# Chapter 11 Antarctica and Neogene Global Climate Change

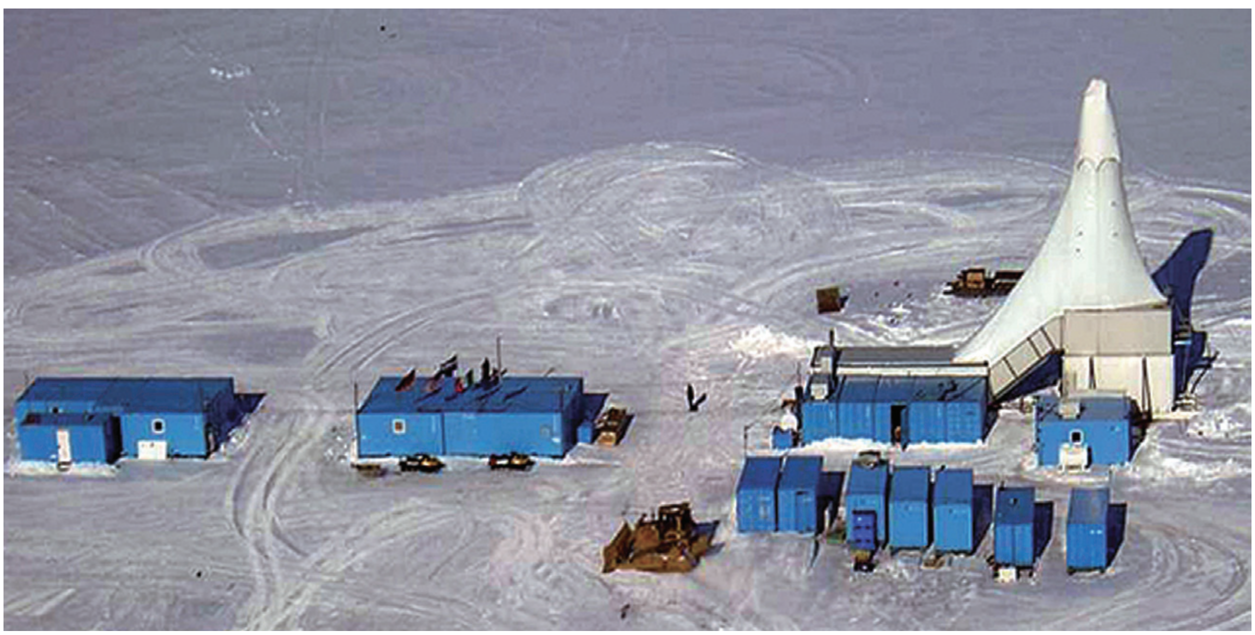

**FIGURE 11.1.** The ANDRILL drill site on the McMurdo Ice Shelf during the 2006/07 field season. From http://antarcticsun.usap.gov/science/contenthandler.cfm?id=2092. Photo provided by the ANDRILL program.


**SUMMARY**

This investigation introduces you to the status and role of Antarctica in Cenozoic (specifically Neogene) climate change and sets the stage for evaluating the two sediment cores retrieved from the floor of McMurdo Sound by the Antarctic Geologic Drilling Project (ANDRILL) in 2006 and



*Reconstructing Earth's Climate History: Inquiry-Based Exercises for Lab and Class*,
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2007 (Figure 11.1). The cores are introduced in Chapter 12 (Interpreting Antarctic Sediment Cores). In this chapter you will build basic geographic and geologic knowledge of Antarctica and use geologic reasoning. In **Part 11.1,** you will review your understanding of the oxygen isotope curve, interpret global climate conditions from this curve, and assess the validity of your global interpretations based on the global distribution of sediment cores. In **Part 11.2,** you will become familiar with the geography and geologic units of the Ross Sea region of Antarctica and review or build your knowledge of southern hemisphere seasons, sea-ice, ice-shelves, and the challenges associated with obtaining a sediment core from the floor of McMurdo Sound. You will also build and use your understanding of simple geologic maps, cross sections, and the geologic time scale, so you can explain the reasons for selecting drill sites in McMurdo Sound. In **Part 11.3,** you will review the existing data from sediment cores in the Ross Sea region of Antarctica and use the knowledge gained in Parts 11.1 and 11.2 to identify a target stratigraphic interval and select two drill sites. Evaluation of the ANDRILL core is undertaken in Chapter 12 "Interpreting Antarctic Sediment Cores".

# Antarctica and Neogene Global Climate Change

## Part 11.1. What Do We Think We Know About the History of Antarctic Climate?

### Introduction

Over the last 40 years, numerous studies have used sediment cores recovered from the ocean floor to examine the history of the Earth's climate during the Cenozoic (the last 65 million years). Many of these studies have identified changes in the Earth's climate during the Cenozoic and have invoked conditions in Antarctica as a major influence on climate and environments elsewhere around the world. In particular, the steps in the Antarctic climate that have been interpreted from these studies include those shown in Table 11.1.

**Table 11.1.** General interpretation of Oligocene–Holocene Antarctic climate from the late 1970s (Kennett and Shackleton, 1976 a, b; Shackleton and Kennett, 1975; Kennett, 1978).

| | |
|---|---|
| Approximately 34 million years ago | The first major cooling in Antarctica and the first development of large ice sheets in Antarctica |
| Approximately 15 million years ago | A second additional cooling step and development of major ice sheets in Antarctica |
| Approximately 15 million years ago to present time | Persistence of a cold polar climate and large stable ice sheets in Antarctica |

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**1** The oxygen isotope curve (Figure 11.2) was constructed using data from multiple ocean drilling sites and is used to interpret Antarctic ice volume. Explain how and why this curve supports the three major steps listed in Table 11.1.

