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Teaching Climate Literacy Using Geospatial Tools

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TEACHING CLIMATE LITERACY USING GEOSPATIAL TOOLS

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ABSTRACT

Antarctica is the world's coldest, driest and windiest continent. It is a harsh environment that few people will ever see but it is a very important part of our Earth system. Over the past 34 million years the climate in Antarctica has deteriorated from one that supported lush vegetation to the conditions observed today. By studying this trend and the associated changes to ice and vegetation we can gain critical insight into climate changes taking place today.

This thesis presents three pieces of curricula that will help students and the general public understand some of the research currently underway in Antarctica while introducing them to geospatial tools that can be used to study climate and other large spatial and temporal events. The first paper guides students through an investigation of changing palynological distributions over time. In the activities described, students will use these data to infer climatic change on different geologic time scales and in different locales. Students will use published data-sets to trace changes in plant assembly over the past 34 million years on the Antarctic Peninsula as well as to understand the demise of the North American Ice Sheet during the last 20,000 years. The activity also introduces the use of GeoMapApp mapping software for the preparation of geo-spatial imagery and data processing. In the second paper, I outline a forensics activity that is based on actual cases where pollen has been used to solve crimes. This paper outlines a method to geo-locate a crime scene by combining Google Earth and data from NOAA's paleo-climate website. Here the focus is on spatial, rather than temporal, changes in climate and flora. Finally, I present an activity that uses GeoMapApp and multi-beam sonar data from the Ross Sea to find and map megascale glacial lineations which can then be used to infer paleo-ice stream locations and grounding zone wedges that were laid down during the last glacial maximum.

CHAPTER 1. INTRODUCTION

1.1 Context

When I began this research, I had been in the classroom for several years. Despite my professional and personal interests I felt cut-off from the pursuit of scientific knowledge and lacked practical research skills. In 2011, I accepted a MNS fellowship funded by Dr. Warny's NSF Career grant. Immediately, I was forced to cast about for some meaningful work that would meet my interest in studying climate and help Dr. Warny develop outreach materials for her grant.

Initially, my goal was to use published palynological data sets to create Antarctic paleo-vegetation reconstructions in the form of a time-series. Although the initial graphics I created were visually interesting and somewhat helpful for interpretation of vegetation changes I quickly learned that the microfossil data are so sparse that only well-sampled locales such as the Antarctic Peninsula would yield results with any resolution. In the process of creating those visualizations, however, I did learn quite a lot about using GeoMapApp software.

At that point, I began working to combine real data and the GeoMapApp tool in ways that could give insight into climate past and present. In particular, I wanted to develop classroom-ready step-by-step tutorials that let users learn the tool and the major concepts while also challenging them to ask their own questions and design new investigations. These three chapters are samples of that work.

1.2 Thesis Style

The chapters presented in this thesis are written in the style of three distinct stand-alone publications. They are united only by the common theme of global change. As such, each chapter has a different structure. The first article (chapter 2) is a web-based interactive tutorial published by the *Earth Exploration Toolbook* (EET). The website is a visually rich user environment that doesn't lend itself well to print publication (see selected screen-shots in Appendix B). Space constraints have caused me to detach most of the images and interactive materials used in the publication and reformat the step-by-step tutorials for a more readable text. The second article (chapter 3) presented here is from the peer-reviewed journal *Science Activities* and follows that publication's format. The final selection (chapter 4) is currently in preparation with EET and the same considerations have been applied to it as to the first article. As each of these selections has its own introductory materials and context descriptions I have chosen to leave them where they are and forgo re-writing that material in the thesis introduction.

1.3 Educational Application

It is commonly thought that climate change is the single largest scientific, political and social issue facing our world today. It is a vast and frankly confusing topic on its surface but understanding is further hampered by what Mark Hertsgaard calls a "disinformation campaign"(citation). It appears that the way forward is to ensure that today's students (who will be tomorrow's decision-makers) have the best information

possible. It also seems that by focusing on change on many different scales some of the "knee jerk" reactions, bias and assumptions students have about changes taking place today can be avoided. The chapters presented here are written with a target audience of students in grades 9-16. Table 1 shows a sampling of some of the educational standards addressed by this thesis.

Table 1: Summary of Educational Standards Addressed by the Materials Presented in Subsequent Chapters.

National Science Education Standards	**Climate Literacy: Essential Principles of Climate Science 2009**	**Common Core English Language Arts Standards for Science and Technical Subjects**
12ASI1.1 Identify questions and concepts that guide scientific investigations. Students should form a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations.	Changes in climate conditions can affect the health and function of ecosystems and the survival of entire species. The distribution patterns of fossils show evidence of gradual as well as abrupt extinctions related to climate change in the past.	RST.11-12.2. Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
12ASI1.3 Use technology and mathematics to improve investigations and communications. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data are also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry.	Scientific observations indicate that global climate has changed in the past, is changing now, and will change in the future. The magnitude and direction of this change is not the same at all locations on Earth.	RST.11-12.3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
12ASI1.6 Communicate and defend a scientific argument. Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.	7A Melting of ice sheets and glaciers, combined with thermal expansion of seawater as the oceans warm, is causing sea level to rise. Seawater is beginning to move onto low-lying land and to contaminate coastal freshwater sources and beginning to submerge coastal facilities and barrier islands. Sea-level rise increases the risk of damage to homes and building from storm surges such as those that accompany hurricanes.	RST.11-12.7. Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
12DESS3.2 Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed.	7E Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change. Animals, plants, bacteria, and viruses will migrate to new areas with favorable climate conditions. Infectious diseases and certain species will be able to invade areas that they did not previously inhabit.	RST.11-12.8. Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Another goal of the activities presented in this thesis is to improve student's spatial and temporal thinking ability. It is recognized that spatial thinking is an essential skill for

students in the K-12 setting (NRC, 2006) but that this skill set is not often addressed in traditional science education programs (Wai, 2009). The study of environmental science and geology, in particular, requires that students and teachers be able to appreciate "deep-time". Spatial and temporal thinking over several orders of magnitude is a requisite skill if we are to address changes in the Earth system (Kerski, 2008).

1.4 Microfossils as Climate Proxies

The notion that Antarctica was once much warmer has been extant for quite some time. Charles Darwin speculated in the *Origin of the Species* that one explanation for the similarity of forms found in South America, New Zealand and Australia was that they were "partially stocked…from Antarctic islands when they were clothed in vegetation before the commencement of the glacial period." Darwin's ideas are supported by fossils recovered by the 1901 Swedish South Pole Expedition and the Scott and Mawson expeditions a decade later. Despite the limited rock outcrop and harsh collecting conditions, twentieth century field work established that on geologic time scales the Antarctic landscape was "clothed in vegetation" more often than not (Truswell, 1982).

Although changing environmental conditions in Antarctica during the Cenozoic have been explored using pollen and other organic materials recovered from terrestrial and marine sediment cores along the continental margin, the records are fragmentary at best (Anderson *et al.* 2011). Typically, one of two approaches is used to infer past climatic settings using plant remains. The nearest living relatives (NLR) of fossil plant taxa allow inferences about past climatic tolerance such as temperature and rainfall (Dolph and Dilcher, 1979). Alternately, the temperature dependent physical characteristics of the plant fossils themselves (leaf character, margin etc.) are used to suggest paleo-climate (Wolfe, 1979). For obvious reasons, palynology (the study of organic micro-fossils such as pollen and spores) relies most heavily on the "nearest living relative" method and uses analog environments found today to understand ancient flora.

While Antarctic vegetation today is extremely sparse consisting of a few genera of mosses and lichens and only two vascular plants: *Deschampsia* and *Colobanthus*, a review of palynological literature shows wide agreement that an angiosperm dominated vegetation of high biomass and diversity was present during most of the Cenozoic (Hill and Scriven, 1995). Most sources agree that after the Eocene/Oligocene climate transition there was decreasing floral diversity that coincided with deteriorating climate and that by the Pliocene Antarctica's floristic regime resembled that seen today (Anderson *et al*. 2011).

1.5 About GeoMapApp

GeoMapApp is a global topography database and software package provided free-of-charge by the Marine Geoscience Data System at Columbia University. The web-based program includes a wide variety of data sets along with a visualization package that allows users to develop maps, graphs and other products. GeoMapApp also supports the addition of uploaded data in formats including, shapefiles, hyperlinks, JPEG's and Excel spreadsheets (Ryan *et al*., 2009). As such, it is a straightforward way to introduce geographic information systems.

CHAPTER 2. GLOBAL CHANGE IN LOCAL PLACES

This chapter previously appeared as "Global Change in Local Places" by Babcock, S., Warny, S., and Nitsche, F. in Earth Exploration Toolbook. It is reprinted by permission of the publisher. The concept of the publication originated with Steven Babcock and Sophie Warny. Frank Nitsche of Lamont-Doherty Earth Observatory graciously helped troubleshoot some of the issues related to the GeoMapApp tool. Steven Babcock designed the activities described, did all the writing and piloted the material with students.

2.1 Description

How do we know what Earth's climate was like thousands or even millions of years ago? What does the study of past environments have to do with our world today? In this chapter of the Earth Exploration Toolbook you will improve the process skills you need to do science and learn more about how scientists study Earth's past climate. You will also refine your technology skills as you use GeoMapApp data and software to solve scientific problems.

You will upload data from recent scientific expeditions to Antarctica into GeoMapApp to investigate Antarctica's past. In particular, you will use pollen data recovered from drill cores to quantify the decline in plant life that began during the geologic time period known as the Eocene. You will relate the Antarctica's past plant assemblages to modern vegetation distribution and produce computer-generated visualizations to communicate your findings.

Once you have become familiar with the GeoMapApp software and have a better understanding of how pollen can be used to understand past climate you will use these skills to design an investigation into the climate history of North America during the past 21,000 years. Finally, you will review the literature on sea level rise projected in response to current warming. You will use these projections to create visualizations of changing coastlines and to identify population centers at risk.

2.2 Teaching Notes

The sample output graph (figure 2.1) and accompanying map shown below were created using GeoMapApp software. The graph shows the changes in % abundance of *Nothofagidites* (southern beech) pollen recovered from sediment laid down 28 million years ago. The sample map shows the locations of the Antarctic Peninsula core sites. This chapter is suitable for students in grades 9-16. After completion of this chapter students will be able to:

1. List several methods for determining past climate conditions
2. Download, install and use GeoMapApp
3. Construct a variety of geospatial data visualizations
4. Describe the climate trend of Antarctica using pollen data
5. Compare pollen records of different locations
6. Predict the timing of North American glacial retreat using pollen data

To complete the activities described students will need the following tools: internet access, the free download of GeoMapApp, and Microsoft Excel.

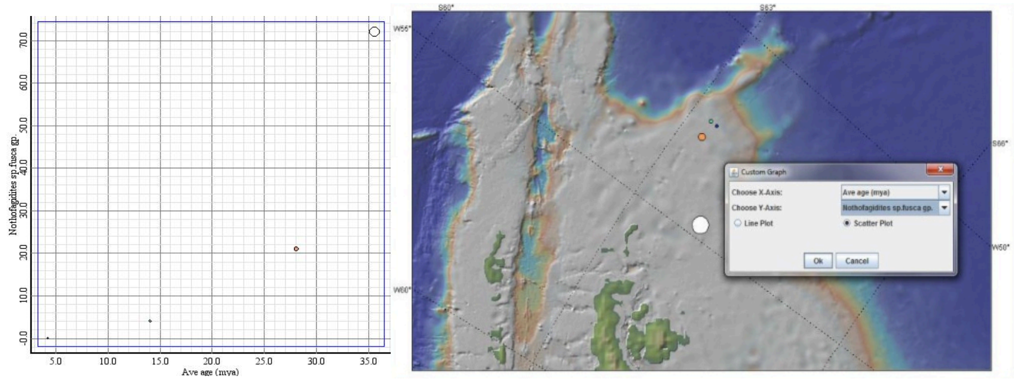

Figure 2.1 Examples of student output showing the relationship between age of core sample and percent of *Nothofagidites* in recovered pollen (l) and map with color-coded age constraints and the % abundance is depicted by diameter(r).

There is a growing emphasis on science, technology, engineering and mathematics (STEM) integration in secondary earth and environmental science classrooms. Access to Antarctic research affords new opportunities for teachers and students to improve their understanding of a range of topics including: climate change timing and intensity during the past 34 Ma, use of microfossils to infer past vegetation, and application of GIS tools to understand the physical environment. Teaching with data and using technology prepares students for real world tasks and helps develop critical thinking and evaluation skills central to science.

Recent research into student inquiry points out that students spend too little time during inquiry connecting to larger concepts and communicating results (Asay, 2011). GeoMapApp is an ideal platform for students to create visualizations that help make sense of multi-modal concepts like climate change and provide them with graphics that can drive discussion and understanding. Interactive visual interfaces like Google Earth and GeoMapApp have been shown to effectively incorporate learning material for students' analysis and reasoning within the contexts of authentic environmental problem-solving tasks (Bodzin, 2011).

Most students have likely used geospatial visualizations like Google Earth and will be somewhat familiar with parts of the GeoMapApp toolbar but will need to recognize the different nature of the images shown on the GeoMapApp screen. These data visualizations are much more like other types of maps they may have used than the satellite and aerial photos that make up Google Earth imagery. A basic understanding of latitude, longitude and map projections in needed.

Students will be asked to create simple spreadsheets without formulas during the completion of the activities found in this chapter. Students may also need to be reminded of the role of pollen in plant reproduction and its distinct morphology. A great resource to review is the short pollen talk by Jonathan Drori available on YouTube. Students may also need to review the geologic time scale and should be encouraged to download one of the free geologic time scale application to their mobile device. Students can also listen to a

radio interview by Sarah Feakins at www.cbc.ca/quirks/episode/2012/09/15/september-15-2012/index.html#4.

Key terms students will explore in this activity include: climate change, sediment core, diversity, succession, pollen, GeoMapApp, CO_2, foundation species, geologic time, ice sheets, Antarctica, paleo-vegetation reconstruction, paleo-climatology, palynology.

