AMERICAN METEOROLOGICAL SOCIETY:

A COLDEX Center for Oldest Ice Exploration PARTNER

Project Ice

Ice Core Science and Engineering

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TEACHER'S GUIDE

Project Ice

This guide is one of a series produced by Project Ice, a National Science Foundation sponsored initiative of the American Meteorological Society (AMS). AMS is a subawardee of Oregon State University on its NSF Science and Technology Center institutional award (OPP-2019719), Center for Oldest Ice Exploration (COLDEX). The purpose of COLDEX is to “explore Antarctica for the oldest possible ice core records of our planet’s climate and environmental history, and to help make polar science more inclusive and diverse.” Project Ice is the annual K-12 teacher focused activity within COLDEX, and is offered via hybrid delivery that includes a one-week residency at Oregon State University. The goal of Project Ice is to create and train a diverse network of master teachers prepared to integrate paleoclimatology and polar science in their classrooms and provide peer training sessions. To support these teachers' educational experience, Project Ice develops and produces teacher's guides, slide sets, and other educational materials.

For further information, and the names of the trained master teachers in your state or region, please contact:

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Figure i. Ice cores stored at –36°C (–32.8°F) at the National Science Foundation Ice Core Facility in Denver, CO. [Photo by Karen Pearce/NSF]

"Don't let anyone rob you of your imagination, your creativity, or your curiosity. It's your place in the world; it's your life. Go on and do all you can with it, and make it the life you want to live."

- Mae Jemison, Engineer, Physician and Former NASA Astronaut

"Life is an opportunity, benefit from it. Life is beauty, admire it. Life is a dream, realize it."

- Saint Mother Teresa of Calcutta (1910–1997)

Module: Ice Core Science and Engineering
Instructor: Project Ice Instructor or Project Ice Graduate
Audience/Grade Level: K-12 Educators

STANDARDS:

Project Ice Objectives

Utilizing Ice as a Scientific Observatory:

1. Examine various proxy climate data sources and their contribution to understanding atmospheric and geologic variables at different temporal resolutions.

2. Understand the complex logistics and the corresponding engineering and technology needed for drilling and coring in harsh polar regions.

3. Investigate the use of ice drilling in collecting data on climate history, ice dynamics, and seismic activity.

4. Discuss future plans for drilling boreholes to study deeper ice volumes and enhance our understanding of climate and ice dynamics.

5. Describe how ice drilling efforts are organized to achieve interconnected science goals, encompassing climate change studies, ice dynamics, and the role of ice as an observatory for broader scientific research.

Climate Literacy Principles from: https://cleanet.org/clean/literacy/climate/index.html

5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling. (a, b, c, e)

Next Generation Science Standards (NGSS)

Performance Expectations

K-2-ETS1-1. Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

K-2-ETS1-2. Develop a simple sketch, drawing, or physical model to illustrate how the shape of an object helps it function as needed to solve a given problem.

K-2-ETS1-3. Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.

4-ESS2-2. Analyze and interpret data from maps to describe patterns of Earth's features.

3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Science and Engineering Practices

1. Asking Questions and Defining Problems
2. Developing and Using Models
3. Planning and Carrying out Investigations
4. Analyzing and Interpreting Data
6. Constructing Explanations and Designing Solutions
7. Engaging in Argument from Evidence

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

ETS1.B: Developing Possible Solutions

ETS1.C: Optimizing the Design Solution

Crosscutting Concepts

1. Patterns
4. Systems and System Models
6. Structure and Function

Engage | The scope of the challenge

Antarctica is the coldest, driest, windiest, and highest-elevation continent on Earth. Antarctica is also the only continent without a history of human civilization, however researchers visit it each year. Consider **Figure 1**, in which ice core scientists carry a drilled piece of ice core in a remote field camp in Antarctica into a small tent for processing. What are some of the questions this picture raises?

Figure 1. Ice core scientists carry a recently drilled ice core in Antarctica. [Photo by Todd Anderson]

Group Discussion:

1.) Speculate on who these scientists might be. Where might scientists drill for ice cores in Antarctica?

2.) How can science and engineering be used to drill for ice cores?

3.) Why do we care about Earth's climate history?

These scientific questions are accompanied by equally interesting logistical questions:

1.) Who are the researchers, the scientists, engineers, and staff, that make up Antarctic ice coring teams?

2.) What do you think people on ice-coring teams need to do before they leave to prepare for life in Antarctica?

3.) What paths might the people and equipment get to Antarctica?

4.) Where do ice coring teams live when they are in Antarctica? What basic necessities must be met to live in such a remote location?

5.) What season would be best for ice drilling in Antarctica?

6.) What equipment do ice coring teams need for ice coring?

7.) How do the ice cores get back to research labs without melting?

Consider these questions as you continue through this module, and any other questions you have once you complete it. These questions reflect the challenges faced by the researchers who work to drill ice cores in the most remote place on Earth.

Explore | Ice cores as a paleoclimate record

Ice cores can provide direct measurements of Earth's past climate or *paleoclimate*. When snow falls, the spaces between these snowflakes are filled with air. If this snow freezes into solid ice, the air gets trapped as bubbles. The air inside these bubbles are tiny samples of the atmosphere at the time the ice froze, providing scientists with direct samples of past atmospheric chemistry. Researchers at COLDEX are particularly interested in measuring the concentration of greenhouse gases like carbon dioxide and methane. Greenhouse gases trap infrared radiation (heat) in the atmosphere, causing an increase in global temperatures. Research scientists can measure the concentration of these gases as far back as 1.5 million years ago, and even earlier, when global temperatures were even higher than they are today. The chemical composition of the ice provides details about the hydrological cycle over time.

Along with the atmospheric and hydrological chemistry from ice cores, COLDEX scientists also measure the composition and amount of dust trapped in ice cores. These measurements inform scientists how dry the climate was at the time the ice formed, as well as give details about whether the Earth was in a colder glacial (more ice frozen on Earth's surface) period or warmer interglacial (less ice frozen on Earth's surface) period. The chemistry of the dust can point to where the dust came from, as well as calculate the age of the dust and the surrounding ice. Volcanic ash trapped in ice (**Figure 2**) can tell us when and where a volcanic eruption happened.

