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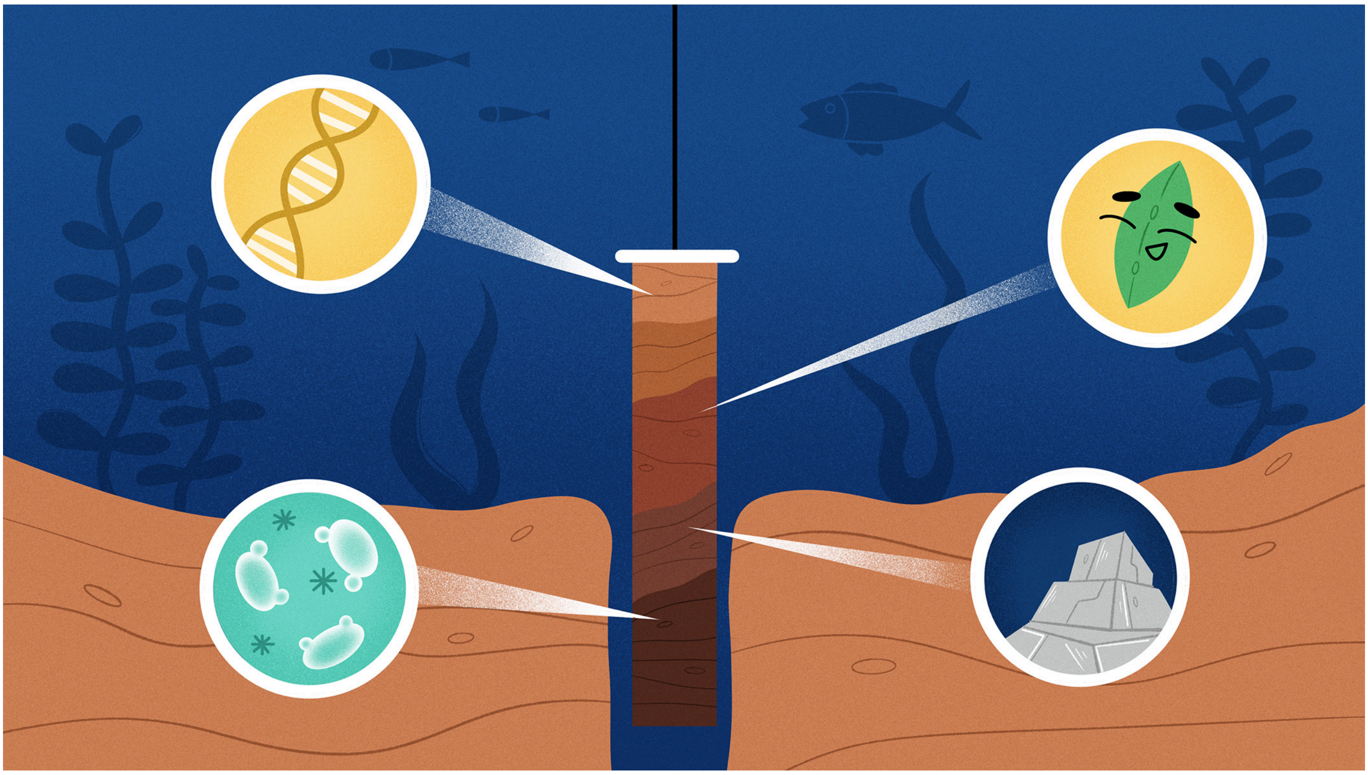

HOW SCIENTISTS USE LAKE MUD LIKE A TIME MACHINE

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AGE: 12

CATALINA
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MOMO
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Our surroundings are always changing because of natural and human factors. To understand how much our surroundings have changed, it is important to know what the environment was like in the past. Unfortunately, these data are often unavailable. But there is a silver lining: lake mud, or sediment, settles at the bottom of lakes, creating a time capsule that preserves information about the environment from up to thousands of years ago. By carefully extracting sediment, through a process called sediment coring, scientists can look at the clues within the sediment to understand environmental changes over time. In this article, we explore how scientists collect sediment cores and interpret what is found inside, like a "time machine", to inform policymakers about environmental change. We hope to show how sediment is a valuable tool for scientists and explain its potential role in addressing current environmental challenges.

AN EVER-CHANGING WORLD

The environment faces various challenges like pollution, habitat destruction, and overfishing. On top of that, climate change often makes these challenges even worse [1]. In response, scientists and policymakers work together to identify problems in the environment and to find ways to keep it healthy. Importantly, this job needs long-term data, which is not always available because most serious environmental monitoring only started in the 1960s. When data are available, they are typically only for information collected *after* environmental problems were identified. This gap in information leads to major challenges for scientists trying to provide effective advice to help solve these issues.

