

Physical Landscapes and the Geosphere (ACNA 4007)

Antarctica: Extreme Antarctic Ecosystems

Activity Outline:

Antarctic phytoplankton in the ocean form the bottom of the food chain that supports all Antarctic life, but a very low diversity of plants exists on the continent itself. Most of the modern vegetation consists of lower plants, such as moss, lichens, fungi and liverworts, that grow on the 1-2% exposed land around the coastline, on the Antarctic Peninsula and on sub-Antarctic Islands. There are just two species of flowering plants growing in Antarctica today, though flowering plants make up 80% of global vegetation, that are now just remnants of higher biodiversity in Earth's deep past. Fossils open a window into the past environments and climates of this fascinating continent. We will look at fossil plants from Antarctica and ecosystems that were able to survive at high latitudes until relatively recently in geological time. The fossils are evidence of past continental drift in the Southern Hemisphere and the existence of the ancient supercontinent Gondwana. They also give evidence of past greenhouse climates with high CO₂ when Earth was warmer than today, and near-tropical rainforests covered the Antarctic continent in the absence of icesheets. How did such significant cooling occur through the Cenozoic? We will study how fossil forests help us to understand Earth's natural climate change and the formation of the Antarctic ice cap.



Key Reading:

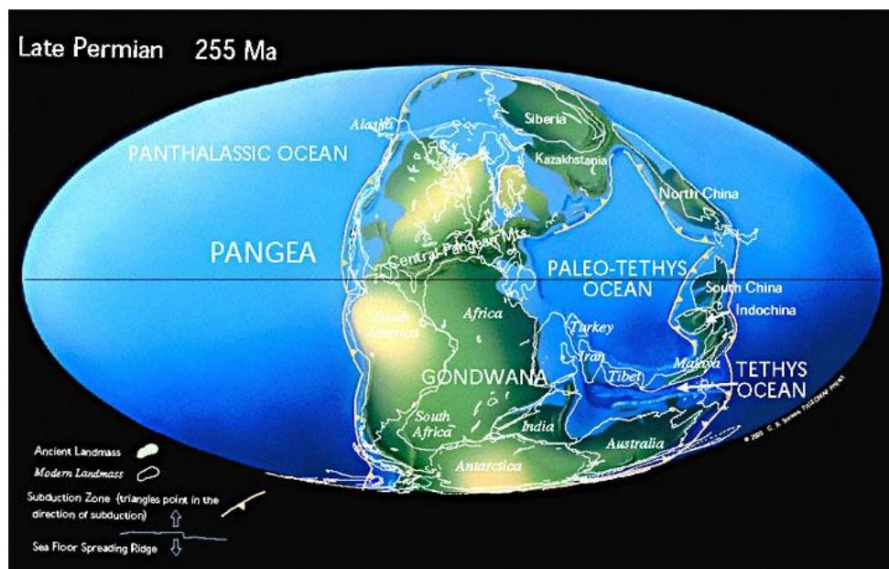
1. Fossil plants: [What Fossil Plants Reveal About Climate Change | Smithsonian Voices | National Museum of Natural History Smithsonian Magazine](#)
2. Climate drivers: https://climate.nasa.gov/nasa_science/science/

Geological Time Scale:

	Eon	Era	Period	Epoch	
Younger Older	Phanerozoic	Cenozoic	Quaternary	Holocene	← Today
				Pleistocene	← 11.8 Ka
			Neogene	Pliocene	
				Miocene	
			Paleogene	Oligocene	
				Eocene	
		Mesozoic	Cretaceous	~	← 66 Ma
				~	
			Jurassic	~	
			Triassic	~	← 252 Ma
			Permian	~	
			Carboniferous	Pennsylvanian	~
				Mississippian	~
			Devonian	~	
			Silurian	~	
			Ordovician	~	
			Cambrian	~	← 541 Ma
	Proterozoic	~	~	~	← 2.5 Ga
	Archean	~	~	~	← 4.0 Ga
	Hadean	~	~	~	← 4.54 Ga

(ka =1000 years, Ma= million years, Ga = billion years)

Map of Gondwana (Southern Hemisphere) & Pangea (largest supercontinent in Phanerozoic time):



Exercise 1: Journey of Discovery

Fossil leaves called *Glossopteris* were discovered within sedimentary rocks from the Permian Period, 252 to 300 million years ago. The fossil leaves come from extinct trees known as 'seedferns' because they reproduce by seeds but have fern-like leaves with reticulate veins (Fig. 1). Even though they looked like modern trees, they did not have true flowers and lived in warm, swampy environments. They are an amazing example of how fossils can be used as evidence of past continental configurations and dramatic changes on our Earth, by making

oceans and breaking continents through Geological Time. This forms the scientific Theory of Plate Tectonics.