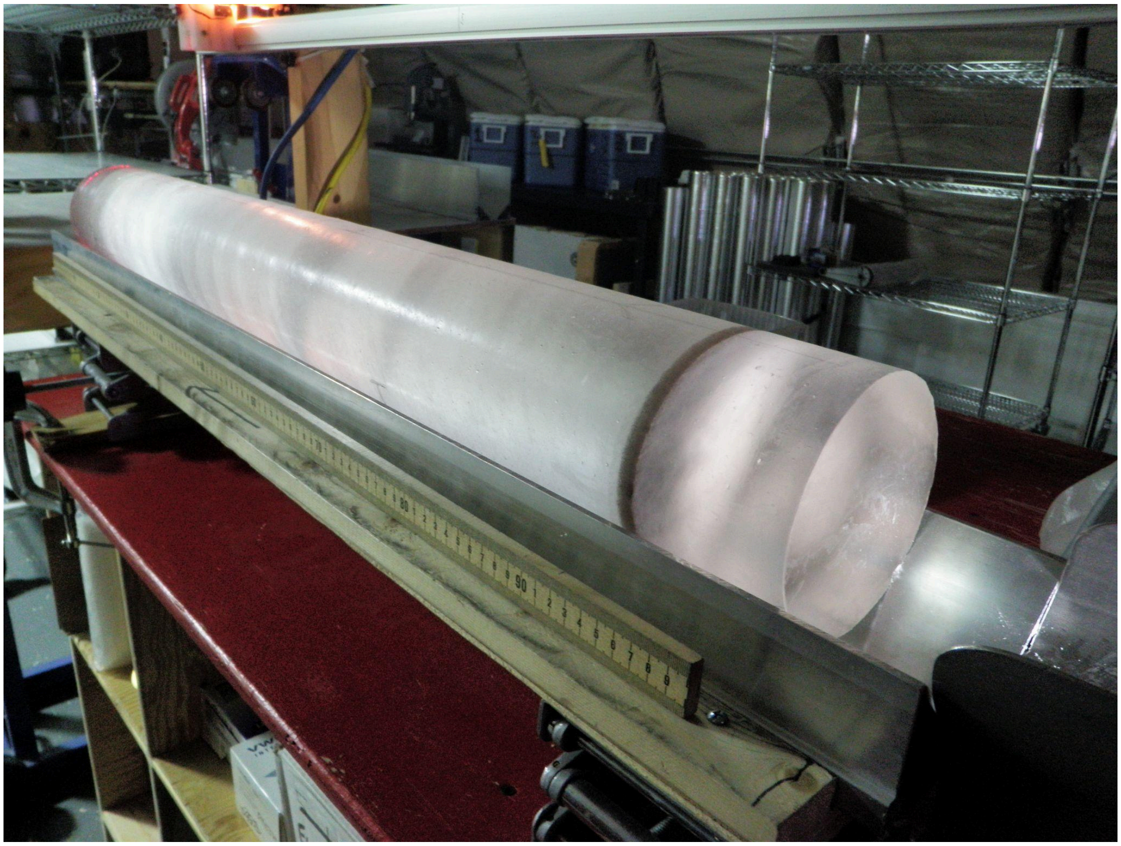

Figure 2. An ice core from the West Antarctic Ice Sheet with a very dark layer of volcanic ash that fell approximately 21,000 years ago. [Photo by Heidi Roop/NSF]

Most of these measurements will take place in laboratories far away from where the ice was drilled. Ice cores taken by the U.S. Ice Drilling Program and COLDEX are transported back to the National Science Foundation Ice Core Facility (formerly the National Ice Core Laboratory) in Denver, CO, where they are stored until they are processed.

Group Review and Discussion:

1.) Try to imagine drilling into the Antarctic ice sheet to retrieve cores of ice. Speculate on the potential challenges facing the field ice coring team.

2.) Imagine you have drilled an ice core with a COLDEX science and engineering team. Now you and your team have to cut the core into 1 m pieces and pack it for transport. What information needs to be logged on the ice core or its packaging?

3.) What is the highest priority on the trip from Antarctica to Denver? Why do you think that is?

4.) Watch the video: "The Long Haul" by the U.S. Ice Drilling Program featuring Michael Davis, the U.S. Antarctic Program Cargo Supervisor. What steps are taken to get the ice cores from the field site (or "deep field") to Denver?

Explain | Ice core science and engineering in Antarctica

In the Explore section, you listed the many steps that Davis described in the U.S. Ice Drilling Program video "The Long Haul." Keeping ice cores frozen is a significant challenge but an important one. Even small, abrupt changes in the temperature could cause the ice to partially melt or fracture, which can disrupt some of the ice core's characteristics. For example, the air bubbles in the ice are essentially tiny pressurized capsules of the air, and melting or fracturing of the ice could cause that air to be lost.

There are also many challenges to keeping the ice in good condition for scientific analysis while drilling the core. Drilling teams need to consider not only the specific drills they will use but also computer models and other techniques to predict the condition of the ice before drilling.

Deciding where to drill for the oldest ice

The scientific objective at COLDEX is to drill a continuous core with at least 1.5 million year old ice at the bottom as well as to find older ice, up to 5 million years old, in shallower cores. To find ice older than the current oldest continuous ice core record of 800,000 years, scientists are focusing on the high-elevation plateau region of the East Antarctic Ice Sheet (EAIS).

Old ice may be found in the EAIS in one of two ways, as part of a continuous core of ice, with the ice getting progressively older with depth, or as pieces of old ice folded upward from deep below the ice sheet into younger ice. Some of the instruments used to explore the Antarctic ice sheets are shown in **Figure 3**. Instruments like radar can image layers in the ice below the surface. Radar instruments send waves of microwave radiation through the ice, where the waves bounce off of the layers below the surface and return to sensors at the surface. The time a wave takes to return allows scientists to calculate the depths to these layers. Radar instruments may be placed on the ground, where a snowmobile pulls the instrument across the snow surface, or flown over the ice surface in aircraft.

The University of Washington Applied Physics Laboratory in collaboration with COLDEX is developing a new tool called the Ice Diver Probe. The Ice Diver Probe is a thermal probe that melts its way through ice layers quickly, collecting samples of dust embedded in the ice. By dating the age of the collected dust, scientists get an idea of how old the ice is and find good locations to drill.

Computer models take all the collected data, and use mathematical and physical calculations to estimate likely ice flow paths. From there, scientists can predict how deformed or folded ice layers are before drilling.

