Lesson Plan: Paleoecology in the Okanagan Highlands

Special thanks to Joan Sharp and Simon Fraser University for developing this activity.

Before the Lesson

The time required for this activity is 90 minutes, with 30 minutes of instructional time and 60 minutes of activity time. The break down of numbers supplies is for a class of 30 students, please adjust as needed.

Curriculum Connections

Earth Science 11
Geology 12

Learning Objectives

After this lesson students should be able to:

- Identify the genus of eight fossil plants from the Okanagan Highlands of the early Eocene
- Identify the nearest living relative (NLR) of each fossil plant
- Graph the range of mean annual temperature (MAT), coldest month mean temperature (CMMT), and mean annual precipitation (MAP) of the nearest living relatives of the eight identified plants.
- Predict the climate of the Okanagan Highlands in the early Eocene, as inferred from the likely habitat of fossil plants from this era

Lesson Plan Overview

1. Introduction
    a. Acronyms used in this activity
    b. Paleoecology
    c. Climate parameters
    d. Early Eocene Okanagan Highlands
2. Main Activity
    a. Identify fossils using guide of nearest living relative (NLR)
    b. Plot the climate parameters for each genus
    c. Estimating the climate of the Okanagan in the Early
3. Wrap-up

Materials Required:

- Paleoecology and paleo climate summary (**See Appendix I**)
- Climate change and conservation paleobiology (**See Appendix II**)
- Geological time scale summary (**See Appendix III**)
- Paleoecology in the Okanagan Highlands worksheet (**30**)
- Pencils (**30**)
- Rulers (**30**)
- Graphing paper (**as needed**)
- ID guides, printed or digital (**5**)
- Sets of photo cards of fossils (**5x8**)

Introduction

Acronyms used in this activity

CMMT (coldest month mean temperature)
MAP (mean annual precipitation)
MAT (mean annual temperature)
NLR (nearest living relative)

1. Paleoecology

Paleoecology is the study of constructing past ecosystems from fossils and other geological evidence. Paleoecology can look at climate, landscapes, populations, and ecosystems, and can focus on any time in ancient life and any place in the world. This activity focuses on the Early Eocene and the Okanagan Highlands.

Figure 1: This painting by SFU paleoecologist Dr. Rolf Mathewes shows the Quilchena site from 51.5 mya. Note the rare birds (based on fossil feathers and bones), a giant lacewing insect in the foreground, Taxodium (bald cypress) in shallow water with mats of Azolla (an aquatic fern), waterlilies, and Metasequoia (dawn redwood) and Alnus (alder) on shore.

2. Climate Parameters

Fossil assemblages of plants from past environments can be used to estimate the paleoclimate features in which the plants lived. Plant fossils are identified to genus and the **nearest living relative (NLR)** of each genus is identified. The **mean annual temperature (MAT)**, **mean annual precipitation (MAP)** and the **mean temperature of the coldest month (CMMT)** are identified for each NLR. The range of each of these climate parameters for each NLR is graphed, and the overlap of these ranges is used to estimate these conditions at the time when the extinct species lived.

Figure 2: Map showing location of Early Eocene fossil sites of the Okanagan Highlands.

3. Early Eocene Okanagan Highlands

The Okanagan Highlands stretch for 1000 km, from Republic in northern Washington to Driftwood Canyon in central British Columbia. The Eocene, the second epoch of the modern Cenozoic Era, began 56 million years ago (mya). Paleolakes in the Okanagan Highlands contain beautifully preserved **fossils** (**lagerstätten**) of organisms that formed in subtropical upland areas in the early Eocene, approximately 52 million years ago. This was after the **Paleocene-Eocene thermal maximum**, when global temperatures rose by 5-8^{0}C.

Main Activity: Using nearest living relatives to estimate climate parameters

1. Identify each plant fossil with their nearest living relative:
    - Arrange students into groups of 5-7 and ensure that each group has an ID guide, eight fossil cards, and worksheets
    - Have students read through the ID guide before starting to identify to familiarize themselves with all of the plant genera prior to starting.
    - Now, using the fossil cards, have students identify the NLR of each of the fossils on the provided cards with the help of the ID guide.
    - Have students fill out their worksheet accordingly.
    - **Note:** There are no doubles or tricks in the answers! There is one individual for each species, so have students use the process of elimination to fill out their worksheet.