Little evidence existed for large scale movement of continents around the Earth and few scientists ever considered such dynamic shifts could occur. During the early 1900s, a German scientist named Alfred Wegener realised how the continents from around the globe appeared to fit together, like pieces of a jigsaw puzzle and they provided evidence for continental drift in Earth's past. In particular, the coastlines of west Africa and east South America have a striking similarity in shape and, together with the other southern hemisphere continents, they must have been joined in one, large, supercontinent in the Southern Hemisphere. *Glossopteris* had been discovered in Africa, India, South America and Australia (Fig. 2). However, one piece of the puzzle was missing: any fossil evidence that *Glossopteris* grew on the icy continent of Antarctica in the past.

In 1911, Roald Amundsen and his men won the race to the South Pole when, travelling by dog sled, they were the first to reach the site and raise their Norwegian flag, 34 days before the British arrived. Robert Falcon Scott may have been the biggest loser of the Great Explorers, but he was well educated. On the return journey, when he and four men were man-hauling sleds, they came upon a rocky outcrop jutting out above the ice. After cracked open the layers they found fossil leaves of *Glossopteris* and recognised their critical importance proving the existence of the ancient southern landmass, Gondwana (Fig. 3). Scott and all four men tragically were trapped in their tent during a blizzard and perished from starvation in the extreme conditions, 11 miles from their food supply. Maybe pulling the sleds laden with heavy rock were to blame, but they had made a great journey of discovery for science. Click here for a virtual Antarctic tour: [Cape Evans | Virtual tour generated by Panotour \(antarctic.eu\)](https://www.panotour.eu/antarctic).

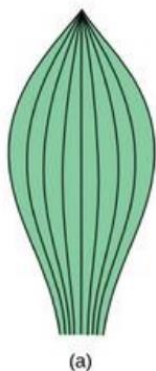
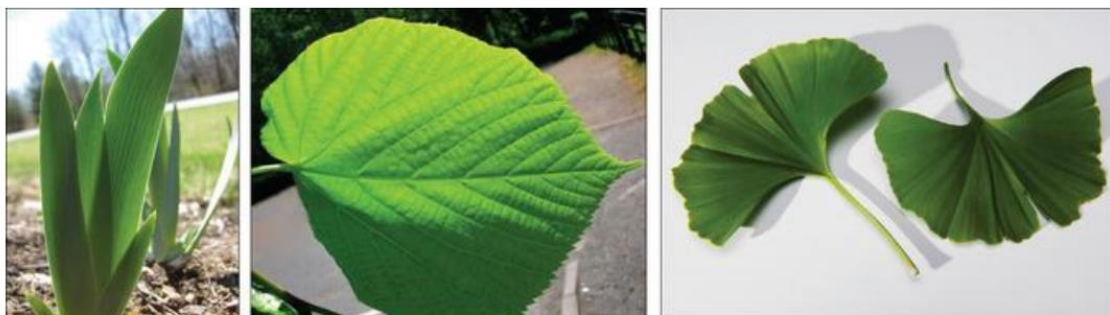
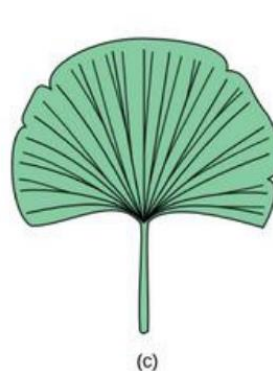


Fig. 1: Parallel veins



Reticulate (netted) veins



Dichotomous (dividing in two) veins



Fig. 2: Fossil *Glossopteris* leaves of Permian age, >250 million years old, from Australia but also found in Antarctica.

- a. What is the importance of fossil *Glossopteris* being found on the Antarctic continent?

Palaeogeography: *Glossopteris* was the final piece in the jigsaw puzzle. Fossils had already been found in Africa, India, Australia, South America. Finding *Glossopteris* on Antarctic continent was critical evidence for continents of Southern Hemisphere being joined in past to form ancient supercontinent, Gondwana.

- b. What can this tell us about movement of continents in Earth's natural history?

