Chapter 16

Paleoecology as a Classroom Tool to Address Global Climate Change

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Contents

Introduction

This laboratory exercise was designed to provide students with an understanding of 1) past climate change and causes of climate change, 2) ecosystem responses to climate change, 3) how paleoecologists utilize fossil pollen to determine past vegetation and climate changes, 5) how paleoecology is practiced through a hands-on exercise utilizing fossil pollen assemblages. This exercise was first designed for a non-majors class that met for 3 hours for combined lecture and lab. It can easily be adapted for most labs but does require 3 hours to complete if the lecture material is presented during the lab period. While this exercise is based on a lake core from Idaho (Beiswenger, 1991), the exercise could be changed to focus on a local site of interest. To do so, we suggest contacting a paleoecologist near you and/or examining the paleoecological literature to find a study with a local record that can be simulated. While this study focuses primarily on climate change over thousands of years, one could design a similar exercise to examine successional changes using pollen or examine fire frequencies using charcoal in addition to pollen. This exercise requires a substantial amount of time to prepare initially. However, the exercise can be repeated on many occasions with little further preparation.

Notes for the Instructor

A substantial amount of background information is required for this lab and should be presented to the students either during the lab period or during a lecture section prior to the lab. By presenting the background information during a prior lecture period, the lab could be completed during a 2 hour period. We provide the necessary background information below for the lecture portion of the lab exercise, and also provide additional references for more information on the topics presented. We have also designed a web page which includes pictures shown during the lab to depict lake coring, pollen types, vegetation types, and pollen preparation.

(www.uwyo.edu/Botany/Qpel/Ablephotos.htm) We encourage you to utilize this page when taking your students through this lab.

Milankovitch Theory

We know that climate has changed in the recent past based upon several lines of evidence. Glacial striations on bedrock, glacial till, and shrinking extant glaciers attest to a much colder climate of the ice ages, or Pleistocene period, which lasted from 2 million years ago until nearly 10,000 years ago. Several theories have been put forth to explain the causes of glacial times, but one is most commonly preferred. This is known as the Milankovitch Theory (Milankovitch, 1930), which describes changes in the earth's orbital parameters (Figure 16.1).

Three primary changes with respect to the earth's orbit can affect the amount and distribution of the sun's radiation reaching the earth. The first cycle, known as the “obliquity of the ecliptic”, has a cycle length of 90,000 to 100,000 years. It is the change in the shape of the earth’s orbit around the sun, from a nearly circular path to a more elliptical one. When a circular orbit occurs, the earth is equidistant from the sun throughout the year, providing a constant, year-round radiation input; with an elliptical orbit, the earth is closer to the sun at some times of the year than others, creating a potential increase in the difference between the seasons. The second orbital cycle, “eccentricity”, is a change in the tilt of the earth, varying between 21.8^{o} and 24.4^{o}, which occurs over a 40,000 year cycle. Because the tilt of the earth causes the seasons, a more pronounced tilt causes a sharper contrast between the seasons, while a more vertical tilt leads to less difference between summer and winter. Presently, the tilt of the earth is 23.4^{o}, roughly half way between the two extremes. The third cycle is known as the “precession of the equinoxes” and occurs over 21,000 years. Because of this cycle, the season at which the earth is closest to the sun (the perihelion) gradually changes; roughly one day later each 60 to 70 years. Currently, the earth’s perihelion occurs during the northern hemisphere winter, while 9,000 years ago the perihelion occurred during the northern hemisphere summer. Summer and winter showed more contrast in the northern hemisphere 9000 years ago because the earth was getting more radiation during the summer and less during the winter. It is the interaction of these cycles through time that is proposed to have caused the glacial and interglacial cycles of the ice ages. For another explanation of these parameters, see Gribbin (1979).