List for ease of marking and instructing:

Fossil genus	Common name	Nearest living relative
Taxodium	Bald cypress	*Taxodium*
Pinus	Pine	*Pseudolarix*
Alnus	Alder	*Alnus*
Comptonia	Sweet fern	*Comptonia peregrina*
Sassafras	Sassafras	*Sassafras albidum*
Gingko	Gingko	*Gingko biloba*

2. Plot the climate parameters for each genus:
    - Using the range of the **MAT, CMMT,** and **MAP** for the **NLR** of each plant fossil in the ID guide, have students graph each of the parameters for the species.
    - There will be a separate graph for each of the climate parameters with all of the NLR included. This would be the name of the NLR on the x-axis and the parameter values on the y-axis.
        - The end graph should be a whisker plot (no box).
        - The line should be done using a ruler.
    - Once they have plotted the values for each NLR, have students identify the limiting factors for each climate parameter.
        - This range will include the MAT, CMMT, and MAP for all eight NLRs. This will be the values that produce the **smallest** range.

3. Estimating the climate of the Okanagan in the Early Eocene:
    - Students should use a ruler to draw lines enclosing the upper and lower limits for each climate parameter that includes values within the range for all NLRs.
    - Fill out the worksheet accordingly.

Debrief

- Discuss the students' responses and compare graphed results of different groups.
- Encourage thought and discussion about when this method would work in other geographic regions and where it might not be successful.

Appendix I – Paleoecology and Paleoclimate

Paleoecology is the science of the reconstruction of past ecosystems, including the physical features of the environment and the biotic and abiotic interactions between species and their environment. Evidence for this reconstruction includes body fossils (including gut contents), ichnofossils, geological features, taphonomy, and isotopic composition of fossils and sediments, and other lines of evidence.

Paleoclimate
While the fossil record provides direct and indirect evidence about organisms that lived in the past, abiotic components of an ecosystem (e.g., temperature, precipitation, and seasonality) don't fossilize. Paleoclimatologists get evidence that allows them to reconstruct past climates by studying marine and lake sediments, coral reefs, glaciers, polar ice caps, and tree rings to obtain information about rainfall, temperature, seasonality, and other climatic features.

Climate parameters (MAT, MAP, CMMT)
Fossil assemblages of plants from past environments can be used to estimate the paleoclimate features in which the plants lived. Plant fossils are identified and the nearest living relative (NLR) of each species is identified. **The mean annual temperature (MAT) and precipitation (MAP) and the mean temperature of the coldest month (CMMT) are identified for each NLR**. The data for the range of each climate parameter for each NLR are graphed and the overlap of these ranges is used to estimate these conditions at the time when the extinct species lived. For example, if it is known that *Ginkgo biloba*, the only living species from the *Ginkgo* genus, prefers a MAT temperature of between 5-23 ^{0}C than it can be assumed that the extinct species of ginkgo lived in similar climates. The native range of the ginkgo tree used to be much bigger, and in areas with fossil evidence of ginkgoes, it was likely within that temperature range at the time when the fossils are traced back to.

Climate equability
Equable climates have little variation in monthly mean temperature and precipitation over the course of a year. In the modern day, tropical environments are more equable, without seasonality and with relatively low annual temperature variation, while temperate areas are cooler and have seasons that differ in temperature. Think about Vancouver and the broad range of temperatures between seasons, in comparison to the Marshall Islands which are hot all year-round. In the early Cenozoic era, the poles were much warmer and temperate regions were quite equable, with low seasonality.

Resources:

How do scientists study ancient climates? | National Centers for Environmental Information. NOAA. https://www.ncei.noaa.gov/news/how-do-scientists-study-ancient-climates

Global Climate Change in Perspective | The Smithsonian
https://naturalhistory.si.edu/education/teaching-resources/paleontology/global-climate-change-perspective

Appendix II - Climate Change and Conservation Paleobiology

What is weather?

Weather refers to conditions of the atmosphere are over a short period of time. Weather consists of the short-term (minutes to months) changes in the atmosphere. Most people think of weather in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure; as in high and low pressure. When trying to conceptualize the difference between weather and climate change, it can help to consider temperature changes between seasons in contrast to changes in winter conditions between thirty years ago and the present day.