Plate Tectonics Theory that Earth's crust is broken into plates that move over geological time. Continents drift as plates shift, but mainly the plates collide (where they can be destroyed) or pull apart (where they can form new rock). Evidence is found from volcanoes, earthquakes, palaeogeography, new sea floor forming, new mountain ranges and other seismic or geological data.

- c. What was the name of i) the ancient supercontinent in the Southern Hemisphere and ii) the largest supercontinent in Earth's history?

i. Gondwana ii) Pangea

- d. Explain the break-up of Gondwana in terms of Plate Tectonic boundaries that formed around the edges of Antarctica?

Break-up of Gondwana occurred from Jurassic to Cretaceous times where the supercontinent of Gondwana broke up and formed rifting around the edges of the new Antarctic plate. New continents of Australia, Africa, India, South America rifted away from Antarctica, then drifted north, while Antarctica stayed over the South Pole for the past 100 million years.

- e. Write out the key chemical reaction of weathering in the long-term Carbon Cycle? Include the opposite reaction caused by metamorphism, such as when the Himalayas formed.

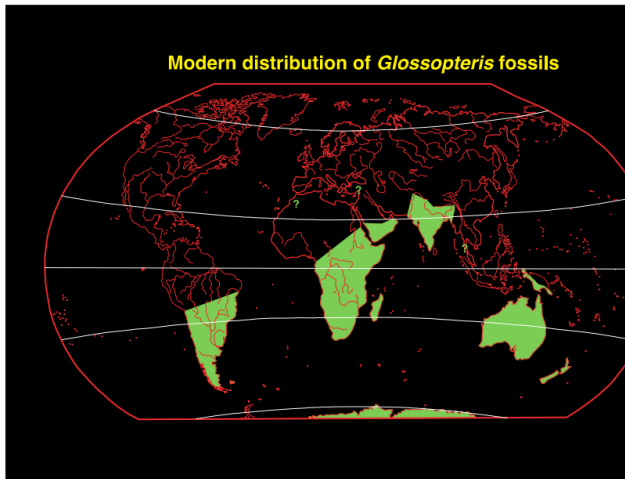


Figure 3: Modern distribution of fossil *Glossopteris* across the globe.

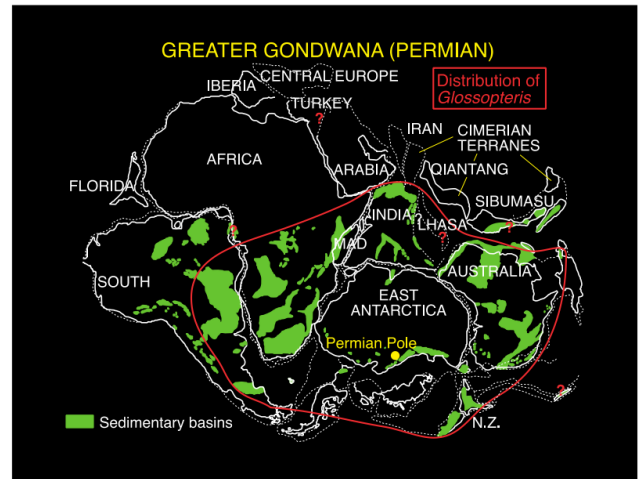


Figure 4: *Glossopteris* distribution in the Permian Period as evidence for ancient Gondwana supercontinent.



Fig. 5. *Glossopteris* reconstruction of the tree (a) with leaves (c), reproductive structures (b, c, e, f), fruits (g) and seeds (d), but they did not have true flowers. Drawing by Dr Rose Prevec, Albany Museum, Grahamstown, South Africa.

Exercise 2: First flowers & Southern Beech: warm to cool temperate rainforests

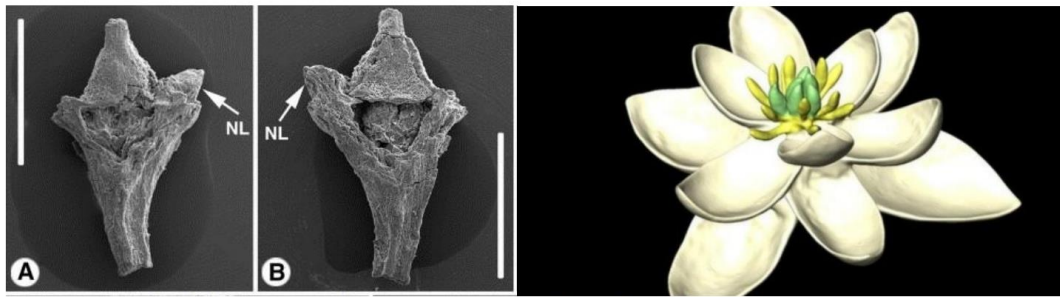


Fig. 6: A, B: A fossil flower that was burnt and preserved as charcoal in mudstones from 100 million years ago (Ma) provides evidence for the earliest flowers appearing in Antarctica (Eklund et al., 2004). C: A recent reconstruction of the earliest flowers on Earth, originating in Asia about 140 Ma, was probably related to Magnolias (Sauquet et al., 2017).