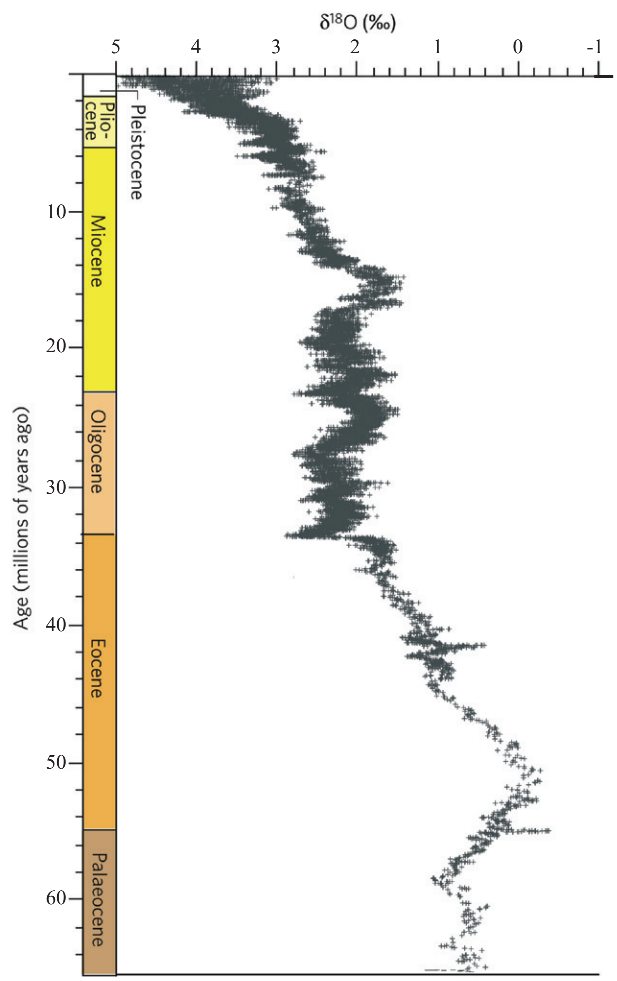


**FIGURE 11.2.** Composite marine record for $\delta^{18}O$ from benthic foraminiferal calcite. Modified from Zachos et al., 2008.

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**2** What do you notice about the distribution of deep sea drilling sites (Figure 11.3), some of which were used to build the composite oxygen isotope curve in Figure 11.2?

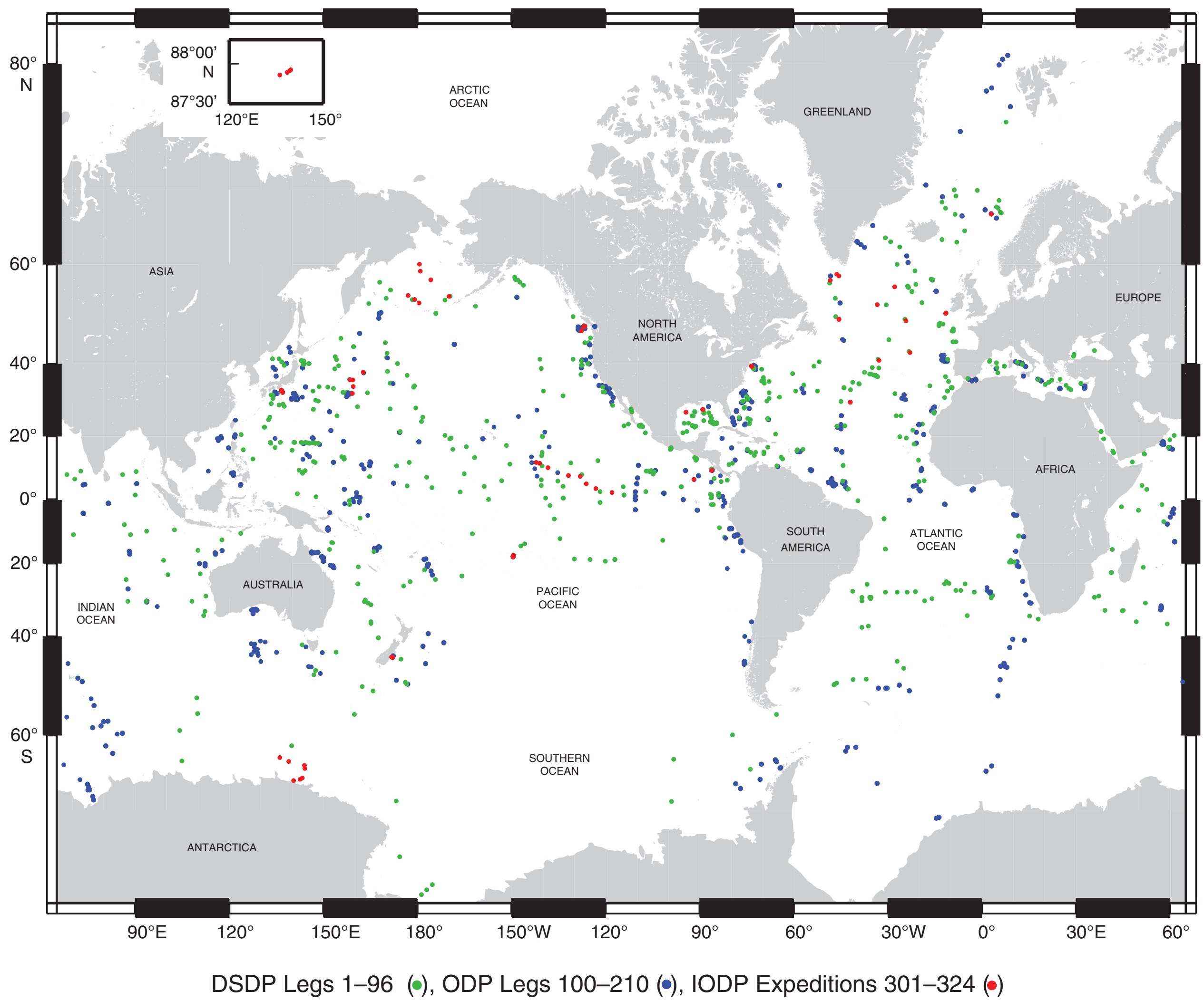


**FIGURE 11.3.** Map showing distribution of DSDP, ODP, and IODP core locations. Map courtesy of IODP.

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**3** Does the distribution of sites in Figure 11.3 provide a relatively direct indicator of climatic conditions near the Antarctic continent? Explain your answer.

