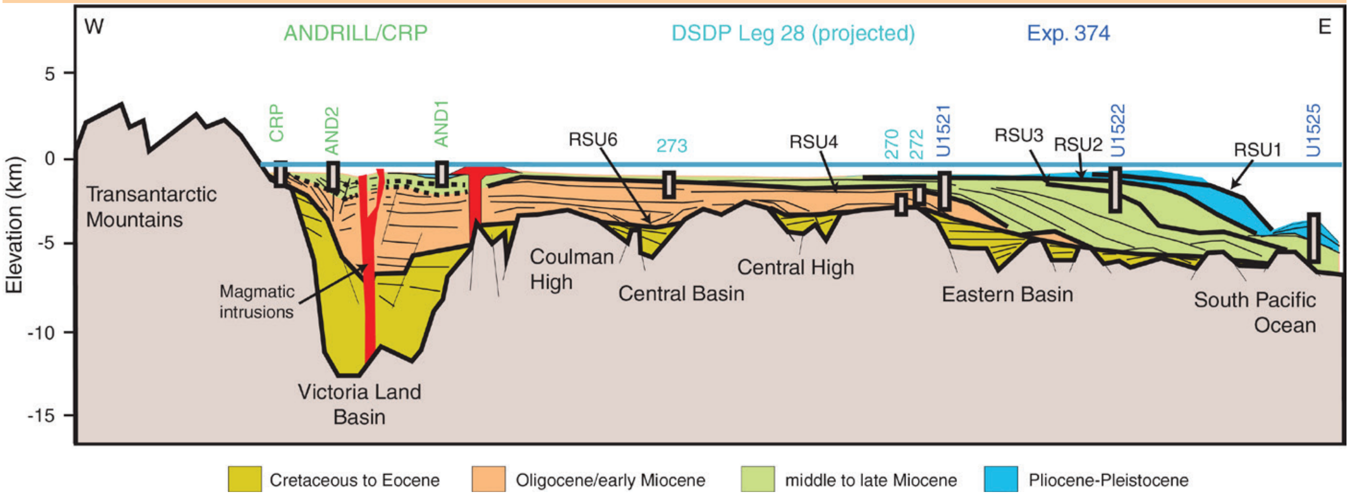
CLOSURE

1. Exit ticket options:

   a. A fifth site was cored during Expedition 374, Site U1525. Revisit the site map to see where this site was located. Use what you have learned to hypothesize what types of sediment you would expect to find there

   b. The diagram shows a cross-section of the Ross Sea and the location of some of the core taken from it during three different expeditions (ANDRILL/CRP, DSDP Leg 28, and Expedition 374, which you have analyzed). How would you expect the cores from the ANDRILL/CSP and DSDP Leg 28 to compare to the ones you analyzed from Expedition 374? What similarities and differences do you think you would find and why? (You may want to reference the **Geologic Time Scale** to support your response.)

Figure TE-1. Cross-Section of the Ross Sea Floor.



Credit: McKay et al, 2019.

2. Follow-up lessons:

   a. Specific changes in Earth's climate history, such as the Paleocene-Eocene Thermal Maximum (PETM);

   b. Ice coring and what evidence that can reveal;

   c. Other environmental conditions that can be inferred by studying sediment in ocean sediment cores.

References

Geoscience LibreText. (n.d.). Diamictites, pebbly sandstones, and outsized clasts. Available at: **https://geo.libretexts.org/Courses/SUNY_Potsdam/Sedimentary_Geology%3A_Rocks_Environments_and_Stratigraphy/05%3A_Siliciclastic_Sedimentary_Rocks/5.04%3A_Diamictites_Pebbly_Sandstones_and_Outsized_Clasts**

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Reconstructing Earth's Climate History: Inquiry-Based Exercises for Lab and Class, First Edition. Kristen St John, R Mark Leckie, Kate Pound, Megan Jones and Lawrence Krissek. © 2012 John Wiley & Sons, Ltd. Published 2012 by John Wiley & Sons, Ltd.