Fig. 7: Fossil leaves of Southern Beech found in Antarctica that survived from 90 to merely 3 million years ago.

- What is the genus of these fossil leaves? **Nothofagus**
- Where do modern relatives grow today? **Tasmania, e.g. Tarkine forest, Victoria, e.g. Otways or Tarra Bulga in Gippsland, New Zealand (also New Guinea and New Caledonia) and South America.**
- What era/periods of the Geological Time Scale do they come from? Use ages given on the Geological Time Scale, page 2. **Mesozoic Era (Cretaceous Period) to Cenozoic Era (Paleogene and Neogene Periods) [Cenozoic Epochs: Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, Holocene, and Recent.]**
- What were some of the vertebrate animals living in these forests? **Large flightless birds (similar to Emu) and 2 m high penguins, large herbivores like ungulates, smaller marsupials on the ground, marsupials in trees like possums, sloth relatives, etc.**
- What do these forests tell us about what global temperatures and climate conditions were like in the early Cenozoic (Paleocene to Oligocene) times? **Warm and wet climatic conditions prevailed in the Early Cenozoic, where the warm to cool temperate forests grew under high CO₂ conditions in globally warmer climates with no permanent ice caps at the poles.**

Exercise 3: Planktonic microfossils as proxies for past climate change



Fig. 8: Microfossil phytoplankton, silica diatoms (left), and planktonic or bottom-dwelling calcareous forams (right) are found in limestones from sampled from the bottom of the ocean, from approximately 90-0 million years ago.

Microfossils are skeletal remains of plankton trapped in rock (Fig. 8). When they were alive, they precipitated limestone (CaCO_3) straight from the water column in the ocean and, thus, record the level of oxygen isotopes in the water at the time they were alive. Oxygen isotopes act as a palaeoclimate proxy that gives us a record of past climates. A proxy in this sense is any physical, chemical and biological materials preserved within the geologic record (paleoclimate archives) that can be analyzed and correlated with climate or environmental parameters in the modern world. Paleoclimate archives can include rocks, such as deep ocean limestones or lake sediments, the Antarctic and Arctic ice sheets, or even fossil and modern corals and wood.

Oxygen atoms have an atomic number of 8, which means that they contain 8 protons and 8 neutrons in the nucleus, surrounded by a cloud of 8 electrons. The number of neutrons in the nucleus can change, called isotopes (Fig. 9), that make an atom heavier or lighter. Different numbers of neutrons give oxygen a different mass number, where 8 neutrons = ^{16}O , 9 neutrons = ^{17}O , or 10 neutrons = ^{18}O . ^{16}O is the most common in nature and is the lightest oxygen isotope, but ^{18}O , which is the heaviest, also exists in the atmosphere and oceans. If we measure oxygen isotopes from paleoclimate archives, we can determine how the ratio of ^{18}O and ^{16}O isotopes differs to a universal standard to learn about climate change through Geological Time. The ratio (relative amount) of these two types of oxygen in water changes with the climate.

Higher amounts of lighter ^{16}O isotopes preferentially evaporate from oceans at the equator and the heavier ^{18}O isotopes are first to precipitate as rain out of clouds close to the equator. This means that rain at the poles only contains the lighter ^{16}O isotopes. If there are no ice sheets at high latitudes over the poles, then the lighter isotopes in the rain water wash off into the ocean and mix with the heavier isotopes (Fig. 10). During warm climates and low ice volume on Earth, there are lower ratios of the isotopes. During cold periods, the rain at the poles gets trapped in the ice, so it locks up greater amounts of ^{16}O isotopes in ice. This increases the relative amount of ^{18}O in the ocean and gives greater ratios of the isotopes in cold climates (Fig. 11).