**4** Based on the distribution of drill site locations, where would you go to test the interpretations in Table 11.1 further? Put three X's on the map to indicate your selection of future drill sites. Explain the reasoning for your site selections.

**5** Based on what you have learned from other exercises in this book that you have done thus far, what observations and data from sediment cores can be used to help interpret past climates?

**6** Thinking back to Chapter 2, what type(s) of sediment would you expect to be deposited (a) adjacent to a glaciated Antarctica and (b) to an unglaciated Antarctica?

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(a)

(b)

**7** How might changes in global climate, such as an increase in global average temperature or a change in global precipitation patterns, have an impact on Antarctica?

**8** Not only can changes in global climate affect regional climate (Question 7), but changes in regional climate can in turn affect global climate. Use your understanding of the Earth's system feedbacks (Chapter 5), of thermohaline circulation (Chapter 10), and sea level to explain how melting of the Antarctic ice sheets might affect global climate?

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# Antarctica and Neogene Global Climate Change

## Part 11.2. What is Antarctica's Geographic and Geologic Context?

**1** Antarctica has been described as the coldest, windiest, driest, and harshest place on earth. Find out what the **current weather** is at McMurdo Station, Antarctica. http://www.wunderground.com/global/AA.html.

| | |
|---|---|
| Date/Time: | |
| Precipitation: | |
| Windspeed and Direction: | |
| Temperature (°F): | |

**2** What is the temperature (from question 1) in °C? _________
Conversion °F to °C = ([F]–32) × 0.55556) Show your calculations below.

Watch the videos and peruse the websites introduced in Questions 3–5 to learn about the Antarctic geography as well as logistical, technological, and scientific challenges associated with scientific research in Antarctica, then answer Questions 3 to 8.

**3** Watch "A Tour of the Cryosphere: Earth's Frozen Assets" produced by NASA at: http://www.nasa.gov/vision/earth/environment/cryosphere.html (select the version with narration). What are the main types of ice body that make up the cryosphere in the Antarctic region?

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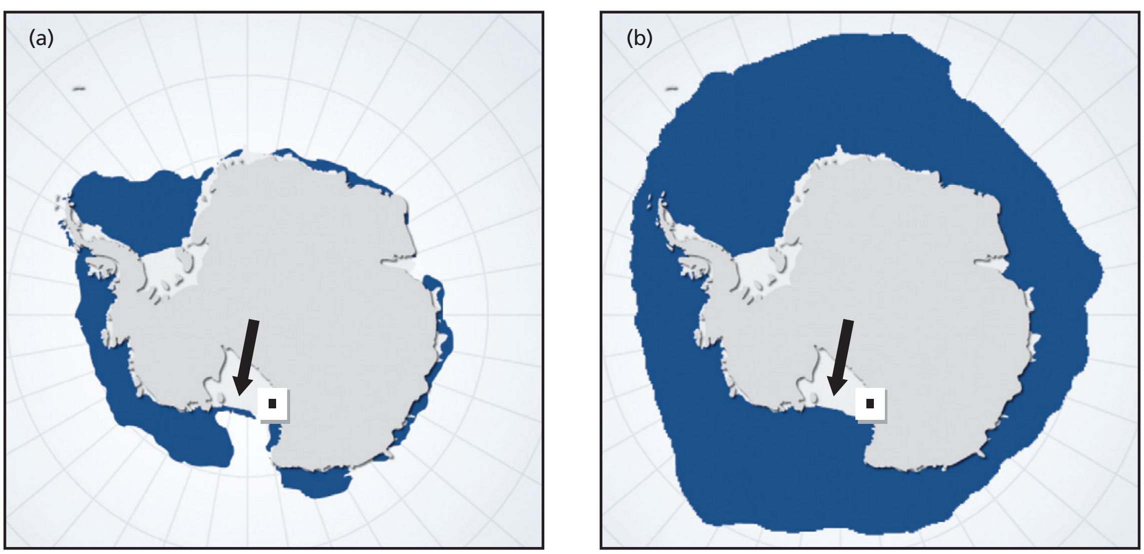
4 Learn about Antarctic sea ice and its seasonal variability at: http://earthobservatory.nasa.gov/Features/WorldOfChange/sea_ice_south.php.

(a) On each of the maps below (Figure 11.4) indicate which specific month is represented.

(b) Explain how you used the reasons for seasonal variability in sea-ice extent to select your answer to 4(a).




| Month: | Month: |
|---|---|

**FIGURE 11.4.** Maps of Antarctica and the Southern Ocean; extent of sea ice shown in dark blue. Ross Sea region indicated by an arrow and McMurdo Station by a black square in a white box. Maps courtesy of the Australian Antarctic Division (http://www.classroom.antarctica.gov.au/6-climate/6-3-annual-ice-cycle).

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**5** Watch: "Southbound" (ANDRILL, 2006) at: http://www.andrill.org/iceberg/videos/2006/index.html, and "Antarctica Today" (ANDRILL, 2007), "Antarctic Geology" (ANDRILL, 2007), and "Historical Journey" (ANDRILL, 2007) at: http://www.andrill.org/iceberg/videos/2007/index.html.