What is climate?

Climate is how the atmosphere "behaves" over relatively long periods of time, or the average of weather over time and space. You can think of climate as a description of weather over long periods of time, for example a trend observed over several years.

What is climate change?

Changes in climate conditions that persist over multiple decades or longer. Climate change can be a reference to human-generated climate change that is happening present day or climate change in the past that was caused by events like large volcanic eruptions.
There is a positive feedback loop, meaning a system that amplifies changes, which results from this increase in atmospheric temperatures and CO_2. Glaciers melt, increasing flow of water to the ocean, leading to increasing sea levels. The ocean acts as a buffer to help maintain global conditions by absorbing CO_2 and heat. The ocean cannot absorb CO_2 as fast as it is being produced which is contributing to global rising temperatures. The larger amount of CO_2 being absorbed by the ocean also lowers the overall pH of the ocean which leads to ocean acidification.

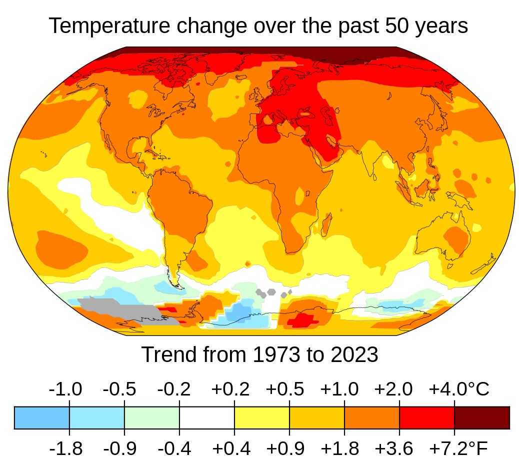

Figure 3: Climate change over the last 50 years. Wikimedia user NASA, CC license 4.0.

How does climate change affect humans?

That's a tough question to answer since we rely on the Earth to provide us with habitable conditions and food. The need for food and a safe place to live is important to all people on the planet, climate change has a substantial impact on these basic needs. For example, the Food and Agriculture Organization estimates that one billion people rely on fish as their main source of protein. There is evidence that fish populations are being affected by increasing temperatures, and this may cause food security issues.

Extreme weather events such as floods, fires, and hurricanes are also predicted to increase in frequency and intensity in coming years as a result of climate change, disrupting the lives of many. Extreme weather events impact: food systems, from traditional food sources to commercial agriculture; homes; cities; and our ability to find safe shelter.

Conservation paleobiology

Conservation paleobiology is the study of conservation using geological records. This field of study was only formally named in 2002, but relevant work had been going on prior. Conservation paleobiology has been used to create an objective baseline for conservation projects, evaluate extinction risks, and identify drivers of degradation as well as many other roles.

Global climate change over geological time

Climates have changed throughout the history of life on Earth. At the end of the Proterozoic eon, Earth's surface was likely covered with a kilometre or more of slushy ice. It is possible that no region of the world ocean was exposed to the atmosphere. This hypothesis is known as Snowball Earth. During the Phanerozoic eon, global temperatures have fluctuated with cycles of alternating cold and warm periods.