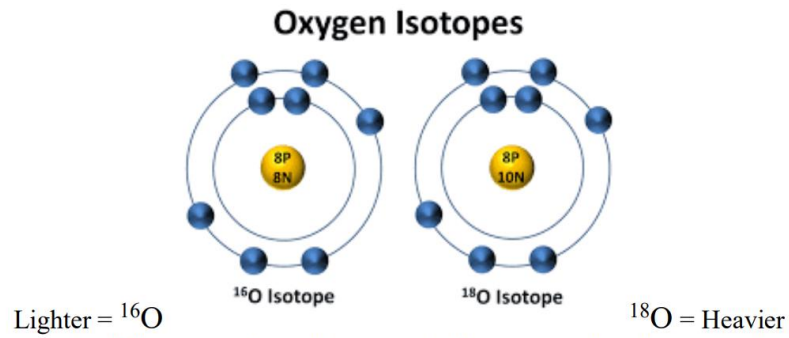


Fig. 9. Oxygen isotopes contain different numbers of neutrons in the atom nucleus that make them lighter or heavier.

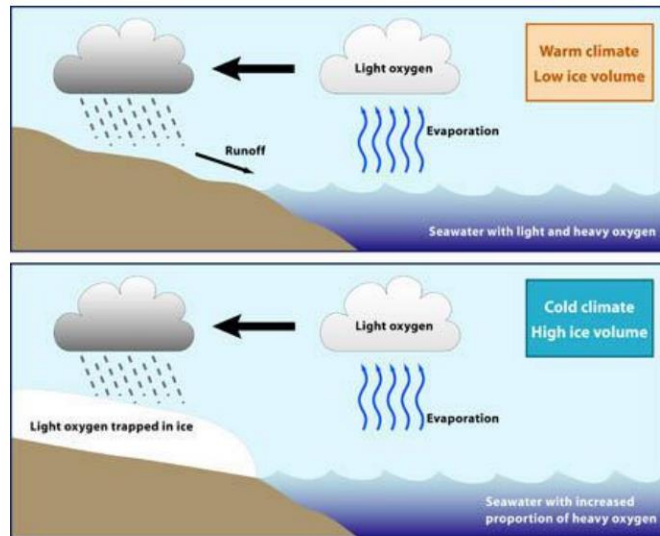


Figure 10. ^{16}O is lighter so it evaporates more easily at the equator. ^{18}O is heavier, so water vapour will condense more easily, close to the equator. The vapour gradually loses ^{18}O as it travels from the equator to the poles and at higher latitudes it becomes colder and drier, and full of lighter isotopes. Snow that forms the glacial ice is depleted in ^{18}O and as the ice melts, it returns ^{16}O -rich fresh water to the ocean. Oxygen isotopes preserved in ocean sediments act as proxies that provide evidence for past warm and cold climates and past ice ages.