SEDIMENT

The material that settles at the bottom of lakes over many years. It is made up of material that comes from within the lake and the surrounding environment.

PROXIES

The measurable clues, such as sub-fossils, studied in sediment cores to reconstruct past environmental conditions in lakes and the surrounding environment.

PALEOLIMNOLOGY

The study of the physical, chemical, and biological information stored in lake and river sediments. Someone who studies paleolimnology is called a paleolimnologist.

Fortunately, many environmental challenges leave clues in the mud at the bottom of lakes, known as **sediment**. These clues are called **proxies**, and they can be analyzed to understand how the environment has changed [2]. In the rest of this article, we explain how a lake can track environmental changes, how some of the proxies can be studied, and how these clues are used to help fix environmental problems.

A LAKE'S TIME MACHINE

One of the most effective tools scientists use to understand past environmental changes is **paleolimnology**, a scientific field that studies lake sediment to understand changes in the environment. Lakes form through many processes, like glacier movement digging out holes in the Earth. Once water fills the hole, sediment begins to collect at the bottom. The sediment can come from the atmosphere, from the land, and from within the lake (Figure 1). Over time, sediment layers build up, tracking the physical, chemical, and biological history of the area where the atmospheric (air-based), terrestrial (land-based), and aquatic (water-based) inputs came from. Sediments can accumulate for thousands of years.

The process of studying the environment using paleolimnology follows a few common steps (Figure 2). Imagine, for example, that you were a paleolimnologist (a scientist who studies lake sediments) interested in understanding why fish populations are changing in certain lakes. You would first select a lake where the fish species are affected (Figure 2A). Then, you would use a tool that looks like a big plastic straw, called a corer, to collect the sediment sample. The corer is inserted into the sediment to collect the core.

Once a sediment profile is collected, you would take it to a lab and cut it into sections, like slicing a loaf of bread. Next, the sediment is dated so that you know how far back in time your "time machine" goes (Figure 2C). Various methods can be used for dating, like counting

Figure 1

The various routes that inputs are incorporated into lake sediments. Once inputs enter a lake, they slowly settle to the bottom, continually collecting to form sediment. Some of the key pathways are atmospheric inputs (air-based), such as pollution from buildings and cars; terrestrial (land-based) inputs, such as fertilizers and plant material; and aquatic (water-based) inputs, such as algae and animals.

