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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Antarctic Ice Sheet

Computer animations and paper model

By
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Open-file Report 98-353A

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1998

Description of Report

This report illustrates, through computer animation and a paper model, why there are changes on the ice sheet that covers the Antarctica continent. By studying the animations and the paper model, students will better understand the evolution of the Antarctic ice sheet.

Included in the paper and diskette versions of this report are templates for making a paper model, instructions for its assembly, and a discussion of development of the Antarctic ice sheet. In addition, the diskette version includes a animation of how Antarctica and its ice cover changes through time.

Many people provided help and encouragement in the development of this HyperCard stack, particularly Page Mosier, Sue Priest and Art Ford. This report was enhanced by reviews from Bonnie Murchey, Peter Stauffer and Stephen Eittreim.

Table of Contents for paper version of this report.

Description of Report

Requirements for using the diskette version are: Apple Computer, Inc., HyperCard 2.2™ software and an Apple Macintosh™ computer with an internal disk drive. If you are using System 7, we recommend having at least 8 MB of physical RAM with 4.5MB of memory available for HyperCard.

The animation is accompanied by sound. If no sound is heard, change the memory of HyperCard to 4500K and ensure that the control panel "Sound," which is in the "Control Panels" folder under the "Apple" menu, has the volume set to at least 2. To change the memory available to HyperCard, quit this stack. Highlight the HyperCard program icon and choose "Get Info" from the File Menu. Change the "memory requirements" to 4500K and start this stack again.

Purchasers of the diskette version of this report, which includes all of the text and graphics, can use HyperCard 2.2™ software (not supplied) to change the model (by adding patterns, symbols, colors, etc.) or to transfer the model to other graphics software packages.

To see the entire page (card size: MacPaint), select "Scroll" from the "Go" menu and move the hand pointer in the scroll window. If you are experiencing trouble with user-level buttons, select "message" from the "Go" menu. Type "magic" in the message box and press return. Three more user-level buttons should appear.

The date of this Open File Report is 6/30/1998. OF 98-353-A, paper copy, 49p.; OF 98-353-B, 3.5-in. Macintosh 1.4-MB high-density diskette.

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Teachers Guide:

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Learn about Antarctica

Antarctica lies at the "bottom of the world" and is the highest (in elevation), driest, and coldest continent on earth. It is nearly one and a half times larger than the continental United States, and its coastlines are longer than those that surround North America. The continent is surrounded by the largest of all the oceans – the Southern Ocean – that includes parts of the Atlantic, Pacific, and Indian Oceans. Yet, Antarctica has not always been this way, and at one time it was a more hospitable place. In the following descriptions, you will discover how Antarctica evolved from a giant land mass called **Gondwanaland** to a continent surrounded by water and covered by ice. And, you will learn how the massive ice sheet that now covers Antarctica evolved, and how the **ice sheet** acts as the "Earth's refrigerator" to strongly control our global **climate** and sea level. Antarctica is a remote continent of great beauty and is a challenge to adventurous explorers and scientists who want to know more about "The Last Place on Earth".

The Great Southern Continent

Antarctica is a vast continent that lies below an even larger "slab" of ice called the Antarctic Ice Sheet. When we look at maps, we see mostly the outline of the edges of the Ice Sheet. But, when we lift up the ice sheet (as you can do with the paper model that comes with this report), we see that there is water and land beneath the ice. There are large seaways and bays that go far into the continent and lie below sea level. And, there are large isolated lakes. Mountain ranges also lie under the ice. They are as long and high as those that cross the western United States. All that we know about what lies under the ice comes from remote sensing "radar" surveys that have been done by scientists from many countries. These surveys cover only a very small part of Antarctica, and there are many surprises yet to be discovered under areas of the ice sheet that have not been studied. But, in general, the continent under the ice is much like any other land areas without ice.

Index map of Antarctica

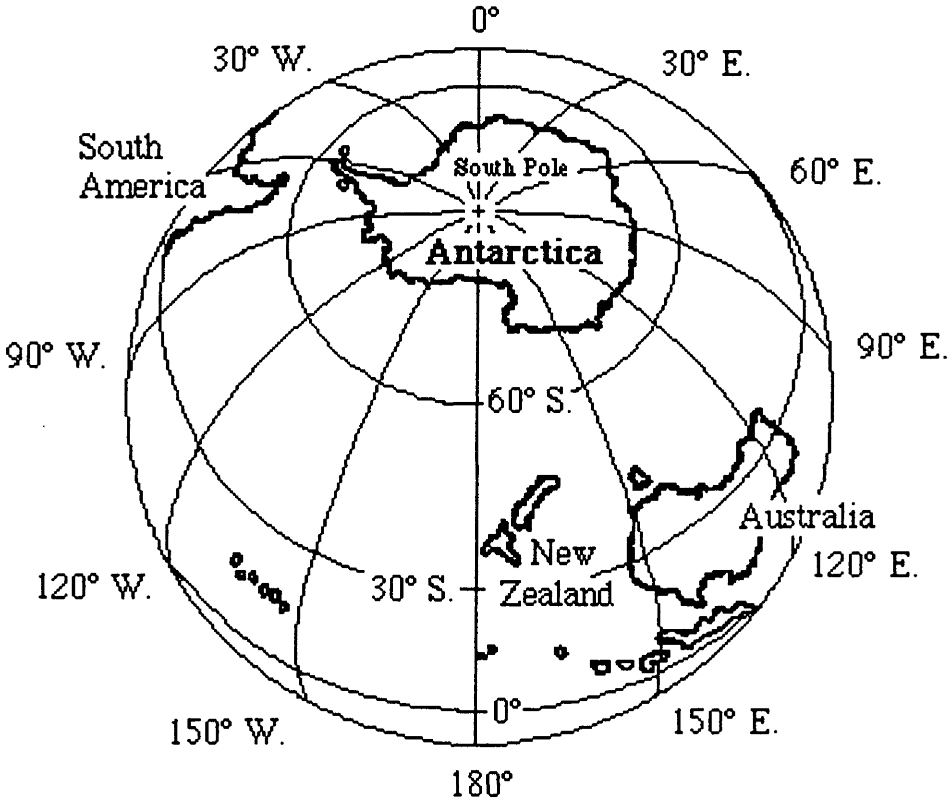

Figure 1. A view of the South Pole and an Index map of Antarctica, showing the relationship of South America, New Zealand and Australia.

Relative size of Antarctica and the Continental United States

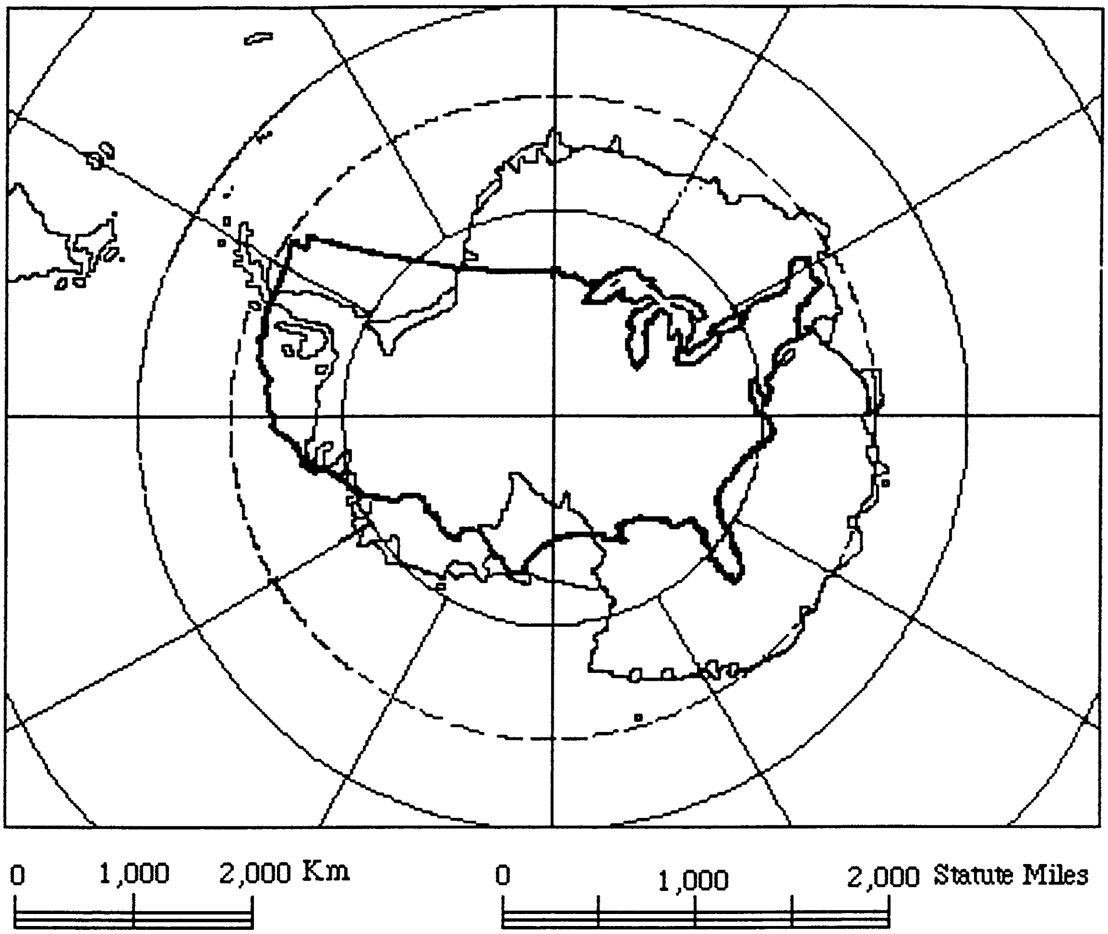

Figure 2. Relative size of Antarctica and the continental United States. Antarctica is estimated to have a surface area of 5,500,000 square miles and the continental United States 3,022,387 square miles. The lines of longitude and latitude that make up the graticule locate only Antarctica.

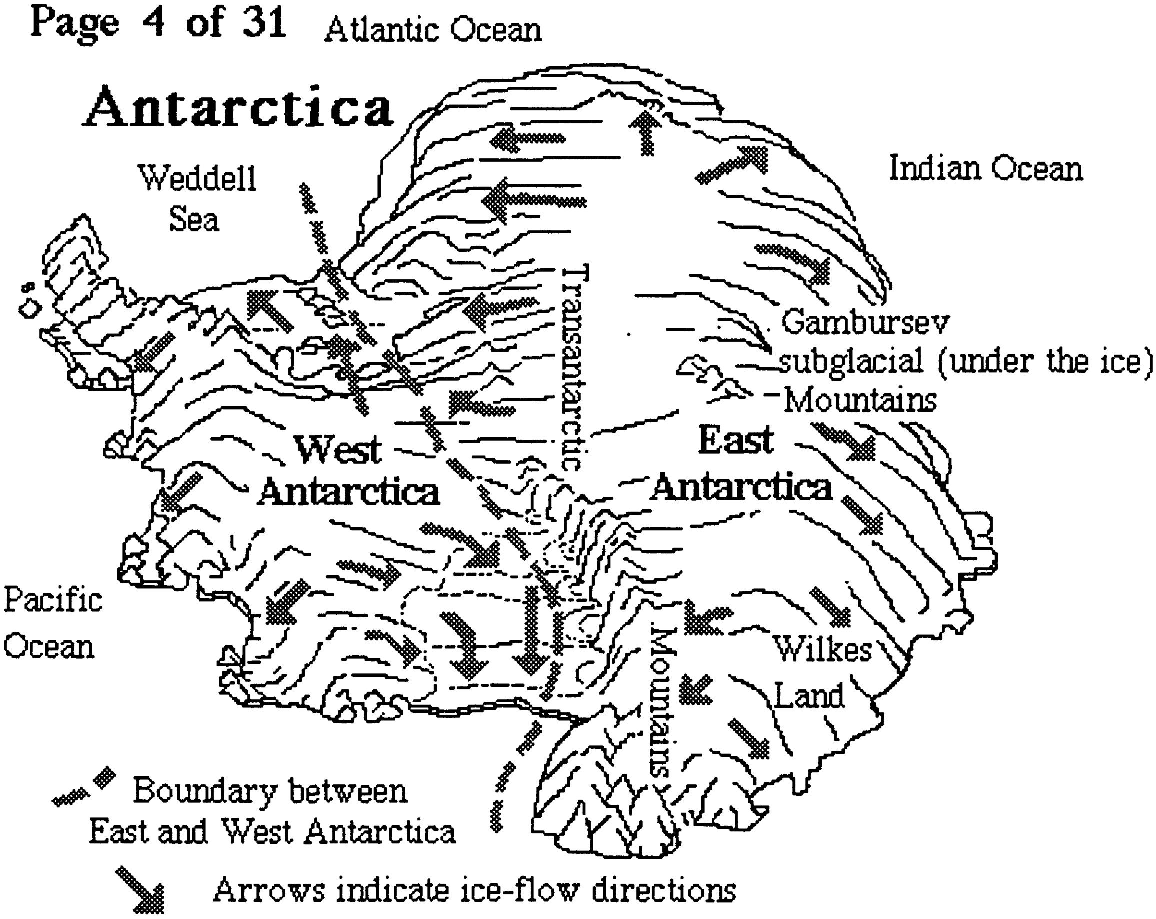

Figure 3. Index map of Antarctica today showing features and ice-flow directions for the Antarctic Ice Sheet.

Deep oceans surround Antarctica today, but 180 million years ago, the Antarctic land mass was at the center of a super-continent called Gondwanaland. The super-continent was pulled apart into many pieces by the processes of **sea-floor spreading**. Over the last 175 million years, Antarctica has remained near the south pole while the other pieces of Gondwanaland moved north to become the continents and land masses that we now know of as Africa, India, Madagascar, Australia, New Zealand, and South America. The areas between the land masses became great ocean basins. Antarctica has been in its position at the "bottom of the world" for about the last 100 million years. See Figure 1.