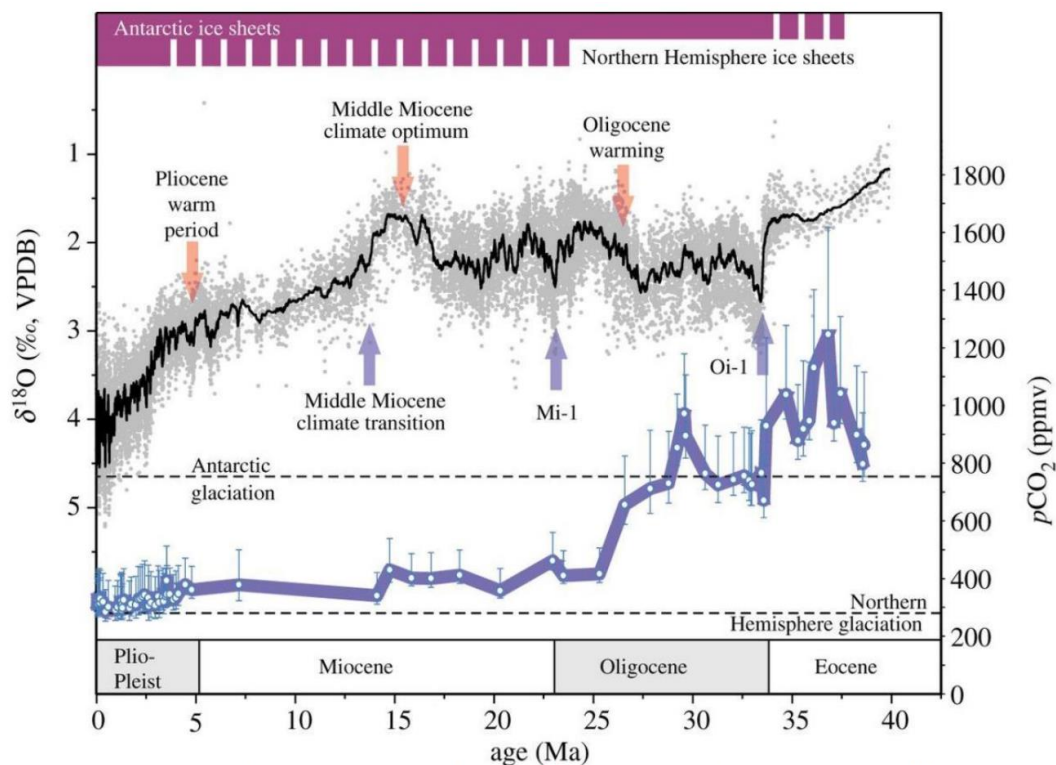


Figure 11. Proxy record for climate change in the Cenozoic, from changes in oxygen isotopes ($\delta^{18}\text{O}$) and changes in the atmospheric CO_2 . Changes in

Changes in carbon dioxide in the atmosphere are more complex to measure and calculate from paleoclimate archives. Sedimentary rocks and fossils have given us proxy records through the Cenozoic at the crucial time when Antarctica became glaciated and Earth's climate shifted significantly from a Greenhouse to an Icehouse world across the Eocene – Oligocene boundary (called **Oi-1**, see Figure 11).

- How can modern relatives help us to determine the different depths in the ocean where these fossils lived in the past?

Plankton (swimming or planktic) and bottom-dwelling (benthic) microorganisms live at different depths in the ocean today and are very similar to ancient relatives, going back through time. Microfossils occur in limestones that have been discovered on the bottom of the ocean. Going down through these sedimentary layers is equivalent to going back in geological time to 90 million years ago. We can compare the microfossils from limestones to their modern relatives to determine how deep the oceans were in the past and how different currents formed in the oceans.

- How do oxygen isotopes act as a proxy for past climate?

Oxygen can exist in the ocean water (H_2O) as isotopes O^{16} or O^{18} , depending on how many neutrons occur in the nucleus of the atom ($\text{O}^{16} = 8 \text{ protons} + 8 \text{ neutrons}$; $\text{O}^{18} = 8 \text{ protons} + 10 \text{ neutrons}$). O^{16} is lighter and O^{18} is heavier. Maximum evaporation occurs at the equator due to the most direct sunlight and the sun's rays are spread over a narrow area. The clouds that form here journey away from equator towards the poles. O^{16} preferentially gets taken up during evaporation of sea water at the equator. Some O^{18} in the sea water is evaporated

at the equator but it is too heavy to travel all the way to the poles. It will rain out of the clouds closer to the equator, before it reaches the poles. The clouds that reach the poles contain rainwater that is entirely made of O16, with no O18 in it. The rainwater (snow) at the poles gets trapped in the glaciers and ice sheets. When there is more ice on Earth, the O16 is trapped in ice and there is less O16 in the oceans. This makes the ratio of O16/O18 in the oceans higher. Thus, high oxygen ratios occur when the Earth is colder. When the ice melts into the ocean during warmer periods, the O16 is released back into the ocean and this reduces the ratio of O16/O18. Thus, lower oxygen isotope ratios occur when the Earth is warmer.

c. Explain how can we measure past temperatures from these microfossils?

Scientists who study past climates need to look in the depths of the ocean. Plants and animals sink to the ocean floor after they die in a steady rain of debris that settles in successive layers over time. Since different species thrive at different depths and in different climates, scientists can gauge the depths and temperature of the ocean by looking at fossils in a vertical column of rock from the ocean floor. The most plentiful, and perhaps the most useful, are the fossilized skeletons of microscopic plants and animals—foraminifera. Not only do the species of foraminifera at a particular location provide an approximate temperature range, but the very chemistry of the scales that coat them changes based on temperature. The microfossils can also be dated, giving scientists a clue as to the age of the layer of sediment in which the fossils were found. Scientists have been studying sediment from the ocean floor for decades in an attempt to understand past climate change.

d. What was the dramatic change in global temperatures and climate conditions at the Eocene-Oligocene boundary as evidenced from these microfossils?

Significant cooling in the Cenozoic saw a change from an Eocene Greenhouse, with a warm, wet climate and high CO₂ world, to a rapid and dramatic shift to Oligocene Icehouse, when the ice sheets formed and grew over the poles.