Use the information from these online videos to summarize the technical, logistical, and scientific challenges of doing research in Antarctica:

**6** Based on the information conveyed in the videos above (Questions 3–5), outline the climatic history of Antarctica for the past 350 million years. Record your responses in the table below. (For more information on icehouse vs. greenhouse conditions see Chapter 5.)

| Name and Age (in millions of years) of Time Block | Climatic Condition: Icehouse or Greenhouse? | Proxy Evidence for the Climatic Condition |
|---|---|---|
| | | |

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**7** In Questions 1 and 2 you examined data on current weather at McMurdo Station. In Question 6 you summarized data on Antarctic paleoclimates. Use your knowledge and resources to:

(a) Explain the difference between weather and climate at a given location (e.g. Antarctica):

(b) Explain the difference between "local climate" and "global climate":

In the past 50 years much research has taken place near McMurdo Station, the largest US research base in Antarctica (Figure 11.5). McMurdo Station is located on Ross Island, an island in the western Ross Sea built from active and recently active volcanoes. The Ross Island volcanoes and other volcanic features in the region form the Erebus Volcanic Province, where volcanic activity has occurred throughout the past approximately 15 million years. The Trans Antarctic Mountains (TAM) mark the eastern margin of East Antarctica, and are well exposed approximately 60 km to the west of Ross Island. The TAM are composed of older rocks (Figures 11.6 & 11.7). Note that on average only 2% of the surface of Antarctica today is exposed rock; the rest is covered by ice.

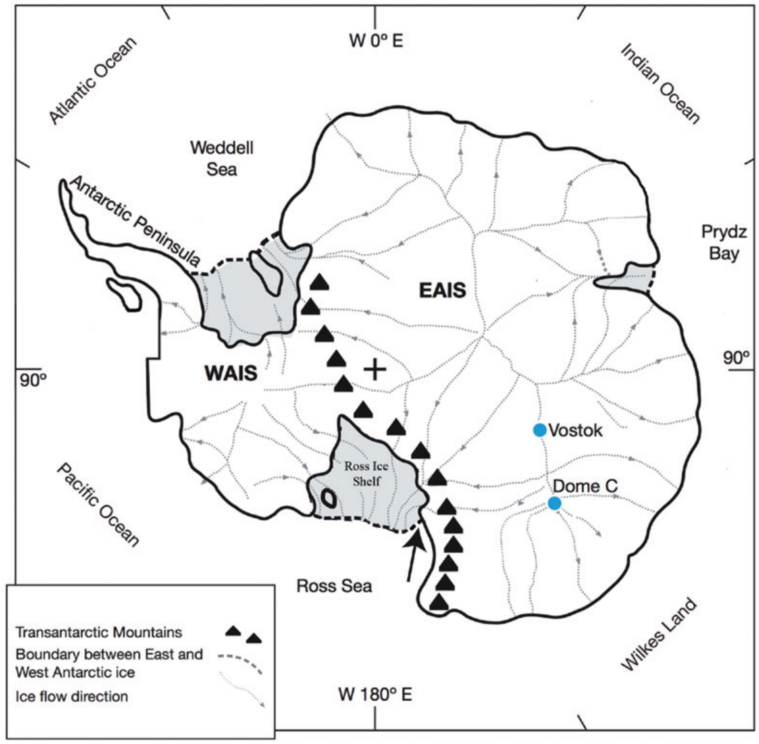


**FIGURE 11.5.** Map of Antarctica showing location of the East Antarctic Ice Sheet (EAIS), the West Antarctic Ice Sheet (WAIS), the Trans Antarctic Mountains (TAM) and the Ross Ice Shelf. The map also shows the main ice divides. The arrow points to Ross Island. Modified from Hambrey et al, 2003.