The Great Ice Sheets

Antarctica has not always been covered by ice. In fact, until 45-50 million years ago, there was little, if any, glacier ice in Antarctica. The climate was temperate and warm, and there were lush forests. We know this from examining rocks from some of the few areas on Antarctica that are not covered by ice in Antarctica. Today, only 2% of Antarctica's land mass is exposed, with the rest under ice. We also have sedimentary rock samples from drilling operations done by ships in the oceans around Antarctica. The rocks contain information such as fossils, **oxygen isotopes**, clay minerals, and ice-rafted debris that we can use to piece together what the climates were like and how much of Antarctica was covered by glaciers. The evidence indicates that the first of many large ice sheets of the Cenozoic glacial era began to grow between 36-45 million years ago.

Ice sheets are composed of snow from frozen fresh water. In fact, the Antarctic Ice Sheet currently holds 68% of the world's fresh water. Where does all this water come from? The answer lies in how ice sheets grow. Many times in the past,however, enormous ice sheets have covered large parts of the Northern Hemisphere, including Greenland, Scandinavia, northern Russia, and North America, as well as Antarctica. Today the ice sheets are smaller, and only exist on Greenland and Antarctica. Before describing the history of the Antarctic Ice Sheet, let us learn a bit more about other great ice sheets and how and why they get thicker or "grow". The last **glacial period** was at its maximum about 20,000 years ago. During maximum glaciation 20,0000 years ago at both the north and south poles, the ice sheets were probably 12,000 - 14,000 feet thick, and the waters of the ocean were about 300 feet lower than today.

Ice sheets will "decay" or decrease in size when temperatures become warm enough so that the accumulated yearly snowfall and ice melt during each year. The meltwater runs back to the sea and the levels of the oceans rise. Hence, the growth and decay of the massive ice sheets near the north and south poles is closely related to the level of the oceans. There are many other factors that affect sea level such as temperature, sea-floor spreading, and others, but the growth and decay of ice sheets is the most important factor over at least the past 100 million years.

Ice sheets are made of layers of snow that are compressed into ice. Ice sheets "grow", or get bigger, when temperatures are cold enough for snow to stay on the ground all year. As the snow remains on the ground and covers broader areas, more and more of the incoming sunlight is reflected away and so the earth's surface is not warmed --- hence, the temperatures generally get colder. As the snow-pile accumulates, it turns to ice, and the ice sheet grows. As the ice sheets get thicker and higher, the level of the oceans around the world gets lower. An ice sheet will continue to grow outward and upward until it reaches places where there are no longer any restraining forces to hold the ice sheet from expanding outward, such as the friction of ice moving across the ground (or across the sea-floor) or large mountains that effectively "dam" the movement of the ice. In all cases, ice sheets cannot extend beyond the edge of the continental shelf, where the sea-floor rapidly deepens to more than 800 meters (about 2600 feet), which is the greatest depth that ice is known to have "scraped" the sea floor.

How long does it take for an ice sheet the size of Antarctica to grow to a thickness of 12,000 feet? In geologic terms, this can happen in a very short time. Mathmatical models tell us the ice sheet can grow to such a size in as little as 25,000 years when temperatures are cold, as they are today, in Antarctica. Ice sheets decay much faster than they grow. With a 20 degree (Fahr.) rise in temperature, the Antarctic ice sheetb could break up and melt away in less than 10,000 years. The models are probably correct, because we know from geologic evidence that a massive ice sheet covered northern North America about 12,000 years ago, and that ice sheet is now gone.

Evolution of the Antarctic Ice Sheet

Now that we know a little about ice sheets and Antarctica, let us look at a set of models that shows how geologists (who study rocks) and glaciologists (who study glaciers) think the Antarctic Ice Sheet may have grown to its present size. We use mathmatical models that are based on the physical properties of today's ice sheets to estimate prior ice-sheet sizes. There is another indirect way of estimating ice-sheet volumes from the chemistry of ocean waters, and we will describe that process in the next section. As you look at the models, in the pictures and computer-animation, it is important to keep in mind that we only show one cycle of ice-sheet growth. In reality, there were probably many cycles of growth and decay over the past 45 million years, as global temperatures and climates varied. There is geologic evidence for many ice-sheet fluctuations, and these fluctuations in turn had large effects on the worlds ocean's and climates.

The pictures in this report show how and where the Antarctic Ice Sheet may have grown in response to changes in average air temperatures at sea level around Antarctica. The thermometer in each picture shows the average air temperature for the corresponding ice-sheet size. Generally, as temperatures get colder, the ice sheet gets larger. The pictures also show a drawing of the level of water in the sea for each ice sheet. As the ice sheet gets larger, the sea level gets lower. We know that today the Antarctic Ice Sheet holds 90% of the worlds ice, and if all the ice on Antarctica were to melt, the level of the sea would rise about 67 meters (about 220 feet).

We know from model studies (Figures 4-12) that ice sheets could grow and decay in as little as 20,000 to 30,000 years. That means there could have been as many as 1500 different ice sheets in the last 30-40 million years. But, did this happen? Not likely, but there is geologic evidence that the volume of the Antarctic Ice Sheet has changed by a large percentage many times since it first began to grow about 35-45 millon years ago.

The ice-sheet on Antarctica began to form in the middle of the continent (Figure 12), as glaciers first filled valleys in the high Gamburtsev Mountains of the continental interior. At this time, and thereafter, Antarctica was surrounded by oceans that supplied the moisture for the snows. With decreasing temperatures, the ice-sheet expanded outward to cover all parts of East Antarctica, which is the name for the main land mass of Antarctica that is bordered by the Transantarctic Mountains (Figure 3). All of East Antarctica was covered by ice when the temperatures dropped to about 10 degrees. This volume of ice resulted in sea level dropping by nearly 60 meters (about 197 feet) below the level that it was when there was no ice on Antarctica (Figure 8). As temperatures dropped by another 10 degrees to the average temperature of 0 degrees of today, the ice expanded to cover West Antarctica, where there are many areas beneath the ice that lie below sea level. The growth of the West Antarctic Ice Sheet can be seen in Figures 4-7. The volume of ice in West Antarctica is now only about 1/10 that of East Antarctica, and when the West Antarctic Ice Sheet formed, sea level dropped by about only 6 meters (about 20 feet). Today, the thickest ice, about 4000 meters (about 13,000 feet) is found in the middle of East Antarctica -- if such an ice sheet were to cover the United States today, it would bury everything except a few high-mountain peaks of the western U.S.

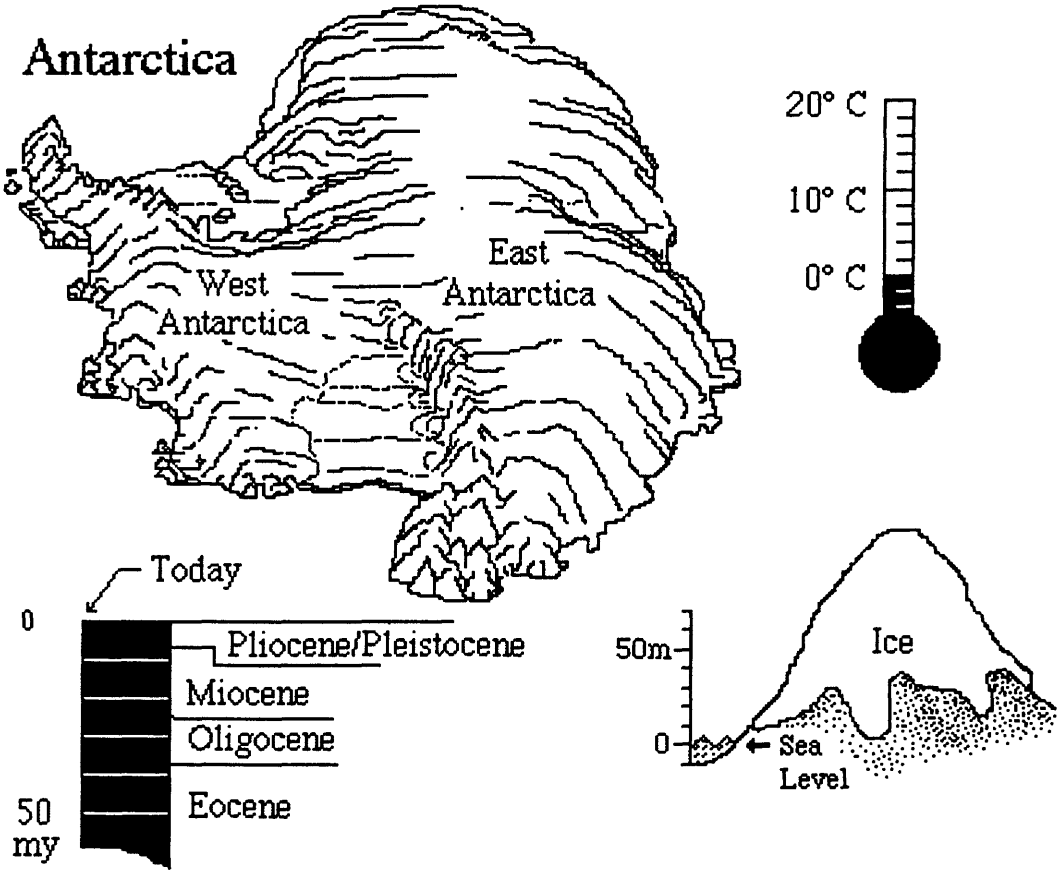

Figure 4. Antarctica today showing the shape of the Antarctic Ice Sheet. The thermometer shows the average air temperature at sea level around Antarctica in degrees **Celsius**. The sea-level cartoon shows the relative height of global sea level (i.e., sea level is 0 m today and would be 67 m higher if all the ice on Antarctica melted). The geologic time scale shows when temperatures are believed to have been at this level (i.e., 0 degrees today). For prior times, temperature estimates are based on oxygen-isotope measurements from the deep ocean around Antarctica (Miller et al., 1987), and ice-sheet sizes are based on glaciological model studies (Huybrechts, 1993) using the temperature shown.

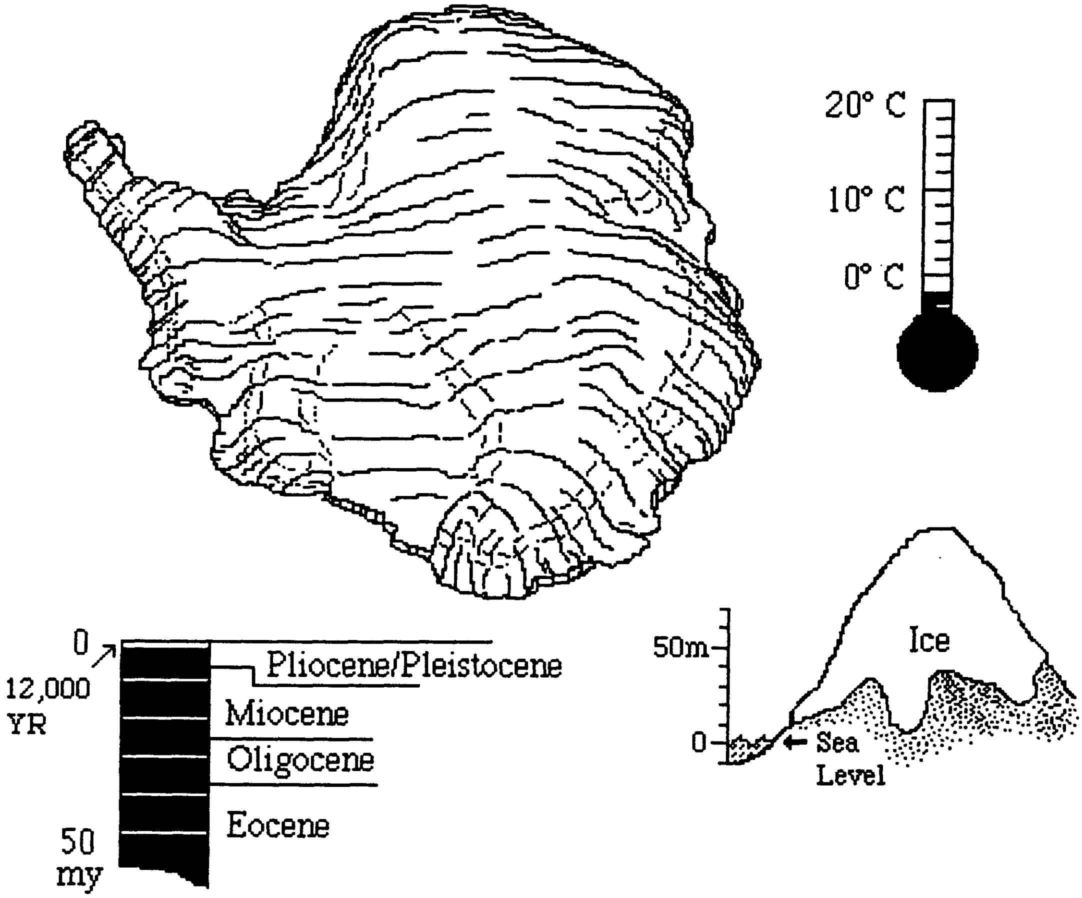

Figure 5. Model of the Antarctic Ice Sheet at a time of likely colder temperatures (-2 degrees **Centigrade**) than today, near maximum glaciation about 12,000 years ago. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams. Model is modified from Denton et al. (1991).