Other Causes of Climate Change

While changes in the earth's orbital parameters are the most widely accepted cause of the ice ages, other potential causes of climate change exist which merit brief discussion. Increases (or decreases) in greenhouse gases, such as carbon dioxide, is likely a familiar topic to most students (the greenhouse effect). The sun transmits shortwave (0.3 – 3.0 µm) radiation to the earth. This is absorbed by the earth and is re-radiated back to space in the form of heat as longwave radiation (>4.0 µm with a peak at 10 µm). It is thought that an increase in greenhouse gases will trap more of the heat the earth re-radiates, thereby increasing global temperatures. Alternatively, a decrease in greenhouse gases could lower global temperatures, as lower atmospheric CO_2 concentration estimates have been obtained from ice cores for the last glacial maximum (Neftel et al., 1982; Barnola et al., 1987). Volcanic eruptions are also capable of altering climate, but on a much shorter time scale. Eruptions discharge large quantities of fine particles high into the atmosphere which can block out the shortwave radiation emitted by the sun, thereby cooling the earth. Recent volcanic eruptions provide evidence of the magnitude of their effect on global temperatures. The eruptions of Tambora (1815), Krakatau (1883), Agung (1963), and Pinatubo (1991) resulted in hemispheric and global temperature decreases of 0.2^{o} to 0.5^{o}C for 1 to 5 years following the eruption (Self et al., 1981; Rampino and Self, 1982;

Bassett and Lin, 1993). Some regions even experienced temperature decreases of 2.7°C (Rampino and Self, 1982). Empirical estimates of global temperatures during the last glacial maximum (18,000 to 21,000 years ago) range from 3° to 11°C colder than today (in Wright et al., 1993). While volcanic eruptions result in a smaller change in global temperatures, the global effect from such a point source is impressive.

Ecosystem Response to Climate Change

Once the causes of climate change have been addressed, our students are asked to speculate about ways in which the organisms within an area might react if the climate of that area changes. Three main possibilities are likely to be presented. 1) A population may not be able to cope with the change and die out, becoming locally or more regionally extinct. 2) The population may move to another area. This is more easily done for mobile animals than sessile plants. Plant movement is accomplished through population migration using seed dispersal as the means of movement. Such migration takes many generations for plants to move effectively to a new area. 3) A species may also become adapted to the altered environment. As the climate changes, some individuals in the population may posses certain characteristics that enable them to survive better in the new environment. Such individuals will be more likely to survive and successfully reproduce, thus passing on the beneficial characteristics to their offspring.

Paleoecology

Paleoecologists try to determine how communities have changed through time from which they can interpret how the climate of an area has changed over that time period. To do so, they examine fossils, or preserved parts of once living organisms. These fossil records can be found in lakes, bogs, and packrat middens and they can include bones, teeth, insects, pollen, seeds, leaves, and chemicals. Paleoecologists who examine fossil pollen are called palynologists. Changes in the plant population of an area can be inferred from changes in the pollen percentages from different species through time. Fossil pollen is most commonly obtained from lake sediments. As time passes, a lake is continually filling with sediments. Pollen that is deposited on a lake is incorporated and preserved within those sediments. If left undisturbed, the sediments act as a timetable with the oldest sediments at the bottom and the youngest at the top.

Sediment cores are taken from a lake in such a way that a continuous lake record is obtained. The sediment is processed to eliminate everything except pollen, which is made of a highly resistant substance. The pollen is identified from different sections of the core and used to determine how the vegetation of the area has changed. Based upon the ecological requirements of the species represented in the core, the climate change of the area can be reconstructed. Knowledge of how vegetation has responded to past climate changes can allow us to predict how vegetation might respond to future climate changes.

Materials

2-3 pollen slides of each represented time period
1 compound microscope for every 2 students
1 calculator for every 2 students
Kodachrome slides of pollen types, plant types, and vegetation types (optional)
Kodachrome slide of coring and pollen processing in progress (optional)

Student Outline

Questions to be Considered

1. What causes long-term changes in global climate?

2. Why do ecologists study past climates?
3. How has the earth's climate changed over the past 2 million years?
4. How do we know it has changed?
5. How have the earth's ecosystems responded to changes in climate?
6. How do scientists detect long-term changes in plant and animal communities?

Long-term Climate Change

If you live in the Rocky Mountains you know how quickly and frequently the weather can change. Climate can change too, but it is much slower and less frequent. Perhaps you have heard of the "ice age", or "Pleistocene". From about two million years ago until nearly 10,000 years ago, the earth experienced alternating glacial and interglacial episodes. During glacial times, much of the earth's land mass was covered with ice. In the Rockies, this ice sculptured today's jagged peaks and scoured depressions presently occupied by lakes and rivers. Glacial scratches, or striations, can be seen in the Medicine Bow Mountains west of Laramie, WY, and in many other mountain locations in the western part of the United States. Glacial periods were about ten times longer in duration than interglacials, so, with respect to the recent history of the earth, we are living in atypically warm times.