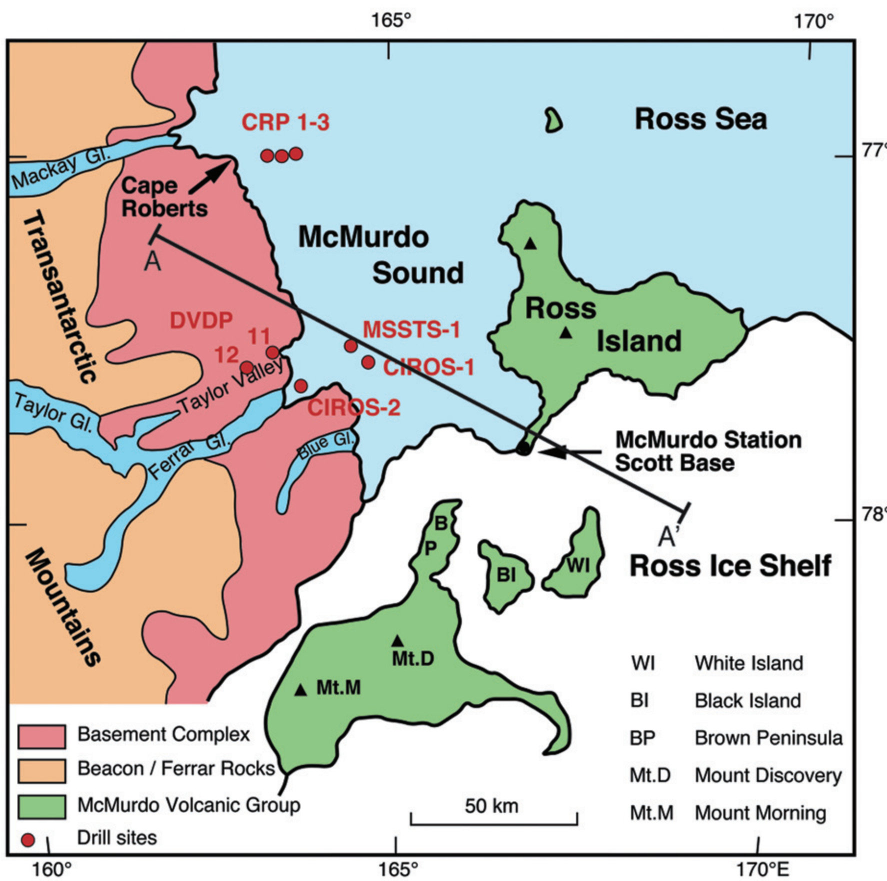


**FIGURE 11.6.** Simplified geologic map of McMurdo Sound region showing Ross Island and the Trans Antarctic Mountains, as well as location of selected drill sites (CRP, DVDP, CIROS and MSSTS). Rocks identified as "Basement Complex" and "Beacon/ Ferrar" on this map constitute "Bedrock" and are detailed in Figure 11.7, as are the McMurdo Volcanics. The line of cross section in Figure 11.8 (A–A') is also shown. **The Ross Sea (ocean) is blue** in this image, and **the Ross Ice Shelf is white**. Outlet glaciers shown in bright blue. Map drawn by Werner Ehrmann, Universitat Leipzig.

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McMurdo Sound is a southward extension of the seasonally open-water portion of the Ross Sea; it lies between Ross Island and the East Antarctic mainland (Figure 11.6), and is covered during the southern hemisphere winter by sea ice approximately 2–6 m thick. During the southern hemisphere summer, most of this sea ice melts and open-water conditions are present. The McMurdo Ice Shelf lies to the south of Ross Island and connects to the east and south with the larger Ross Ice Shelf. Both of these ice shelves are fed by glacial ice flowing from the large West Antarctic Ice Sheet and the much larger East Antarctic Ice Sheet and cover the remainder of the Ross Sea. Water depths beneath the ice shelves are as much as approximately 1000 m.

**8** Based on the geologic map and related key for the western Ross Sea area near Ross Island (Figure 11.7), **estimate the percentage of land area exposed in the western Ross Sea area**. Consider only areas above sea level.

**9** Is this more or less than is exposed in Antarctica in general? (Note: In Figure 11.5 areas of white are covered by ice and gray is ice shelf.)

**10** Based on the summary information provided and that presented in Figures 11.6 & 11.7, what are the general rock types and ages exposed in the **Trans Antarctic Mountains**?

| Trans Antarctic Mountain Rock Types | Trans Antarctic Mountain Rock Ages |
|---|---|
| | |
| | |
| | |
| | |
| | |


**FIGURE 11.7.** (a) Portion of geologic map and (b) legend from Geologic Map of Antarctica, Sheet 14, Terra Nova Bay – McMurdo Sound Area, Victoria Land, Note that south is towards the top of the map, and that white regions on the map indicate ice (and therefore no exposed bedrock). From Warren, 1969.