To engage students, the teacher may want to begin by holding up a sedimentary rock and a large flower such as a lily. Questions to pose could include: "What do these things have to do with each other?" "What is the difference between living and non-living?" "What do rocks and plants have to do with climate?" Teachers may also want to query students on the modern Antarctic environment. Before beginning this chapter, teachers should take time to familiarize themselves with GeoMapApp. Getting to know GeoMapApp can be done by trial and error interactions with the toolbar or by utilizing the tutorials under the education menu.

Students can be organized into small groups or work independently, but it is important that they have the opportunity to share their findings and imagery. This can be done by hosting a poster session at the end of the series of investigations. Students should write captions for the figures they create and include citations where possible. To this end, it is valuable to have printed copies of several relevant publications on hand for student review (see resources).

Students should also be encouraged to record their results in written form. Answers to prompts throughout the chapter can be kept in a word processing document or in student journals.

The learning activity entitled "There and Back Again" presents an excellent opportunity for student inquiry. Students should be encouraged to identify relevant variables and develop an investigation into temporal and spatial patterns of glacial retreat revealed by palynological data North America. Students should describe a method for collecting data from the web, process the data using numerical or graphical techniques, and develop a conclusion and analysis of the results. A generic scoring guide for open-ended inquiry tasks is included in the appendix.

The following questions can be used to gauge student understanding prior to completion of this curricula:

1. How do scientists know past climate conditions?
2. How is pollen used in climate reconstruction?
3. What is the significance of the "nearest living relative"?
4. When did the North American Ice sheet retreat?
5. What was Antarctic like in the past? What is the time scale?

Upon completion of this curricula students will be assessed on the following:

1. Quality of geospatial imagery illustrating distribution and abundance of key plant groups over geologic time scales.
2. Ability to communicate data support for inferences about past climate change.

While the activities presented here can be completed in three or four class periods, teachers may choose to extend any of the activities outlined in this chapter. Each part

contains a section of suggestions for further investigation. For example, environmental science students may use the pollen % abundance data in part 2 and 3 to calculate diversity at different time periods using a simple statistical approach such as Simpson's Index. Geography students can export GeoMapApp images into other software programs such as Adobe Illustrator or Photoshop to add illustrations of plant groups or to add shading, text or other objects to their maps. If desired, notes and figures can be used to write a scientific report as a culminating project.

The following websites provide students with background information, ideas and extensions to the activity presented here:

1. NOAA Paleoclimatology: A great resource that includes more info about climate proxies-What is Paleoclimatology? http://www.ncdc.noaa.gov/paleo/primer.html.
2. The Discovery of Global Warming: A hypertext history of how scientists came to (partly) understand what people are doing to cause climate change by science historian Spencer Weart: http://www.aip.org/history/climate/index.html.
3. NOAA Pollen Viewer provides an interactive map that tracks distribution and abundance of key plant groups since the last glacial maximum: http://www.ncdc.noaa.gov/paleo/pollen/viewer/webviewer.html.
4. GeoMapApp main page has extensive video tutorials and links to educational materials: www.geomapapp.org.
5. EPA Climate Change Home is the official government site providing information on the issue of climate change and global warming. The site includes an overview of climate change science: http://www.epa.gov/climatechange/.
6. Students can also listen to a Sarah Feakins interview discussing this research: www.cbc.ca/quirks/episode/2012/09/15/september-15-2012/index.html#4.
7. A great short introduction to pollen and how it is used in a variety of disciplines from researcher Jonathan Drori: www.youtube.com/watch?v=vXDJ-nAykKE.
8. Overview of how Antarctic pollen was recovered and what it suggests is included in this video of Dr. John Anderson: www.youtube.com/watch?v=R0Z7Ir8ZN00&feature=player_embedded.

2.3 Case Study: A Lost World

> The ice covered Antarctic continent, bathed by seas of uniform coldness, is in the grip of the polar anticyclone. High winds blow from the land and repel any warming influence that might seek to penetrate it. The mean temperature of this bitter world is never above the freezing point. On exposed rocks the lichens grow, covering the barrenness of cliffs with their gray or orange growths and here and there over the snow is the red dust of the hardier algae. Mosses hide in the valleys and crevices less exposed to the winds, but of the higher plants only a few impoverished strands of grasses have managed to invade this land. There are no land mammals; the fauna of the Antarctic continent consists only of birds, wingless mosquitoes, a few flies, and microscopic mites.
>
> Rachel Carson, <u>The Sea Around Us</u>

In 1994, two researchers from Augustana College made a strange discovery in the mountains of Antarctica. While excavating a siltstone formation 650 km from the South Pole, William Hammer and William Hickerson uncovered the skull and bones of a large carnivorous dinosaur (figure 2.2). Found alongside the gnawed ends of the bones were the teeth of other smaller scavenging dinosaurs and fossilized tree trunks. What could explain the presence of these plants and animals in a location that today is so cold and lifeless? It seems obvious that Antarctica's climate must have been quite different during Jurassic when the organisms were alive. But how do scientists fill in all the gaps and piece together Earth's climate history?

Earth's history is a long story going back 4.6 billion years. So great, in fact, are the lengths of time that the current geologic era we live in (the Cenozoic) stretches all the way back to the extinction of the dinosaurs 65 million years ago. But if we took our era and compared it to all of Earth's history, the Cenozoic would represent less than 2% of total time! Scientists study past climates using a variety of techniques.

Instrument records of temperature, rainfall and other factors can be used to study only a very small segment of climate history. For instance, direct measurement of air temperatures only extends back to the 1860's and much of the early data is subject to error. Written records such as diaries, ships logs and harvest information go back further but usually give us only qualitative data about past conditions.

Scientists can use a wide variety of indirect methods called proxies to understand Antarctic's past climate. Ice cores from drilling in Antarctica contain valuable information about the past 740,000 years. Essentially, a long narrow cylinder of ice is lifted from the ice sheet and studied by scientists. The deepest parts of the cylinder are made up of snowfall from long ago. When researchers sample these ancient layers they have several methods of learning the climate at the time the layer formed. Isotopic ratios from several elements can be used to infer temperature and precipitation. In addition, gas bubbles trapped in the annual layers of ice allow researchers to sample the composition of the ancient atmosphere.

Sediments found in ocean basins around Antarctica contain microfossils that are used to reconstruct past atmospheric and sea-surface conditions. Sediment, you recall, is naturally occurring material transported by wind or water. Sometimes sediment found in the ocean contains fossils and other material from nearby continents along with fossils

from the ocean environment. Sediment cores are studied in ways similar to ice cores. For example, changing distributions of phytoplankton different layers of sediment can be tied to changing water properties. Sedimentary rates are also important indicators of wet/dry cycles. Sediment sequences from deep undisturbed locations give us information going back millions of years. Typically, scientists will remove small portions of a sediment core to look for microscopic fossil remains as shown in figure 2.2.

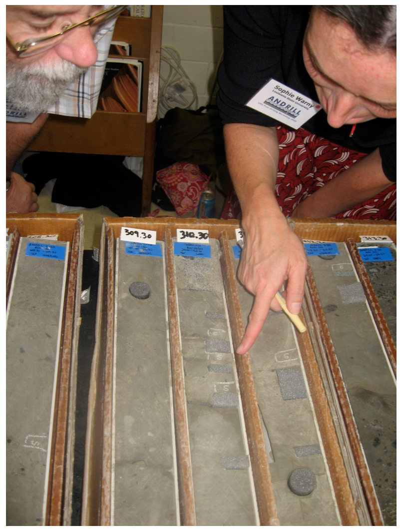

Figure 2.2 Examining a sediment core. Note foam blocks where material has been removed to process for microfossils. Photo courtesy of Sophie Warny.

Some cores recovered near land can also tell scientists about terrestrial conditions. Pollen, which is very resistant to decay, is produced in large quantities by plants. It can be transported by wind or water and buried with sediment. Many types of pollen have such characteristic shape and size researchers using microscopes can use to identify the plants that produced them (figure 2.3). This allows them to isolate vegetation type and distribution in both time and space. Past climate in turn can then be inferred by understanding the temperature and rainfall where similar species are found today.

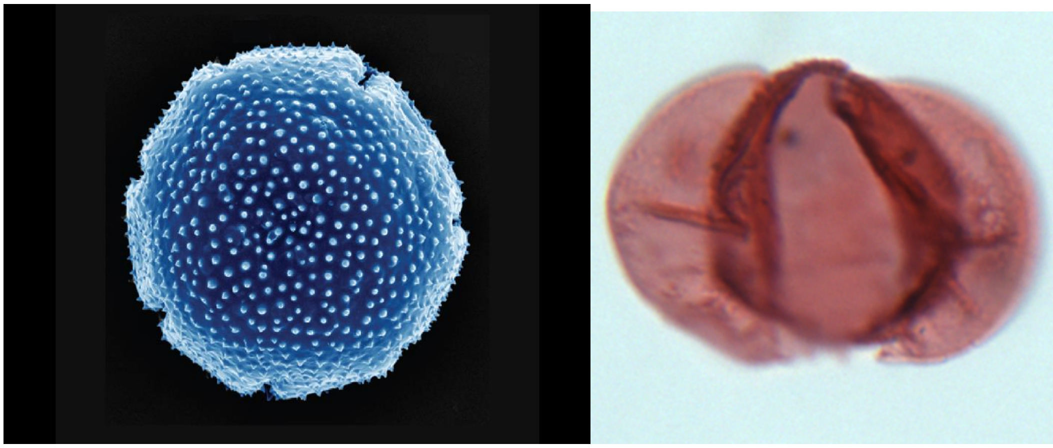

Figure 2.3 *Nothofagus fusca* (l) and conifer (r) pollen recovered from Antarctic sediment core. Photo credit Sophie Warny.

Climate records archived in sediment is made more valuable by techniques which allow them to be age dated. This is done by combining and correlating observations from various techniques such as paleomagnetic data with radioactive decay of materials contained in the sample and identifying characteristic biological remains called biostratigraphic markers, and in some cases simply counting the number depositional layers. Together, all these lines of indirect evidence can be assembled to help fill in the details that explain just how dinosaurs fit into Antarctic's ancient landscape.

2.4 Step-by-Step Tutorial

Part 1 Exploring Seafloor Topography

If you are new to GeoMapApp complete this Earth Exploration Toolbook activity. In this activity you will learn to manipulate the toolbars and create visualizations using the data: http://serc.carleton.edu/eet/seafloor/part_1.html. If you are already familiar with the tool, skip to Part 2.

Part 2-From Nice to Ice

Take a moment to review the short video on recent Antarctic research found at: http://www.youtube.com/watch?v=R0Z7Ir8ZN00&feature=player_embedded#!. Once you have completed the video of Dr. John Anderson describing his research, answer the following questions in your journal: How are sediment cores different from ice cores? What clues were initially found in the sediment that allowed identification of a warm period? Why is Antarctic research important to help us understand today's climate?
You may also want to read a short summary of Dr. John Anderson's paper: Progressive Cenozoic cooling and the demise of Antarctica's last refugium (Anderson, et.al. 2011). The paper can be found at: http://phys.org/news/2011-06-fossilized-pollen-reveals-climate-history.html

The data shown in table 2.1 below were collected during a research cruise to the Antarctic Peninsula. Fossil pollen recovered from core samples obtained by the scientists was identified and correlated to sediment age. As you review the data consider the

following questions: Which core is the oldest? Use the geologic timescale from the case study along with the age constraints shown in the table to identify the epoch name for each core sample. Compare the *Nothofagidites fusca* abundance with the conifer group abundance. What pattern do you notice? What are the main classification differences between these two plant groups? Which is a conifer? Which is deciduous? To view the entire data set see page 17 of the PNAS paper appendix. It can be found at: http://www.pnas.org/content/suppl/2011/06/21/1014885108.DCSupplemental/Appendix.pdf.

Table 2.1. Palynological data (adapted from Anderson et al. 2011) shows location, age, core ID, and average relative abundance for several major taxa of pollen fossils. Note that the %abundance figures are averages of all pollen returns within the associated sequence.

Latitude	**Longitude**	**Age Range (mya)**	**Ave age (mya)**	CORE	BOTTOM DEPTH	*Nothofagidites* sp.*fusca* gp.	*Nothofagidites brassii* gp.	*Nothofagidites menziesii* gp.	Conifer pollen	Proteaceae
-63.3378	-52.3672	5.3-3.6	4.2	6C-2	58	0	0	0	0	0
-63.8477	-54.6535	37-34	35.5	3C-7	8	72	3	2	16	1
-63.2726	-52.825	34-23	28	12A-2	35	21	0	0	19	1
-63.2515	-52.3657	16-11.6	14	5D-12	11	4	1	0	1	0

Step 2-Open GeoMapApp and Import Data. Take a moment to examine the start screen. Notice how the Mercator projection to the left distorts Antarctica. Cartographers have struggled for centuries to depict our spherical world on chart paper. Their best solutions have been ones that have the least distortion in the area of interest. Mercator has the least distortion near the equator but maximal distortion near our area of interest. For this part of our investigation you will use the South Polar Projection. Select the South Polar Projection in the center of the box and click Agree. In this activity you will learn to upload your own data into GeoMapApp. Go back to the table you used earlier in this activity. Highlight and copy the entire table to your clipboard. Make sure you copy the column headers as they will be used in GeoMapApp. On your GeoMapApp screen select File>Import Table or Spreadsheet > From Clipboard… (If you have a saved Excel file you can select From

Excel-formatted file… in this same window.) The Excel file you copied on your clipboard should now be pasted directly into the highlighted box. After clicking OK you will see a new window. Notice that the latitude and longitude columns you loaded will automatically be used as the GeoMapApp latitude and longitude values. Any future tables you want to load must have columns of latitude and longitude for location reference. These coordinates must be in decimal form. (Note: If you are working with sexagesimal (degrees, minutes, seconds) latitude and longitude you can convert the data using the online calculator found at http://www.overspoor.nl/convert/sexagesimal2decimal.asp. North latitudes should be entered with positive decimal values and south with negative values. West longitudes should be entered with negative values and east with positive values.) Click Ok to go ahead and load the data:

Step 3- Manipulating Symbol Size and Color. Notice that the uploaded table now appears on the GeoMapApp dock at the bottom of the screen and that the core coordinates have been loaded into the map as round icons. Continue by zooming into the area where the core icons are located using your zoom tool as you did in Part 1. Put away the zoom tool and select the arrow pointer from the toolbar. Click one of the core icons with the arrow pointer tool. What did you notice? Each symbol you select causes the corresponding row in the data table to be highlighted. Now you will manipulate the symbols to enhance image. First you will color-code the symbols by age then you will size them for one of the fossil pollen % abundances. To change the symbol color, use the pointer tool to select the "Color" tab to the right on the vertical Tool Box. Click the arrow to the right on the "Select Column" box to open the dropdown menu. Select "average age > Ok". We now see our core locations sorted by age along with a histogram that shows how color relates to age. What color is automatically selected for the oldest samples? Which is the youngest? (Note that you can drag the vertical lines on the histogram to change the colors.) What do you notice about the pattern of age distribution in relation to distances from the nearest shoreline of the Antarctic Peninsula?