Past Climates – Causal Factors

The cause of glacial and interglacial cycles is not completely understood. One theory (Milankovitch, 1930) attributes much of the responsibility to the orbital parameters of the earth (Figure 16.1). Three parameters change with periodicities within the timespan of glacial to interglacial oscillations (100,000-10,000 years). The shape of the earth's orbit around the sun changes from elliptical to nearly circular, the degree of tilt of the earth's axis changes, and the time when the earth is closest to the sun changes in relation to whether the earth is tilted towards or away from the sun. These changes alter the amount of incoming solar radiation and the timing with which it is received on the earth's surface. Seasonal differences as well as yearly temperatures change as a result of the interaction of these three factors.

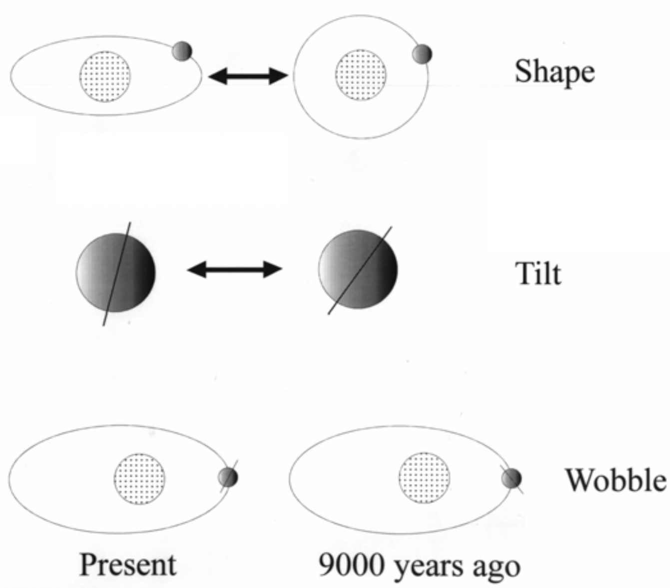

Figure 16.1. Orbital parameters of the earth; astronomical causes of long-term climate change.

Use the space below to describe the changes illustrated above:

shape

tilt

wobble

Other Causes of Climate Change *(students fill in)*

Using information about past climates *(students fill in)*

Ecosystem response to climate change

When the climate of an area changes, the organisms that inhabit the area react to the change in various ways.

List some ways in which organisms might react to a climate change.

Detecting changes in communities

Paleoecologists use fossil data to tell them how communities have changed through time.

What kinds of fossils do you think they use?

Where do they find the fossils and how do they collect them?

How do they prepare the fossils for examination?

What do they do with the fossils when they are ready?

Crane Lake Exercise

You will look at slides with five different types of pollen grains. The slides simulate a site in southeastern Idaho that records vegetation changes from approximately 60,000 years ago to the present time (Beiswenger, 1991). We will call our simulated site "Crane Lake".

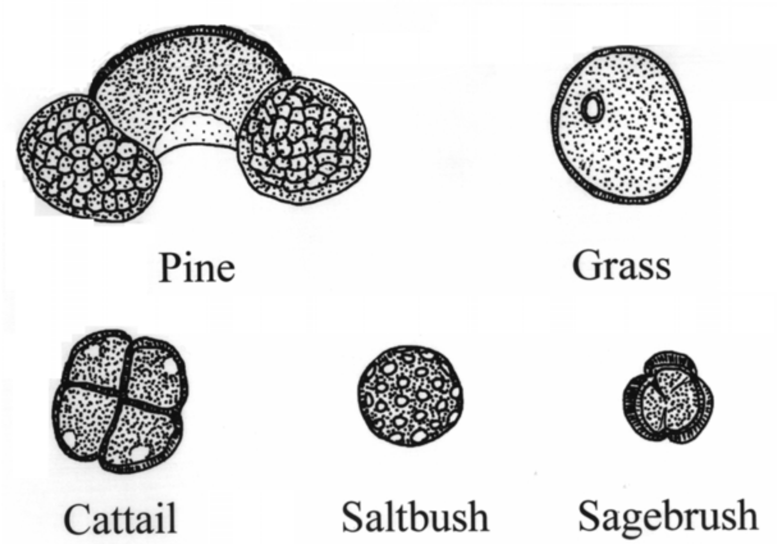

Figure 16.2. The sizes of the grains shown are roughly in the correct proportions to one another. The grains differ as described below.