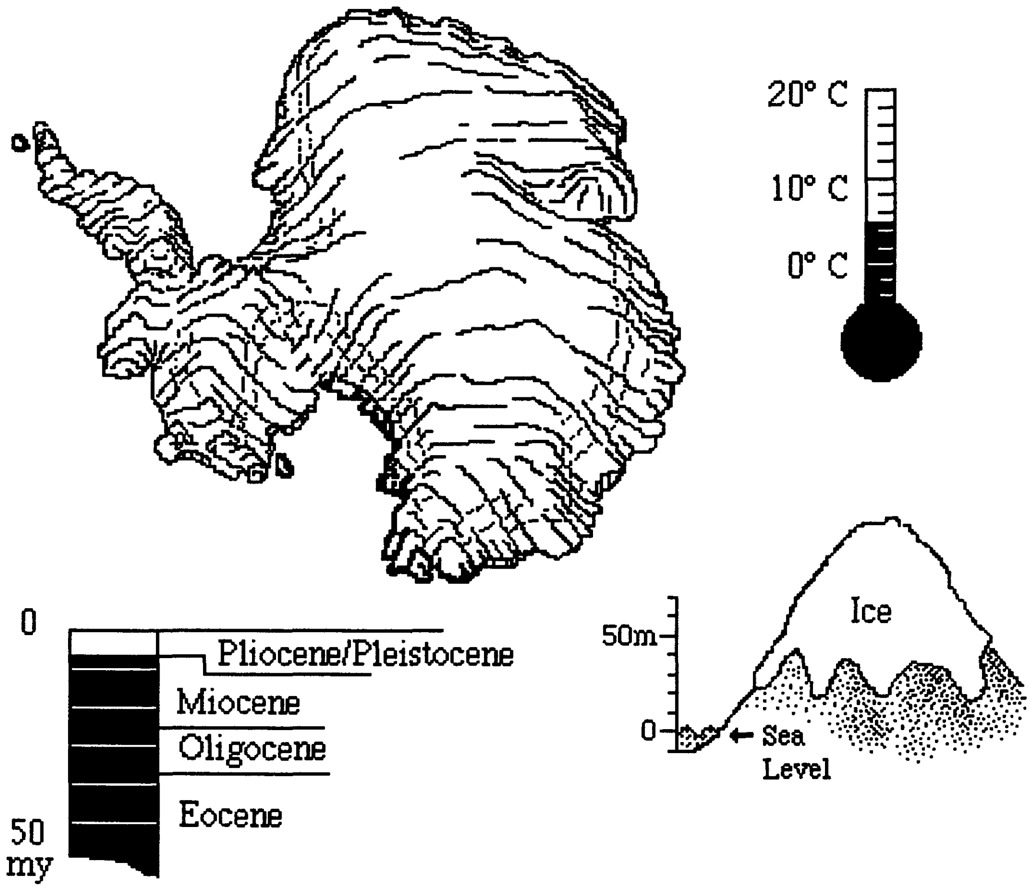

Figure 6. Model of the Antarctic Ice Sheet for a temperature 5 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams.

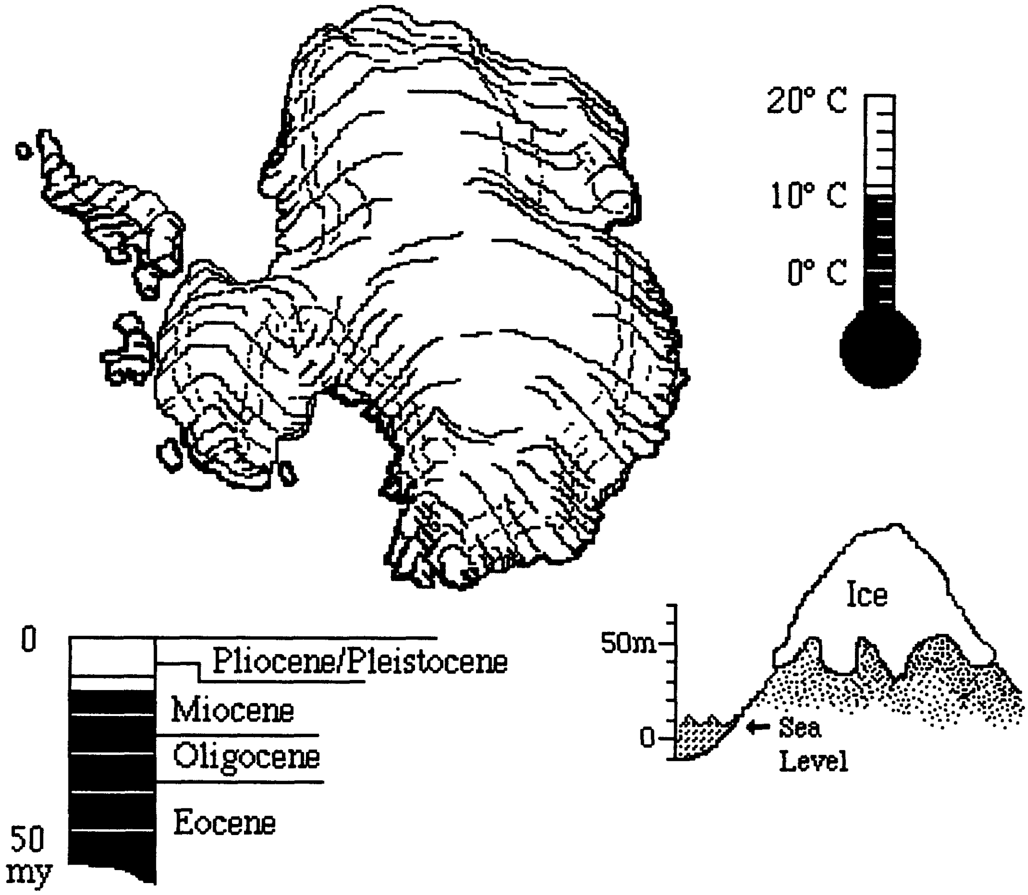

Figure 7. Model of the Antarctic Ice Sheet for a temperature 9 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams.

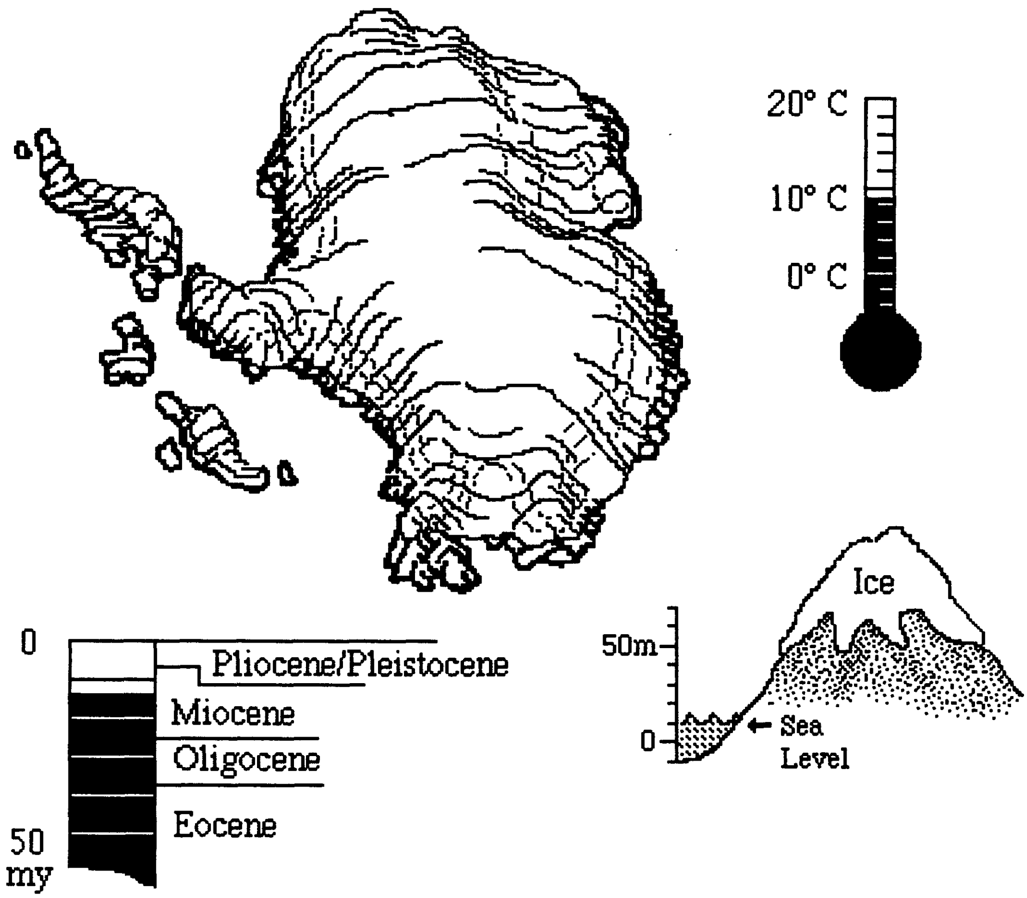

Figure 8. Model of the Antarctic Ice Sheet for a temperature 10 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams.

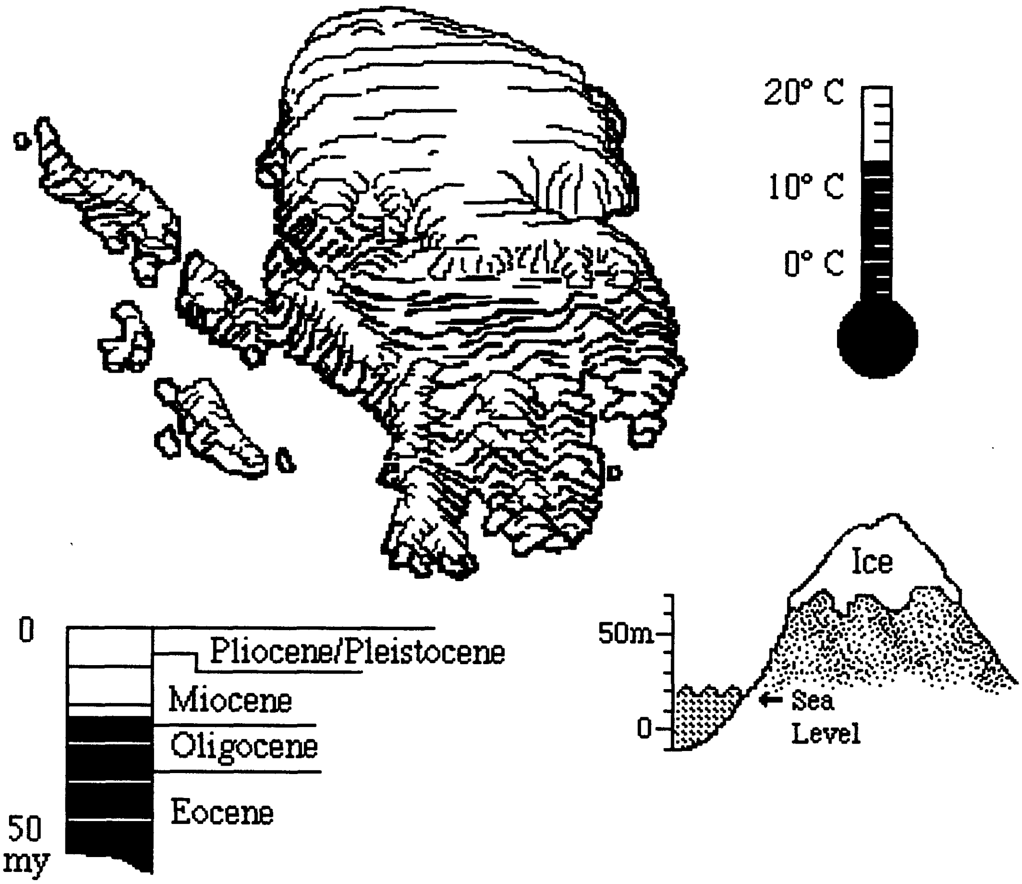

Figure 9. Model of the Antarctic Ice Sheet for a temperature 12 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams. The ice-sheet model is modified from Webb (1990).

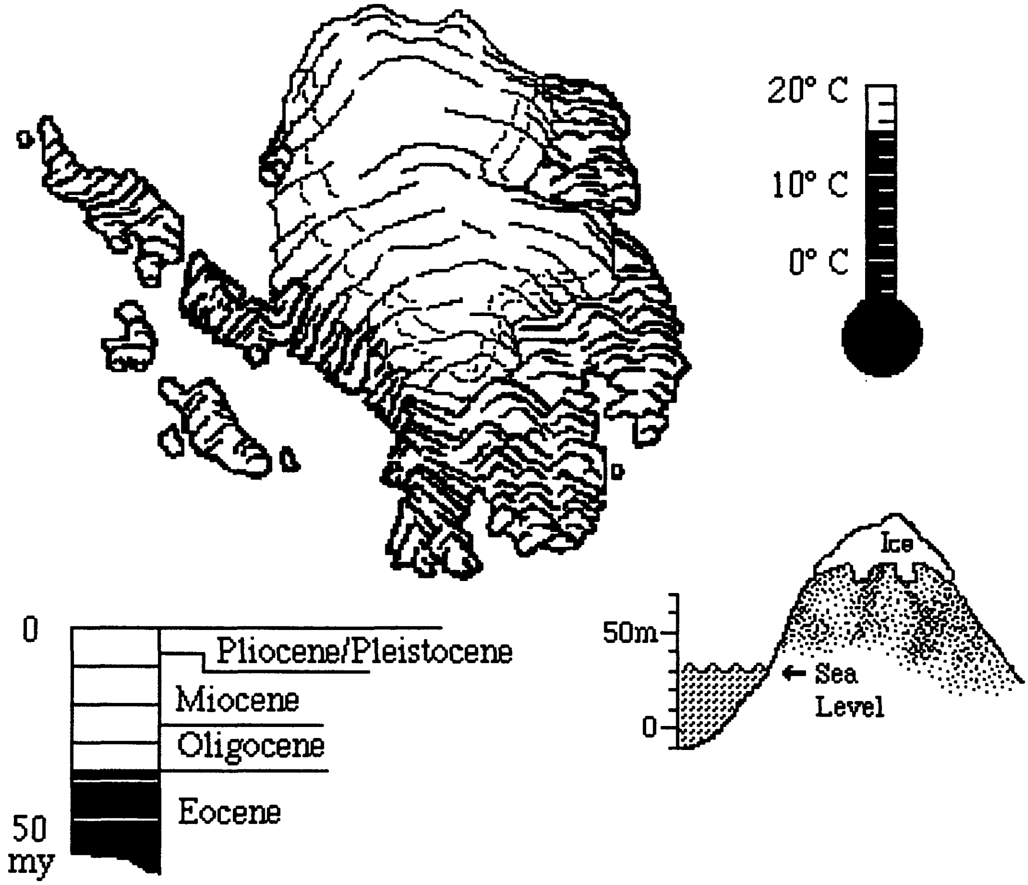

Figure 10. Model of the Antarctic Ice Sheet for a temperature 15 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams.