Use the profile tool from the top tool bar as we did in Part 1 to determine the distances from the core sites to the Antarctic Peninsula shoreline. Consider the following questions: how far is it from the shoreline to the oldest core? How deep is the water at the oldest core location? Look at figure 2.5 below. This artistic rendition of the Shaldrill project shows how core samples were recovered from the seafloor by the drill ship Nathaniel B Palmer. Note how the sediment layers down dip moving to the right of the image as the ship moves away from land. In your journal, write a hypothesis about why the oldest sediment is closest to the land.

Now you will change the core icon size to illustrate the changes in % abundance of a particular type of pollen recovered with the sediment. To change the symbol size, use the pointer tool to select the "Scale" button on the "Tool Box" to the right. Click the arrow to the right on the "Select Column" box to open the dropdown menu. Select "*Nothofagidites fusca* > Ok." Which core has the greatest abundance of *Nothofagidites fusca*? In your journal, describe the trend over time? Save the screenshot (FN+F11) and paste it into your journal to use in your report.

Step 4- Creating Graphs with GeoMapApp. Although you can see the relationships pretty well with your map, you can also create graphs using the data you uploaded. Use your pointer tool to select the "Graph" button from the "Tool Box" at the right. Follow the prompts to select "average age" as your x-axis and "*Nothofagidites fusca*" as your y-axis.

You can select either "line" or "scatterplot" depending on your preference. Note the line graph has a trend-line about the data points. Copy the graph and save it in your working file. Make sure to give the graph an appropriate descriptive title and a caption explaining what the figure shows. You may want to try these techniques with the conifer pollen listed in the data set to identify similarities and differences among the two taxa.

Step 5- Finding the Nearest Living Relative: Palynologists (scientists who study small organic-walled microfossils such as pollen) often infer past climate using a technique known as 'nearest living relative" or NLR. In essence, they identify modern sites that have plant assemblages matching the fossil pollen in a sediment sample and use the modern site as an analog for the past climate condition. Use the web to research and write a brief description of *Nothofagus fusca* and where it is found today. What can you infer about the climate of the Antarctic Peninsula 34 million years ago based on the presence of *Nothofagus* pollen? Briefly describe the evolution of Antarctica's climate from 34 million years ago to the present. Be sure to cite relevant evidence to justify your conclusion.

Part 3 There and back again or the demise of the North American Ice Sheet

In Part 2 you examined the fossil record of *Nothofagus* in Antarctica. The trends in plant distribution that you uncovered helped you infer past climate by considering where similar plants grow today. In this part of the chapter you will use the skills you developed in Part 2 to investigate the timing of the last major glacial episode of North America. To complete this task you will access data from NOAA's Pollen Database and create a spreadsheet like the one you used before.

Step 1: Open GeoMapApp's Mercator base map and select a site with pollen data. If you still have GeoMapApp open from the last activity close it and restart the program. This time you will open the Mercator projection shown at the left. Select it and click Agree. Notice the difference in this projection and how it distorts high latitude areas. Select the zoom tool (magnifying glass with a plus sign on it). Use the zoom tool to click and drag a box that covers the region of North America between the Great Lakes and the Atlantic Ocean. Remember you may need to wait a few seconds for the server to import the higher resolution data!

Now that you have zoomed in, you may want to select the "hand" tool to center the image so that you can see the Great Lakes to the west and the Atlantic to the east in one view. Select the arrow pointer tool to ensure you do not change the image. Select "Datasets >World Data Center Paleo Climate Open Archives> Pollen" from the drop down menu at the top of your screen. The list that appears shows authors who have published pollen data to the database. Drag the list to the right of your screen and check the box labeled "Show on Map". Each box that appears on the map represents the general area of a particular pollen study site. Like the core sites in Antarctica, these areas have been studied by identifying pollen abundance and distribution through time. Why do you think the number of studies is so much greater in this region than it is in Antarctica? Scroll down the alphabetical list and highlight the entry entitled: "Spear, R.W. Lost Pond (LOSTPOND) Global Pollen Database". Notice that this study area is now highlighted on your map. You may need to drag the window out of your way. Once the entry is highlighted click "Ok" at the bottom of the window. This will direct your web browser to open the Lost Pond dataset on the NOAA Paleoclimatology Website: http://www.ncdc.noaa.gov/paleo/metadata/noaa-pollen-

7415.html. Note the site's Latitude and Longitude (44.246944N and -77.251389W). You will use these coordinates to locate the sediment core on our map. Also note the age constraints are much different than those we used in Antarctica. The Carbon 14 age constraints of the sedimentary sequence range from 13,480 years before present to 20 years before the present.

Step 2: Create an Excel file of the p15 data for the site. In our study of Antarctica, we used a very small set of data to look at vegetation patterns over 10's of millions of years. In this section we will create our own spreadsheets to format a lot more data representing a much shorter time span. For this investigation we will use the conifer genus *Tsuga*. Write a brief description of *Tsuga canadensis* in your journal. Recall that in Part 2 you wrote about an angiosperm: *Nothafagidites fusca* and discussed how it differed from conifers. Here you will provide details about a particular conifer species: *Tsuga canadensis*. However, there is a close relative of the *Nothofagidites* you studied before in this sample set also: *Fagus*. If you prefer you can add the *Fagus* % abundances to the following instructions. Create an Excel spreadsheet with the following column headers: Latitude, Longitude, Age and *Tsuga* % abundance. Save this file to your desktop as "Lost Pond Pollen" and minimize it. On the NOAA Paleoclimatology page for Lost Pond that you opened in the last step double click the data link labeled: pollen/asciifiles/fossil/p15files/gpd/lostpond_p15.txt.This file shows the abundance data for the 15 most common types of pollen recovered at the Lost Pond site. Enter the Latitude and Longitude values for the Lost Pond site in the first two columns of your spreadsheet. For GeoMapApp to correctly process the location you must use the digital values shown in parenthesis. As you can see north latitudes have positive values and west longitudes have negative values. Copy and paste the values down to row 35 in your spreadsheet. Now look back at the P^{15} data display. This data table shows the percent distribution of the most commonly occurring 15 plant genera for the site. It is quite confusing at first glance. Let's break it down by answering the following questions: What country and state is Lost Pond located in? What is Lost Pond's elevation? Take a look at the columns below the age bounds. Notice they are numbered 1-17. To the right of these numbers is an abbreviation for a genus and further right the names are spelled out. We will be using % abundance for *Tsuga*. What number between 1 and 15 is assigned to *Tsuga*? Scroll down a bit more and you will find the data themselves. The column to the extreme left reads 1, 20, 30, 50, 75 etc. This represents the depth in centimeters of the samples. Just to the right of these numbers is the sample age. What is the age of the sample recovered from 1 meter (100 cm)? Each depth/age has a record to the right for the most abundant species recovered. Since we are interested in the records for *Tsuga* we will need to count over to the 13th entry. Do this for each depth. Note that it is the third entry in the second row for each depth. What was the % abundance of *Tsuga* at the depth of 1 meter (100 cm)? Enter the ages and corresponding % abundances for *Tsuga* down your spreadsheet. When you are done make sure to save your work.

Step 3: Import Lost Pond Data into GeoMapApp. Use your mouse and hold down the left click button to highlight the entire Lost Pond Pollen Spreadsheet. Make sure to include the column headers as they will be used in GeoMapApp. Use Ctrl + C or other command to copy the entire spreadsheet to you clipboard. Minimize the spreadsheet. On your GeoMapApp screen click on "File" in the upper left above the toolbar. Move your pointer down the menu and select "Import Table or Spreadsheet". Choose "From Clipboard". The spreadsheet data should show up in the Window automatically. If it does not you will need

to repeat the appropriate steps above and try again. Click “Ok**”.** As you did in Part 2 verify that your latitude column is labeled latitude and your longitude column is labeled longitude. Click “Ok”. Notice your core location icon appears now on the map just inside the area location box for Lost Pond. Use your zoom tool to examine the topography around the lost pond core location. (Note: you may want to close the Pollen database sites from Step 1 to clean up your images.)

Step 4: Compare *Tsuga* Abundance to Glacial Retreat. Use the skills you learned earlier to create a line graph of the change in *Tsuga* abundance. When did *Tsuga* pollen first appear in the fossil record at Lost Pond? When did it peak? Describe changes in Tsuga abundance over the last few centuries. Create a new tab on your web browser and open the pollen viewer website: http://www.ncdc.noaa.gov/paleo/pollen/viewer/webviewer.html. Click on the down arrow to the right of the box that appears above the map. From the drop down menu scroll down to select *Tsuga*. Use the forward and back buttons under the **Play** button on the Pollen Viewer to move forward and back though time. Locate and review the general area of Lost Pond on the map image displayed. Did you observe a spike in *Tsuga* abundance similar to the one you observed in your graph? Write a brief description of the relationship between the location of the North American Ice Sheet and the abundance of *Tsuga* pollen. Compare the results of this investigation with the one you conducted in Part 2. What similarities and differences do you observe? List factors which influence the advance and retreat of glaciers.

Step 5: Developing and testing a hypothesis. Use the knowledge and skills you have acquired in Part 3 to develop and test a hypothesis to answer the following question. Include data, figures and citations to justify your response. How would the distribution graph for *Tsuga* differ if the data came from a core 100 km northwest of Lost Pond?

2.5 Going Further

You may want to review another genus at the Lost Pond site. Not all species respond to climate changes in the same way since they have unique environmental tolerances. Interestingly, the angiosperm genus *Fagus* (beech) found at the site is a distant relative of the *Nothofagidites* we examined in the Antarctic.

CHAPTER 3. FORENSIC PALYNOLOGY AS CLASSROOM INQUIRY

This chapter previously appeared as “Forensic Palynology as Classroom Inquiry” by Steven Babcock and Sophie Warny in *Science Activities: Classroom Projects and Curriculum Ideas*. It is reprinted with permission (see appendix A). SB and SW originated the concept. SB completed the research, developed the activities described and wrote the manuscript.

3.1 Abstract

This activity introduces the science of forensic palynology: the use of microscopic pollen and spores (also called palynomorphs) to solve criminal cases. Plants produce large amounts of pollen or spores during reproductive cycles. Because of their chemical resistance, small size and morphology, pollen and spores can be used to link individuals or objects to specific locations where the parent plants grow. Students will use a digital pollen database and Google Earth to link pollen trace evidence to a specific crime scene. The methods presented are based on actual criminal cases and palynological techniques used by forensic scientists. Step-by-step instructions for a hands-on investigation and a case simulation are presented.

3.2 Keywords

This activity is referenced in publication by the following keywords: palynology, forensics, pollen and spores.

3.3 Introduction

Forensic science in the classroom provides a high interest, topical setting for student inquiry. A science in itself, forensics has roots in many areas of the traditional high school curriculum including math, biology, chemistry, physics and earth science. Forensic scientists apply principles learned in these fields to explore legal issues. The goal of any forensic investigation is to use scientific methodology to find links between people, places, and things. Palynology is the study of organic-walled microfossils. Two of the most abundant of these microfossils are pollen and spores.

Forensic palynology uses “trace” evidence in the form of tiny grains of pollen and spores in a legal context (Warny, 2013). Published case histories of forensic palynology demonstrate its use in crimes including rape, homicide, genocide, terrorism, drug dealing, robbery and others (Milne et al., 2004). Despite the successes of forensic palynology and its suitability for use in the United States owing to the country’s great regional plant diversity and well-documented pollen studies, there has been limited application of the technique in the U.S. It has been suggested that this under-utilization is due to the lack of available information about forensic palynology (Bryant and Jones, 2006). Case in point, many popular high school level texts in forensics science do not even mention pollen. This is unfortunate as forensic palynology draws together diverse disciplines from geography, computer science, biology and mathematics. Moreover, pollen is “right under our noses” and fairly easy to study with conventional light microscopy.

This activity is built upon and incorporates key parts of the NGSS <u>Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts</u> including the

following practices: asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence and obtaining, evaluating, and communicating information. Several NGSS crosscutting concepts are also implicit in this activity: understanding how patterns of forms and events guide organization and classification, explaining causal relationships and mechanisms, recognizing how changes in scale, proportion, or quantity affect outcomes, defining system boundaries and making models. Additionally, the lesson is subdivided into corresponding parts of the 5E lesson plan model (Bybee, 1997).

3.4 Background

While most people think of pollen only in terms of hay-fever allergies and human health, its story is really much more interesting. The term palynomorph includes both pollen and the spores of ferns or bryophytes, as well as any other organic-walled microfossils such as dinoflagellates and acritarchs. Forensic palynology mainly deals with the pollen and spores. In cone- and flower- producing plants, pollen carries the male sex cell from one plant to another of its same species in the process of fertilization. Recent scientific studies of pollen have resulted in major breakthroughs in our understanding of Earth's vegetation history. For example, using fossilized palynomorphs recovered from sediment cores off the coast of Antarctica, geologists have been able to reconstruct the continent's climate millions of years ago (Warny et al., 2009). Similarly, surface pollen has been used in a variety of criminal investigations ranging from drug trafficking to war crimes (Milne et al. 2004).