pine: Conifer pollen grains resemble Mickey Mouse hats because of their air-filled bladders. The bladders facilitate dispersal. Some species have grains that are somewhat larger or smaller than the one illustrated.

grass: Grass pollen grains are distinguished by a large pore that is bordered by a thickened ring.

cattail: One of the most common species of cattail has pollen in groups of four grains (called a tetrad). Other species have single grains. Whether single or in tetrads, all cattail pollen grains have one pore that is not surrounded by any type of ridge.

sagebrush: Sagebrush pollen grains have three slits (or colpi) and a very thick wall. Often, the layers in the wall separate, making the wall appear even thicker.

saltbush: These grains look like tiny golf balls. Their surface is covered with several to many pores.

Counting Pollen

You and one or two partners will be assigned a pollen slide. Record its number and age below. Focus the slide under the 4X objective, then under 10X. Count and record (in the chart below) the number of each type of pollen that you see in the field of view. Move to another field and repeat the process. Continue until you have counted five fields. Now, have your partner count five fields. If there are three of you, each of you should count four fields. Total the numbers of each type and determine the percentages of each pollen type.

Sample # ____________

Age of sample as indicated on the slide _____________

Record your team pollen data in Table 16.1.

Table 16.1. Team pollen data.

Pollen type	**Number of Grains Counted**	**Type Total**
Pine		
Sagebrush		
Saltbush		
Grass		
Cattail	**Pollen Total** (count at least 150 grains)	

Record the class pollen totals in Table 16.2.

Table 16.2. Class pollen totals.

Pollen type	**# Pine**	**# Sagebrush**	**# Saltbush**	**# Grass**	**# Cattail**	**Sample Total**
Sample 1 Present						
Sample 2 4,000						
Sample 3 8,000						
Sample 4 12,000						
Sample 5 25,000						
Sample 6 40,000						

Record the average pollen percentages for the class data in Table 16.3.

Table 16.3. Average class pollen percentages.

Pollen type	Pine	Sagebrush	Saltbush	Grass	Cattail
Sample 1 Present					
Sample 2 4,000					
Sample 3 8,000					
Sample 4 12,000					
Sample 5 25,000					
Sample 6 40,000					

Diagram the class percentages of the 5 pollen types on Figure 16.4. The diagrams of Pine and Sagebrush below show how these should look (Figure 16.3). The vertical axis is time (in this case 40,000 years ago [at the bottom] to the present [at the top]) and the separate horizontal axes are percentages. Each sample number of the class data is a different age. 1 = present, 2 = 4,000, 3 = 8,000, 4 = 12,000, 5 = 25,000, and 6 = 40,000 years ago.