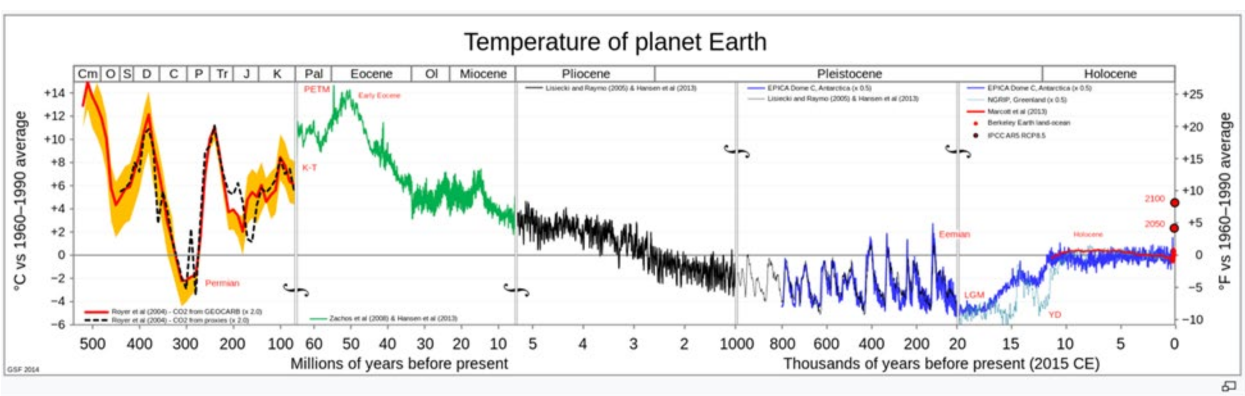

Figure 4: Global temperature fluctuations over time. Note that the scale on the x-axis changes to show the current temperatures in more detail. Used through CC 3.0, Wikimedia user Glen Fergus.

Global climate change, past and present

Global climate change is arguably the greatest threat facing the Earth. Increasing levels of greenhouse gases cause global warming, resulting in changing temperature and rainfall patterns, decreasing pH levels in the world ocean, increasing frequency and intensity of storms and droughts, and altering the distribution and abundance of many species. The current rate of change caused by human activities is unprecedented.

Climate has changed throughout Earth's history. We are currently in the Cenozoic era, which began 66 million years ago (mya) when an enormous asteroid struck the Earth, causing a mass extinction that wiped out the non-avian dinosaurs. The Cenozoic era began with the Paleocene epoch, which lasted 10 million years and ended with a period of significant climate change and global warming called the Paleocene-Eocene Thermal Maximum or PETM. During the height of the PETM (55.75 mya), global temperatures rose by 5–8^{0}C. Temperatures remained that high for 200,000 years.

The PETM was caused by the release of huge amounts of carbon into the atmosphere. The cause of the carbon release is not certain, but the most likely explanation is that release of CO_2 due to volcanic activity caused global warming, which increased marine temperatures and triggered the release of methane (CH_4), a potent greenhouse gas, from frozen methyl hydrate present beneath the seafloor in the world ocean. This release, which occurred over a period of 20,000 years or more, caused an increase in carbon in the atmosphere equivalent to the burning of all the fossil fuel reserves present on Earth. Note that the current rate of carbon release into the atmosphere due to human activity is ten times the rate seen during the PETM.

Understanding the effects of global warming during and after the PETM may help us understand and address the consequences of modern global climate change. As Scott Wing, a Smithsonian paleobotanist studying the PETM, explains, "The central truth about predicting global climate change is that these systems are very complicated and very interconnected. We can make all the supercomputer models we want, but we won't really know how well these models predict the future until we get there. And then it will be too late. The great advantage of the fossil record is that we can study events that have already happened and work out the links. It seems that the least we can do, now that we are modifying the planet we live on, is to read the operator's manual written in its rocks."

Resources:

What is conservation paleobiology? | Frontier in Ecology and Evolution
https://www.frontiersin.org/articles/10.3389/fevo.2022.1031483/full

Conservation Paleobiology | Digital Atlas of Ancient Life
https://www.digitalatlasofancientlife.org/learn/conservation-paleobiology/

What's the Difference Between Weather and Climate? | NASA
https://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html

Indicators | U.S. Global Climate Change Research Program
https://www.globalchange.gov/browse/indicators

Climate Change | U.S. Global Climate Change Research Program
https://www.globalchange.gov/climate-change

How do we determine past climate? | National Institute of Water and Atmospheric Research
https://www.niwa.co.nz/climate/faq/how-do-we-determine-past-climate

What is ocean acidification? | PMEL NOAA
https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F

Humans are having huge influence on evolution of species | CBC News
https://www.cbc.ca/news/technology/humans-evolution-1.4906534

Appendix III - Geological Time Scale

The geological time scale is the sequence of eons, eras, periods, and epochs that describe the geological history of Earth. The timescale is put together and updated by the International Commission on Stratigraphy. When different sections of the timeline begin is based off of geological features and fossils. It is a tool to help conceptualize and discuss deep time.

Figure 5: Wheaton walk through time at the Beaty Biodiversity Museums - a different way to conceptualize deep time.