Pollen's usefulness for reconstructing Earth's past and its use in forensic investigations arise from its unique characteristics. First of all, pollen is small and produced in great numbers. This means pollen can be picked up by clothing, tools or other items associated with a crime and transported without a suspect's knowledge or ability to eliminate it. Because of its role in reproduction, pollen grains have evolved to protect the plant's male gametes until fertilization. As a consequence, a pollen grain has highly chemically-resistant organic outer wall called the exine that protects it from destruction. These outer walls have morphologies unique to the plant's genus, even species, and can be identified by experienced palynologists. (Figure 3.1) For example, many gymnosperms (e.g. conifers) produce pollen with bi-lateral air bladders that help during airborne transport of the pollen. Some pollen produced by angiosperms (flowering plants) has characteristic hook-like structures on the exine wall that allows it to become attached to the legs of insect pollinators. Finally, just as each geographic location has its own ecosystem and unique vegetation assembly, it also has a unique pollen profile (Adams-Groom, 2012). These profiles or "fingerprints" are typically arranged as percent distributions of the major genera or species of plants represented at a site. In fact, while we would expect pine woodlands to contain a higher percent of pine pollen than a desert area, pollen fingerprints can often be unique to very small geographic areas.

Figure 3.1. “Every contact leaves a trace.” - Edmond Locard. Forensic palynologists collect and identify pollen and spores from a variety of sources. The palynomorphs can be organized into a palynological spectrum or fingerprint that correlates to a specific site. 100x pollen photomicrographs (top to bottom) show *Abies balsamea, Pinus banksiana*, and *Quercus alba*.

Pollen profiles for many locations in the United States can be easily accessed online. NOAA’s National Climatic Data Center has archived data of pollen found in lake surface sediments in many parts of the United States. These data include pollen counts along with geospatial coordinates and other related information. The database can also be searched geographically by viewing its content in Google Earth maps. Surface pollen data (indicating current conditions) can be downloaded and processed using spreadsheet programs to create graphical representations of pollen profiles. Typically, students of forensic palynology will be interested in “P^{15}” data that show the top 15 most common pollen genera recovered at a location represented as a percent distribution of abundance. These percent distributions, in turn, can be shown in a graphical format such as a pie chart to create a visual impression of a location’s pollen fingerprint (Figure 3.2).

Pollen Analysis Lab Results

Sample ID: LG 001 Date: 8/15/13
Technician: SB

Light Microscope Raw Counts

Genus	#	%
Abies	17	
Populus	3	
Poaceae	16	
Ranunculus	2	
Artemisia	44	
Cyperaceae	5	
Ambrosia	4	
Pinus	99	
Quercus	2	
Picea	39	
Amaranthaceae	48	
Salix	1	
Cupressaceae	3	
Asteraceae	7	
Other tree	5	
Other shrub	5	
Total	300	

Notes:
Sample was processed to remove silica and other soil components, organic matter and debris. Counting was halted when a total of 300 grains were identified.

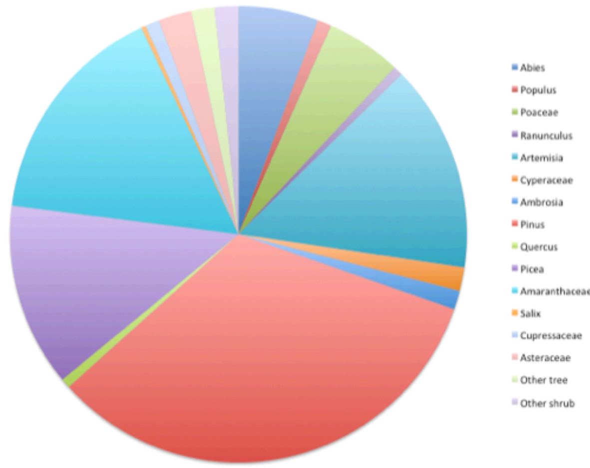

Figure 3.2. A pollen fingerprint**.** The table at the left shows a raw count distribution of pollen genera collected in a sample. The chart at the right shows the percent distribution of organic matter other than the 5-150 micrometer fraction that includes pollen. Tables and charts like these can be used to establish a link between two people items or places.

Adams-Groom (2012) describes how palynological analysis can be used in a variety of types of investigation: relating a suspect or item to a crime scene or victim, estimating the seasonality of time of death or exposure, narrowing search areas for graves or victims and tracing items to geographic source. This activity presents a simulation based on actual events wherein pollen was used in a forensic investigation in the United States. Interested teachers can access a media account of this case online at: http://usatoday30.usatoday.com/news/nation/2005-12-02-bodies-found_x.htm. In the activity, students will first review limited fictionalized circumstantial evidence including a transcript of a police interview, a credit card billing statement and a "fingerprint" of pollen found on items in the suspect's possession. Students will use these materials in conjunction with data from NOAA's fossil and surface pollen records to develop a theory of the suspect's activities, narrow the potential search area and guide investigators to a proposed crime scene.

3.5 Tools and Materials

Google Earth, Microsoft Excel or other spreadsheet program, Pollen database P15 files (http://www.ncdc.noaa.gov/paleo/pollen.html), Light microscopes, Transparent adhesive tape, Fabric swatches, 3-4 Lilies (*Lilium stargazer*)

3.6 Safety Considerations

Part 1 of this lesson utilizes "live" pollen from lilies. Teachers may want to consider minimizing exposure to pollen in the case of student allergies. This can be done by preparing the pollen slides in advance and by using photographs to illustrate the reproductive parts of the flowers.

3.7 Procedure

Engagement: To introduce the use of pollen trace evidence, teachers may obtain flowers such as lilies (*Lilium sp*.) that produce large pollen grains. Teachers should ensure that the flowers used have intact stamens since many florists remove the "messy" pollen prior to retail sale. Prior to student investigations, pollen should be dusted on an article of clothing or other artifact. Students can perform "tape lifts" of pollen by using ordinary transparent adhesive tape. Small pieces of the tape placed on slides for light microscope examination will give students the opportunity to observe some features of pollen morphology. Students can also view a short introduction to pollen and forensic palynology by viewing Jonathan Drori's TED talk available on YouTube. An introductory PowerPoint presentation by Francesca Beer is also available at Slide Share: http://www.slideshare.net/fbeer1/forensic-palynology-12819754.

Exploration: Students should review the Truth or Consequences Case Synopsis (Appendix A) and Credit Card Statement (Appendix B).

Figure 3.3. Students using credit card records to establish suspect's route on Google Earth.

Class discussion should explore how these two document fragments can be used in conjunction with Google Earth to determine a route followed by the suspect. If students are unfamiliar with the tool, teachers may want to review a few key functions of Google Earth.

For example, many students will have seen television programs that depict investigators placing pushpins on a map to geo-locate a suspect's activities. This can be done with Google Earth by selecting the "Add placemark" icon from the tool bar. Once students have placed pushpins in the map for each location related to a credit card purchase, they can turn on the "Roads" and "Borders and labels" in the layers menu the left of the window. By unchecking all other layers students can easily identify major highways and cities that match up with the pushpins. Finally, by selecting the "Add path" icon from the top menu students will be able to draw a route on the map window (figure 3.3). The location pins and the route will appear each time the user returns to Google Earth thereby saving work if the investigation is interrupted and must be completed at a later time (figure 3.4).

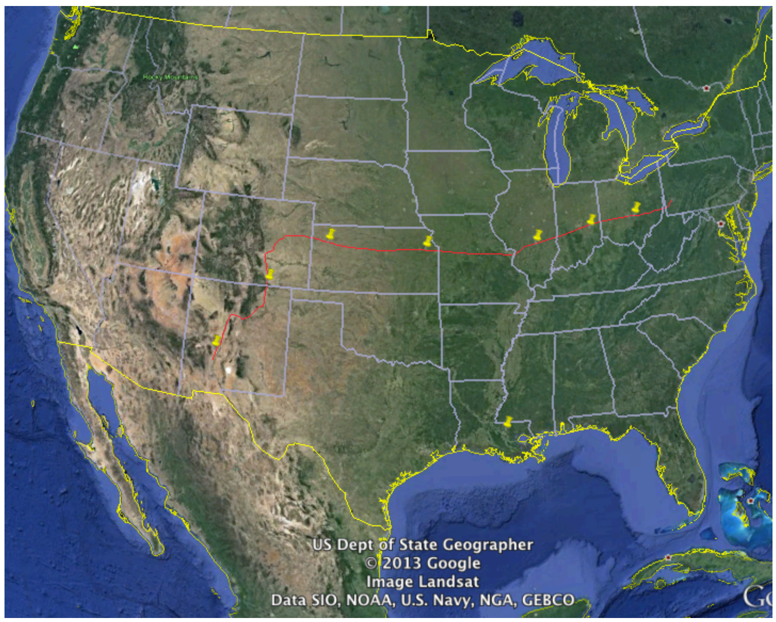

Figure 3.4. Google Earth screenshot showing place marks (yellow pushpins) and path (red line) illustrating how Google Earth tools can be employed in developing forensic investigations.

Exploration II: In this part of the activity students will use "Pollen fingerprints" from the proposed route with physical evidence recovered from the suspect to propose a route the suspect may have taken. Teachers should distribute Pollen Analysis Lab Results (Appendix C) to students. Have students determine the percent distribution of pollen genera and fill it in on the results sheet. Explain to students that these data represent a count obtained from the shovel found in the suspect's vehicle. Class discussion should include why palynologists often use percent distribution rather than raw count. Have students enter the genera and the percent distributions into an Excel spreadsheet and create a pie chart graphic of the distribution. Explain that this "fingerprint" will be compared to control samples from along the suspect's route across the country. Direct students to the NOAA "Fossil & Surface Pollen Data" page: http://www.ncdc.noaa.gov/paleo/pollen.html. Under the section entitled "Obtaining Data at the WDC" students should select the third item: "Locate and download pollen data via a Google Earth Map". This selection will open a Google Earth window that shows yellow

pushpin icons at each location with a pollen record like those used to locate the suspect's credit card purchases in Part 2. If students have created paths on Google Earth as suggested in Part 2 the path will appear in this window.

Instruct students that they can begin developing a theory of the crime by examining "P^{15}" records at each pollen record site adjacent to the route. Double clicking the icons will open a window on the map page giving the record name, investigator and coordinates. The window also contains a hyperlink labeled: "Access data". By selecting the hyperlink a new Google Earth window will open that gives expanded metadata for the record. In the upper right students should select "Open in Safari". Although the window will look the same, students will now be able to open the "P15txt" data from the download data fields.

Once the P^{15} data is opened teachers will need to take a few minutes to explain how to read the records. Following the metadata (data about the pollen record such as investigator, location, age range etc.) section at the top is a list of the 15 most common pollen types found at this location. Below this is a series of numbers in rows. The first two numbers at the extreme left represent the depth of sample and the age. In this investigation students want the most recent pollen "fingerprint" so they will always use the top entry regardless of age or depth. The indented row below this shows the percent of each type of pollen. The first record in the indented row corresponds to the first genus listed in the column at the top. The second record is for the second genus and so on.

When students find records that do not include the same plant genera, they know they can move on. When there is a similar list of plants (order may vary) they can transfer the data to a spreadsheet as they did in Part 3. Instruct students to list the species in the same order on new spreadsheets they create as they did in the original evidence spreadsheet made in Part 3. Doing so will result in pie charts that assign the same colors and order to species as the original chart and make comparison much simpler. Students should be able to then compare potential matches with the pollen fingerprint taken from the shovel (Figure 3.5).

Figure 3.5. Students creating pie charts for side by side analysis of two pollen fingerprints: one from trace evidence and one from a similar record found in the pollen database.

Evaluation: In this section students should review the interrogation transcript (Appendix D) once they have identified a region whose pollen signature is similar to the evidence. Students may want to use the "Street View" mode of Google Earth to see if they can match the suspect's description of the burial scene with images of the proposed location. Students can save files of any images, screenshots or charts of pollen fingerprints they have created to use in a short presentation of their hypothesis of the crime and their identification of potential search sites.

3.8 Results

This activity was piloted with environmental science students in a diverse urban high school setting as an extension of a unit on ecology. Students were very excited to attempt a forensics investigation and expressed surprise that it was being offered in an environmental science class. Students worked in two-person investigation teams to develop a theory of the crime and create a presentation of their findings. Almost all students had limited prior experience with Google Earth but few reported having used any of the tools or layers included in the application. The most common experiences were zooming in on familiar locations such as homes and entering the "Street view" mode. Pre-tests showed that none of the students had a clear idea of how pollen could be related to specific locations or its potential use for vegetation reconstruction or forensic investigations.

After a brief introduction to Google Earth and the materials included in the investigation packet, students used the credit card transactions handout to infer the suspect's route. Students needed reminders to initially un-check all layers in Google Earth except the "Roads" and "Borders and labels" during the routing process. It was found that if too many layers were open, the map window would be cluttered with icons and make the saved maps difficult to understand. Students progressed through this part of the activity relatively quickly and correctly with one exception. Almost half of the groups needed to be reminded to place an icon on the map at the point of the suspect's arrest instead of only at credit card locations. Most student groups chose to overlay their route on the interstate highway system based on the speed of the suspect's flight. Class discussion centered on the certainty of the route. Students correctly recognized that the route could vary from what they proposed but only by a small amount given the assumption that all transactions were actually recorded in the credit card statement. Several students linked these observations to earlier lessons about accuracy and precision. Although students had no way to calculate certainty, this activity reinforced an important concept of scientific inquiry: science is tentative and always open to new data and observations.