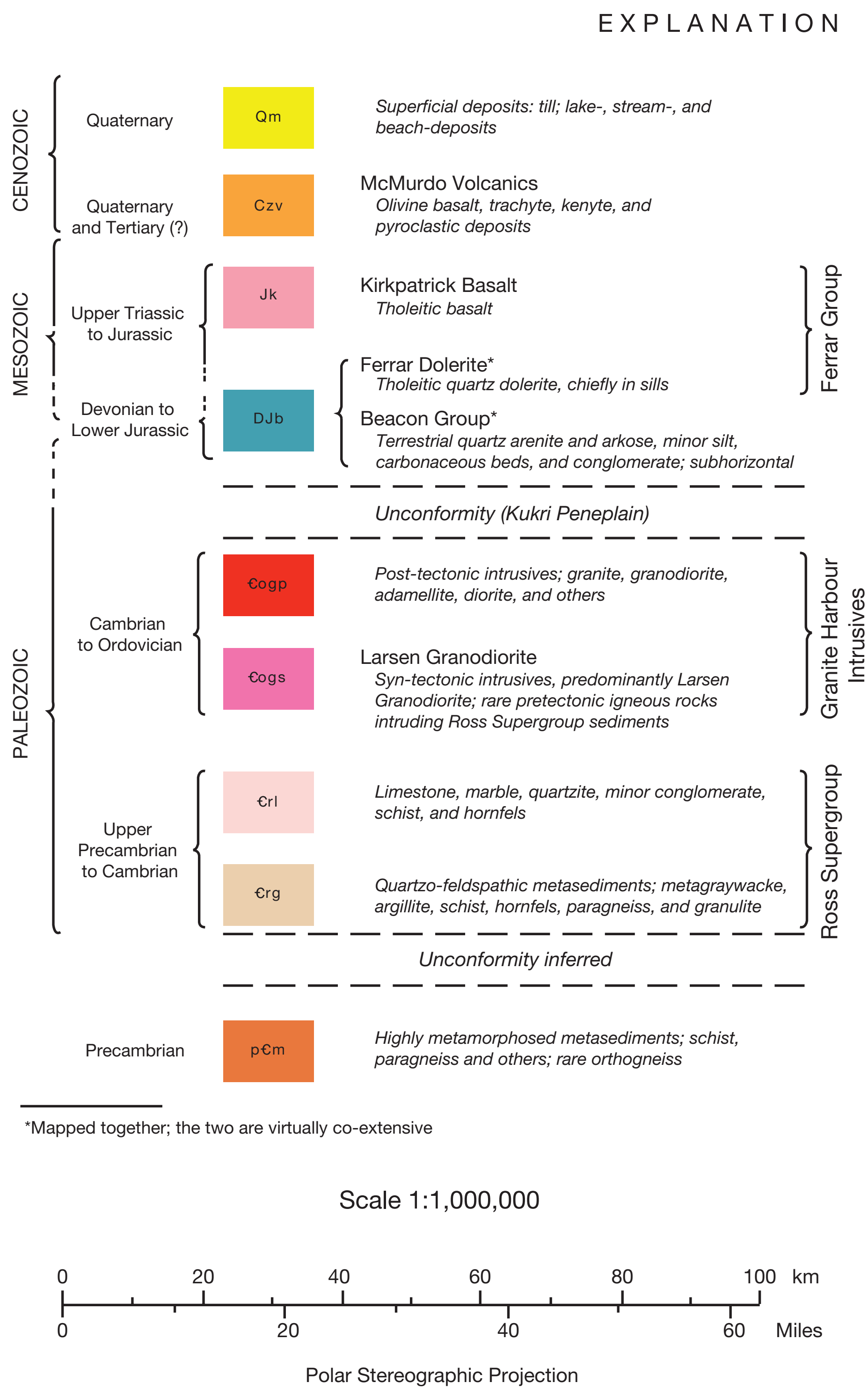


**FIGURE 11.7.** *Continued*

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**11** Based on information given above and on the maps (Figures 11.6 & 11.7) what is the general rock types and ages on **Ross Island** (the location of McMurdo Station & Scott Base)?

| Ross Island Rock Types | Ross Island Rock Ages |
|---|---|
| | |
| | |
| | |
| | |

**12** How much information does the type of rock you identified in Question 11 give you about climate at the time the rocks formed? Explain.

Sedimentary layers are somewhat like wall posts on your facebook wall. Each wall post tells another step or part of a story. The oldest wall posts are at the bottom and the youngest (newest, most recent) wall posts are at the top. Presumably, the more wall posts there are, the more complete the story (or record) is. This general analogy also applies to a book or journal; the more pages there are, the **more complete**, or **more detailed**, the story is.

**13** Using the wall post or journal analogy, consider a complete sequence of sediments (i.e. a lifetime of wall posts!). Broadly speaking, does a **thicker** or **thinner** sedimentary sequence provide a more complete record of geologic events affecting the area adjacent to the basin in which the sediments are accumulating? Explain your reasoning.

**14** Based on the maps (Figures 11.6–11.7) and the cross section (Figure 11.8), where **in general** are you most likely to find a complete Cenozoic sedimentary sequence?

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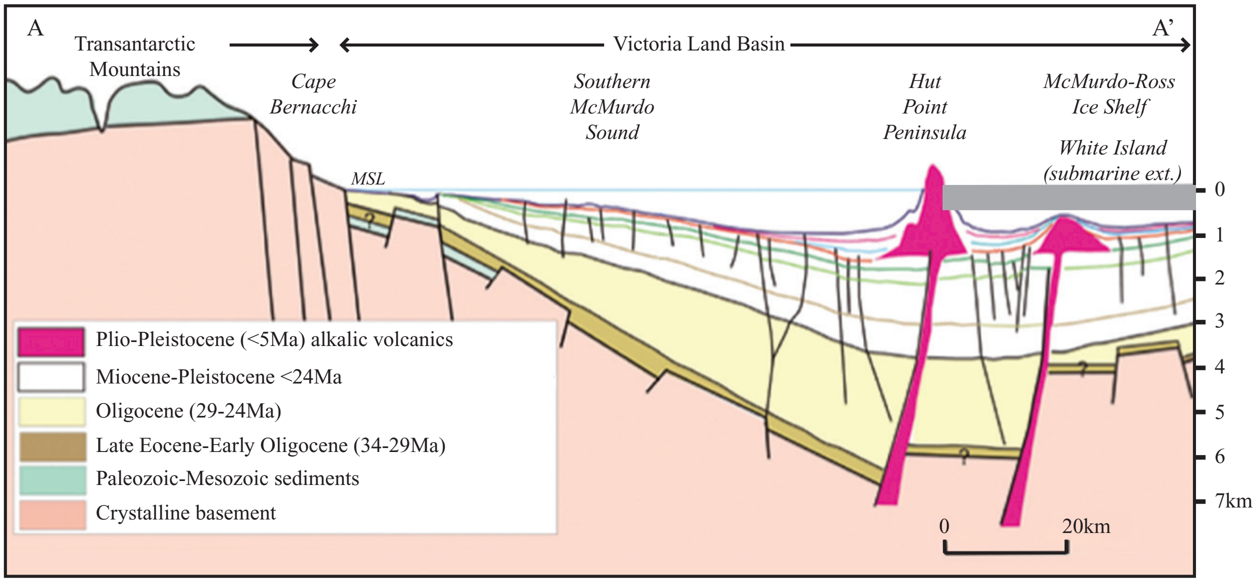


**FIGURE 11.8.** Simplified geologic cross-section of the western Ross Sea region. Adapted from Naish et al., 2005, ANDRILL Contribution 4 http://andrill.org/publications). The line of cross-section is shown on Figure 11.6. The colored lines in the Miocene–Pleistocene sediments are marker horizons (or "reflectors") based on seismic surveys. Hut Point Peninsula is the south-southwest projection of Ross Island. The gray area at sea level is the Ross Ice Shelf; the pale blue line at sea level represents the region covered by varying amounts of sea-ice. MSL = mean sea level. Note that this is essentially the same as Figure 11.11 (which has additional information), however they are used for different purposes. From Harwood et al., 2008–2009.

**15** On Figure 11.8 draw a distinct vertical line where the Cenozoic sedimentary sequence is thickest and is undisrupted by faults.

(a)What was the probable source of the terrigenous Cenozoic sediments?

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(b) Considering that Southern McMurdo Sound and the McMurdo-Ross Ice Shelf are covered with sea ice or ice shelves, how might you obtain a drill core in the location you have selected?

# Antarctica and Neogene Global Climate Change

## Part 11.3. Selecting The Best Drill Sites for the Science Objectives

In the past 35 years, several drilling projects have taken place in the McMurdo Sound region. The sites drilled by these projects are shown in Figure 11.9 and the ages of the sediments recovered are shown in Figure 11.10. For most of these projects, a drilling rig was placed on the sea ice or the ice shelf at the drilling location during the southern hemisphere spring and early summer, in other words, the ice (rather than a ship) acted as the “drilling platform”.