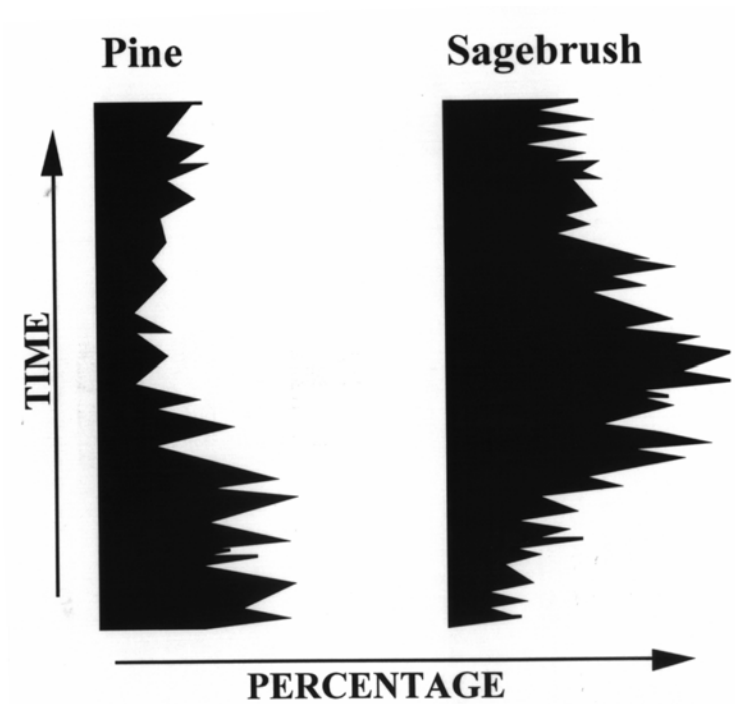

Figure 16.3. Example of pollen percentage diagram.

Ecological information about the species you have been investigating appears on the page following the space for your pollen diagram. This information pertains to the Rocky Mountain Region of North America. Use it to help you interpret the pollen diagram you draw from the class data.

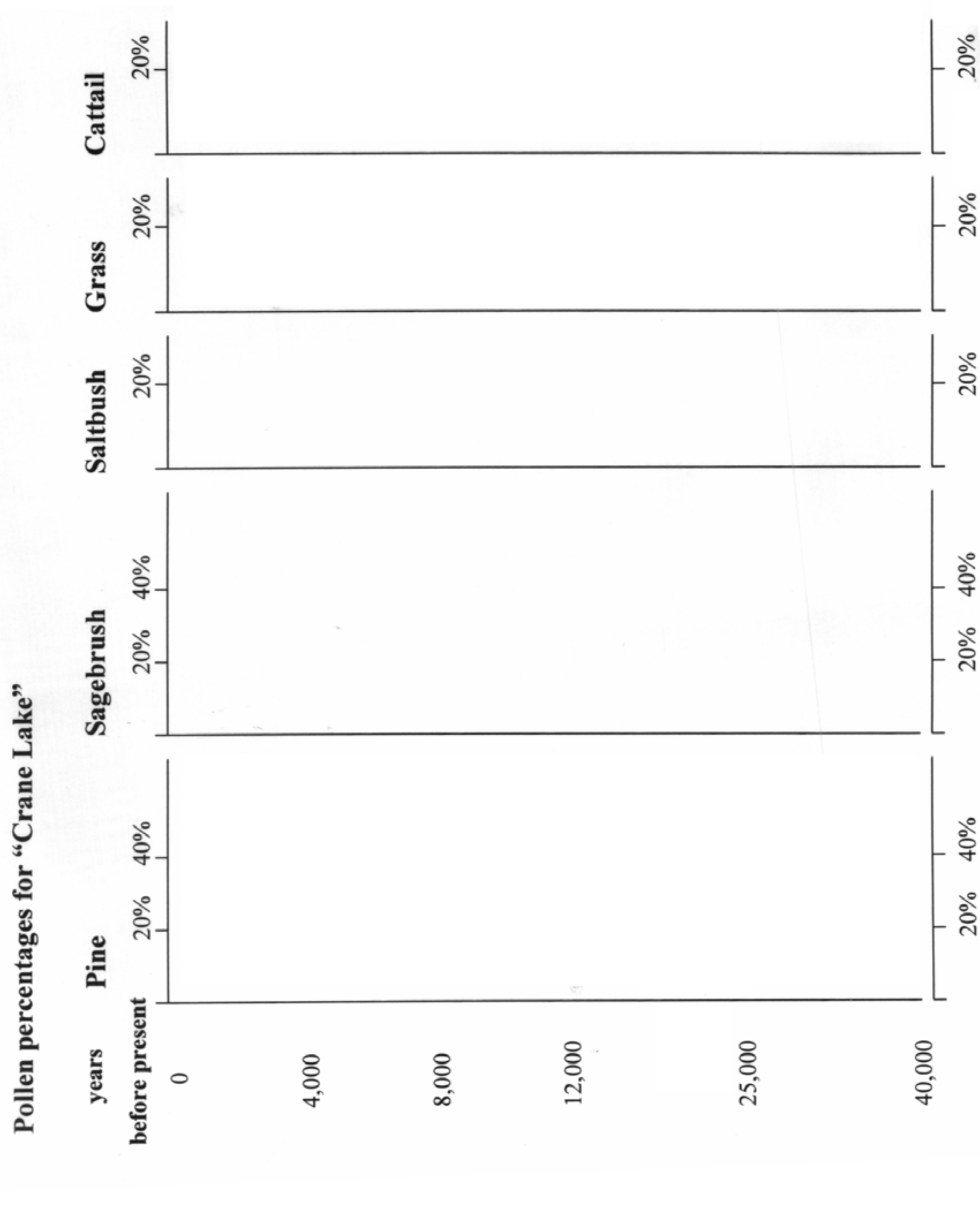

Figure 16.4. Pollen diagram for class pollen percentages.