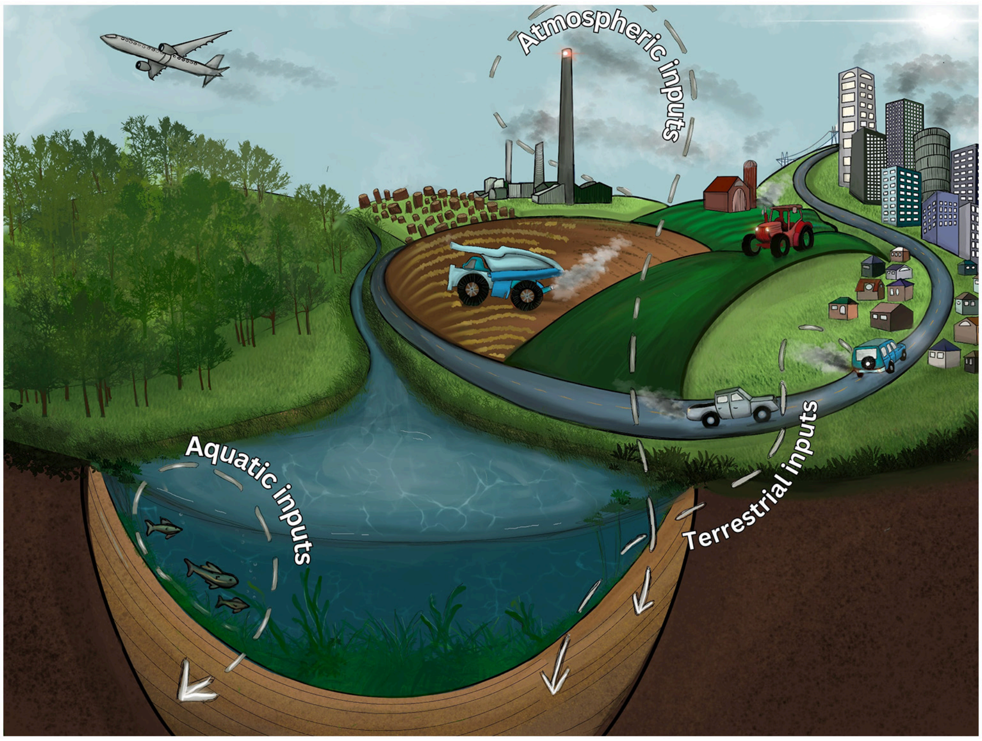

Figure 1

Figure 2

A plan of action illustrating the scientific process in paleolimnology. **(A)** Scientists identify a lake that is impacted by factors in the environment. **(B)** A sediment core is collected using a corer. **(C)** The core is cut into sections and dated. **(D)** The proxies within the core are analyzed to figure out what the environment used to look like.

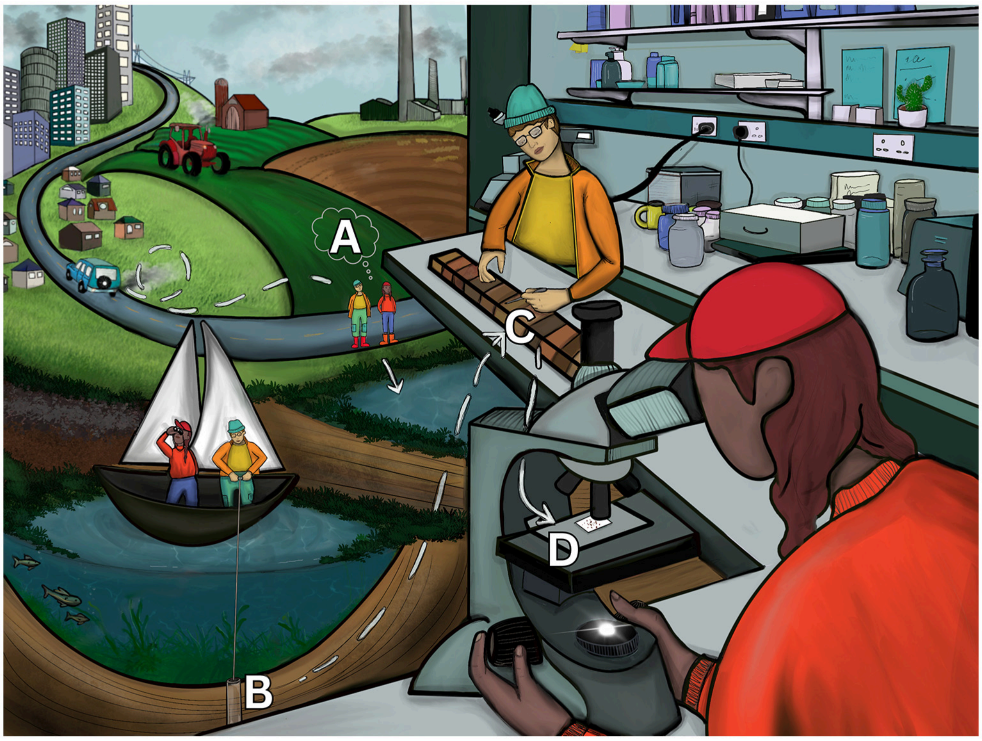

Figure 2

annual layers, similar to counting the rings of a tree to learn how old it is.

RADIOISOTOPES

Unstable forms of elements present in the environment, typically used to determine the age of a sample. Typical radioisotopes used in paleolimnology are carbon-14 and lead-210.

The most common way to age sediment is by using **radioisotopes**, which are elements that decay (or disappear) over time because they are unstable. You may have heard of one of the radioisotopes that paleolimnologists use: carbon-14. Carbon-14 or radiocarbon is often used by archaeologists who age bones that can be thousands of years old. For sediment that is not quite so old, a different radioisotope called lead-210 is most often used. Different radioisotopes decay at different speeds. If the element decays slowly, like carbon-14, it can be used to age things up to 50,000 years old—after that, there is too little carbon-14 left to measure. In comparison, lead-210 disappears after just about 150 years. Once a sediment core is dated, you will next choose which clues, called proxies, you will examine to address the environmental problem at hand (Figure 2D).

PUTTING TOGETHER THE EVIDENCE

A sediment core holds clues about the environment in the form of physical, chemical, and biological information called proxies. Paleolimnologists will select proxies that change because of the environmental problem that is being studied. Ultimately, the goal of the paleolimnologist is to unlock all the clues in the "time machine", to understand what the environment used to look like. Below, we talk about a few essential proxies and how they can be used (Figure 3).