Students were readily able to add the surface pollen data push pins to their maps but needed help decoding the format of the "P^{15}" records of surface pollen. This was done by displaying a sample record and pointing out its key features. Students quickly identified which records of pollen were close enough to the proposed route to warrant investigation. Students were reminded that they did not need to examine all records adjacent to the route and to direct their attention to only those after the suspect stopped at the hardware store (presumably to purchase the shovel). At any rate the pollen records east of the 100th meridian have a very different distribution of species that that in the sample taken from the suspect's belongings. Occasionally students encountered problems accessing particular

pollen records from the NOAA database. In those cases the website routed students to a password protected file transfer protocol (ftp) URL. When this happened students resolved the issue changing the web address format in their browser from ftp.ncdc.noaa.gov... to http.www1.noaa.gov…..

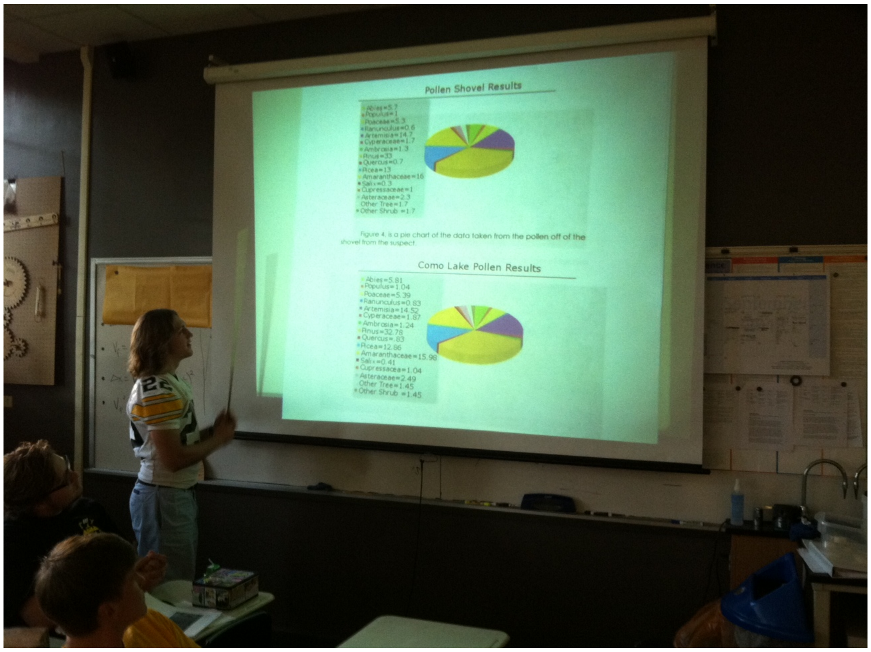

Figure 3.6. A student presents his fingerprint match and explains his theory of the case.

All groups successfully identified the sample pollen distribution as most closely matching the surface pollen record from Como Lake, Colorado. Students were able to show this match by creating pie charts of the two distributions. This effectively reduced the search region to roads southeast of Como Lake. Students needed to be reminded at this point to carefully review the interrogation transcript for further clues that could reduce the search area even further. Some groups developed a map with the search area circled by using the “Add path” as a drawing tool. Most groups used the “Street view” mode to take snapshots of locales that matched information from the transcript such as the first appearance of trees, big hills, and the pull-off area on Highway 61 (figure 3.7). These were included in the presentations along with area maps. Overall, students were able to reduce a nation search area to one a few kilometers long on a specific highway in the foothills of the Rocky Mountains!

3.9 Conclusion

Forensic science is appealing to students because of its prominence in popular media. This provides a means of generating excitement about inquiry in the classroom. Forensic palynology and forensic ecology in general can harness this excitement and focus student attention on subtle aspects of ecosystems such as the role of pollen and spores in plant propagation, the global distribution of biomes and plant succession. This activity is an excellent way for students to engage in key science practices while gaining insight into cross cutting concepts such as patterns, similarity and diversity. Forensic palynology can

also lay the groundwork for exploring disciplinary core ideas ranging from earth and space science to life science. For example, students in this class transitioned from this activity to designing investigations that used temporal rather than spatial pollen distributions to test hypotheses about plant succession following the retreat of the North American Ice Sheet at the end of the last glacial maximum. Finally, students improved their ability to use geo-spatial tools to aid in both analysis and presentation of results.

CHAPTER 4. RECONSTRUCTING THE WEST ANTARCTIC ICE SHEET AT THE LGM

This chapter is currently in preparation with *Earth Exploration Toolbook* and will appear under the name Reconstructing Ancient Ice Streams by Steven Babcock and Philip J. Bart. SB and PB conceived the activity described. SB completed the research and wrote the manuscript. PB reviewed the manuscript and suggested changes. SB is the sole author of this publication.

4.1 Description

In this activity, you will learn about how scientists study changes to Earth's climate over the last 20,000 years by searching for evidence of glacial expansion and retreat. Ice sheets have left a variety of geologic features on the Antarctic continental shelf that can be observed using bathymetric data collected by the RV/IB Nathaniel B. Palmer , the ice-breaker class polar research vessel leased by the National Science Foundation (Figure 4.1). These data hold clues about the timing and scale of glacial retreat and can be used to infer how current observed warming might impact ice-sheet mass balance. This is particularly important given the potential for economic and social disruption from sea-level changes associated with Antarctica's changing ice volume.

You will upload and use the free online web-based GIS (geographic information system) tool GeoMapApp and published data sets to search out and map geologic features generated by glacial processes in the Ross Sea. You will produce a research report of your findings modeled on peer-reviewed papers in the field of glaciology.

Figure 4.1. The RV/IB Nathaniel B. Palmer in Charlotte Bay, Antarctic Peninsula in 2005. Photo courtesy of Julia Smith Wellner.

4.2 Background

Antarctica is the most inhospitable and remote place on Earth yet it has been the focus of intensive scientific study over the last half century. Much of this research has concerned the evolution of the massive ice sheet that obscures most of the continent. The

ice sheet has a surface area of over 12 million km^2 and is the single largest control on world sea level (Vaughn, 2006). According to the National Snow and Ice Data Center, the 30 million km^3 of ice would cause a 60 m sea-level rise if completely melted. Antarctica's ice cover is divided by the Trans Antarctic Mountains into two distinct ice sheets: the land – based East Antarctic Ice Sheet and a faster moving, smaller sheet called the West Antarctic Ice Sheet (WAIS).

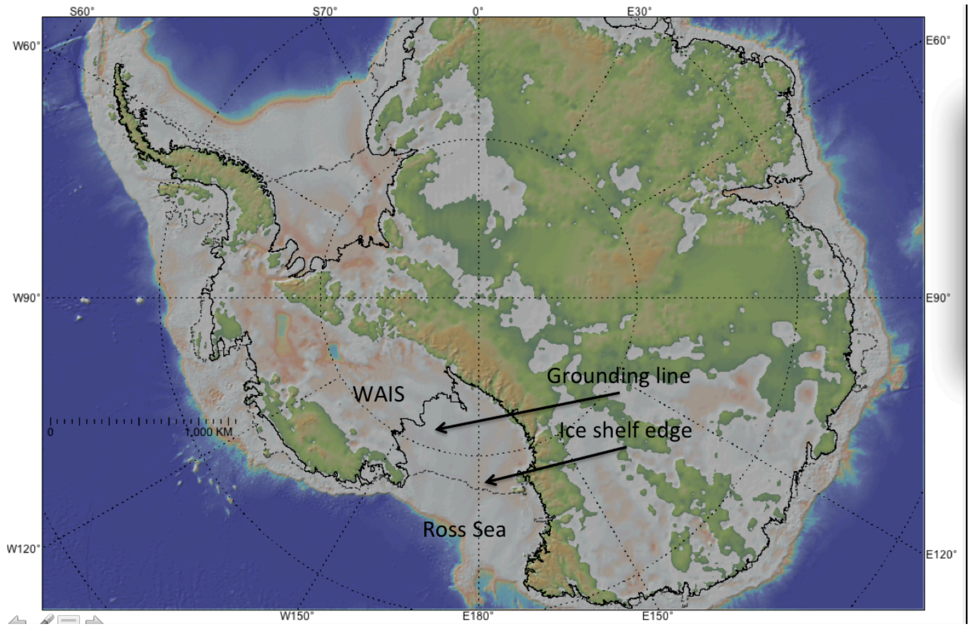

Figure 4.2. Sample output: Map showing edge of Ross Sea ice shelf and West Antarctic Ice sheet grounding line. Map was created using GeoMapApp.

The focus of the present activity is on the West Antarctic Ice Sheet. This marine based ice sheet is grounded below sea level and is less stable than the larger East Antarctic Ice Sheet because of the potential for melting by warm water below the floating ice shelves at the ice sheet's marine termination (Bart and Cone, 2011). Lythe, *et al*., 2001, estimate the WAIS contains the equivalent of 5 m of sea-level rise. This is important in light of concern about anthropogenic warming and recently observed retreat of ice sheets in Antarctica. Changes in the WAIS have the potential for economic and social disruption in low-lying coastal areas. Improving our knowledge of the behavior of the WAIS since the last glacial maximum is needed to develop models that enhance our understanding of current and future ice sheet conditions and associated potential contributions to sea-level changes.

As shown in Figure 4.2, almost half of the WAIS drains into the Ross Sea and is comprised of two major components: a floating ice shelf fringing a grounded ice sheet toward the interior. The WAIS is typically grounded to depths of more than 800 m below sea level with ice thinning to form the floating ice shelf in deep embayments seaward (Anderson, 2001). The grounding line demarks the transition from ice sheet to ice shelf. The current position of the WAIS's grounding line on the Siple Coast (Figure 4.2) runs roughly between the 150W meridian and the 160W meridian (Vaughn, 2006).

The WAIS is drained by rapidly moving ice streams (Figure 4.3) that are translated into the floating ice shelf. Ice velocities vary over the continent with a bi-modal

distribution peaking at 4-5 m yr^{-1} for East Antarctica and more than 800 m yr^{-1} for fast flowing ice streams and shelves such as those in the Ross Sea area (Rignot, 2011). Anderson *et al*. (2001) have echoed other researchers in suggesting that the potential instability of the WAIS hinges on the fact that sea-level rise can cause a landward shift of the grounding line and result in enhanced under ice melting. This may be amplified by positive feedbacks within the system such as acceleration of the ice streams and loss of equilibrium between ice accumulation and ablation that, in turn, has the potential to further raise sea level.

As it turns out, there is ample evidence that the grounding line has shifted dramatically in the past. Earth has gone through many glacial/interglacial cycles in its history. At times the configurations of sea level and ice cover have been radically different than they are today. At the time of the last glacial maximum (LGM) around 20,000 years ago, ice sheets covered vast areas of northern Europe and North America and sea level was much lower than today (Stanley, 2009). It stands to reason that the extent of grounded ice in Antarctica would have also been much greater during the LGM.

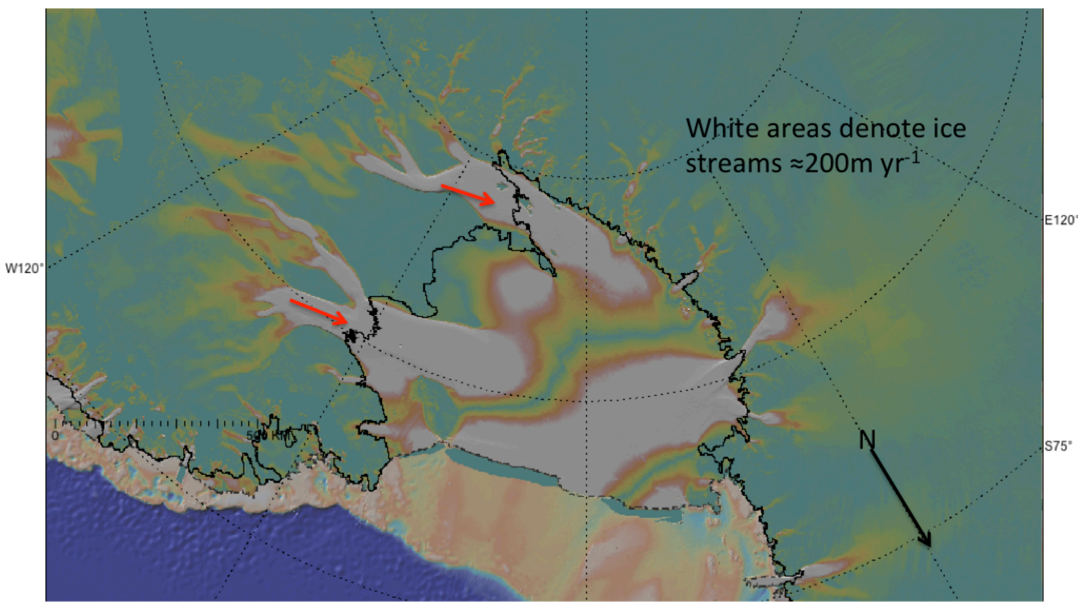

Fig. 4.3. Sample output: WAIS ice stream velocities in Ross Sea embayment. Image adapted from GeoMapApp (Rignot, 2011).

Since they were first observed in Landsat images of northern Canada almost twenty years ago, mega-scale glacial lineations (MSGL) have been hypothesized to be the result of fast-flowing paleo-ice streams associated with the retreat of the North American Ice Sheet (Clark, 1993). These geologic features are massive waveforms in the landscape running parallel to ancient ice flow. Typically MSGLs range from 8 to 70 km in length with widths of 200 m to 1300 m and spacing ranging from 300 m to 5 km (Clark, 1993). While debate continues on the exact mechanism of MSGL development, their current formation beneath the WAIS has been confirmed (King *et al*., 2009). MGSLs have also been revealed across several troughs in the Ross Sea by high-resolution multi-beam swath measurements begun

in the 1990's (Nitsche *et al.*, 2012). There is broad agreement that MGSLs are direct evidence of the extent and flow direction of grounded ice during the Last Glacial Maximum.