Lodgepole pine *(Pinus contorta)* Lodgepole pine forests are usually located in mountain environments at middle elevations. These sites are usually cooler than those at lower elevations and they receive greater precipitation because of the effect of mountains on local climate. Soils are typically coarse textured.

Sagebrush *(Artemisia sp.)* Sagebrush communities generally occur at lower elevations than lodgepole pine. These locations are usually warmer and dryer than forested areas and the soils are mainly fine in texture. Sagebrush depends on the precipitation it receives in the winter and spring; summers are frequently dry.

Saltbush *(Atriplex confertifolia)* Saltbush grows in warm, dry environments and can tolerate dryer conditions than sagebrush. It can tolerate soils with high salt concentrations.

Grass (Poaceae [family name]) Grasses occur in a wide variety of environments and can be used as indicators of local conditions. They are often abundant in lowland areas with sagebrush, but they can grow in wet areas as well.

Cattail *(Typha latifolia)* Cattails are known as "emergent" aquatic plants, that is, their roots and the lower parts of their stems are submerged while their "heads" (flowers) are above the surface of the water. They typically grow in lake margins and drainage ditches where the water depth is between 1 and 3 feet.

Your interpretation of the pollen record you have just graphed:

For each of the pollen types, when (at which time) were the percentages the highest and the lowest?

Pine?

Sagebrush?

Saltbush?

Grass?

Cattail?

What does this information suggest about the changes in vegetation and climate in the vicinity of "Crane Lake" between 40,000 years ago and today? Give your interpretation of the vegetation and climate for each of the time periods represented by the samples. Use the ecological information about each species to help you determine what the climate of each period was like. State what the climate was like in terms of temperature and moisture (i.e. warm and dry, cool and moist, etc.) Pine, sagebrush, and saltbush percentages tell you about the regional climate. Grass and cattail will give you information about the local aquatic conditions. **Start with the oldest time period and work up to the present**.

The present time

4,000 years ago

8,000 years ago

12,000 years ago

25,000 years ago

40,000 years ago

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Appendix A
Making Pollen Slides

Obtaining Pollen

There are several ways to obtain pollen for making slides for this exercise. You can collect your own pollen in the field, or you can buy some from a pharmaceutical company. Collecting in the field is fun and you can get whatever pollen types you like. Buying from a pharmaceutical company is relatively easy and there are a remarkable number of pollen types to choose from. We obtained pollen from Bayer Pharmaceutical (Bayer Pharmaceutical Division, P.O. Box 3145, Spokane, Washington, 99220).

Preparing Pollen

If wet lab facilities are available, we advise preparing pollen as described below (also see Faegri and Iverson, 1989, and Jackson, 1997). If lab facilities are not available, the exercise is still possible using "raw" pollen that has not been processed. While pollen identification is easier with processed pollen, identification of unprocessed pollen is not much more difficult for students.