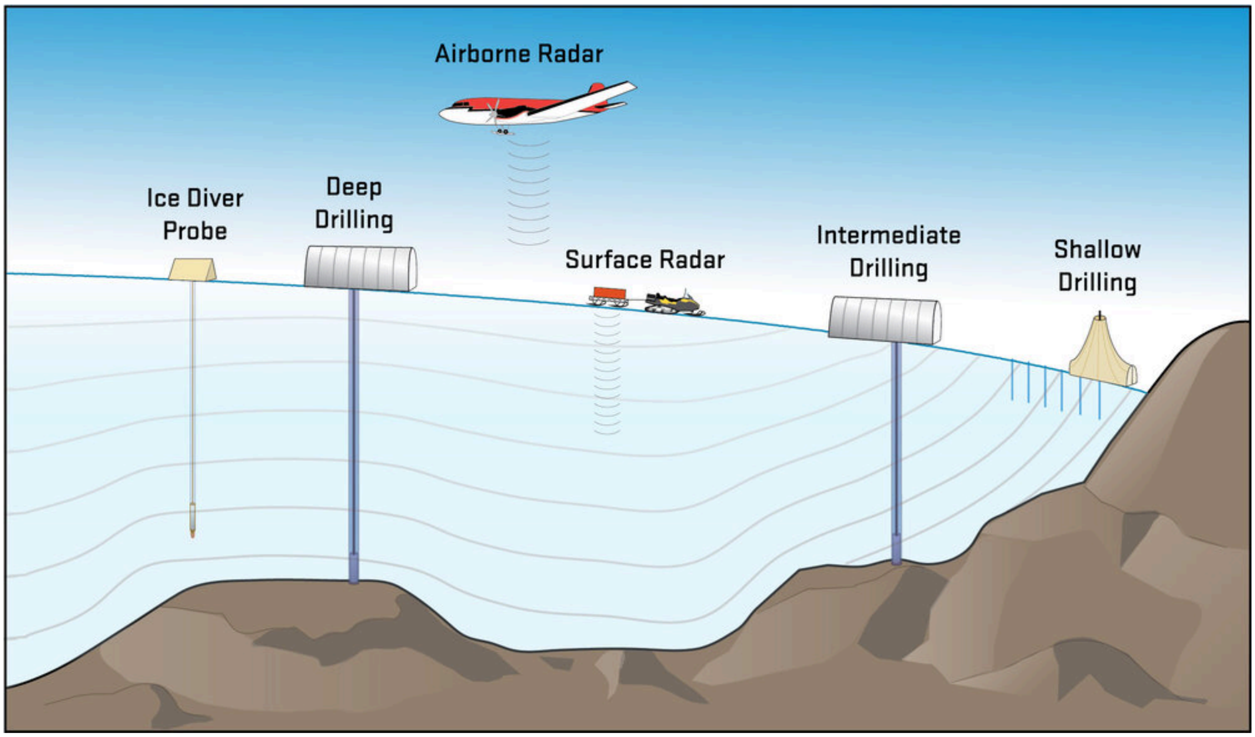

Figure 3. COLDEX instruments to discover 1.5 million year old ice, and deep, intermediate, and shallow drilling field stations. [COLDEX]

You might notice in Figure 3 that COLDEX uses both deep and shallow drilling to find old ice. The depth of the ice core will be determined based on whether the ice coring team is looking for a continuous core or pieces of older ice. Pieces of older ice folded upward into younger ice (called discontinuous ice) can often be found where ice flows up against mountainous terrain, such as the Transantarctic Mountain Range.

As the ice flows toward this mountain range, older ice is folded upward beneath the ice sheet surface. Where ice sublimates, or transitions directly from solid ice to gaseous water, faster than new snow accumulates, is known as a *blue ice area*. These areas are often the target for pieces of old ice in shallower regions of the ice sheet, as shown in **Figure 4** as dark blue dots. In blue ice areas, older ice is exposed at the surface as surface ice is sublimated and they appear blue due to the way light is absorbed by the ice and air bubbles within the ice. One such blue ice area that COLDEX has investigated for old ice is in the Allan Hills region of the Transantarctic Mountain Range.

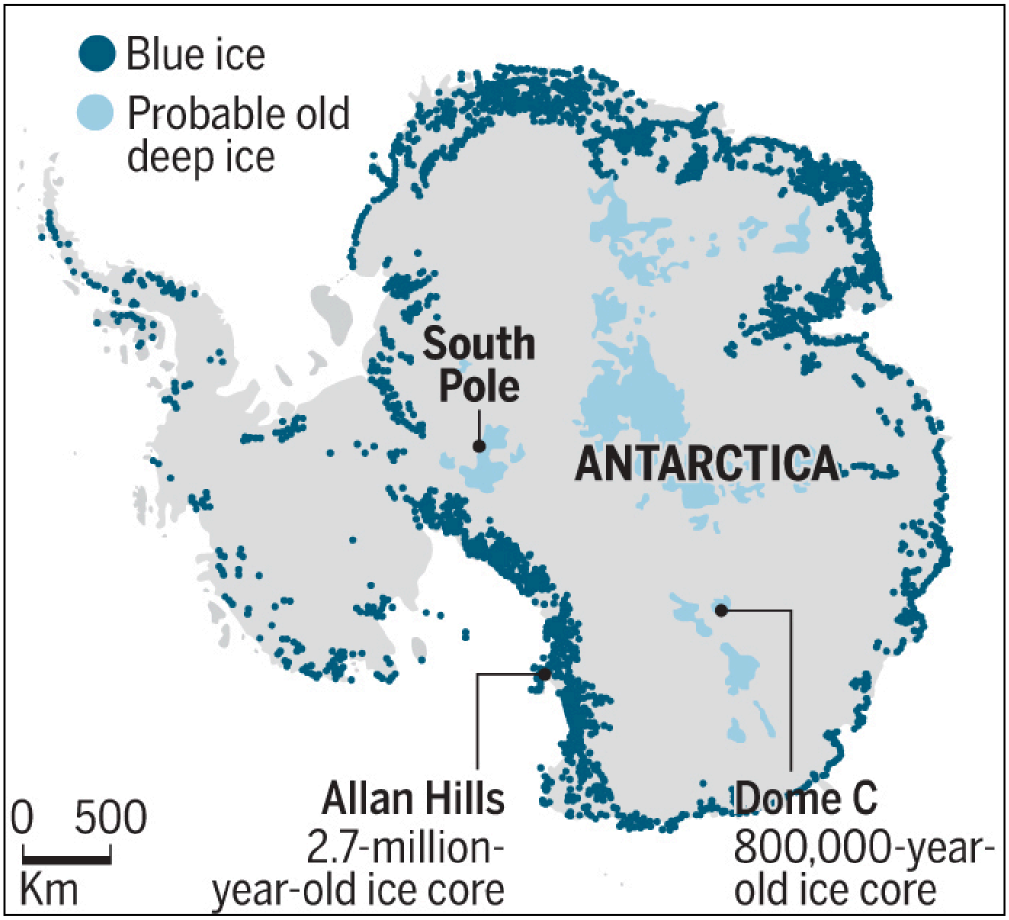

Figure 4. Blue ice areas (dark blue), and probable old deep ice (light blue) across the EAIS and West Antarctic Ice Sheet (WAIS). [Grullón, G./Science]

Deep, continuous ice cores are often drilled near *ice divides*, also called *ice domes*, where snow and ice accumulate faster than they melt or sublimate. These flow outward from the center of the dome in a pattern, pictured in **Figure 5**, and result in the center of the dome being the thickest and the layers underneath relatively undisturbed from ice flow. In undisturbed ice layers, the oldest ice is found at the bottom of the ice sheet.