Grounding zone wedges (GZW) are end moraine features that occur at an ice stream's transition from grounded ice to floating ice. As basal ice comes into contact with warmer seawater and melts, sediment falls out of suspension and accumulates to form wedge shaped fans or till deltas wherever the grounding line pauses for extended periods. Along with MSGL features, GZW locations can be used to infer the maximum extent of grounded ice. More importantly, grounding zone wedges provide insight about the manner and timing of glacial retreat (Bart and Owolana, 2011). While GZWs can be revealed by bathymetric data they are best shown with seismic stratigraphy. These data clearly show a series of broad, low-relief GZWs along the axes of paleo-ice-stream troughs on the outer continental shelf (Bart and Owolana, 2011). Mosola and Anderson (2006) infer these features to represent a series of pauses and liftoff retreats of the WAIS ultimately resulting in today's configuration.

4.3 Teaching Notes

The sample map (Figure. 4.4), shown below, displays ice velocities, paleo-ice stream locations and minimum grounding line extent at the last glacial maximum.

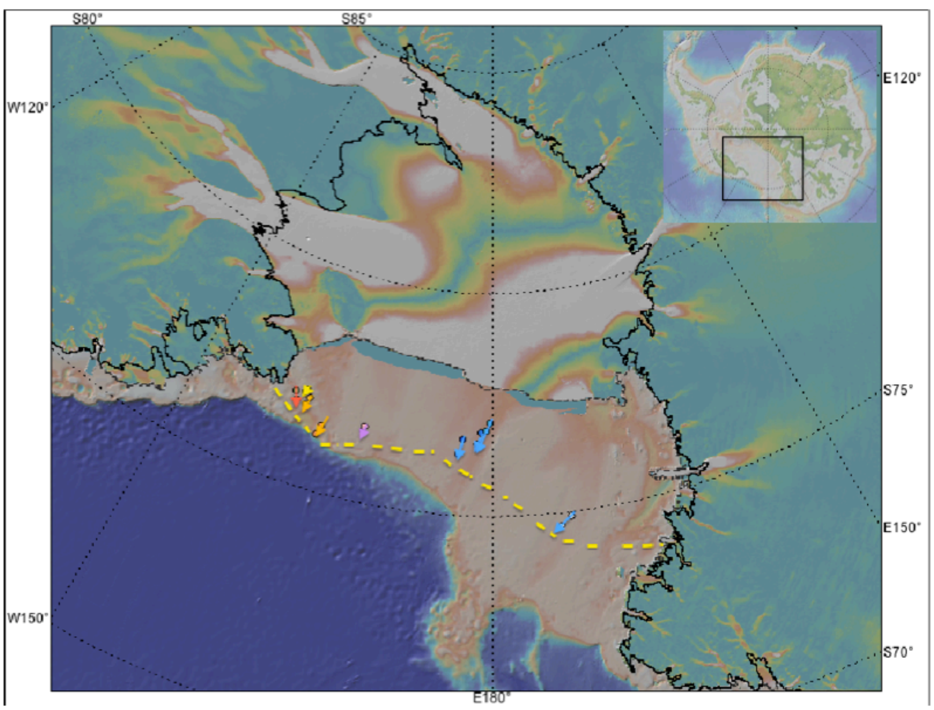

Fig. 4.4. Sample output showing current ice stream velocities (white ≥ 200myr^{-1}), current grounding line (heavy black lines), current ice shelf extent (lightly stippled black lines), paleo-grounding minimum (dashed yellow line), paleo-ice stream locations and directions (colored arrows).

This activity is suitable for students in grades 9-16 and will require three or four class periods to complete. Required materials include: internet access, report outline, step-

by-step instructions, “Seeing the Seafloor” article (available on the web at: http://oceanexplorer.noaa.gov/explorations/09bermuda/background/multibeam/multibeam.html), “Multi-beam sonar” article (available on the web at: http://www.tos.org/oceanography/archive/25-3_nitsche.pdf). The software tools required for this activity are the free web-based application called GeoMapApp and Excel or other appropriate spreadsheet program.

After completing this chapter, students will be able to:

1. Describe how multi-beam sonar works
2. Outline multi-beam sonar findings around Antarctic
3. State a rationale for study of Antarctica’s glacial history
4. Download, install and use GeoMapApp
5. Construct a variety of geospatial data visualizations
6. Compare the position of WAIS today with its position during the last glacial maximum
7. Define several key terms relevant to this study of glacial geomorphology including: Ross Sea, glacier, grounded ice, ice stream, multibeam sonar, seismic profile, glacial trough, till, moraine, grounding zone wedge (GZW), last glacial maximum (LGM), eustacy, climate change, ice sheet, ice shelf, mega-scale glacial lineations (MSGL)
8. Use evidence to defend an argument about the past history of glaciers

A good pre-assessment strategy to gauge student knowledge prior to the activity is to pose the following questions in a discussion setting or in a pen and paper instrument: How does multi-beam sonar work? What has it revealed about the seafloor? Why do scientists study past Antarctic ice sheets? What geologic formations can be used to piece together glacial history? How has the West Antarctic Ice Sheet changed in the last 20,000 years?

Upon completion of this activity, students will create a research report that shows evidence that they can: use the key vocabulary correctly, explain the physical science basis and application of multi-beam sonar, communicate the relevance of glaciology in today’s world and use data to support inferences of past glacial conditions. Students will also be assessed on the quality of geospatial imagery they produce to illustrate their findings. An outline for the report is provided with this activity. Papers can be scored using the free rubric provided at LabWrite. This activity is divided into three sections: a video and discussion introduction, a reading-based case study and a set of step-by-step instructions that will guide students in the use of GeoMapApp.

4.4 Introduction

If this is the first climate related activity of the class, teachers may want to ask students what they have heard about climate change. Ask students how scientists know about the Earth’s past climate by focusing on the most recent “ice age”. Ask students if they can think of any place that is still in an “ice age”.

Show students the video “Antarctica’s Ice on the Move” available online at Antarctica's Climate Secrets. This NET Nebraska series includes five short (7 minute) YouTube videos detailing the work of Antarctic scientists on climate change. Although the selected video doesn’t feature the collection of bathymetric data such as that used in this

activity, it does give a good overview of the difference between ice sheets and shelves along with a convincing argument on the need for continued Antarctic research. As time allows, students may wish to view other episodes and should be encouraged to cite the video in their reports.

After the video, give students an opportunity to review the material presented in the background section of this activity. This can be done either as a reading assignment or lecture/discussion format. Teachers should make sure that students gain exposure to key terms, concepts and imagery in the background.

4.5 Case Study: Seeing the Seafloor

Prior to this part of the activity, teachers should print classroom copies of each of the following two articles described in the materials section above.

Students should be divided into reading groups of four and each group should receive a different article. As they read the articles, ask them to highlight key information. As students finish reading, they should discuss with their group the important points in the article. (Teachers may want to remind students of the activity goals related to this reading.)

Each student should pair off with a member from a group who read the other article. Students should take turns explaining to each other what the main points of their respective articles.

4.6 About GeoMapApp

Before beginning the step-by-step portion of this activity, teachers should take time to familiarize themselves with GeoMapApp. This can be done by trial and error interactions with the toolbar or by utilizing the tutorials under the education menu at the top of the GeoMapApp page.

Most students have probably used geospatial tools such as Google Earth and thus will be familiar with the GeoMapApp toolbar since it has a similar layout and icons. Students may need to be reminded about latitude and longitude coordinate systems and different map projections. It is doubtful that students have ever used south polar projections such as they will use in this lesson. Care should be taken to familiarize students with the map and its cardinal directions. For example, in a polar projection of the Ross Sea region northwest will be at the bottom right of the map. It is helpful to have a globe handy to clear up confusion students may encounter.

Teachers should distribute the research paper outline and review the scoring guide with students before beginning the step-by-step instructions. Teachers may need to remind students that they already have two sources they can cite and a good start on the rationale and multi-beam sonar overview.

Teachers have the option to print and distribute the step-by-step instructions or direct students to digital copies. Complete step-by-step instructions are provided with this activity.

4.7 Teaching Resources

An annotated list of teaching resources appears in Appendix D.

4.8 Going Further

Students may want to explore other GeoMapApp climate activities such as Global Change in Local Places available online in the Earth Exploration Toolbook. This chapter uses pollen and spore data from sediment recovered off the coast of Antarctica to understand past climate conditions. It also includes a section on the LGM and its effect on vegetation distributions in North America.

4.9 Science Standards

This curriculum supports and several standards in all three areas of the Framework for K-12 Science Education: Practices, Core Ideas, and Crosscutting Concepts including:

Practices of science and engineering:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Crosscutting concepts:

1. *Patterns.* Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.
2. *Cause and effect: Mechanism and explanation*. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
3. *Scale, proportion, and quantity.* In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
4. *Systems and system models.* Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. *Energy and matter: Flows, cycles, and conservation.* Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. *Structure and function.* The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

7. *Stability and change.* For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Disciplinary Core Ideas:

ESS1.C The history of planet Earth: The rock record resulting from tectonic and other geoscience processes as well as objects from the solar system can provide evidence of Earth's early history and the relative ages of major geologic formations.
ESS2.C The roles of water in Earth's surface processes: The planet's dynamics are greatly influenced by water's unique chemical and physical properties.
ESS2.D Weather and climate: The role of radiation from the sun and its interactions with the atmosphere, ocean, and land are the foundation for the global climate system. Global climate models are used to predict future changes, including changes influenced by human behavior and natural factors.
ESS2.E Biogeology :The biosphere and Earth's other systems have many interconnections that cause a continual co-evolution of Earth's surface and life on it.
ESS3.D Global climate change: Global climate models used to predict changes continue to be improved, although discoveries about the global climate system are ongoing and continually needed.
PS4.C Information technologies and instrumentation: Large amounts of information can be stored and shipped around as a result of being digitized.

4.10 Step-by-Step Instructions

Part 1

Download and launch GeoMapApp Software by opening the GeoMapApp home page in a new window. From the Download Links panel on the left of the page, click the link for your computer's operating system. On the new Web page that comes up for your computer, scroll to the bottom of the page, read the terms of distribution, and click "AGREE" to download the software.

Figure 4.5. Screen grab of GeoMapApp home page.

When the download is complete, locate the program file on your computer (wherever your downloads are stored) and double-click the GeoMapApp icon to start the program. When GeoMapApp launches, three maps are displayed. Click on the center map and “Agree” to select the default Base Map in South Polar projection. Once GeoMapApp is running, the base map is displayed. If you prefer, you can launch GeoMapApp directly from the Internet using Java Web Start. To do this, use the "here" link on the GeoMapApp home page instead of the Download Links. Click on the question mark if you need help using Java Web Start. Take a few minutes to explore the built-in tools and the base map.

Now you will learn how to work with the GeoMapApp Toolbar and begin creating visualizations of the current configuration of the Ross Ice Shelf and the WAIS grounding line. Take a few minutes now to review the map projection you have loaded. Notice that the south pole is in the center of the map. To the upper left is South America and the southern Atlantic. In the lower right you will find Australia. It can be easy to confuse directions with this map projection. For example, both the top and the bottom of the map are north! As you work with this projection keep the big picture in mind and consider direction carefully.

Click the magnifying glass icon at the upper left of the tool bar. When this tool is selected you will be able to zoom to any area of interest by moving the mouse over a location and clicking. Go ahead and zoom in to the Ross Sea (3 clicks should be enough).

You may have noticed that Antarctica looks a bit different than you have seen on other maps. Since much of the continent is covered in ice, the actual coastline is not always visible. From the menu at the top of the GeoMapApp window choose Overlays. From the dropdown menu that appears select Coastlines and finally select Antarctic Coastline (low resolution-fast).

You should now be able to see Antarctica’s coastline on your map. Technically, not all the coastline depicted is actually as we might imagine. The line moving from south to north along the edge of the Ross Sea is actually the grounding line of the West Antarctic Ice Sheet. Although the WAIS covers most of the southern Ross Sea, the grounding line is the transition from the floating ice shelf to the ice sheet sitting on bedrock. In this investigation, you will be looking for Ross Sea floor evidence of changes in location of the grounding line.

You probably also noticed that a window called “Layer Manager” appears as you access parts of the toolbar and menu. Essentially this is a list of what overlays you are placing on your map window. You can change the transparency of the layer by moving the slider and change the order of the layers by clicking the up/down arrows on the right. You can also use your mouse to drag the layer manager to the side as you work or minimize it by clicking the yellow icon. You should not close the layer manager (red icon) as this will remove the layers from the map window.

Select the “Distance/ profile tool” icon. It is the sixth icon from the left under the menu and looks like an inverted “V” on a grid. This tool will bring up a higher resolution set of elevation data and enable you to make graphical profiles of elevation. After selecting the tool, it may take a few seconds to load. Again, notice that a new layer appears on your layer manager. Once the layer has loaded, you will also see a “Global Grids” window open. Take a few moments to review this window before proceeding. For example, notice that the histogram shows the elevations represented by different colors on the map window.

You may have wondered what happened to the grounding line. Remember you will need to move it higher on the layer manager list to place it over the new elevation data.

Click the up arrow to the right of the Antarctic Coastline layer to position it on top of the GMRT layer.

Now you will create a profile running perpendicular to the grounding line that runs along the W150 longitude. To do this simply click and drag across the line while the Distance/profile tool is selected. Once you release the mouse at the end of the transect, a graphical profile of elevation along your transect will appear. (Remember, as with all pop-up windows, you can move the profile to a convenient spot on your desktop.) Move your mouse cursor along the graph. Did you notice that the location on the graph is correlated to the location on the map window by a small icon that moves along your transect?

1. What is the elevation of the grounding line where the transect crosses? (hint: you can read this at the top of the profile window or off of the graph.)
2. What are the longitude and latitude coordinates at the start of your transect?
3. What is the vertical exaggeration of the profile?
4. Why do you think this exaggeration is done? (Hint: think back to the sonar articles.)

You can save profiles you create to folders on your desktop by selecting "Save" from the Profile menu. You will need to save profiles and map images in part 2 as you design and complete your investigation. For now, close the profile by clicking the red button on the Profile window.