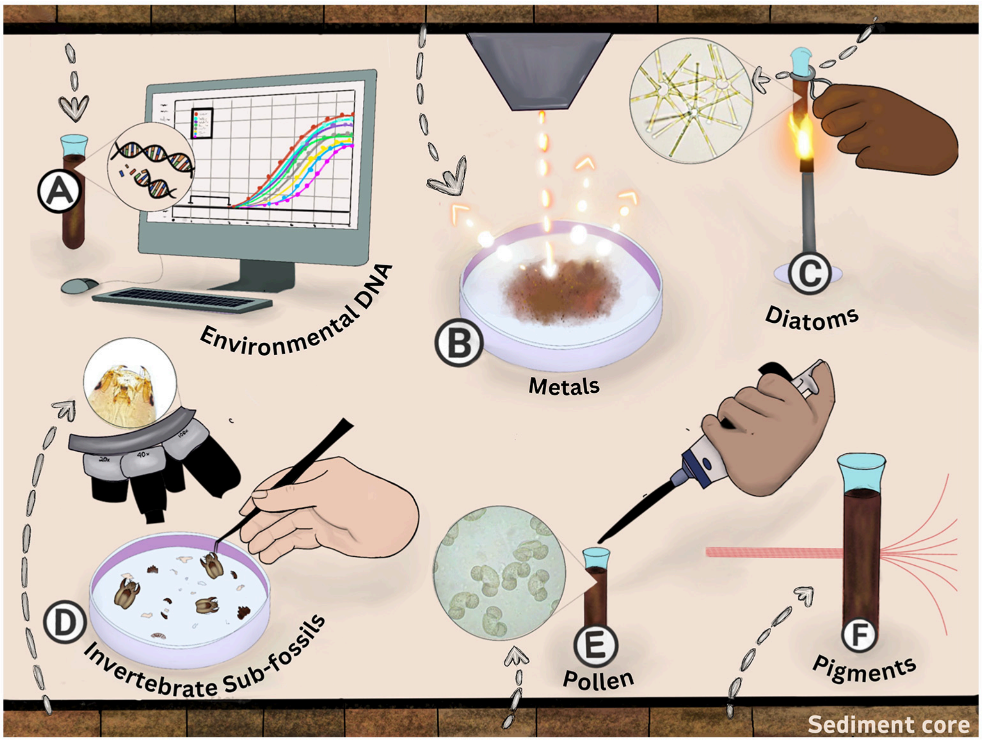

Figure 3

Figure 3

Some of the proxies that can be found in a sediment core to reconstruct past environmental changes. These proxies include: **(A)** environmental DNA, **(B)** metals, **(C)** diatoms, **(D)** invertebrate sub-fossils, **(E)** pollen, and **(F)** pigments.

Environmental DNA

All organisms, from microbes to plants to animals, shed cells, leaves, and hair into the surrounding environment. These materials contain DNA, a molecule that holds the genetic information unique to each organism. When it rains, DNA is washed into nearby lakes and is preserved in the sediment, allowing scientists to measure changes in biological communities through time (Figure 3A). For example, scientists have used the presence and disappearance of mammoth DNA in sediment cores to help learn when these animals went extinct [3]!

Metals

The concentrations of metals in sediment change due to natural processes, like erosion, or from human activities, like mining. If, for example, a factory is built that releases toxic metals like cadmium or lead as a by-product, these metals can pollute the nearby environment as they leave the factory from smokestacks or through wastewater from factory processes. When these pollutants reach a lake, they can collect in sediment and the metal concentrations can be measured.

Sub-Fossils from Aquatic Organisms

There are lots of algae and tiny animals that get preserved in sediment profiles when they die. These tiny, preserved organisms are called **sub-fossils**. Given their small size, scientists use microscopes to identify the sub-fossils (Figure 3C). One example is the group of algae called **diatoms**, which have cell walls made of glass! Because these cell walls are so strong, they do not decompose, so they are preserved in sediment. Different diatom species can only survive in certain water conditions, so changes in the diatom communities found in sediment cores can be used to understand changes in lake conditions. For example, some diatom species need lots of light to survive, and others do not. If a lake's water gets darker, the diatom community will shift from types that need lots of light to survive to those that need less light.

The larval stages of certain fly species, such as **chironomids**, are also common in lakes. Their mouth parts are preserved in sediment (Figure 3D), and different species can be used to understand changes in the lake that diatoms cannot tell us about, like changes in temperature or oxygen concentrations. Paleolimnologists look at how the diatom and chironomid communities have shifted throughout a sediment core to understand how the lake has changed over many years.