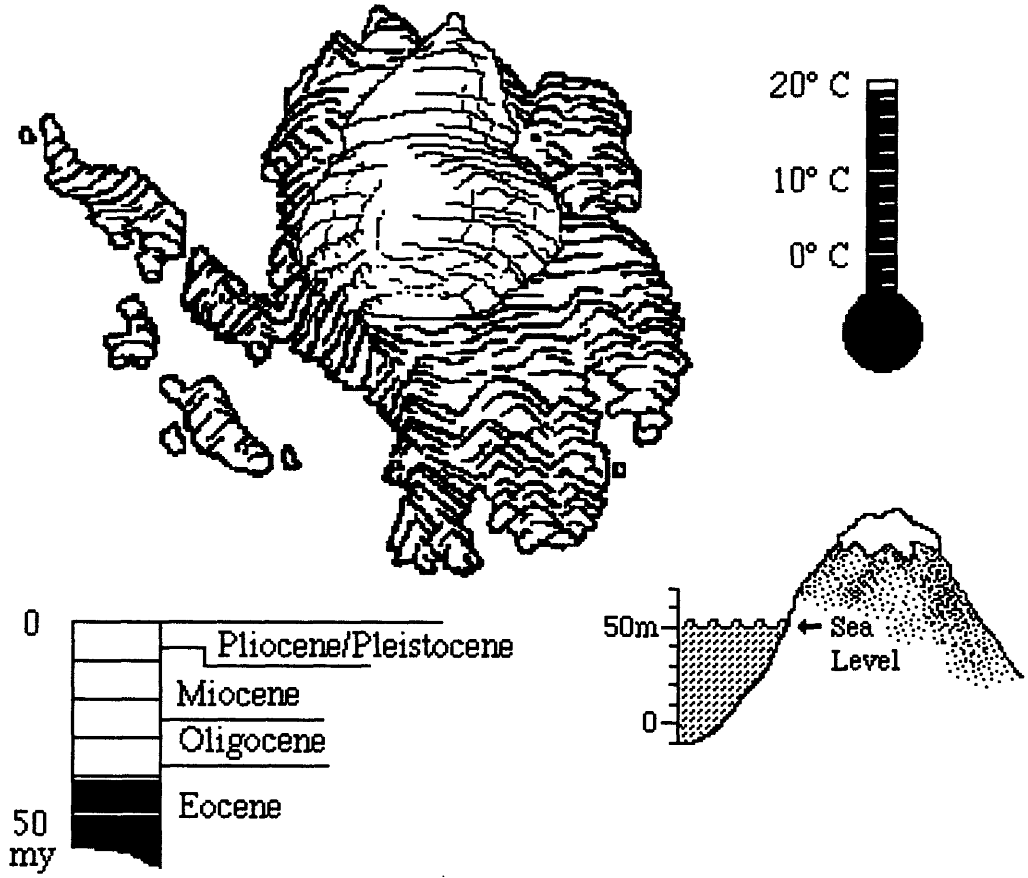

Figure 11. Model of the Antarctic Ice Sheet for a temperature 19 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams.

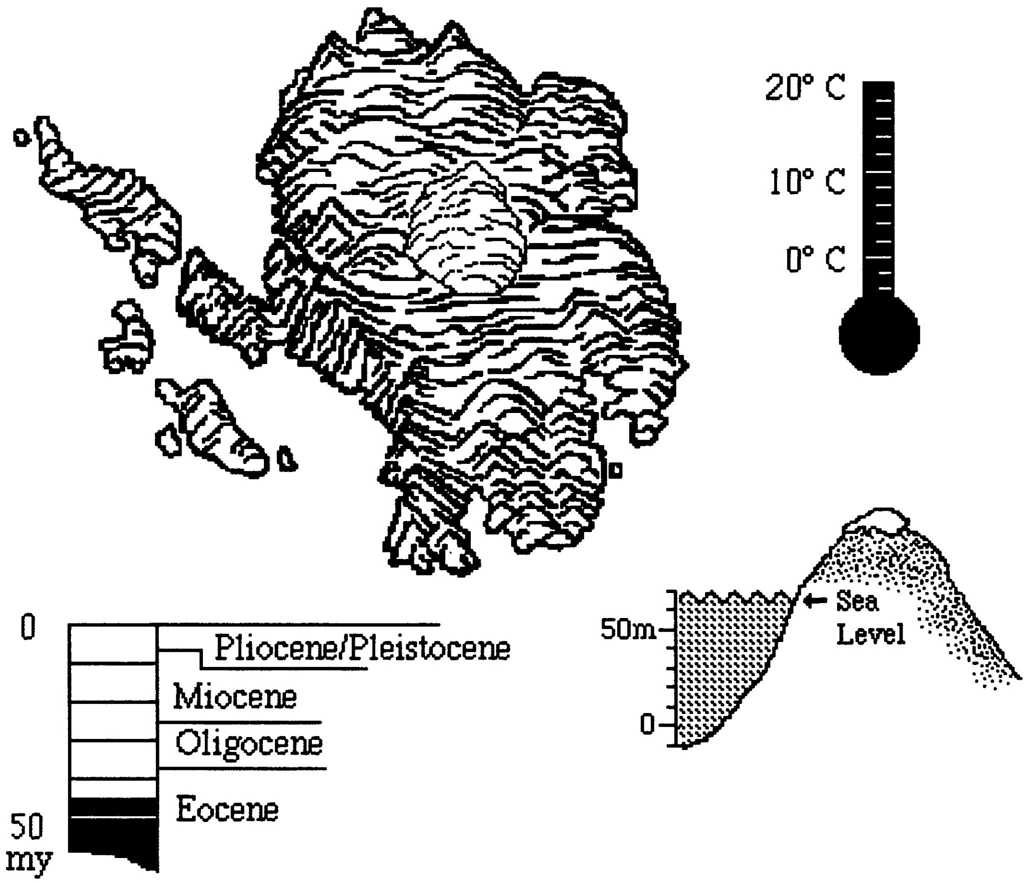

Figure 12. Model of the Antarctic Ice Sheet for a temperature 20 degrees warmer than today. See caption of Figure 4 for explanation of sea-level, temperature, and geologic-time diagrams.

We know from model studies (Figures 4-12) that ice sheets could grow and decay in as little as 20,000 to 30,000 years. That means there could have been as many as 1500 different ice sheets in the last 30 - 40 million years. But, did this happen? Not likely, but there is geologic evidence that the volume of the Antarctic Ice Sheet has changed by a large percentage many times since it first began to grow about 35-45 million years ago.

The geologic time scales that are put on each of the ice sheet models in figures 4-12 are based on current "best guesses", from analyses of deep-ocean oxygen -isotope data and interpretation of geologic features such as ice-erosion surfaces, ice-rafted debris, of onshore and continental-shelf regions of Antarctica.

The principal evidence for growth and decay of ice sheets comes from measurements of different isotopes of oxygen (see, glossary for definition of oxygen isotopes) that are found in the skeletons of calcareous microfossils of microscopic plankton that once lived in the oceans around Antarctica. As fresh water was removed from the ocean to form ice, the amounts of oxygen isotopes in the oceans changed. By measuring the ratios of these isotopes, scientists can estimate how much fresh water was removed from the ocean (to go into ice) and what the likely ocean temperatures were at that time. There are some ambiguities about the isotope interpretations, but in general the oxygen isotope values at different geologic times tell us that
< the world's oceans began a gradual cooling trend about 40 million years ago, at about the same time that other geologic evidence indicates that the Antarctic Ice Sheet began to form;
< there have been several “episodes” when ocean temperatures abruptly diminished, possibly when there were episodes of major growth in the Antarctic Ice Sheet; and
< over the last 2-3 million years, temperatures have been the most severe, they have changed most rapidly, and that ice sheets of the Northern Hemisphere may have been more important than the Antarctic Ice Sheet in controlling global climates and sea levels.

The geologic time scales that are put on each of the ice sheet models in Figures 4-12 are based on current "best guesses", from analyses of deep-ocean oxygen-isotope data and interpretation of geologic features such as ice-erosion surfaces, ice-rafted debris, and others of onshore and continental-shelf regions of Antarctica. The ice sheet on Antarctica is likely to have changed in size at times that are not shown. But, the general ice-sheet patterns of first growing in the middle of Antarctica, and first melting in West Antarctica, are likely correct as shown in the models.

The Antarctic Ice Sheet and our Global Environment

Antarctica is a large continent covered by ice, but it is far away from most major cities. Why then is it important to our global environment? This is an important question that does not have one simple answer, and is the topic of many ongoing studies. But, all agree that Antarctica is the "the earth's smart refrigerator" that remembers and modulates our climates.

The earth's climate is controlled by many factors including those that arise from complex natural interactions among the oceans, land, and atmosphere, and those coming from mankind's activities, such as increases in atmospheric carbon dioxide and fluorocarbons. Perhaps the greatest "driving force" for our climate system comes from the world's oceans. The ocean currents carry around the heat that is needed to support the local and regional weather systems that we are familiar with. Antarctica plays an important role in this heat transfer process. In general, the sun warms the oceans (and land areas) mostly in the earth's mid-latitude areas. The warm waters remain near the ocean's surface. But, at great ocean depths, cold dense waters move in many directions, both horizontally and vertically, and circulate the ocean waters to different parts of the world.The concept is similar to that of a giant conveyor belt that carries water masses (and heat) in many loops around the world's oceans. The driving forces for the conveyor belt are the deep cold waters that flow generally north from Antarctica and south from the Arctic Ocean. Melted water from the Antarctic Ice Sheet including the apron of floating ice that surrounds Antarctica for most of the year are the source of the cold dense waters that sink to the bottom of the ocean and move north.

Antarctica has many other roles in modulating our climate system. Not only does Antarctica generate large weather systems today, but the ice also holds a record of what earth's climates were like in the past. Today, the high and cold central regions of Antarctica are the source for air masses that flow off the continent and help drive the large cyclonic storms that perpetually cover the great Southern Ocean and move around Antarctica. These weather systems strongly affect the local and regional climates of continents of the Southern Hemisphere, much like the great masses of cold air that come from the North Polar regions affect the climates of the Northern Hemisphere, including the United States.

The climates of prior ages are recorded in Antarctica, in the small gas bubbles that were trapped in the snow when it fell thousands of years ago. From the drilling of ice cores near the middle of Antarctica at the Russian Station Vostok, glaciologists have discovered that the ice is about 160,000 -220,000 years old at the bottom of the ice sheet. The trapped gases within the ice-core indicate that the global climates varied from extreme glacial conditions to warmer periods, like today. Temperatures over the past 160,000 years correlate closely with the concentration of carbon dioxide (CO2), a "greenhouse gas", that existed in atmospheres of the past. Higher concentrations of carbon dioxide result in warmer temperatures, and the highest concentrations correspond with prior times when there was much less ice. Today, the concentration of carbon dioxide in the atmosphere is more than 30% higher than the maximum amount measured in the ice cores, and CO2 is increasing each year due to mankind's activities. Scientists are concerned that if carbon dioxide continues to increase, this may lead to greater global warming, and like other times during the past 160,000 years, the Antarctic Ice Sheet may begin to decay. Does this then mean that the Antarctic Ice Sheet is getting smaller today? The general consensus of glaciologists is no, but there are many uncertainties in their answer.

The processes by which the Antarctic Ice Sheet diminishes in size is mostly by "calving" (i.e., breaking away) of **icebergs**. The large icebergs that transfer the cold temperatures of the ice sheet into the relatively warm surface waters of the Southern Ocean come from all around Antarctica, but principally from those areas where broad streams of ice flow into the sea. The rate at which ice bergs break away from Antarctica is one of many indicators of what our global climates are doing. In times of global warming, like today, ice moves more rapidly in ice streams from the interior regions of Antarctica to the coast, and then breaks off as icebergs. In times of global cooling, ice moves more slowly and fewer icebergs are formed. Recent satellite images taken of Antarctica show that large parts of the massive **ice shelves** around Antarctica are breaking away as tabular icebergs that can be several hundred feet thick (about as thick as a skyscraper is tall) and cover an area as large as the state of Rhode Island. Scientists are carefully monitoring the size of the Antarctic Ice sheet, and tell us that at present it is almost "in balance" because as much snow falls on Antarctica (taking water out of the ocean) as icebergs break off (putting water back into the ocean).

Is there a chance that a large part of Antarctica will break off and cause sea level to rise? This is an important question that glaciologists and geologists are actively studying by drilling holes into the ice and sea floor, and by measuring how fast the ice streams are moving and breaking up into ice bergs. West Antarctica, most of which lies below sea level (Figure 13), would be the most susceptible place for the ice sheet to quickly break apart and disappear because it is more "unstable", and there are fewer land areas beneath the ice to hold the ice in place. If all of the ice in West Antarctica were to melt, the level of the sea would rise about 6 meters, or about 20 feet. This would cause severe flooding of coastal areas around the world. Is the West Antarctic Ice Sheet likely to "collapse"? This is not likely, at least in the next several centuries or longer. The greatest unknown, however, that could affect this conclusion for future generations is the rate at which global temperatures and sea-levels rise. If these rates increase, the potential for "collapse" will increase.