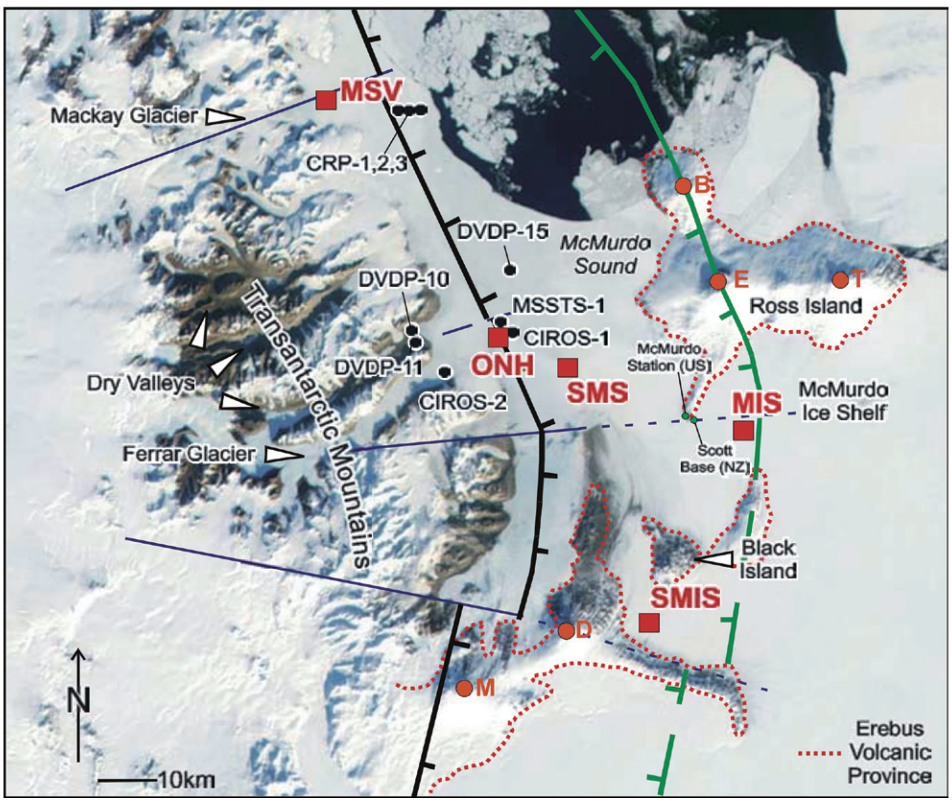


**FIGURE 11.9.** Geography of McMurdo Sound Region, showing geographic and tectonic features and location of drill cores. Red dotted line outlines extent of the Erebus Volcanic Province (Kyle and Cole, 1974). Volcanic centers of Erebus (E), Terror (T), Bird (B), Discovery (D) and Morning (M) are marked. Also shown are locations of previous stratigraphic drill holes (DVDP, CIROS, MSSTS, and CRP) in McMurdo Sound. Completed and Potential ANDRILL sites shown by red squares. From Harwood et al., 2008–2009.

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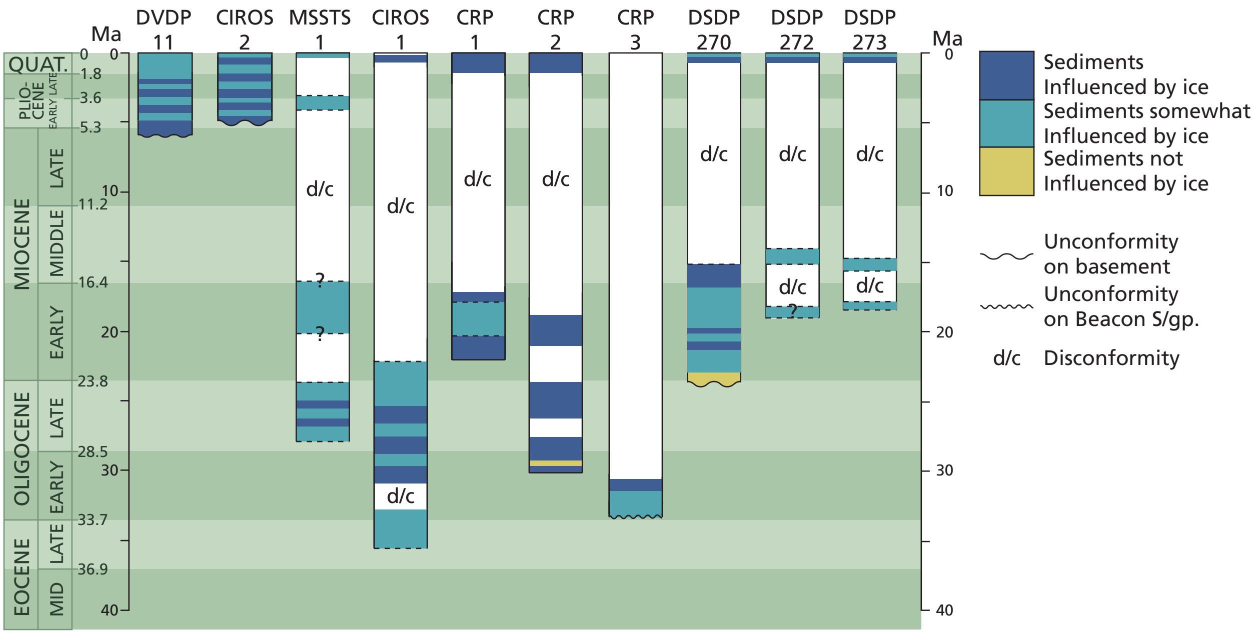


**FIGURE 11.10.** Age of sediments retrieved from drilling projects in the Ross Sea region. Figure adapted from Harwood et al., 2002. The location of the Deep Sea Drilling Project (DSDP) cores is not shown in Figure 11.9.