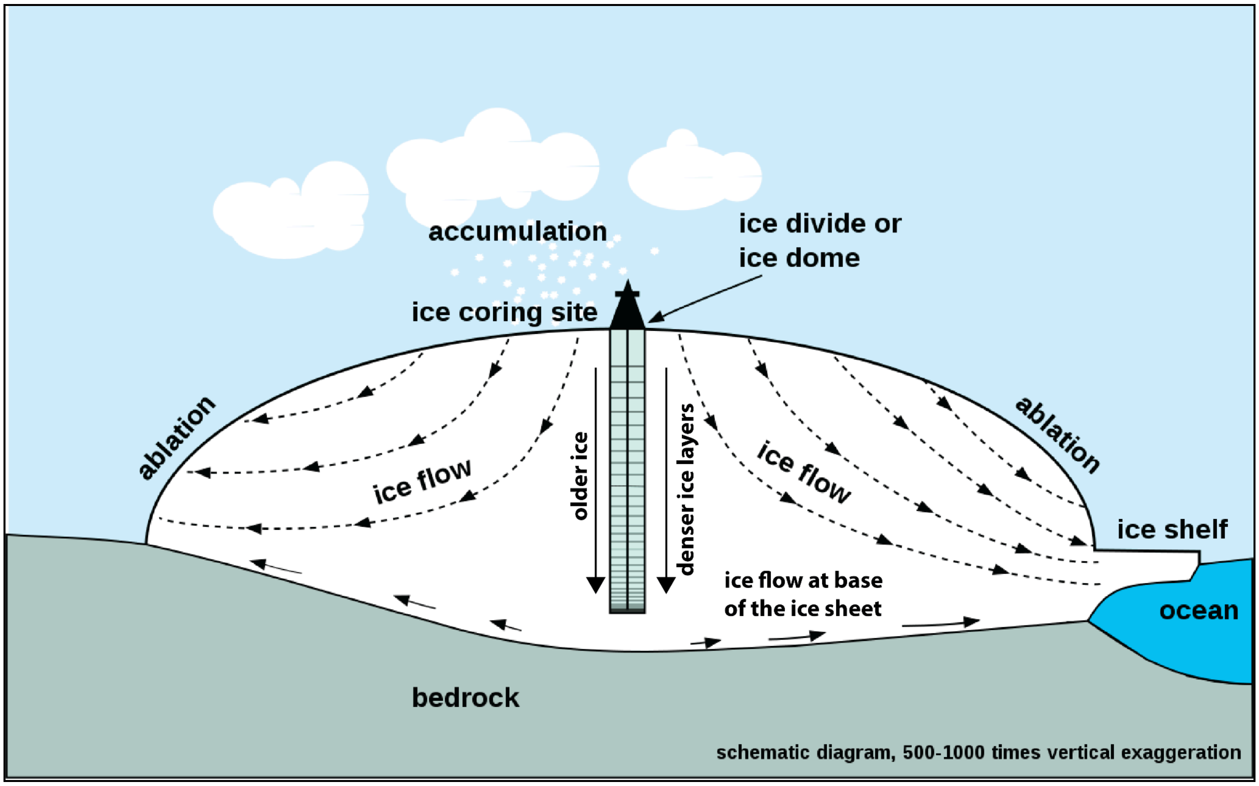

Figure 5. Ice divide or ice dome of an ice sheet. [DeWikiMan/CC BY-SA 4.0]

How old ice at the bottom is varies depending on the properties of the ice sheet, how fast the snow that formed the ice accumulated, and the topography of the bedrock the ice flows over. **Figure 6** below shows the deep ice cores that have been drilled across Antarctica.

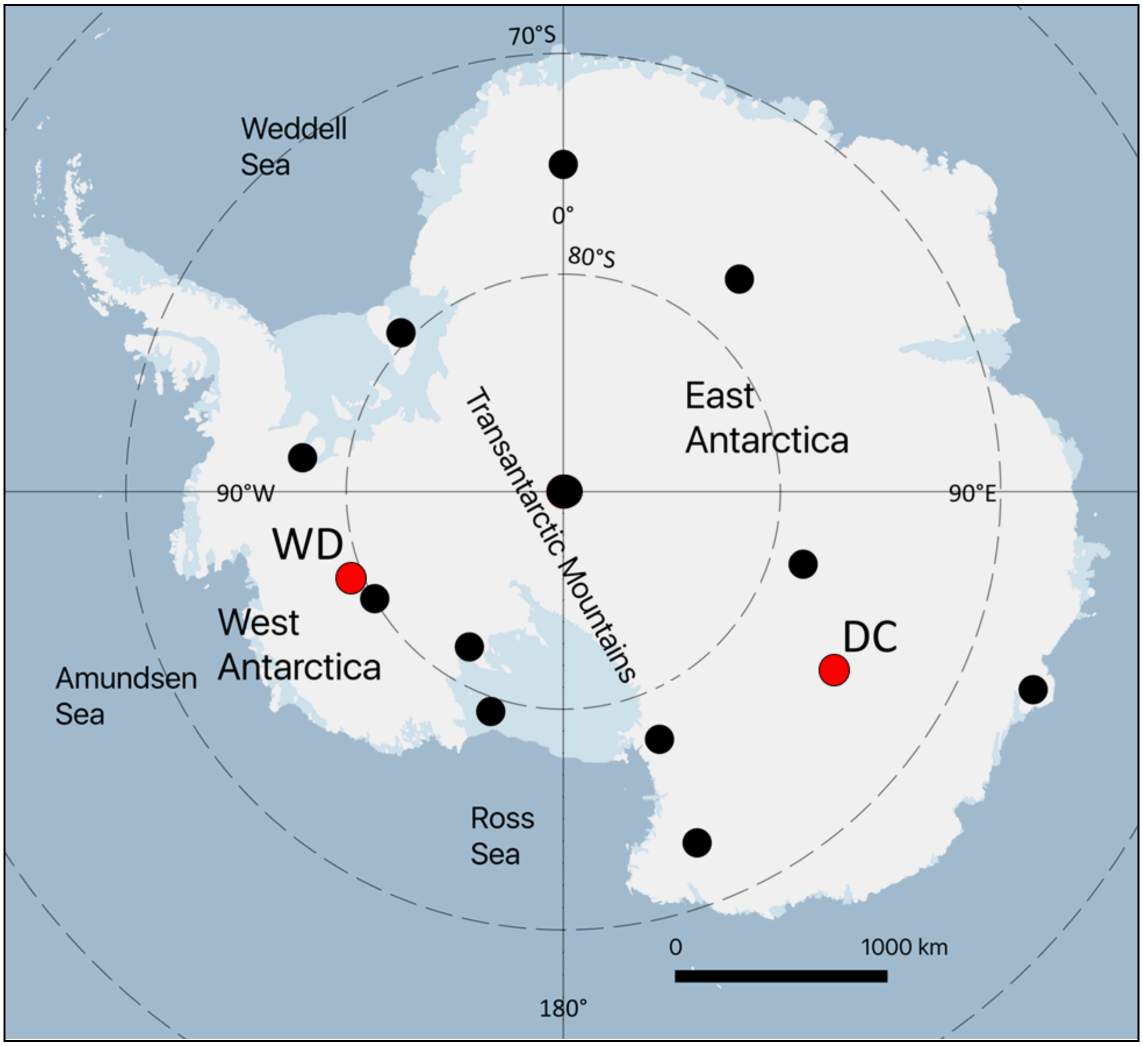

Figure 6. Location of deep ice cores (black circles) drilled to date across Antarctica. The red circles are the WAIS Divide core (WD) and the EPICA Dome C core (DC). [Modified from Souney et al., 2020]