From the dropdown menu under "Overlays", select "Antarctic Ice Shelf Edge". You should now be able to see the outer edge of the ice shelf extending into the Ross Sea. (Remember: The ice shelf is floating ice. The grounding line demarks the transition from floating ice to the portion of the West Antarctic Ice Sheet that is sitting on bedrock.) Take a few moments to study the image and determine the approximate latitude of the ice shelf edge?

Keep in mind that the entire ice sheet is dynamic and in constant motion. Recent research has revealed that the northward flow of the ice is not, however, uniform. In fact, several high velocity ice streams are responsible for the bulk of ice delivery from the continent to the ice shelves. Along with ice volume, these ice streams deliver glacial sediments to the continental shelf. To view ice velocity data select "Basemap" from the GeoMapApp menu. From the dropdown menus select "Regional grids>"Ice Sheet">"Ice Flow Velocities (Rignot et al. 2011)". As with the profile tool, you will notice a window open with a color key histogram to help you interpret the map.

1. What is the ice velocity range in areas shown in green?
2. What is the ice velocity range in areas shown in white?
3. Which color represents a fast flowing "ice stream"?

When you select this layer, the zoom will move back out to full extent automatically. You will need to zoom back in on the Ross Sea as before. Now, move the ice shelf edge and coastline layers back to the top of the layer manager and save a map image for your report. The image should include: coastline, ice shelf edge and illustration of ice stream velocities. As you write your report in part 2, you can use this image to illustrate the current

configuration of the West Antarctic Ice Sheet draining into the Ross Sea. Keep the GeoMapApp Window open and the layers loaded as you begin Part 2.

Part 2

In this part of the activity, you will use GeoMapApp to investigate the following problems:

1. What was the maximum extent of grounded ice during the Last Glacial Maximum?
2. What was the location and direction of paleo-ice stream flow in the Ross Sea during the LGM?
3. What is the relationship between paleo-ice streams and trough location in the Ross Sea?
4. Do paleo-ice streams align with current ice streams in the WAIS?

You will use the skills you learned in the previous section to create your own images and interpretations of data to solve these key questions. As you work, save images and make notes of the steps you take to create them. These notes and images will assist you in writing your final report. Make sure to review the outline and scoring before you begin your research.

To determine just how far grounded ice extended in the Ross Sea at the Last Glacial Maximum (≈20,000 years before present), you will use multibeam sonar data that reveals trace evidence of glacial advances. In particular, you will be searching for the geomorphic features known as mega-scale glacial lineations (MSGLs). These large features are thought to be formed under fast-flowing grounded ice. Take a moment to study the following two images in Figure 4.6.

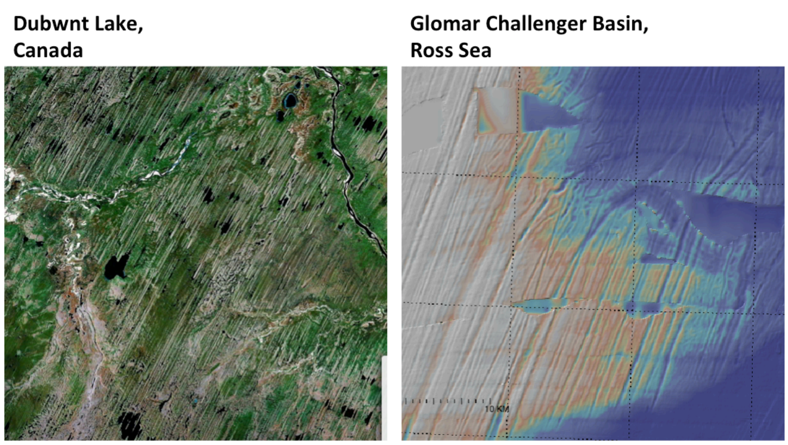

Figure 4.6. The image on the left is a Google Earth satellite image of a region in northern Canada showing MSGLs formed during the LGM when ice covered large parts of North America and Europe. The image on the right is a multi-beam composite of an area in the Ross Sea basin. Note that both images are presented at the same scale and cover approximately 50km^2. These formations are direct evidence that grounded ice moved over this section of seafloor.

As you search the Ross Sea for MSGLs be on the lookout for iceberg furrows! Make sure that you don't confuse the two. Iceberg furrows are arc-shaped gouges in the seafloor. They can often be found over running the MSGLs. This makes sense. These features are formed by large bergs that break off the leading edge of the ice shelf and have such deep drafts that ocean currents push them like ploughs over the sea floor. This can only take place after the grounded ice and the floating shelf have retreated.

To make your search for MSGLs easier, you can place a layer of multi-beam sonar transects on your map image. To do this select "Portals" from the menu at the top of your GeoMapApp screen. From the drop down menu, select "Multibeam Swath Bathymetry". Wait a few seconds for the data to load. Notice the black track lines of the multi-beam swaths. Think back to your readings on multi-beam sonar.

1. Why are so many tracks back and forth parallel transects similar to the path of a lawn mower?
2. Why do you think there are no transects in the southern parts of the Ross Sea?
3. Why do you think the swaths are concentrated on the continental shelf region north of the ice rather than far out to sea?

Select the zoom tool from the tool bar and click on an area where the tracks are very dense. These areas will have the greatest multi-beam coverage since the swaths of images made with each pass will have overlapping bathymetry data. Remember to be patient as each magnification loads. You may need to reposition your mouse as you zoom in.

As you zoom in, use the select tool from the extreme left of the toolbar (looks like a black arrow) and click on one of the lines. This will allow you to access reference information for your report by clicking the "Cruise info" button that appears to the right of the window. The page that pops up will have the number and allow you to find the dates and principal investigators of the cruise. Clicking the "Supporting Information" button under the map on the IEDA page will allow you to find the scientific publications that resulted from this expedition. You can then search these out for review and possible inclusion in your own paper's reference section.

Continue to zoom in on an area of interest to you as you search for MSGLs. Once you have zoomed in to about 128x (this number is shown in the extreme right of the toolbar just past the coordinates under the menu) you should be able to recognize MSGLs if they are present. Don't forget that you must be patient after each click of the zoom tool to ensure that the map has time to focus! You can reposition the map view by selecting the hand tool from the menu and clicking and dragging the image to center it on a set of MSGLs.

Once you have found a part of the seafloor with lineations, select the profile tool as you did in the previous section of the activity. Use the tool to drag a transect line along parallel to the lineations you have found. Notice how the start and stop coordinates of the line are shown in the pop up window with the graphical profile. Minimize all your GeoMapApp windows (do not close the program).

Open an Excel spreadsheet and name it MSGL. Label the first three columns: "MSGL #", "lon", and "lat". In the first and second cell below "MSGL#", enter 1. In the third and fourth cells below "MSGL#", enter 2 and so on through 10.

Bring your GeoMapApp window and profile back to the front. In the Profile window, you will see a longitude and latitude to the right of the button labeled “Enter Start”. These are the coordinates of the start of your transect line along the MSGL feature. Below that, you will see the coordinates of the end of your line. Copy the starting longitude by highlighting it and using your computers copy function (mac command+c, pc control+c). Paste this value (make sure you have the sign and the number) into the first cell under “lon”. This should be adjacent to the first “1” under the “MSGL#”column. Now copy and paste the latitude value and place it in the first cell under “lat”. Repeat this process by copying and pasting the “lon” and “lat” values from the end of your line in the second “1” row under “MSGL#”. Make sure to save your Excel file as you go!

Your task is to follow this procedure as you search the Ross Sea basin and collect data on the locations of MSGLs. Each time you find an area with MSGLs, use the profile tool to place a line parallel to the lineations and then take coordinate data from that line to put into your Excel worksheet. Each numbered profile line will have two entries in Excel: longitude and latitude at the start and at the end of the line you drew.

Once you have collected sufficient data on MSGL locations and entered them into Excel, you can place these locations on your map as icons. This will allow you to see the minimum extent of grounded ice during the last glacial maximum (LGM). Additionally, since each MSGL that you located has a start and stop coordinate, you will be able to show the direction they point and hence direction of paleo-ice stream flow. To begin, use the Opacity slider to make the Multibeam Swath Bathymetry layer transparent. Now zoom out until you can see the entire Ross Sea area.

Use your mouse and hold down the left click button to highlight the entire MSGL Spreadsheet. Make sure to include the column headers as they will be used in GeoMapApp. Use “Ctrl + C” or other command to copy the entire spreadsheet to you clipboard. Minimize the spreadsheet.

On your GeoMapApp screen, click on “File” in the upper left above the toolbar. Move your pointer down the menu and select “Import Table or Spreadsheet”. Choose “From Clipboard”. The spreadsheet you highlighted will now be imported automatically. Choose “Okay” to import your spreadsheet data. The next window that appears will allow you to double check that the icons you are creating on the map are in the correct place. You should ensure that “Latitude Column” is “lat” from your spreadsheet and Longitude Column is “lon” from your spreadsheet. This should be the default. Choose “Ok” at the bottom of the window. You should now see icons on the map window along with a copy of your spreadsheet attached to the bottom of the map. The spreadsheet data should show up in the window automatically. If it does not you will need to repeat the appropriate steps above and try again. (note: If you select “close” from the Tool Box at the right the entire data set will be deleted and you will have to re-import!)

To differentiate between the different MSGL start and stop points you can color-code them. Click the “Color” button on the Tool Box at the right of your GeoMapApp window. In the window that opens choose color by MSGL#. Now the starting and stopping points of the different lines you made parallel to the MSGLs are shown in different colors. You will now be able to “connect the dots” and see which points go together. Assuming your search for MSGLs was thorough, you can also visualize the extent of the former grounding line. You know that since MSGLs are created by ice in contact with the seafloor the grounding line was at least as far north as your most northerly points on the map! You

should also be able to compare the orientation of the matching color icons and determine the direction of paleo-ice stream flow and whether the continental shelf was scoured by uniform glacial process or if the effects of ice streams was concentrated in certain regions. Finally, you can begin to infer whether paleo-ice streams (as evidenced by MSGLs) correlate to the location of modern ice streams as shown in the Rignot et al. (2011) data.

Zoom to an extent that allows you to view all of your paleo-ice stream (MSGL) locations. Use the profile tool that you learned about earlier (top tool bar) to transect the Ross Sea. Make sure your line crosses the MSGL data points and is perpendicular to them. Move your cursor along the graphical profile as you did before and determine whether the paleo-ice streams of fast moving grounded ice correlate to deep troughs in the continental shelf or the shallower banks.

To save map images, select “file” above the tool bar. From the drop down menu, use your pointer to “Save Map Window as Image/Grid File”. You will be prompted to choose the file extension that you prefer and destination folder. Make sure to give your file a name that will allow you to find it later.

Take a few minutes to look back at the research paper outline. Consider the data you are now able to access and the maps, graphs and visualizations you know how to produce. Carefully select data that you can use to help you answer the research questions posed in the outline and begin assembling a draft of your paper. You have the option of manually adding annotations, text and symbols to your images or opening the images in programs such as Powerpoint, Paint or Photoshop to add to them.

CHAPTER 5. CONCLUSION

The three activities presented here can help students to better understand a wide range of topics including climate, geologic time, palynology and forensics. Students who use these materials will also develop improved spatial thinking skills through the use of GIS software such as Google Earth and GeoMapApp. Data based learning activities such as the investigations presented in this thesis allow students to participate in science as science is actually done: looking for patterns and trends and making explanations supported by data. All three chapters presented have been successfully implemented in the secondary settings over the last three years. Students have been engaged and energized by the curricula and pre-test post-test learning gains have shown that the materials improve understanding of key science standards.

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APPENDIX

Appendix A: Request of permission to use published materials:

2/28/2013
Dr. Wellner,

I am a student of Dr Sophie Warny here at LSU and I am in the final stages of publication of a chapter for inclusion in The Earth Exploration Toolbook. My chapter is a set of activities that use the online GIS tool GeoMapApp and published palynological data to help students understand paleoclimate. Since most the data used in the chapter were obtained from cores recovered by the Nathaniel B Palmer, your image of the rig in Charlotte Bay would be a great addition to the chapter. The photo is beautiful and will inspire students while giving them context. Of course you will be credited if you allow use of the image. What I need for my editor is a written permission including your name and contact info, a short description of the image and a jpeg copy.

I am attaching the pdf Dr. Warny sent me if you are not sure which image I am thinking of. I have my fingers crossed! Please let me know if you have any questions.

Cheers
Steve Babcock

Response:

UNIVERSITY *of* HOUSTON
Department of Earth and Atmospheric Sciences

312 Science & Research Bldg. 1
Houston, TX 77204-5007
http://www.geosc.uh.edu

713.743.3399
Fax 713.748.7906

Mr. Steve Babcock
Department of Geology and Geophysics
Louisiana State University
E235 Howe-Russell building
Baton Rouge, La 70803
USA

March 1, 2013

Dear Mr. Babcock,

Congratulations on your Earth Exploration Toolbook chapter. I am delighted to share permission to publish the photo below showing: the RV/IB *Nathaniel B. Palmer* in Charlotte Bay, Antarctic Peninsula in 2005. Photo by Julia Smith Wellner.

Please let me know if you have any questions.

Sincerely,

Julia Wellner
jwellner@uh.edu
713-893-1273

Request of permission to use Forensic Palynology as Classroom Inquiry chapter published in *Science Activities*:

Monday 14 July 2014

Dear Mr. Swanson,

First of all thank you for the taking the time to guide this article to publication. You and your reviewers made this work stronger and more useful to teachers. I appreciate this opportunity and hope we can work together again.

I am preparing a Master of Natural Science thesis document at Louisiana State University and I would like to use this publication (Forensic Palynology as Classroom Inquiry) as one of my chapters. As part of the defense process, the thesis will be viewable on the web after acceptance by the graduate school at LSU. I am requesting permission to use this material as part of my thesis and that you grant written permission that I may do so. Please contact me if you have any further questions.