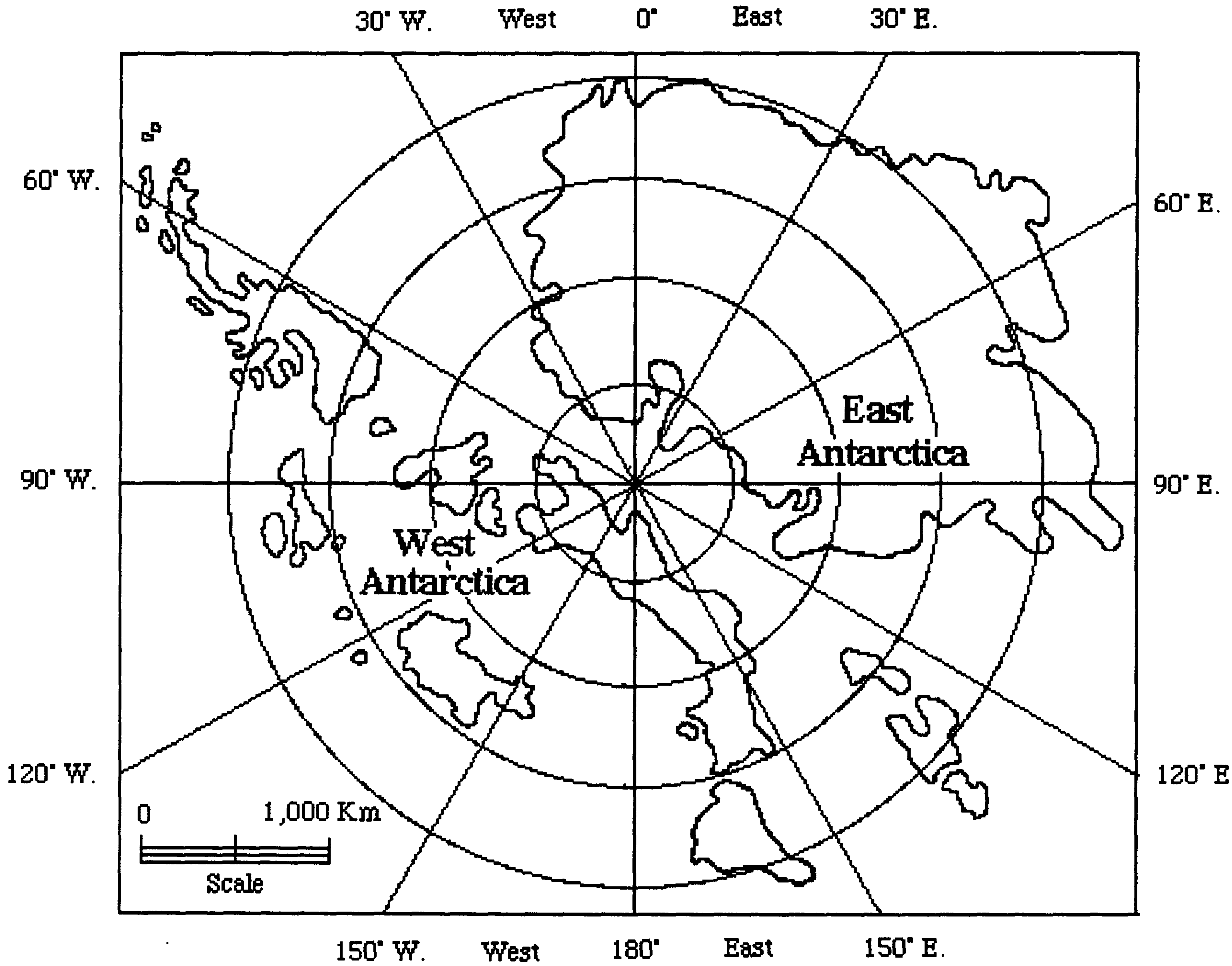

Figure13. Map of Antarctica without the ice sheet.
Large regions lie below sea level and would be the sites of seaways if the ice were not present.

What can I do ?

Antarctica, by International Treaty, is a "continent for science" that is part of our global heritage and in effect belongs to everyone. What can I do, you ask?

Learn more about Antarctica – this is perhaps the most important thing you can do. Antarctica may be a long way from where you now sit, and may seem like a cold and inhospitable place, but it may be one of the few places left on earth that remains nearly pristine and charged with great potential for new scientific discoveries that you can participate in. Just as you have made your paper model of Antarctica that comes with this report, and have lifted up the paper "ice sheet cap" to see what lay under the ice sheet, scientists today use airplanes and satellites with remote-sensing equipment to "image" deeply into the ice sheet. Just as you probably poked your finger at the paper model to feel the texture of the top of the paper ice sheet, scientists today are "poking" drill holes into the ice and sea floor to look at the textures of the ice and rocks to study their evolution. And, just as you might dream of how cold and difficult it must be to live and work in Antarctica, scientists today are there actively living this dream, and enjoying and learning from it.

Beyond dreams and imagination there lie true discoveries. This report describes the general histories of the continent and ice sheets, and how they have been used to better understand our climates of today. There will be more discoveries in all the major sciences such as biology, astronomy, and meteorology, that bring hundreds of scientists from around the world to Antarctica each year. The continent of Antarctica was first sighted less than 200 years ago, the explorers reached the South pole less than 90 years ago, and the greatest discoveries about Antarctica have been made since the International Geophysical Year in 1956, about 40 years ago. Compared to all other places in the World, the science of Antarctica is truly in its infancy. Become part of the scene, and use this report and its references to books and the World Wide Web to learn more about Antarctica.

Glossary

Antarctic The area within the Antarctic Circle, latitude 66° 30" South.

Arctic The area within the Arctic Circle, latitude 66° 30" North.

Climate The average long-term atmospheric conditions, including temperature, wind, and precipitation, that prevail in a particular place.

Degrees Celsius The new name for the temperature scale formerly called "centigrade".

Degrees Centigrade A system of measuring heat in which the freezing point of water is 0 degrees and the boiling point of water is 100 degrees.

Glacial period A cold period of widespread glaciation on the earth's surface.

Glacier A mass of ice nourished by snowfall and flowing downhill under the influence of gravity.

Gondwanaland A supercontinent made up of South America, Africa, India, Antarctica, Australia, and parts of Asia.

Iceberg A large, massive piece of floating ice detached (caved) from a glacier into a body of water.

Ice sheet A large glacier of more than 50,000 square kilometers (19,000 square miles) in area. It may rest upon rock which may be partly beneath sea-level.

Ice shelf An ice sheet that is connected to land on one side and ends flooting over a body of water on the other side.

Oxygen isotope A higher-order unstable form of the element Oxygen. The rato of Oxygen-18/Oxygen-16 is commonly used to derive the temperature of formation of geologic materials.

Sea-Floor spreading The upwelling of volcanic magma along the mid-oceanic ridge resulting in the oceanic crust moving away from the ridge.

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Related articles, maps and books:

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"SCIENTIFIC LITERACY FOR ALL STUDENTS is a National goal. The National Science Education Standards are a contribution toward achieving that goal." (Draft, November 1994, National Science Education Standards, prepared by the National Research Council, National Academy of Science)

After building these models and reading the text all students should have developed a basic understanding of the following fundamental concepts of Earth and Space Science as recommended in the National Science Education Standards. Some of these concepts for grades 5-8 and 9-12 are:

Grades 5 - 8

+ The Earth processes we see at work today are similar to those that operated in the past.

Grades 9 - 12

+ Geologic time can be estimated by observing rock sequences and using fossils to correlate similar sequences at various locations.

+ Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

+ Changes in natural systems can exceed the limits of organisms to adapt naturally or humans to adapt technologically.

+Human activities can enhance the potential for hazards. Students should understand the risks associated with natural and man-made hazards.

+ Humans are part of the natural system. Changing the natural system can affect the quality of humans life, i.e. sea level rise.

+Understanding chemical reactions and geochemical cycles is important for maintaining the health of natural envirnments.

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These stacks (reports) can be down loaded from self-extracting archives, that are on the U.S. Geological Survey's Learning Web site. The address is: < http://www.usgs.gov/education/animations/ >

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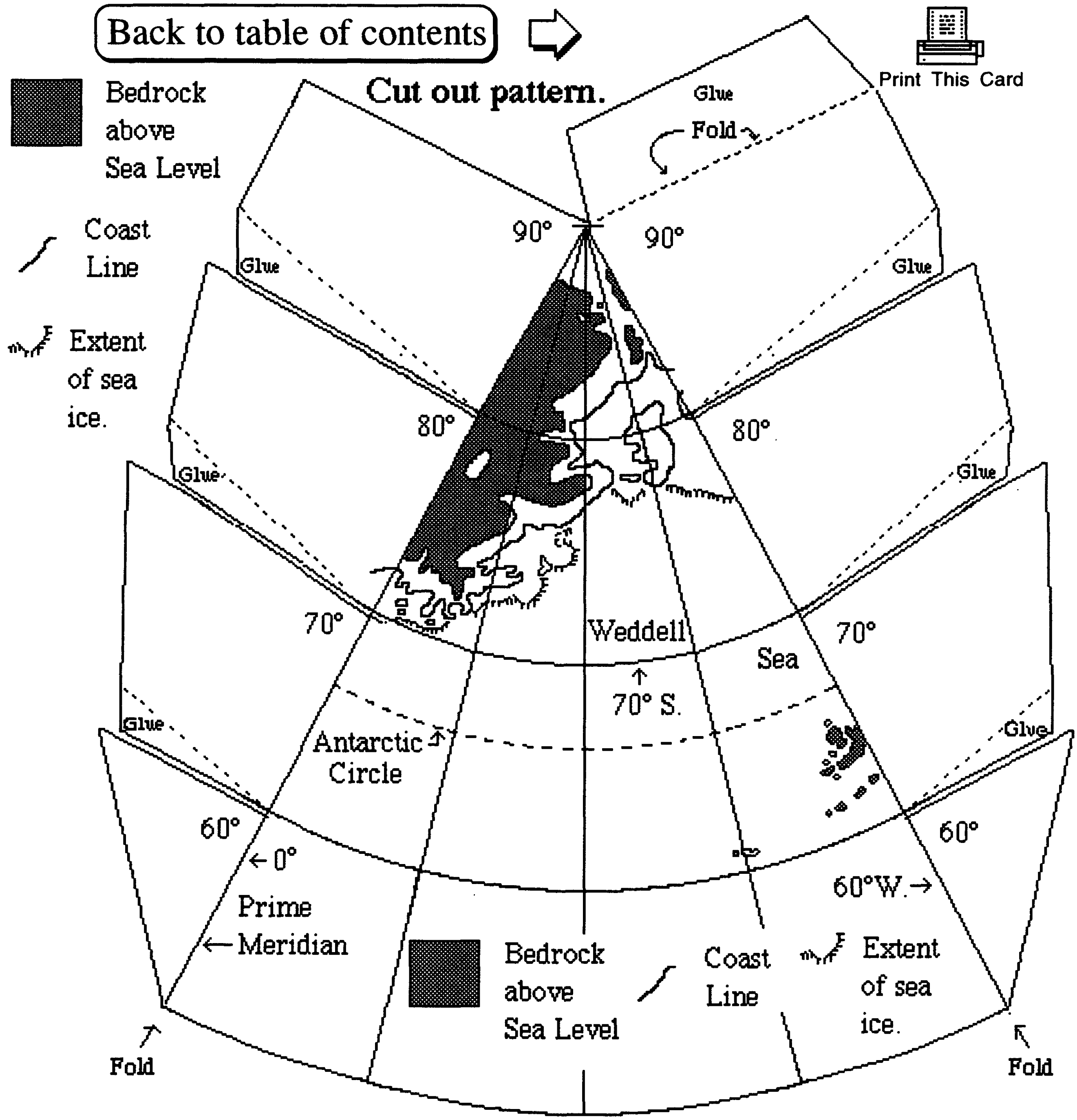
Cut out pattern.



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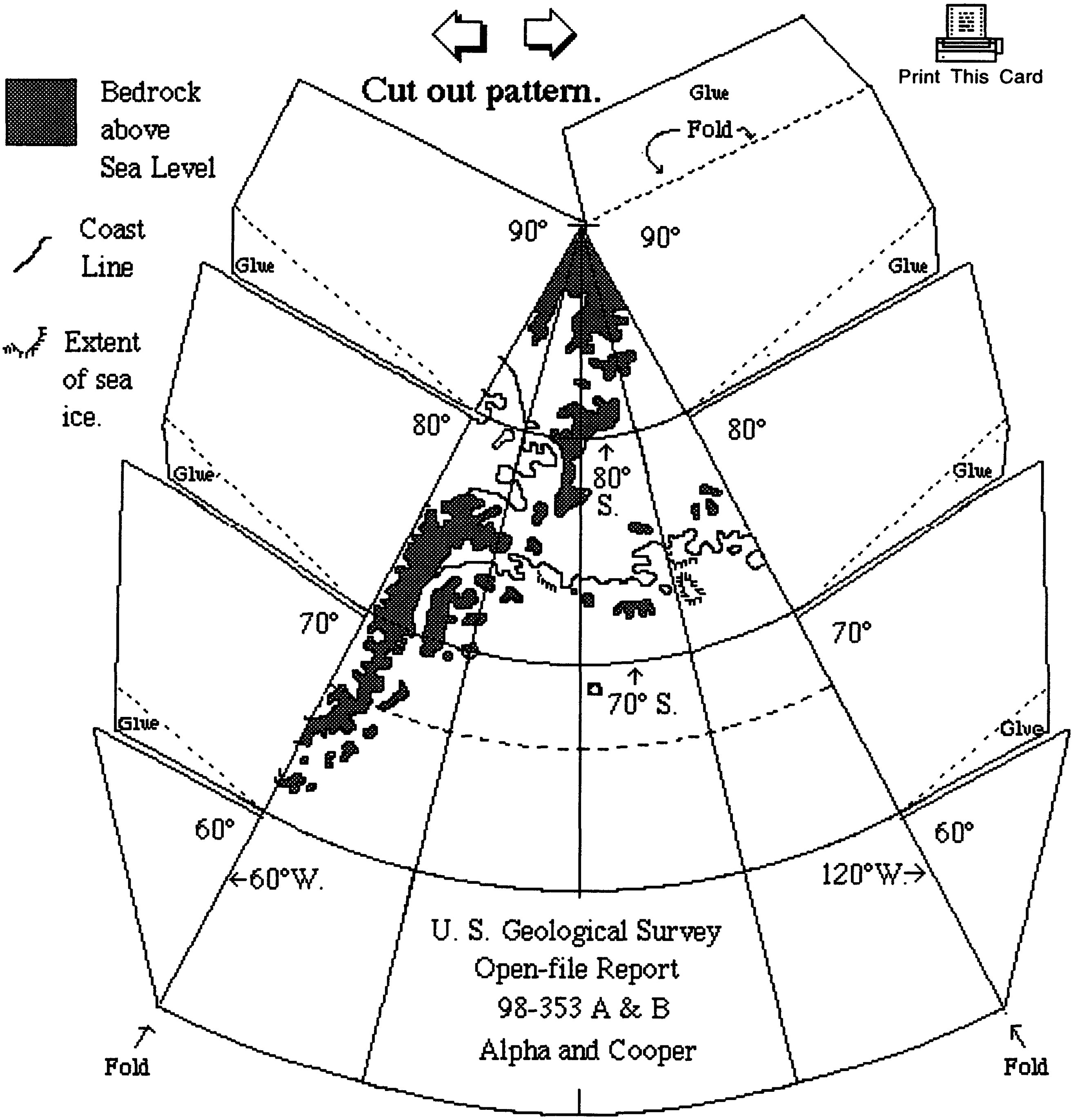