The longest ice core drilled by a United States ice coring team was the West Antarctic Ice Sheet (WAIS) Divide core at 3.4 km. This ice core covers 68,000 years of Earth's history. The oldest deep ice core to date was drilled in the EAIS by the European Project for Ice Coring in Antarctica (EPICA), and although it is only 3.2 km deep, this core covers 740,000 years of Earth's history.

Getting to Antarctica

The U.S. Antarctic Program has three stations in Antarctica, McMurdo, Amundsen-Scott South Pole, and Palmer Stations, shown on the map in **Figure 7**. McMurdo is the largest station and home base for the U.S. Antarctic Program. The average annual temperature at McMurdo Station is –18°C (0°F), with temperatures as high as 8°C

(48°F) in the summer and as low as –50°C (–58°F) in the winter. Before even beginning their journey to Antarctica, members of an ice coring team must complete a medical, psychological, and dental health screening to ensure that they can withstand three months in the remotest and coldest location on Earth. Medical facilities and treatment options in Antarctica are limited, especially for teams that will be deployed to field locations outside the major stations.

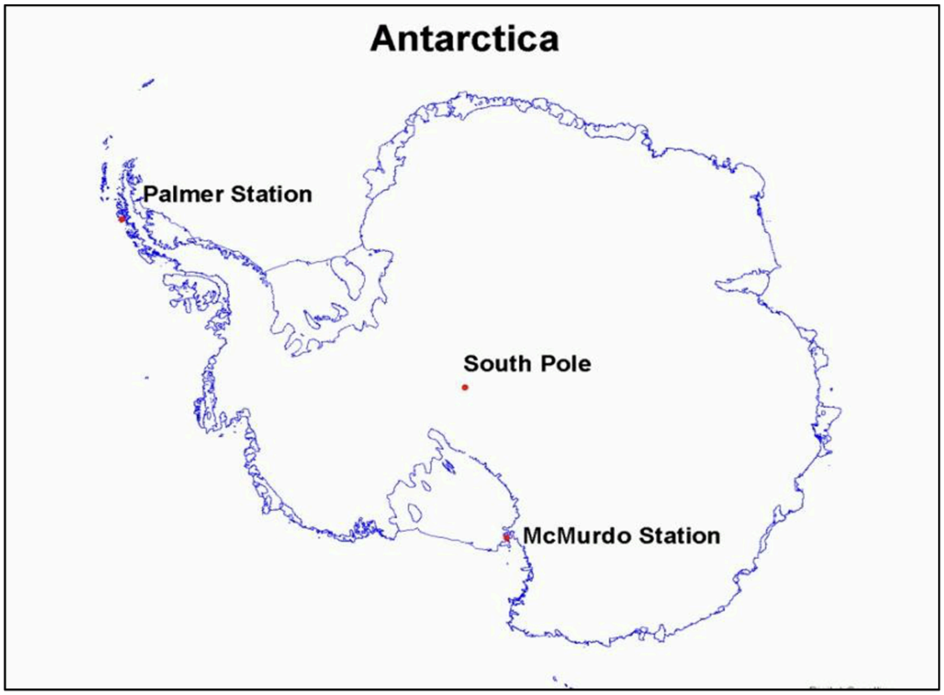

Figure 7. The locations of the three U.S. Antarctic Program stations. [U.S. Antarctic Program]

The scientists and engineers that make up an ice coring team work during the Antarctic summer (October to February), when temperatures are warmer, and the Sun never sets below the horizon. If scientists and engineers are traveling to McMurdo or South Pole stations, they travel to Antarctica on a flight from Christchurch, New Zealand. If traveling to Palmer station, on the Antarctic peninsula, they travel on a research ship from Punta Arenas, Chile. These routes are plotted on a map in **Figure 8**.

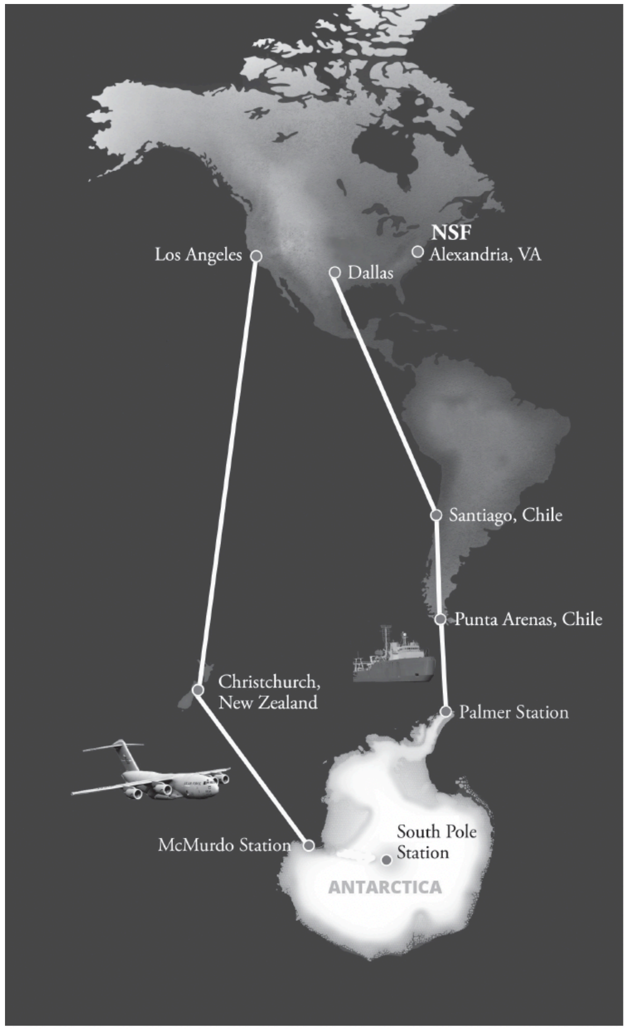

Figure 8. Routes taken by U.S. researchers traveling to different stations in Antarctica. Note that Antarctica's orientation in this figure differs from previous maps. [Modified from U.S. Antarctic Program]

When an ice coring team arrives in either New Zealand or Chile, the researchers are given extreme cold weather gear, like that seen in **Figure 9,** and other supplies to use while in Antarctica. From New Zealand, the ice coring team takes a 5–8 hour flight, called an “ice flight,” to McMurdo Station. If coming from Chile, an ice coring team would take a 4–5 day trip on a research ship to Palmer Station. Transportation to remote field camp locations outside of a station is mostly accomplished by fixed-wing aircraft or helicopters. At remote field camps, members of an ice coring team live in tents like those pictured in **Figure 10**, and snowmobiles are used for transport around remote field camps.