**1** Do the datasets from the Ross Sea region (Figure 11.10) provide adequate data to evaluate the history of environmental and climatic conditions postulated (Table 11.1) for Antarctica **throughout** the past 34 million years? Explain your answer.

**2** How does the drill core data summarized in Figure 11.10 **support or refute** the hypotheses about Antarctic Ice volume and climate that have been proposed (see Table 11.1)? Explain your answers.

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Imagine that you have been assigned the job of developing the next drilling program for the Ross Sea region. Consider the following logistical and financial constraints:

- The project is funded for two drill sites.
- Funding is US$20 million.
- The drill rig is limited to a maximum 1500 m of penetration below the seafloor at any site drilled.

3 Examine Figure 11.10 and identify the **age interval** within the Cenozoic that should be your primary drilling target. In other words, what age interval has been least sampled by previous drilling programs, so that you would obtain the most scientific "bang for the buck" by sampling it? Explain your choice of an age interval.

4 Assuming that your project is enormously successful and recovers 3000 m of core, how much does 1 m of core cost? Show your calculations.

The sediments younger than approximately 5 Ma that have been sampled previously in the Ross Sea region form relatively thin layers and are poorly dated. As a result, the environmental and climatic history of Antarctica for the last 5 million years is poorly known.

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**5** Why might you be particularly interested in developing a detailed history of Antarctica for the past 5 million years? Explain.

Figure 11.11 is a generalized geologic cross section of the western Ross Sea region. The colored lines beneath the seafloor of the Victoria Land Basin indicate the positions of distinctive seismic reflectors (or distinctive sediment layers). Where known, the interpreted ages of these reflectors are listed at the bottom of Figure 11.11.

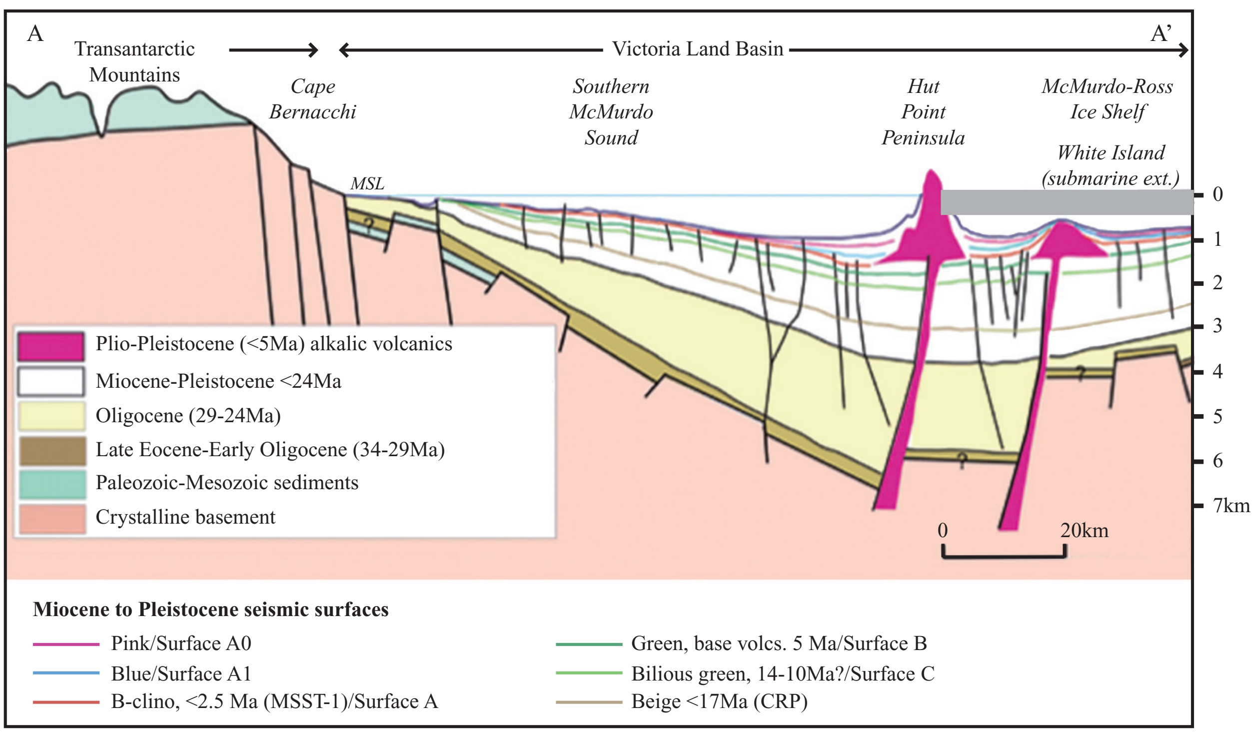


**FIGURE 11.11.** Cross-section of the Victoria Land Basin of western Ross Sea region (adapted from Naish et al., 2005); line of cross-section shown on Figure 11.8; Hut Point Peninsula is part of Ross Island; MSL = mean sea level; gray area to right of Hut Point Peninsula is the Ross Ice Shelf. This figure is similar to Figure 11.8, but it contains more information on the seismic reflectors. From Harwood et al., 2008–2009.

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**6** Use Figure 11.11 to **pick locations for two drill sites –** one to sample the age range you identified as your primary drilling target in Question 3 above and the second to sample sediments younger than approximately 5 Ma. In each case, you want to core through the target interval, but are limited to total penetration into the seafloor of 1500 m or less; you also need to make sure the core does not intersect any faults. Clearly show your drill sites on Figure 11.11 and **explain/justify your choice of drill sites in the space below**.

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