Here is a broad overview of some major events in the geological timeline:

1. The Precambrian is the interval from the formation of Earth 4.6 billion years ago (bya) to the appearance of most animal taxa 541 million years ago (mya).
2. In the Hadean eon (4.6–4 bya), Earth was bombarded with asteroids and other extraterrestrial objects. The first oceans formed. The atmosphere lacked free oxygen.
3. The Archaean eon (4–2.5 bya) saw the origin of life on Earth and the evolution of prokaryotic cells capable of oxygenic photosynthesis. Life was exclusively unicellular. With the origin of oxygenic photosynthesis, atmospheric oxygen gradually accumulated.
4. In the Proterozoic eon (2.5 bya – 541 mya), the first eukaryotic cells arose.
5. The Phanerozoic eon (541 mya – present day) began with the Paloeozoic era (541–252 mya).
   - The initial diversification of major animal taxa took place in the Cambrian period (541– 485 mya). This is sometimes called the 'Cambrian explosion'.
   - In the Ordovician period (485–443 mya), land plants and fungi colonized land together, gradually forming soil.
   - In the Silurian period (443–419 mya), vertebrate life diversified in the oceans with the origin of jaws and paired fins.
   - In the Devonian period (419–359 mya), vertebrate life moved to land with the evolution of tetrapods from lobe finned fishes. Insects, lichens, and the first forests of seedless vascular plants arose on land.
   - In the Carboniferous period (359–299 mya), amniotes arose.
   - The Permian period (299–252 mya) ended with the '*Great Dying*'. The Permian extinction wiped out most living taxa on Earth.
6. The Mesozoic era (252–66 mya) began with the appearance of mammals and dinosaurs.
   - Mammals and dinosaurs arose in the Triassic period (252–201 mya).
   - Tyrannosaurs, birds, and placental mammals arose in the Jurassic period (201–145 mya).
   - Angiosperms, bees, and ants arose in the Cretaceous period (201–66 mya).
   - An asteroid struck the Earth, causing a mass extinction that killed all non-avian dinosaurs, ending the Mesozoic era. (66 mya)
7. The Cenozoic era (66 mya – present day) began with the end-Cretaceous extinction. It consists of three periods (Paleogene, Neogene, and Quaternary), divided into seven epochs (Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, and Holocene). Some biologists suggest we are now living in a new epoch characterized by human impact on Earth's land, oceans, atmosphere, and living things: the Anthropocene epoch.

Resources:
Chart | International Commission on Stratigraphy
https://stratigraphy.org/chart

Walk Through Time | Beaty Biodiversity Museum
https://explore.beatymuseum.ubc.ca/walk-through-time/

Appendix IV - Additional Resources for this activity

Paleoecology | Digital Atlas of Ancient Life
https://www.digitalatlasofancientlife.org/learn/paleoecology/

Okanagan Highlands | National Park Service
https://www.nps.gov/laro/learn/nature/okanogan-highlands.htm

S Bruce Archibald and David R Greenwood. (2005). *The Okanagan Highlands: Eocene biota, environments, and geological setting, southern British Columbia, Canada and northeastern Washington, USA*. Canadian Journal of Earth Sciences. 42(2): 111-114.
https://doi.org/10.1139/e05-012

David R Greenwood, S Bruce Archibald, Rolf Mathewes R, Patrick T Moss. (2005). *Fossil biotas from the Okanagan Highlands, southern British Columbia and northeastern Washington State: climates and ecosystems across an Eocene landscape.* Canadian Journal of Earth Science. 42: 167-185.
https://cdnsciencepub.com/doi/10.1139/e04-100

Appendix V – Glossary

Coldest Month Mean Temperature (CMMT): the average temperature of the coldest month of the year

Fossil: the preserved remains, or traces of remains, of ancient animals and plants.

Lagerstätten: a sedimentary layer of rock that contains a large amount of well-preserved organic remains such as soft tissues or skeletal remains.

Mean Annual Precipitation (MAP): the overall average precipitation (i.e., rain, snow) in a year

Mean Annual Temperature (MAT): the overall average temperature in a year

Nearest Living Relative (NLR): a tool used to estimate the paleoclimatic conditions in which a certain species lived