Figure 9. Ice core scientists arriving at McMurdo Station in their U.S. Antarctic Program issued extreme weather gear or “Big Reds.” [Photo by Austin Carter]

Figure 10. The living quarters for an ice coring team in a remote field camp in Antarctica. [Photo by Jenna Epifanio]

One of the challenges of living in a tent at a remote field camp is the wind and rapidly changing weather. Radios serve as the main method of communication. Ice coring teams at remote field camps must report multiple weather observation reports per day back to McMurdo station and complete daily check-ins with either the McMurdo or South Pole Station to ensure the continued safety of the field team.

Drilling ice cores in Antarctica

After the ice coring team arrives at their remote Antarctic field camp (**Figure 11**), the next step is to drill the ice core! Successful drilling requires extensive teamwork between the ice core scientists and drilling engineers. The scientists decide on the scientific parameters they are investigating, which determine where and how deep to drill. The engineers design the drilling methods to ensure the highest quality ice core is retrieved.

Figure 11. An aerial photograph of a remote ice coring field camp in Antarctica. The long white tube with red ends is the tent where the drilling occurs. [Photo by The National Science Foundation]

Ice core drills are either electromechanical or electrothermal. An electromechanical drill, like the one shown in **Figure 12**, uses a cutter, or drill head, to mechanically cut a core from the ice sheet. The part of the drill that goes down into the hole (called a borehole) in the ice sheet is called a sonde. The sonde is made up of an inner rotating barrel with cutters at the tip and an outer barrel that does not rotate. There is a motor that rotates the inner barrel so that the drill head cuts through the ice. Chips of ice that form as the inner barrel cuts through the ice are removed from the borehole using spiraled threads called flights. The sonde portion of the drill is suspended by a cable that is typically attached to a large tower, allowing the sonde to be moved into and out of the borehole. An anti-torque system ensures that the only piece of the sonde that rotates is the inner barrel, keeping the cable from tangling.

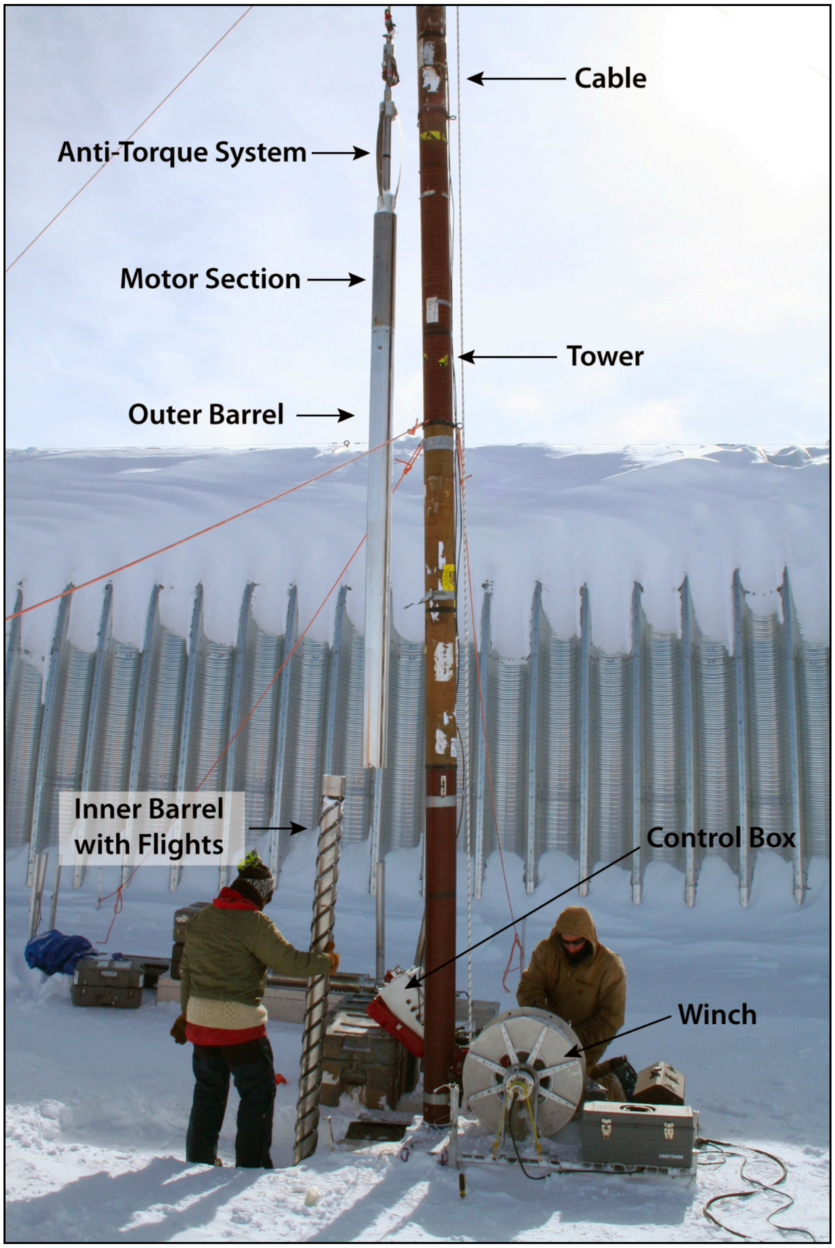

Figure 12. Major parts of an electromechanical drill. [Joseph Souney, Univ. New Hampshire]

An electrothermal drill uses heat to melt through the ice surrounding the ice core. Rather than mechanical cutters at the tip of the drill, an electrothermal drill head has a circular heating element. A benefit of electrothermal drills is that they have fewer moving parts than an electromechanical drill. However, mixing heat and ice presents its own set of challenges. Electrothermal drills are typically only used for ice that is warmer than –10°C (+14°F) because a large temperature difference between the heating element and colder ice can cause thermal shock, resulting in fractures in the ice core or changes to important chemistry.

There are many challenges facing the ice coring team as they drill. If there is too much pressure on the sides of the borehole created by the flowing ice, the borehole in the ice sheet may close. The deeper the borehole goes, the more this force will push toward closing it. To help mitigate this, a special drilling fluid is used for most boreholes that reach depths of 300 m (984 ft.) or more.