1. Place about 0.2 to 0.3 grams of pollen in a 15 ml plastic test tube.
2. Add 10 ml of 10% KOH and place the test tube in a boiling water bath for 2 minutes, stirring the samples with a wooden stick throughout the procedure.
3. Centrifuge samples and decant (C&D), keeping the pellet.
4. Add 3 ml dH_20 and vortex (thoroughly mix) tubes.
5. Add another 7 ml dH_20.
6. C&D
7. Add 3 ml of 10% HCl and vortex.
8. Add another 7 ml of 10% HCl and place the tube in a boiling water bath for 10 minutes.
9. Add 3 ml dH_2O and vortex.
10. Add another 7 ml dH_2O.
11. C&D
12. Add 3 ml glacial acetic acid and vortex the tube.
13. Add another 7 ml glacial acetic acid.
14. C&D
15. Add 5 ml acetic anhydride and vortex.
16. Carefully add 0.5 ml glacial sulphuric acid.
17. Heat the tubes in a water bath for 2 minutes, stirring the samples with a wooden stick throughout the procedure.
18. Even samples out with glacial acetic acid before centrifuging.
19. C&D
20. Add 3 ml glacial acetic acid and vortex.
21. Add another 7 ml glacial acetic acid .
22. C&D
23. Add 3 ml dH_2O and vortex.
24. Add another 7 ml dH_2O.
25. C&D
26. Add 3ml 70% ethanol and vortex.
27. Transfer the pellet to a 1 dram vial.
28. Transfer any remaining pollen from 15ml tubes to 1 dram vials using 70% ethanol.
29. C&D
30. Add 5ml Tertiary butanol (TBA) and vortex.
31. C&D
32. Add silicone oil (dimethylpolysiloxane) to cover and suspend the sample.
33. Stir the sample.
34. Leave the vial uncapped for 24 hours to evaporate any remaining butanol.
35. Cap the sample. You're ready to mix pollen samples!

Making Slides

Making slides with the appropriate percentages of each pollen type you have chosen is not difficult, but does take some time. The procedure we used is not highly quantitative, but it did the trick. After pollen processing, we placed one drop of each pollen type on individual slides with cover slips and counted the number of pollen grains under a field of view (100X) for each type. This gave us a rough idea of how many pollen grains of each type were in a drop. Based on this, we began mixing drops of each pollen type for a slide, making counts for that slide to make sure the percentages were close to what we wanted. If our percentages needed adjustment, we would add the required pollen type to meet the desired percentage. Slides are made for each time period by placing one or two drops of the sample on a microscope slide. Place a cover slip over the sample and spin it slowly one complete turn by gently circling the surface of the cover slip with a dissecting needle. Wipe any excess sample from the edge of the cover slip and seal the cover slip to the slide using fingernail polish around all edges.

Appendix B

Desired Pollen Percentages and Their Interpretation

Desired Pollen Percentages

Sample	% Pine	% Sagebrush	% Saltbush	% Grass	% Cattail
Present day	40	35	15	7	3
4,000	10	40	23	25	2
8,000	35	30	10	5	20
12,000	43	37	7	13	0
25,000	55	35	5	5	0
40,000	35	55	7	3	0

Interpretation
40,000 – When comparing the pollen percentages of the different times, 40,000 years ago looks much like the present day based upon the high *Artemisia* pollen. However, we know from other evidence that the climate of 40,000 years ago was nothing like today's climate. This point exposes one of the weaknesses of palynology. While some pollen grains can be identified to the species level, some can only be identified to the genus or even family level. Unfortunately, sagebrush pollen can only be identified to the genus level. Therefore, we do not know which species of sagebrush is being represented in the fossil record at some times. Many species of sagebrush exist in a wide variety of habitats in western North America. Our inability to identify them to the species level means that a great deal of ecological information is lost in our interpretations. Based upon other evidence, we know that 40,000 years ago was cold and dry. The sagebrush observed at this time is likely from a species which grows in alpine environments.

25,000 – This time period was the wettest time period based upon the high peak in pine pollen and the low in saltbush.

12,000 – This period is warmer and drier than 25,000 years ago based upon the decrease in pine pollen and the increase in sagebrush and saltbush pollen.

8,000 – Students often mischaracterize this time period as the wettest based upon the peak in cattail pollen. However, as indicated in the notes, cattail is only a local indicator. The peak in cattail pollen indicates that cattail became locally abundant, not that the climate became necessarily wetter. Since cattail grows best in shallow water, this might indicate that the lake level lowered or that the lake has filled in considerably, providing prime habitat for cattail. In actuality, this time period is warmer and drier than 12,000 years ago based upon the decrease in pine and the increase in saltbush.

4,000 – This period was the warmest and driest period observed in this record based upon the peak in saltbush and the pine low. Local aridity is also indicated by the peak in grass pollen, indicating a drawdown in the lake providing more suitable habitat for grass to flourish.

Present day – The drop in saltbush and sagebrush with an increase in pine pollen indicates that today is cooler and wetter than 4,000 years ago.