Pollen

Although paleolimnologists are usually most concerned about what is happening inside a lake, changes in the surrounding terrestrial environment (such as changes in vegetation) are also important

SUB-FOSSILS

The remains of organisms, like diatoms and chironomids, that are preserved in sediments. They are different from true fossils because sub-fossils do not mineralize into rocks.

DIATOMS

A group of algae with glass (siliceous) cell walls that are well preserved in sediments. Different species thrive in different environments, so their species distributions can be used to reconstruct past conditions.

CHIRONOMIDS

A group of insects whose larval stages typically live in lakes. Chironomid head capsules are specific to their species and so can be used to reconstruct past underwater oxygen levels and temperature.

to understand. For example, they might ask "When was this area deforested?" or "How did farming affect the environment?". Pollen grains come in lots of different shapes depending on the plant that produced them, all of which can blow into lakes where they sink to the bottom and preserve in the sediment. Paleolimnologists study changes in vegetation by using a microscope to see when shifts in pollen percentages occurred (Figure 3E).

Pigments

All plants and algae produce a **pigment** called chlorophyll to convert sunlight into energy. Scientists can use specialized tools to measure how light bounces off sediments, which can tell them about the amount of chlorophyll that was in the environment (Figure 3F). If chlorophyll increases over time, that means the lake had more plants and algae growing in it, which might happen, for example, when fertilizers from farming are washed into the lake.

PIGMENTS

Natural colored compounds from various plants, algae, and bacteria. Changes in the amount and types of pigments can be used to reconstruct past microbial populations in and around the lake.

BUILDING THE CASE

Once the sediment core is dated and the proxies are analyzed, paleolimnologists can weave the clues together to tell the story of environmental change through time. These results are then shared with policymakers and the public, so informed decisions can be made to fix environmental challenges. The long-term data from sediments are one of the most important things that policymakers use to make changes to protect the environment [4].

PALEOLIMNOLOGY IN ACTION

One of the most famous early uses of paleolimnology was to understand the effects of acid rain on the environment. Over 40 years ago, in the 1970s and 1980s, people in certain parts of the world noticed that rain had become very acidic. Imagine rain with a pH almost like lemon juice! This unhealthy rain caused lakes to acidify and harmed animals and plants in those lakes. Scientists thought that the acidification was coming from air pollution from factories and mines. But, since no data had been collected before those industries were built, some people argued that the lakes were naturally acidic.

To pinpoint what caused the changes in lakes, paleolimnologists looked at changes in diatoms, invertebrate sub-fossils, and pigments in sediments to determine what the environment was like before industries producing acidic emissions began polluting the atmosphere. The results were conclusive—many lakes were far more acidic than they were before emissions began, indicating that pollution from industries were in fact affecting the acidity of rain [5].

After the culprits of environmental harm were identified, many governments established anti-pollution policies to minimize future acidification impacts and to start the recovery process. Many lakes have improved, but some are still on the road to recovery, showing how environmental impacts can have very long-term effects. Without the data from paleolimnology, many of the improvements would not have happened.

PUTTING IT ALL TOGETHER

Lake sediment can be important for protecting the environment because sediment cores can serve as "time machines" that help paleolimnologists understand what the environment was like in the past. Learning how to interpret the clues found in sediment helped scientists understand and communicate about how the world has changed, due to both human and natural factors. This knowledge can help us to protect the environment, keeping it as healthy as possible for many years to come.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

CALEB, AGE: 12
Caleb enjoys all things science, animals, reading, exploring the outdoors, playing the violin, and curling. When he grows up, Caleb wants to be an architect focusing on eco-friendly and animal oriented buildings. He has tried four sports and is always up for trying something new. Caleb's favorite foods are macaroni and cheese or lasagna. He enjoys traveling and would like to go to an animal reserve.

CATALINA, AGE: 13
Hi! My name is Catalina and I love baking, reading and artistic swimming, but most of all I love learning.

MOMO, AGE: 13
Momo loves to travel the world and see new places. Even so, she is a self-proclaimed couch potato when she is at home. The two extremes can coexist in one person! Her favorite couchmate is her fuzzy and affectionate dog, Lita.

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Dr. Matthew Duda is an environmental scientist with interests in birds, fish, aquatic biology, and ecology. Much of his work is focused on using lake sediments to understand how animal populations changed in the past, so that we can understand how to best conserve them moving forward. He hopes that his work inspires young scientists and can help in exciting conservation work in the future. *mattpduda@gmail.com

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