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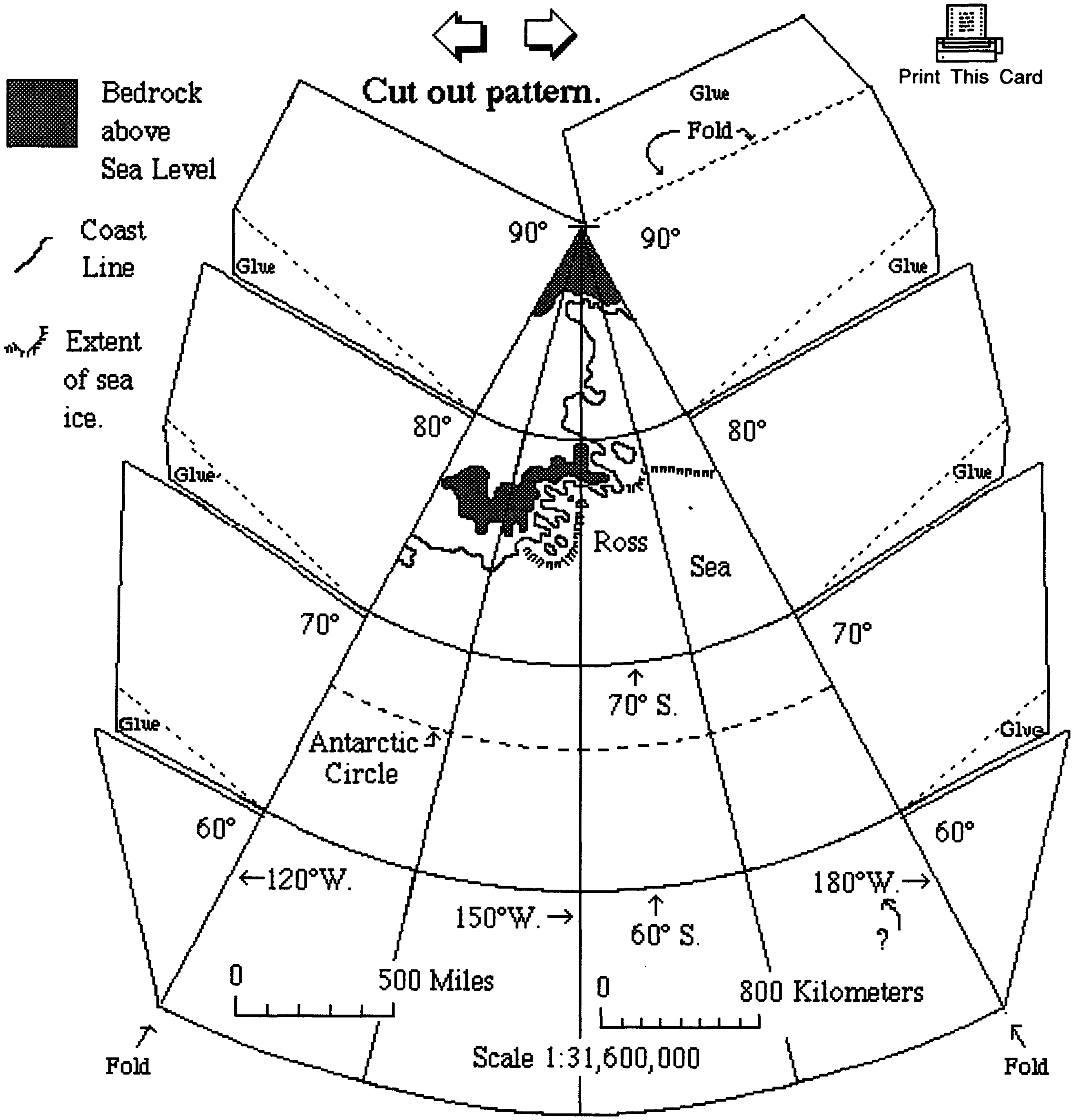

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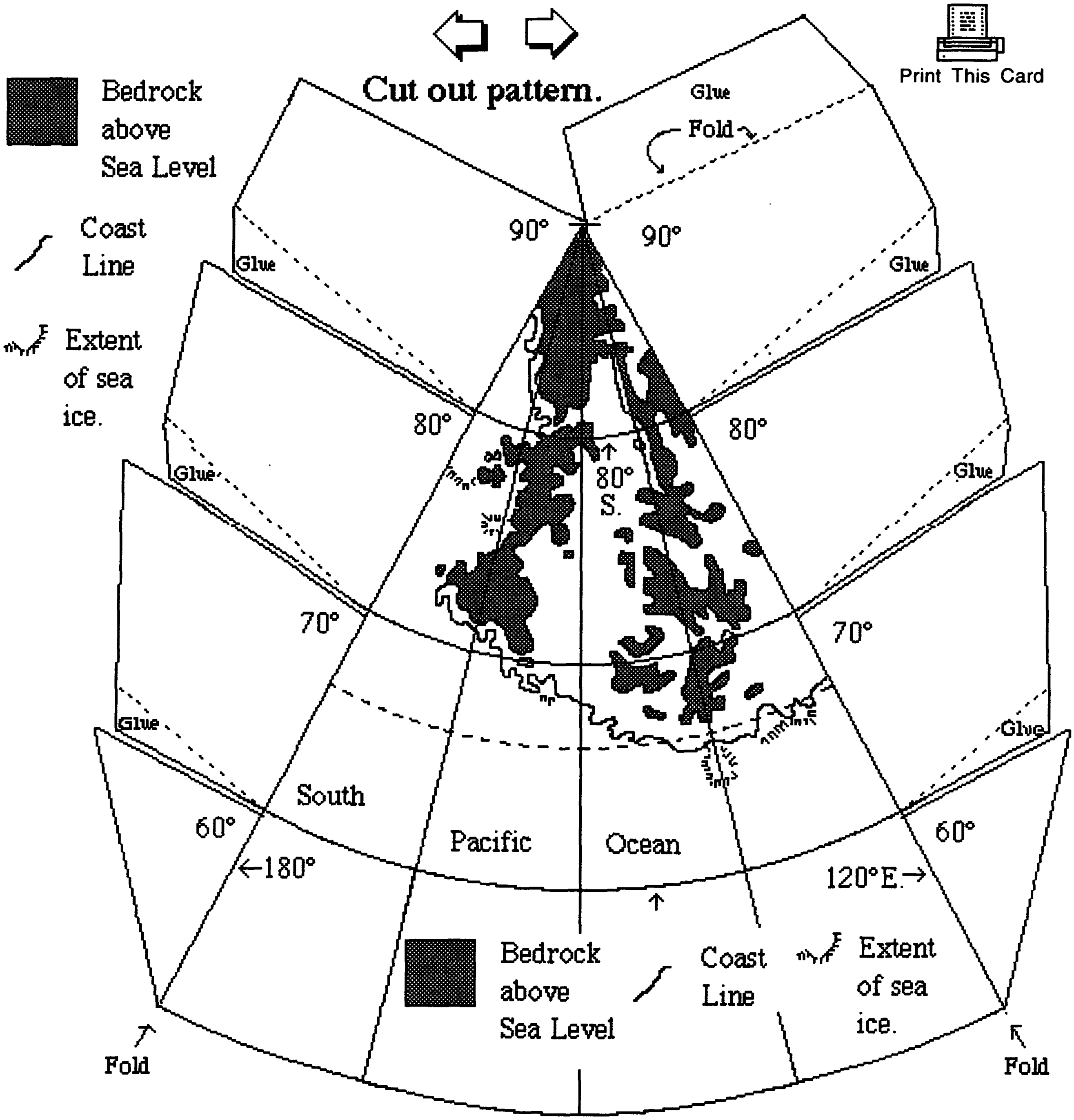

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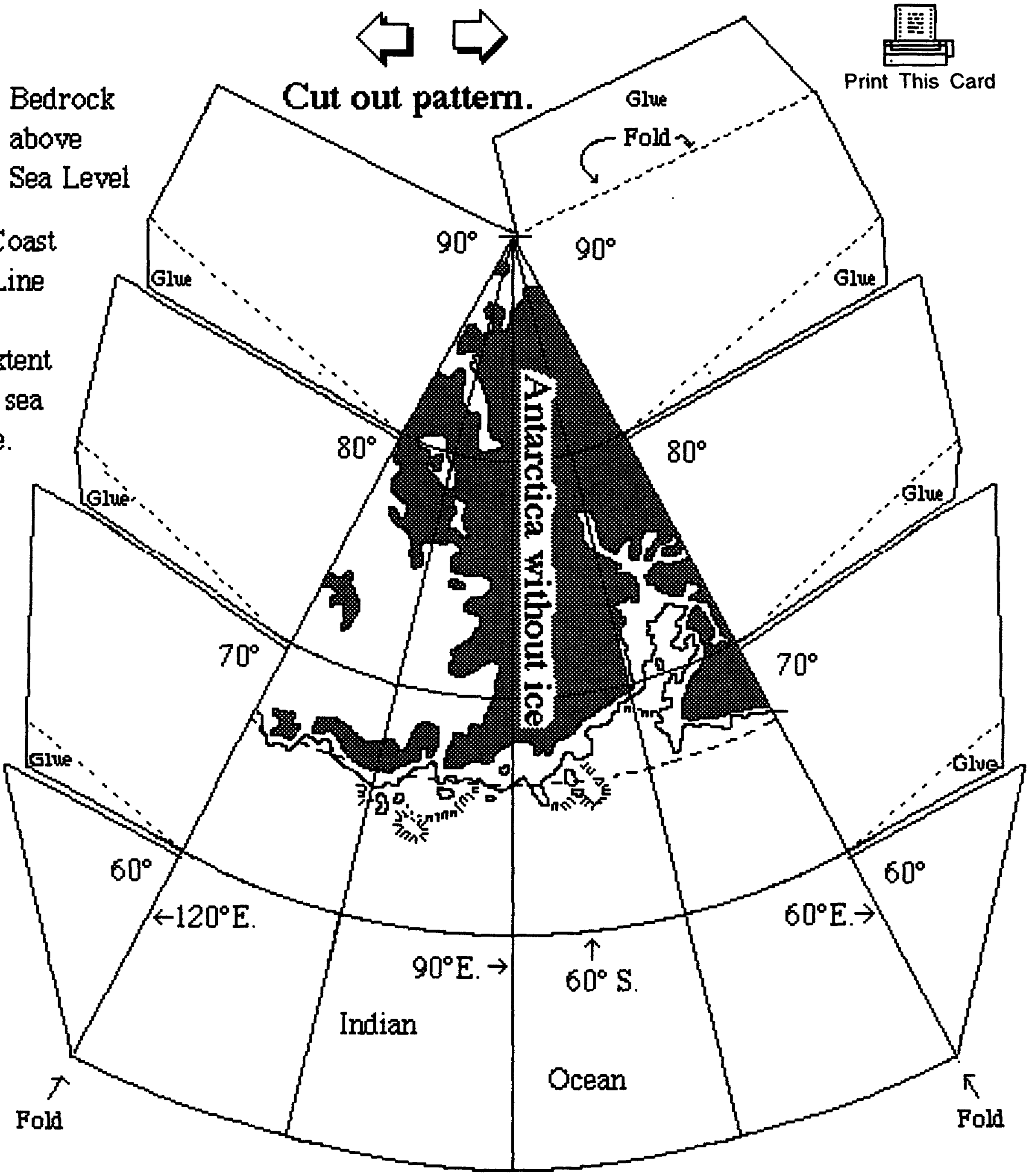
Bedrock above Sea Level

Coast Line

Extent of sea ice.



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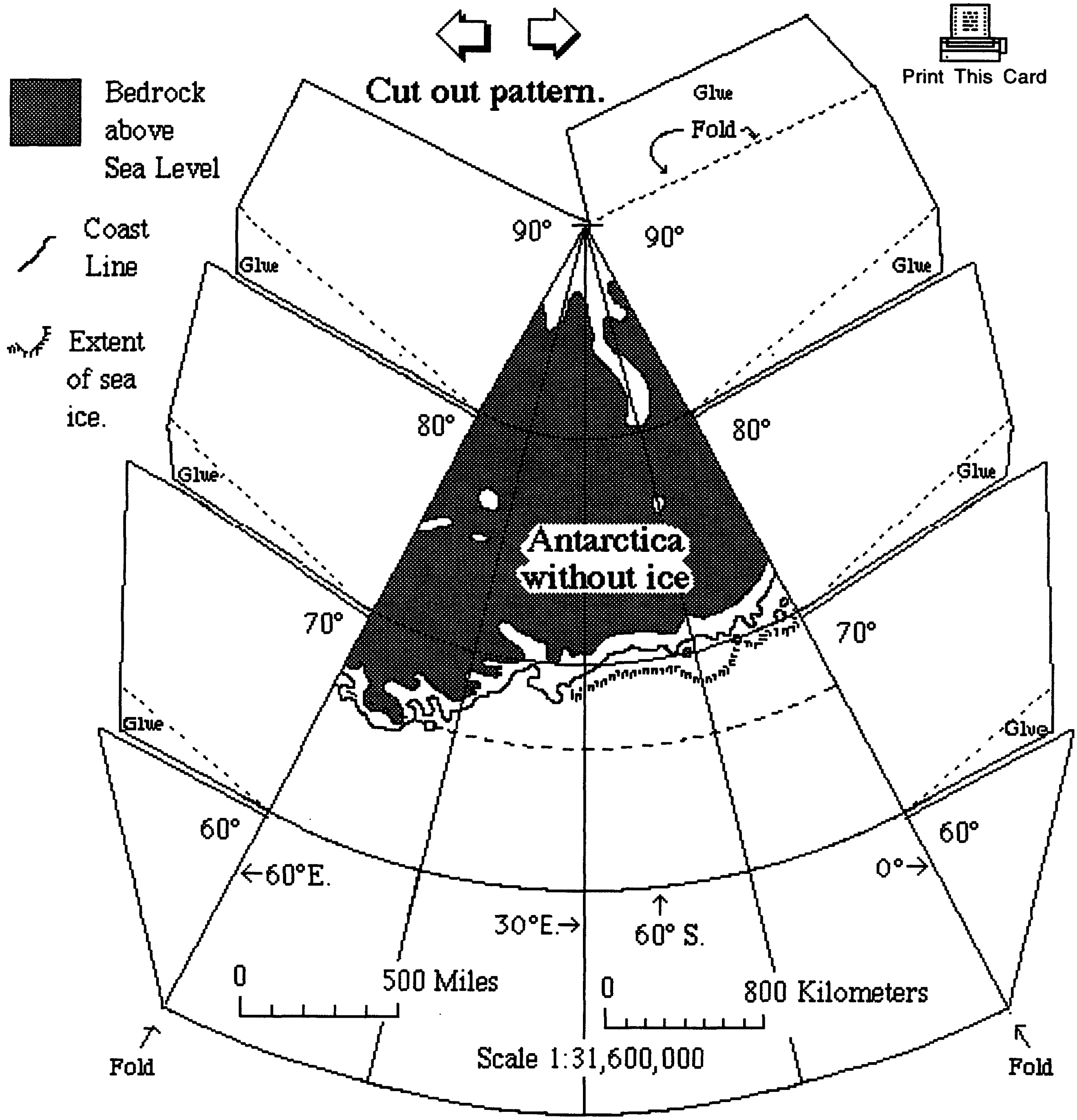
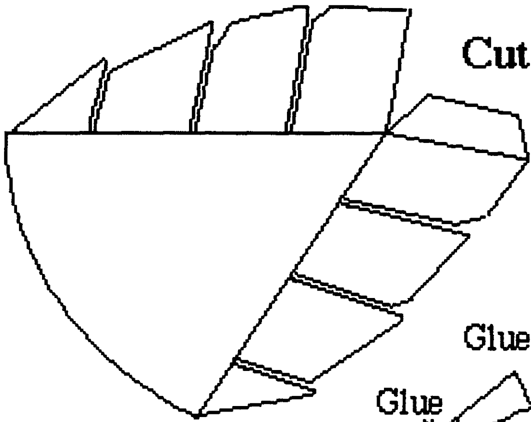
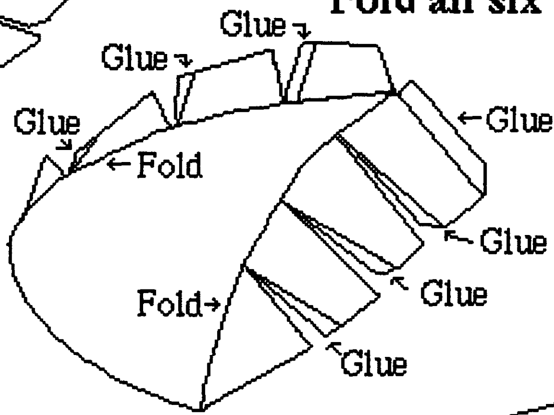