Sincerely,

Steven Babcock
(225) 8120-9313
sbabcock@lsu.edu

Response:

July 14, 2014

Dear Mr. Babcock,

Thank you for the message. Posting the article as part of your thesis chapter falls within the schedule of rights you retain as an author. You are permitted to use the article in this fashion.

Yours truly,

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Appendix B

Selected Screenshots of Published Material

Earth Exploration Toolbook
Step-by-Step Guides for Investigating Earth System Data

Home »

Earth Exploration Toolbook
All EET Chapters
Global Change in Local Places
Teaching Notes
Case Study
Step-by-Step Instructions
Tools and Data
Going Further

Global Change in Local Places

Steven Babcock, Louisiana State University Laboratory School, sbabcock@lsu.edu
Sophie Warny, Louisiana State University
Frank Nitsche, Lamont-Doherty Earth Observatory

Published: May 2013

Description

In this chapter, you will learn more about how scientists study Earth's past climate using sediment cores and fossilized pollen. Organic-walled material, such as pollen, has been recovered by the National Science Foundation's polar research vessel, the Nathaniel B. Palmer, as part of the shallow drilling (SHALDRIL) effort. This drilling effort took place near the Antarctic Peninsula. The fossilized pollen in the core can be correlated to the age of sediments in which it is located, giving scientists information about past climates.

You will upload core data from the recent SHALDRIL expedition to Antarctica into GeoMapApp and investigate Antarctica's past climate and species distribution. In particular, you will use the pollen data recovered from the cores to show the decline in plant life that began during the geologic time period known as the Eocene. You will relate the Antarctica's past plant assemblages to modern vegetation distribution and produce computer-generated visualizations to communicate your findings.

This artist's rendition created from a photograph of Antarctica shows what Antarctica possibly looked like during the middle Miocene epoch, based on pollen fossil data. Photo courtesy of NASA/Dr. Philip Bart, LSU.

http://serc.carleton.edu/eet/shaldril/index.html

Earth Exploration Toolbook
Step-by-Step Guides for Investigating Earth System Data

Home »

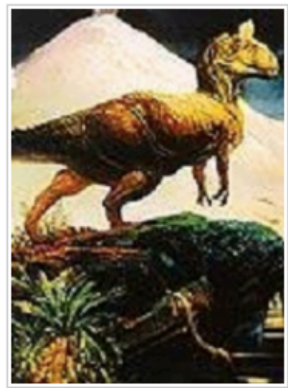
- Global Change in Local Places
- Teaching Notes
- Case Study
- Step-by-Step Instructions
- Tools and Data
- Going Further

Case Study: Antarctica's Past

A Lost World

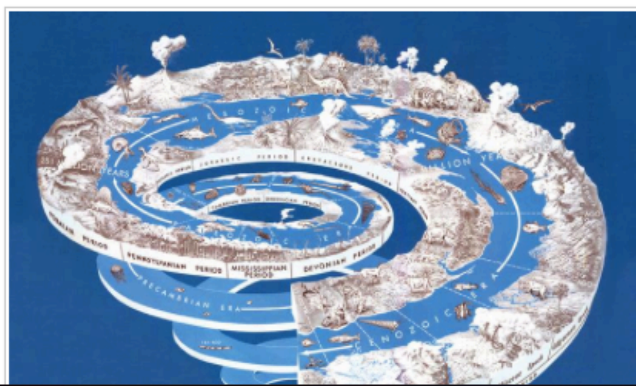
> 'The ice covered Antarctic continent, bathed by seas of uniform coldness, is in the grip of the polar anticyclone. High winds blow from the land and repel any warming influence that might seek to penetrate it. The mean temperature of this bitter world is never above the freezing point. On exposed rocks the lichens grow, covering the barrenness of cliffs with their gray or orange growths and here and there over the snow is the red dust of the hardier algae. Mosses hide in the valleys and crevices less exposed to the winds, but of the higher plants only a few impoverished strands of grasses have managed to invade this land. There are no land mammals; the fauna of the Antarctic continent consists only of birds, wingless mosquitoes, a few flies, and microscopic mites.'
> - Rachel Carson, The Sea Around Us

In 1994, two researchers from Augustana College made a strange discovery in the mountains of Antarctica. While excavating a siltstone formation 650 km from the South Pole, William Hammer and William Hickerson uncovered the skull and bones of a large carnivorous dinosaur. Found alongside the gnawed ends of the bones were the teeth of other smaller scavenging dinosaurs and fossilized tree trunks. What could explain the presence of these plants and animals in a location that today is so cold and lifeless? It seems obvious that Antarctica's climate must have been quite different during Jurassic when the organisms were alive. But how do scientists fill in all the gaps and piece together Earth's climate history?



Artist's reconstruction of Crylophosaurus whose fossilized remains were recovered in Antarctica. Image courtesy of William Stout

Earth's history is a long story going back 4.6 billion years. So great, in fact, are the lengths of time that the current geologic era we live in (the Cenozoic) stretches all the way back to the extinction of the dinosaurs 65 million years ago. But if we took our era and compared it to all of Earth's history, the Cenozoic would represent less than 2% of total time! To help you visualize the long spiral of geologic time consider the image pictured below.



http://serc.carleton.edu/eet/shaldril/case_study.html

Appendix C. Student Handouts (Forensic Palynology)

Student Handout: A Truth Or Consequences Case Synopsis

On the evening of Friday 6/21/2013, Maria Garvitz called the Pittsburg PA Police Department to report that her estranged husband Lenny Garvitz had abducted their young son. Ms. Garvitz reported that they had been fighting about how she was raising the boy. She told investigators that she had reason to believe he was taking the boy to Mexico where he has family. She also reported that Mr. Garvitz was violent and unstable due to his addiction to several drugs and alcohol. A national alert was activated in the search for Garvitz and the boy.

Following a traffic stop on the morning of 6/24/2013 in Truth or Consequences, NM, Garvitz was arrested by New Mexico State Police. The boy was not with Garvitz at the time of his arrest. During questioning Garvitz indicated that his son had been killed in an accident and buried at some point during his flight from the Pittsburg area. Garvitz was unable or unwilling to shed light on the location of the child's body (see "Interrogation Transcript").

Forensic evidence was collected from the trunk of Garvitz's vehicle including: blood, soil and pollen. The soil and pollen were recovered and processed by forensic investigators. Over half a dozen types of pollen were recovered from the shovel found in Garvitz's trunk (see appendix item 2: "Pollen Analysis"). Investigators obtained a subpoena for Garvitz's credit card activity between 6/21/2013 and 6/24/2013(see appendix item 3: "Credit Card Statement).

Unfortunately, Garvitz committed suicide in his cell in Truth or Consequences before giving any other information that could help resolve his son's disappearance.

Your task in this investigation is to use the limited information at your disposal to assist volunteers in pinpointing search sites for the child's remains. To develop your theory about Garvitz's actions between the 21st and the 24th you have several tools at your disposal:

1. Google Earth or other maps can be used along with the credit card information to infer Garvitz's route. Be sure to save screen shots of your maps for you report.
2. NOAA's National Climate Data Center maintains the Fossil and Surface Pollen Database that will allow you to compare the % abundance of the pollen material recovered from the suspect's car to those found along his route: http://www.ncdc.noaa.gov/paleo/pollen.html. Remember to always use the " P^{15}" data as it will give you the percent distribution of the 15 most common types of pollen for each site. This format will allow you to compare potential sites to the pollen recovered from the suspect's shovel. By quickly looking for sites that have a plant list matching the shovel you can toss out most of the pollen records. Once you locate a site with a plant match, put the % distributions of both the shovel pollen and the site in a pie chart format to see if you have a

"pollen fingerprint" match. You should save these graphs and tables for your report.

3. Once the search area is restricted to a specific region, Google Earth Street View mode can be used in conjunction with the interrogation transcript to pinpoint a search site.

When you have identified a potential search site prepare a short illustrated outline or Power Point of your methodology and findings for the search volunteers.

Student Handout: B: Credit Card Statement

Credit Card Statement **USA Corp.**

Send payment to:

PO Box 555

Anytown, USA 00000

Account Number	**Name**	**Statement Date**	**Payment Date Due**
1234 567 8901	Lenny Garvitz	7/15/13	8/15/13
Credit Line	**Credit Available**	**New Balance**	**Minimum Payment**
$2500.00	$500.00	$2000.00	$30.00

Reference	Sold	Posted	Activity	Amount
89XB456	6/21	6/23	Gas-N-Git Pittsburg, PA	44.12
78XB234	6/21	6/23	Handy Hardware Columbus, OH	17.15
23XB334	6/21	6/25	Hiway One Stop Columbus, OH	42.12
34XB234	6/22	6/26	Gas-n-Go Terra Haute, IN	28.16
23XY489	6/22	6/26	Fuel Man East St. Louis, MO	32.00
22XY234	6/22	6/26	Gas Can Kansas City, MO	41.44
34XZ217	6/22	6/26	Sleep Well Motel Kansas City, MO	108.99
34XB376	6/23	6/27	Salina Oil Company Salina, KS	39.19
23XB111	6/23	6/27	One Stop Burlington, CO	44.44
34XY375	6/23	6/27	The Dive Pueblo, CO	37.15
29XZ123	6/23	6/27	Fuel Man Sante Fe, NM	40.68

Previous Balance	**(+) 1524.56**	**Current Amount Due**	**2000.00**
Purchases	**(+) 475.44**	**Amount Past Due**	
Cash Advances	**(+)**		

Payments	**(+)**		**Minimum Payment Due**	**30.00**
Credits	**(+)**			
Finance Charges	**(+)**			
Late Charges	**(+)**			
New Balance	**(=) 2000.00**			
Finance Charge Summary	**Purchases**	**Advances**	For Customer Service	
Periodic Rate	3%	3%	1-800-123-4567	
APR	36%	36%	For Lost or Stolen Card	
			1-888-234-5678	

Student Handout: C: Interrogation Transcript Excerpt

BA: What happened after you fought with your wife?

Garvitz: You know what happened. I already told you. I didn't mean for it to happen she was trying to take my kid from me.

BA: Is that when you decided to kill him?

Garvitz: I told you it was an accident! He tried to jump out of the car! I loved him more than anything.

BA: So you drove to a hardware store and bought a shovel and hid the body.

Garvitz: I told you… I panicked and I knew she would blame me. She knew I was using again.

BA: Listen, you need to tell us where he is buried.

Garvitz: I told you all I remember is that it was on road 160.

BA: That's not much help. When did you bury him?

Garvitz: I don't know. After I bought the shovel and stuff. I mean I drove around with him in the car. It was an accident. I swear it was an accident.

BA: What else do you remember?

Garvitz: There was a big hill. I was trying to get off the interstate and got lost. It was night but I remember all of a sudden there were these trees and it was cool. It was dark.

BA: What else? Tell me more about the spot where you stopped.

Garvitz: It was at the bottom of a hill. I remember because I pulled over in a special lane. They had big trucks coming up slow and loud.

BA: Did they see you?

Garvitz: No I was pulled over in a lane for putting on tire chains. I was on the other side of a guardrail. I put him there in the tarp behind the trees. You have to believe me it was an accident! I swear that's all I can remember.

Student Handout: D: Pollen Analysis Lab Results

Sample ID: LG 001 Date: 8/15/14

Technician: SB

Light Microscope Raw Counts: Calculate the % distribution prior to constructing your graph. You can create your graphs manually or using a spreadsheet program.

Genus	#	%
Abies	17	
Populus	3	
Poaceae	16	
Ranunculus	2	
Artemisia	44	
Cyperaceae	5	
Ambrosia	4	
Pinus	99	
Quercus	2	
Picea	39	
Amaranthaceae	48	
Salix	1	
Cupressaceae	3	
Asteraceae	7	
Other tree	5	
Other shrub	5	
Total	300	

Notes:

Sample was processed to remove silica and other soil components, organic matter (other than that between 5-150 microns) and debris. Counting was halted when a total of 300 grains were identified.

Appendix D: Teaching Resources (Reconstructing the West Antarctic Ice Sheet)

Websites:

http://www.antarcticglaciers.org/west-antarctic-ice-sheet/

- AntarcticGlaciers.org provides a web-based introduction to key concepts in Antarctic glaciology. These are explored in Science Themes, and include descriptions of different types of glacier, ice shelves, and ice streams. This website also explores the recent rapid environmental changes happening today in Antarctica, and how changes in atmospheric and ocean temperatures has led to ice-shelf collapse, rapid glacier recession and sea level rise.

http://www.youtube.com/playlist?list=PL6C40C24E00E1B58B

- Antarctica's Climate Secrets video series.

http://www.ncsu.edu/labwrite/instructors/gradinglwr.htm

- LabWrite Excel grading rubric for lab reports.

Research Paper Outline:

Reconstructing ice stream flow patterns and the maximum extent of the West Antarctic Ice Sheet during the Last Glacial Maximum Writing Guidelines:

- Problem statement and rationale for study of Antarctica's glacial history. Problems to consider include:
    - What was the maximum extent of grounded ice during the Last Glacial Maximum?
    - What was the location and direction of paleo-ice stream flow in the Ross Sea during the LGM?
    - What is the relationship between paleo-ice streams and trough location in the Ross Sea?
    - Do paleo-ice streams align with current ice streams in the WAIS?
- A brief overview of swath multi-beam sonar and sea floor imaging techniques.
- Student-created map figure of Antarctica including labels showing the current configuration of the Ross Ice Shelf and the WAIS grounding line.
- Methods section describing tools and data set used.
- Student-created map figure showing location and direction of paleo-ice streams and inferred grounding line at LGM.
- Strike oriented profile figure showing relationship between bathymetric troughs and megascale glacial lineations on outer shelf.
- Conclusion and discussion section that presents major findings, limitations and sources of error.
- Correctly formatted reference section with at least four citations.

Papers can be scored using the free online rubric provided at LabWrite.

VITA

Steven Babcock teaches environmental science and physics at Louisiana State University Laboratory School in Baton Rouge. He graduated BA from LSU in 1989 and was conferred a Masters of Education at Portland State University in 1994.