Using an electrothermal drill causes additional challenges for keeping the borehole open. An electrothermal drill creates meltwater as the drill melts down into the ice sheet, and the meltwater can refreeze if left in the borehole. The ice coring team adds antifreeze to the meltwater or stores the meltwater inside the drill to prevent freezing. However, the presence of drilling fluid and antifreeze presents further challenges, such as negative environmental impacts and impacts on ice quality.

Transporting ice cores out of Antarctica

Once an ice core is drilled in the field, the core is removed from the inner barrel of the sonde and moved to part of a main station, where it is logged. During logging, fractures and other physical properties of the core are noted. One of the major challenges, often unexpected, is identifying which way is “up!” Arrows are drawn onto the core, like in **Figure 13**, to show which way the ice core was oriented in the ice sheet, ensuring researchers know the direction of layers. Knowing the age of ice layers relative to the rest of the core, and the chemical and physical properties of each ice layer, contributes to the understanding of the climatic conditions on Earth over time.

Figure 13. Recently drilled ice core sticking out of the drill sonde. An arrow identifies its original orientation in the ice sheet. [Photo by Peter Neff/U.S. IDP]

The video "The Long Haul" described the steps to transfer an ice core from a remote field camp in Antarctica to long-term storage at the Ice Core Facility in Denver. The ice core is first cut into 1 m (3.28 ft.) long sections with a saw like the one in **Figure 14**, put into a 1 m tube, and then secured in insulated shipping containers. The ice coring team may work at their remote Antarctic field site for close to two months to pack and ship the cores to McMurdo Station. The ice that has already been packed is stored in underground snow trenches until the cores are ready to be transported.

Figure 14. Ice core scientist cutting recently cored ice into a 1 m section for packaging and shipment. [Photo by Mark Twickler/UNH]

The shipping containers are flown in an unheated aircraft cabin back to McMurdo Station, where they are put into the onsite freezers. From there, they are shipped in a refrigerated cargo ship, called reefer ships, to California before the last leg of their journey to the NSF National Ice Core Facility (NSF-ICF) in Denver, Colorado. Currently, the main freezer at the NSF-ICF, pictured in **Figure 15**, is 55,000 ft.[3] with over 22,000 m of ice and is held at –36°C (–33°F).

Figure 15. Silver tubes of ice stored in the freezer at the National Science Foundation Ice Core Facility in Denver, Colorado. Each tube contains 1 m (3.28 ft.) of ice. The white boxes contain recently drilled ice from the WAIS. [Photo by Peter Rejcek/NSF-ICF]

New boxes arriving from the field, like the white ones in Figure 15, are brought into the freezer quickly when they arrive in Colorado. The ice is allowed to equilibrate to the temperature of the freezer before the tubes are organized on shelves for long-term storage. The tubes are inventoried and recorded in a database available to researchers around the world, who can request access to the ice. Like those in **Figure 16**, scientists can visit the NSF-ICF to examine, and even cut pieces of the ice, which are shipped back to their laboratories for further analyses. This step is called *core-processing* and takes place in a –25°C (–13°F) laboratory. This process requires significant thought and planning to get the most information from each core.

Figure 16. Ice core scientists at the NSF Ice Core Facility in Denver, CO planning how they will cut the ice core into sections that will be delivered to research laboratories across the country. [Photo by Danielle Whittaker]

Elaborate | Drilling for ice cores in Antarctica

In the search for old ice, an ice coring team must consider many different features of the ice sheet and the bedrock under it. To find one continuous core with the oldest ice at the bottom, scientists often search in areas where the ice is thick, and the ice layers are believed to have remained mostly horizontal over time. **Figure 17** shows a computer model of ice thickness across Antarctica.

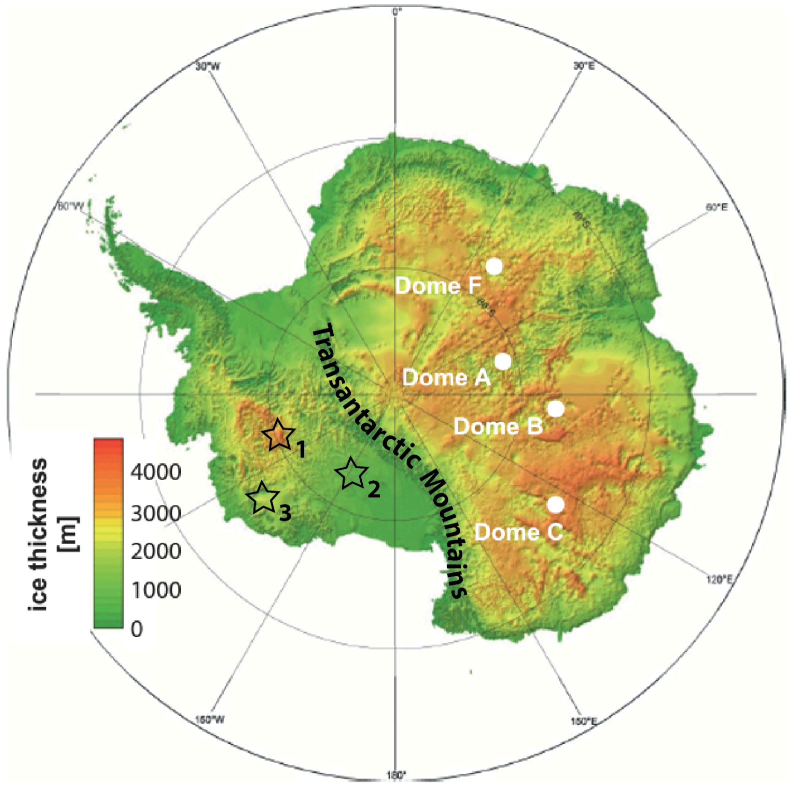

Figure 17. The ice thickness across Antarctica, with darker red for thickest and green for thinnest. The white dots are four known ice domes. The outlined stars discussed in #3. [Fischer et al. (2013)]

1. Recall that the Transantarctic Mountains separate the WAIS to the West and the EAIS to the East. Overall, where is thicker ice found? (Select all that apply)
   a. WAIS
   b. EAIS
   c. Ice domes
   d. The coast

2. Ice cores have been drilled at Dome F, also called Dome Fuji. Based on Figure 17, which of the following describes the most likely length of the Dome Fuji ice core?
   a. Between 1,000 and 2,000 m
   b. Between 3,000 and 4,000 m
   c. Greater than 4,000 m

As of 2023, the WAIS Divide ice core is the longest core ever drilled by a U.S. ice coring team at 3,405 m (11,171 ft.) long.

3. Which location would likely produce the 3,405 m WAIS Divide ice core plotted on Figure 6?
    a. Star 1
    b. Star 2
    c. Star 3

When planning where to drill for discontinuous, older ice, many different features of the Antarctic ice sheets must be considered, including the elevation of the bedrock below the ice sheet. Ice that has flowed over or toward mountainous terrain will likely have layers that have been deformed, making the age of the layers more difficult to calculate. **Figure 18** below shows the results of a computer model of the bedrock elevation across Antarctica.