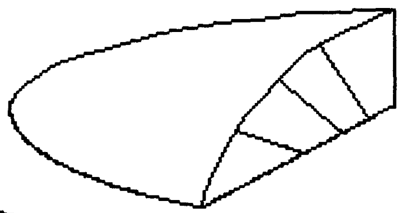


Cut out all six gore patterns.

Fold all six gore patterns

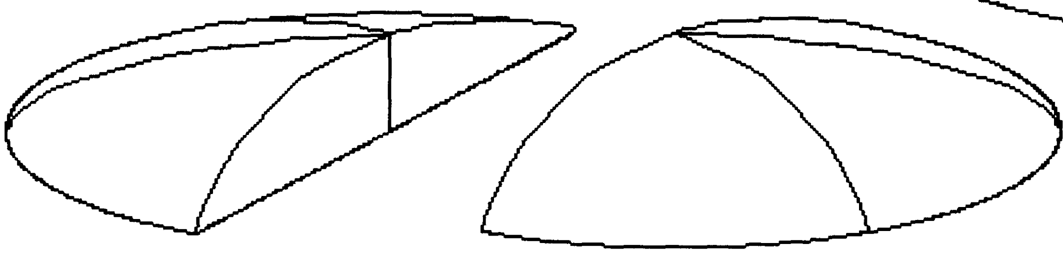


Glued gore should look like this



Glue three model gores together.

Do not glue meridians 120° West and 60° East.



Producing two models of Antarctica without ice.

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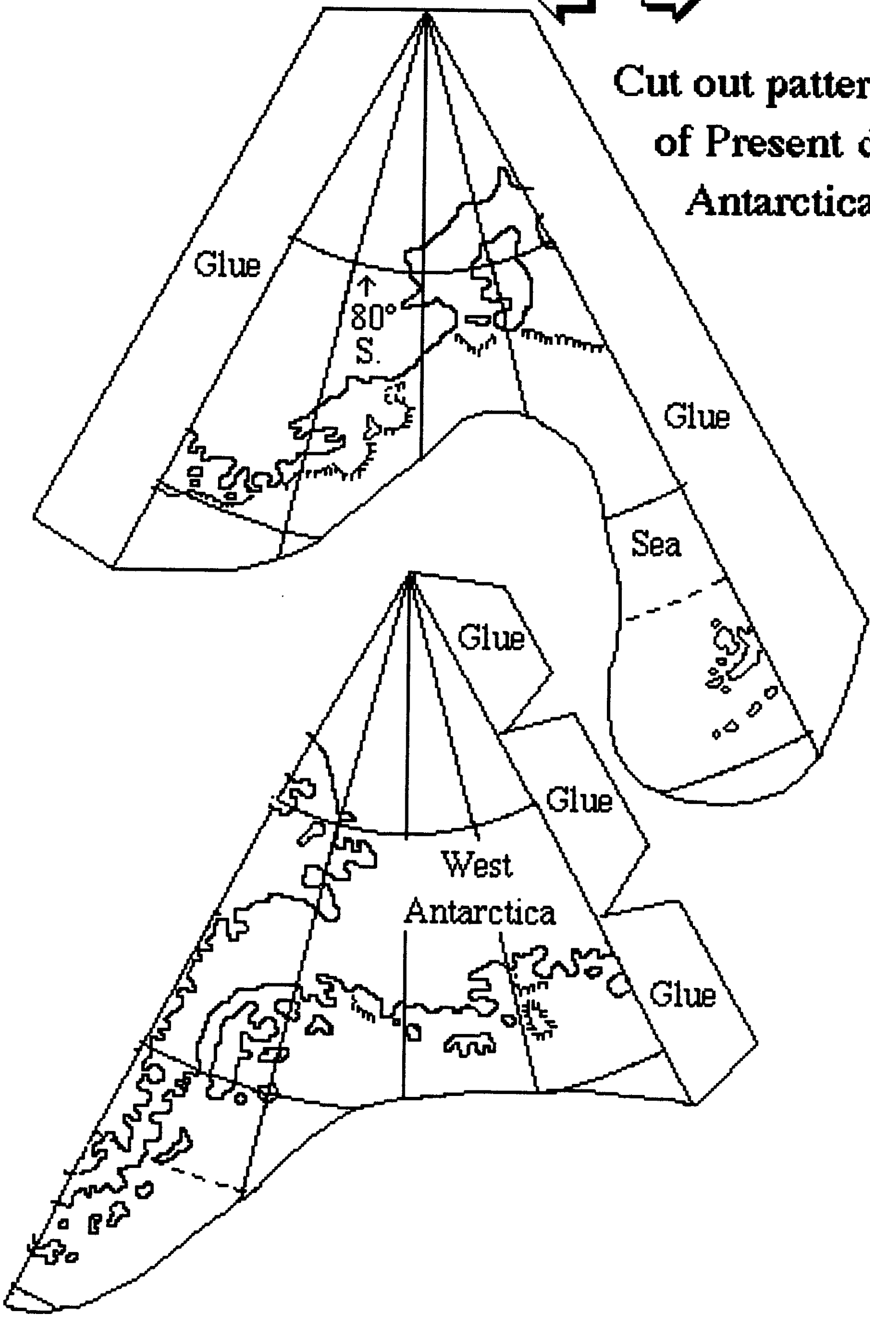
Cut out patterns of Present day Antarctica.



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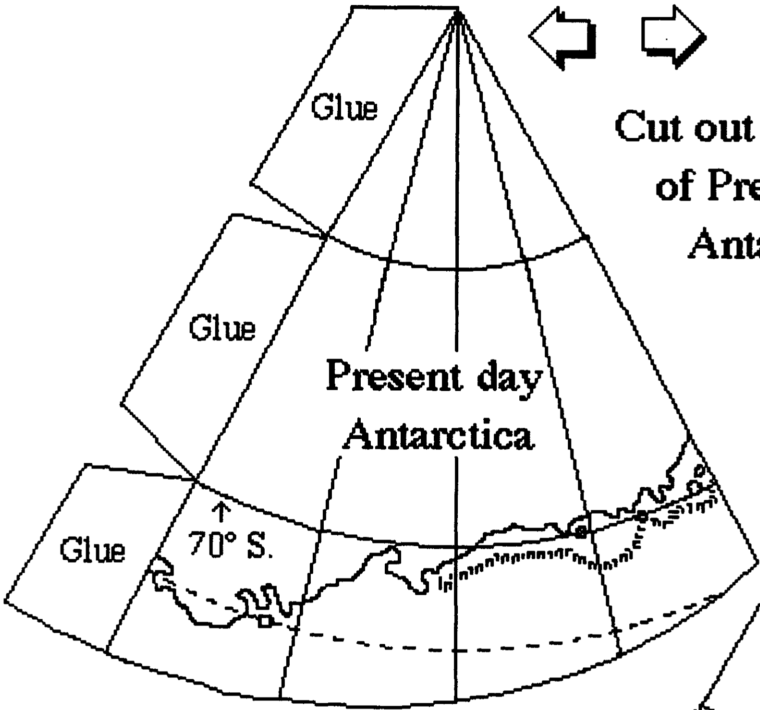
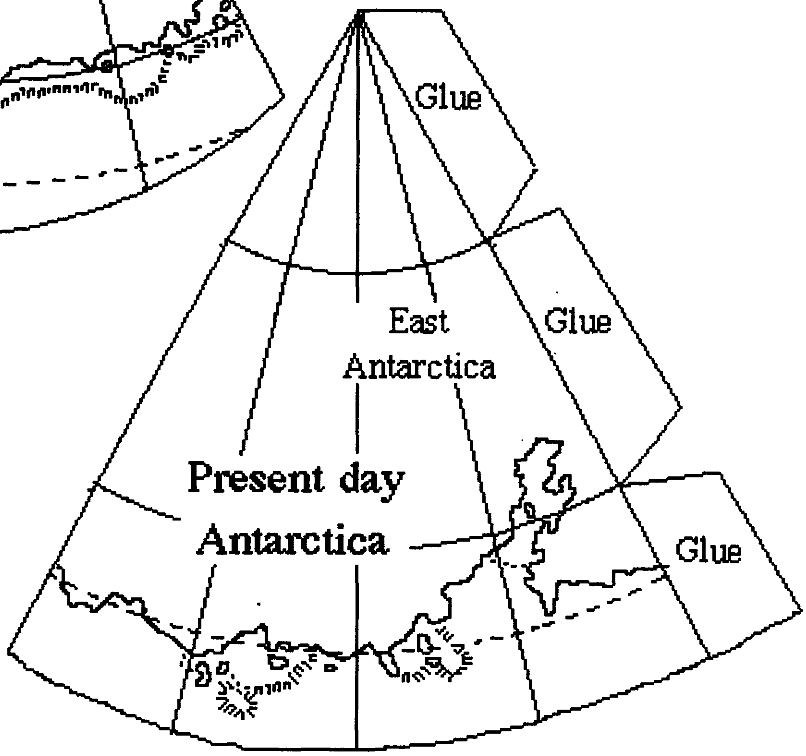
Cut out patterns of Present day Antarctica.





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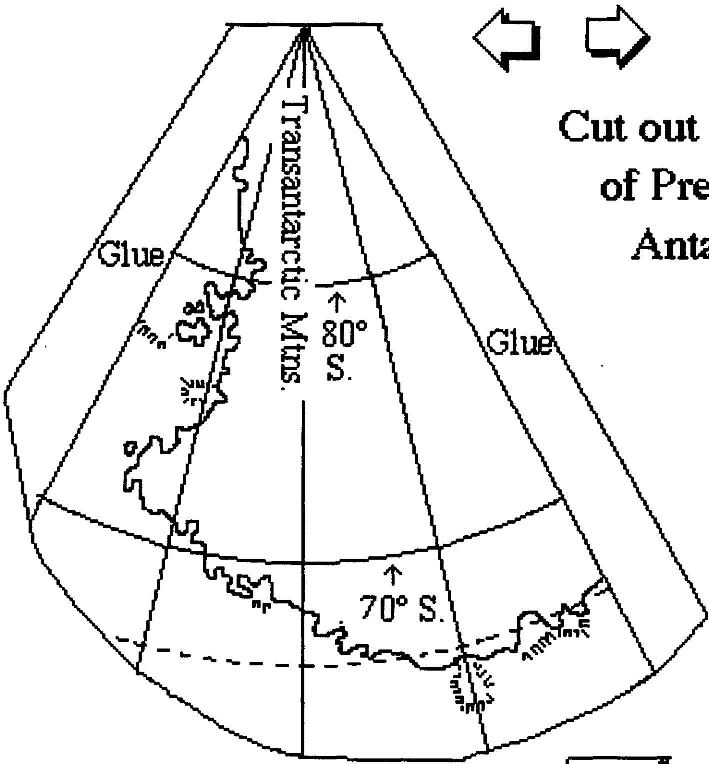

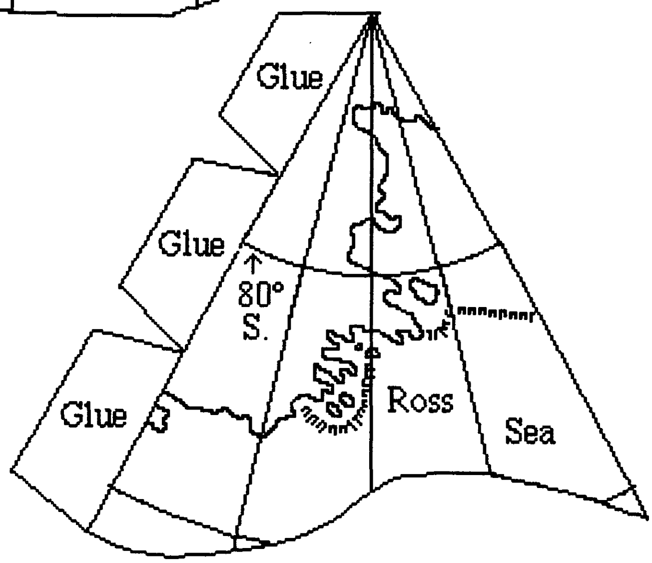

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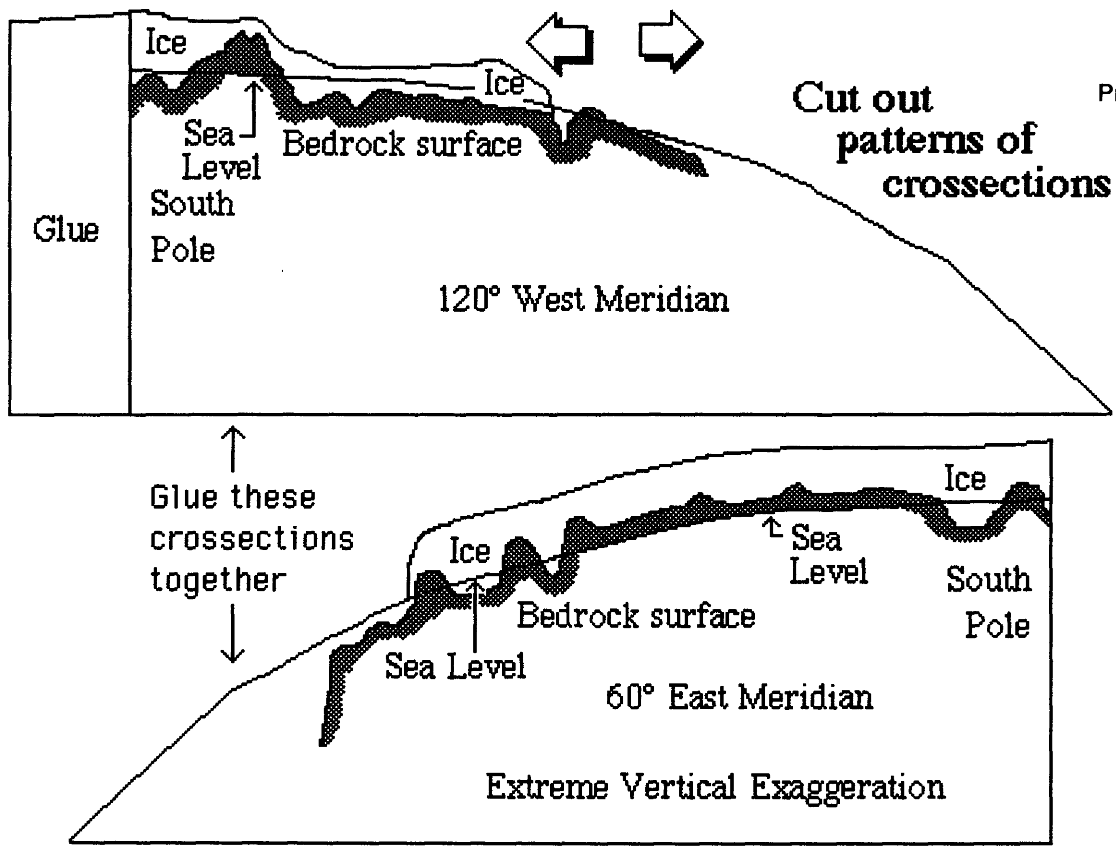
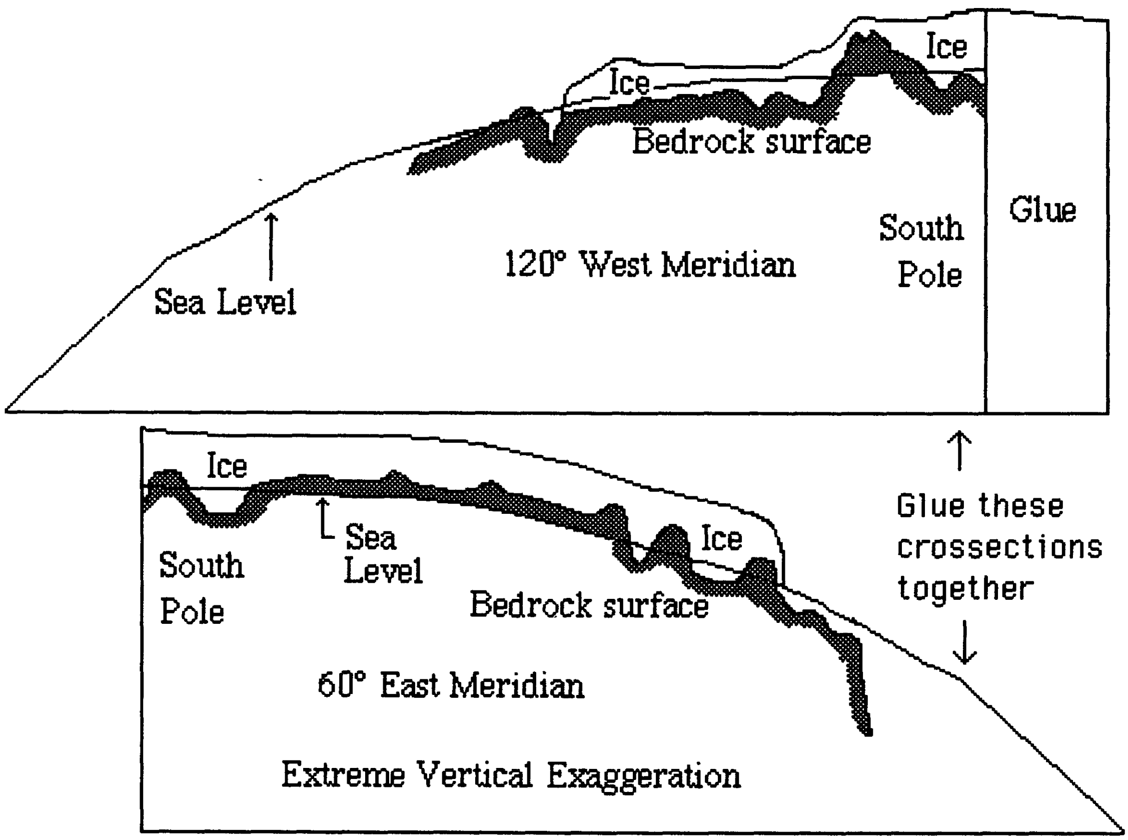
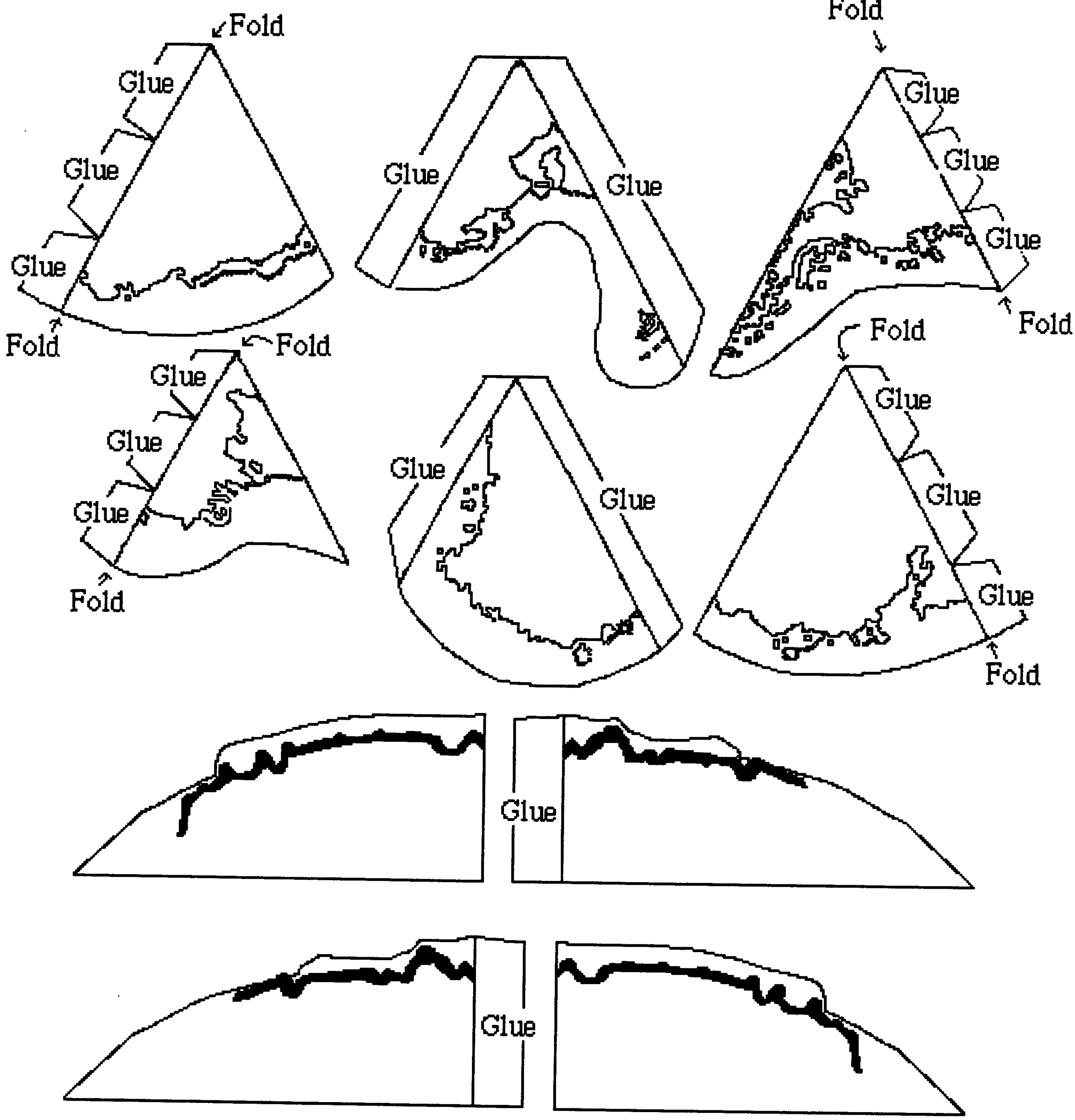
Cut out patterns of crossections



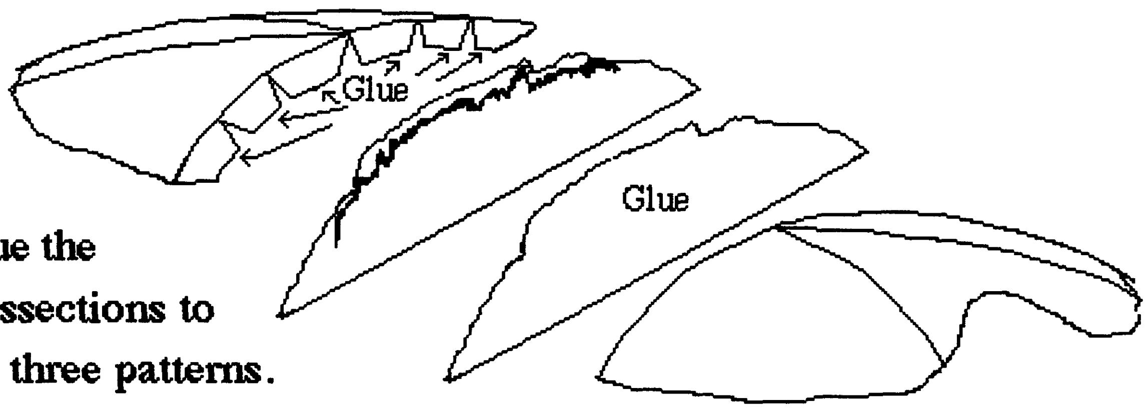


Fold and glue patterns of Present day Antarctica.



Glue three present day Antarctica pattern's together.

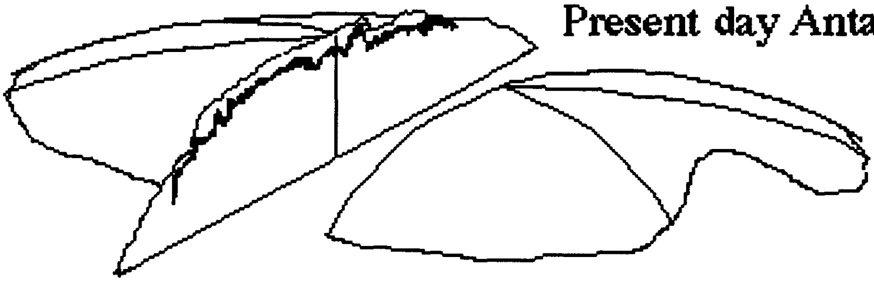
Do not glue meridians 120° West and 60° East.



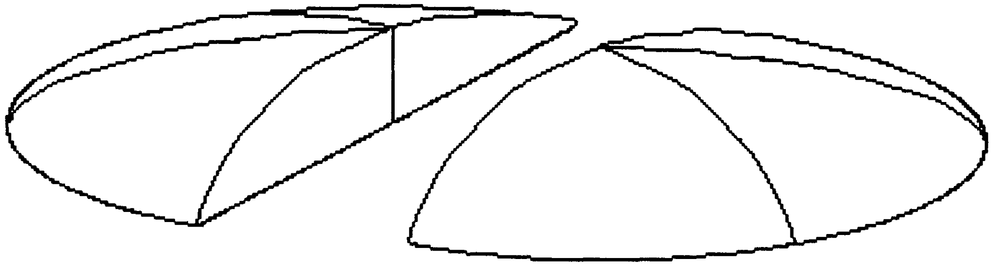
Glue the crossections to the three patterns.

Position patterns so that the top of the pattern is at sea level.

The antarctic model should look something like this.



Present day Antarctica.



Antarctica without ice.

The antarctic model illustrates how much antarctica covers the all curved surface of the earth.

The paper model has the correct curvature of the earth at the scale of 1:31,600,000.

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The End

Alpha and Cooper
Antarctic Ice Sheet

Antarctic Ice Sheet

Antarctic Ice Sheet

by

Tau Rho Alpha and Alan K. Cooper

U. S. Geological Survey O.F.-R. 98-353