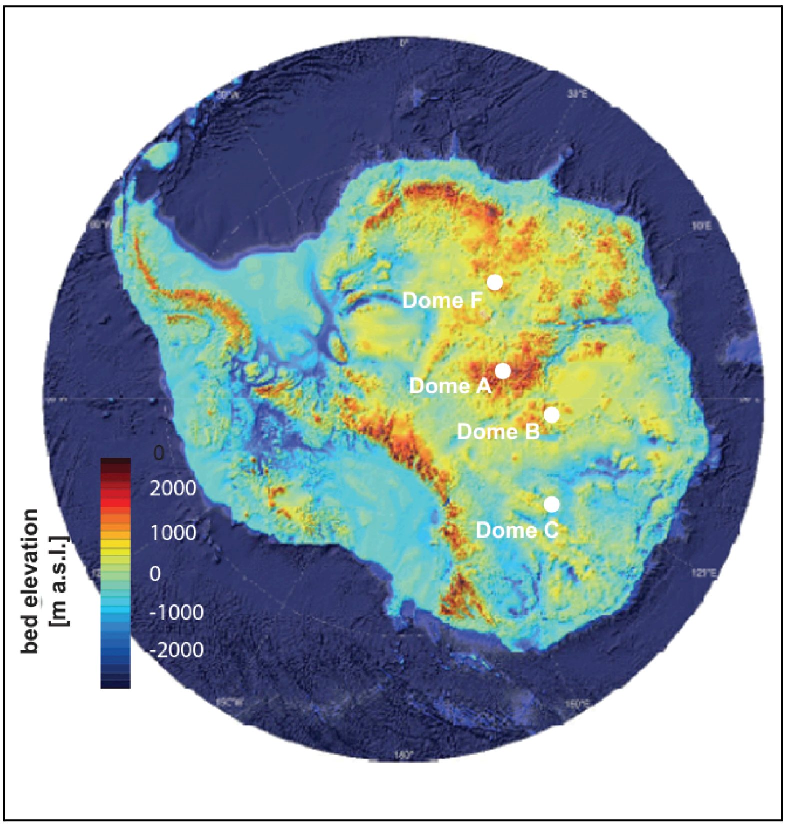

Figure 18. The bedrock elevation across Antarctica with white dots for four known ice domes. [Fischer et al. (2013)]

4. Which of the ice domes is located over the Gamburtsev Mountains, a mountain range that reaches an elevation of over 3,000 m?
    a. Dome F
    b. Dome B
    c. Dome A

5. Sometimes, ice core scientists drill into the bedrock below the ice sheet for rock samples. Which conditions would you look for if this was your main goal?
    a. Thick ice and low bedrock elevation
    b. Thick ice and high bedrock elevation
    c. Thin ice and low bedrock elevation
    d. Thin ice and high bedrock elevation

Watch the U.S. Ice Drilling Program video, "Polar Science and Engineering: Drilling Back Through Time," from the beginning to 6:30.

6. Which of the following best describes the ice core scientists' main scientific question in this video?
    a. Did a series of volcanic eruptions 18,000 years ago contribute to a change in the climate at that time?
    b. Is it possible to drill a "replicate core", meaning an ice core that is drilled directly next to the borehole of a previously-drilled ice core?
    c. Can we extend the WAIS Divide ice core depth even further than the already-drilled 3,405 m?

7. Which of the following best describes the drilling engineers' main objective in this video?
    a. Discover whether a series of volcanic eruptions 18,000 years ago contributed to a change in the climate at that time
    b. Design a way to drill a replicate core from a parent borehole, meaning an ice core drilled directly next to the borehole of a previously-drilled ice core
    c. Extend the WAIS divide ice core depth even further than the already-drilled 3,405 m

8. What was the difference in tilt between the parent borehole and the newly drilled replicate borehole at the WAIS divide camp?
    a. 5°
    b. 10°
    c. 1°

9. After a borehole is drilled and the ice cores removed, scientists can place instruments into the borehole to measure different properties of the ice. What do we call this group of scientists?
    a. Ice core inspectors
    b. Instrument droppers
    c. Borehole loggers

An ice coring team can have fun in Antarctica too! Watch [this video of COLDEX scientist Peter Neff] explaining the unexpected sounds you hear when dropping a piece of ice down a borehole.

10. What causes the sound at the surface to change as the ice falls down the borehole?
    a. The Doppler Effect
    b. The Photoelectric Effect
    c. The Domino Effect

Evaluate | Thinking like an ice core scientist

To review what has been presented and investigated during this module:

11. There are three United States stations in Antarctica: McMurdo, Amundsen-Scott South Pole, and _________.
    a. Casey Station
    b. Palmer Station
    c. Syowa Station

12. Where an ice coring team drills for ice depends on the scientific questions being asked as well as the logistical requirements for drilling. Where would you search for old ice if you wanted to drill a shallow core?
    a. In a Blue Ice Area
    b. At an ice dome
    c. Where the ice sheet flows up against a mountain range
    d. Both a and b are correct.
    e. Both a and c are correct.

13. Which ice coring drill would you use for ice that is colder than –10°C (+14°F)?
    a. An electrothermal drill
    b. An electromechanical drill

14. After drilling an ice core, the ice coring team cleans off any drilling fluid on the core, notes the ice's characteristics, cuts it into 1-meter pieces, and then ______.
    a. melts off the bottom layer of ice
    b. removes air bubbles in the ice
    c. marks the “up” direction in the ice

15. Drilling engineers keep the whole drill setup from rotating and the cable from becoming tangled by using which of the following?
    a. Anti-torque system
    b. A sonde
    c. Flights

16. "The Long Haul" video described that one of the most important engineering challenges is to keep the ice cores _______ on their journey from Antarctica to the National Ice Core Facility in Denver.
    a. clean
    b. frozen
    c. pressurized

17. An ice coring team typically works during the Antarctic summer, when the temperatures are warmer and the sun is constantly up. When is the Antarctic summer?
    a. October to February
    b. May to October
    c. December to June

18. To find potential areas with old ice, which tools do COLDEX scientists use? (Select all that apply)
    a. Airborne and surface radar
    b. Ice Diver Thermal Probe
    c. Computer modeling
    d. All of the above

19. The EPICA Dome C ice core currently covers the longest span of Earth's paleoclimate history. How many years does the ice in the Dome C core correspond to?
    a. 400,000 years
    b. 68,000 years
    c. 740,000 years

20. In undisturbed ice layers, the oldest ice is found at the _______ of the ice sheet.
    a. bottom
    b. top

Workshop Extensions |
"The Long Haul Ice Core Challenge"