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BIODIVERSITY
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UNRAVELING THE SECRETS OF LAKE OHRID, EUROPE'S OLDEST LAKE

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Lake Ohrid is located on the border of Albania and North Macedonia. It is believed to be the oldest and most biodiverse lake in Europe. Several hundred meters of sediments have built-up on the lake bottom since its formation. These sediments are a record of what happened both within the lake and in its environment in the past. Therefore, Lake Ohrid is a unique place to learn more about Earth's history. Drilling down into the lake bottom to get samples of sediment layers allowed us to unravel the secrets of the lake's history. The sediments revealed that the lake formed between 1.9 and 1.4 million years ago. They showed past environmental and climate changes in the Mediterranean region. Tiny fossils showed the evolution of the lake's biodiversity in the past, which benefitted from the lake's long and stable existence. The stability of Lake Ohrid's ecosystem is now threatened by increasing human impacts. Protecting this unique place is needed.

WHAT CAN LAKES TEACH US ABOUT THE PAST?

Lakes are found all over the world in many landscapes and climates. The environment of a region has a strong influence on the processes that occur in its lakes. One process is the build-up of particles, called **sediment**, on the lake bottom. Sediment can consist of mineral particles that enter or form in the lake, as well as the remains of plants and animals. The layers of sediments that form over time, from bottom to top, are like a history of past lake processes—lake sediments are a natural archive describing past environmental conditions in a region. Scientists study sediment layers to understand what processes happened in the lake since its formation.

SEDIMENT

Particles of rocks, soil, or other material like plants that are transported by water or wind and accumulate, for example, at the bottom of a lake or the ocean.

By unraveling how the lake's environment has changed, scientists can also learn how the climate has varied in the past. For example, the types and amounts of minerals in the sediments can tell a story about the erosion around the lake. Changes in erosion can be related to climate conditions, such as the frequency and amount of rainfall. Specific minerals can also reveal changes in the source and amount of lake water. Scientists investigating minerals in the sediments can, for example, reconstruct if the water level dropped in the lake when rainfall was scarce. Fossils of plants, tiny shells, and skeletons of animals found in the sediment can tell us about the species that lived in the lake. As species adapted through time to various environmental conditions in the past, their fossils now tell us about changes in the climate.

THE SCOPSCO PROJECT—STUDYING LAKE OHRID'S SEDIMENTS

Lake Ohrid is located in the central Mediterranean region, on the border of Albania and North Macedonia. The lake is about 30 km long, 15 km wide, and up to about 290 m deep (Figure 1). Lake Ohrid has many **endemic species** which live only in this lake. Their high number indicates the long existence of the lake. Lake Ohrid is thus one of the few lakes worldwide that allow us to study how the environment and the life in the lake developed. Scientists from several countries started a joint project to investigate the lake and its sediments. The project is called Scientific Collaboration on Past Speciation Conditions in Lake Ohrid (SCOPSCO), and it focuses on many questions, such as: *How and when did the lake form?*; *What can we learn from the sediments about the past climate?*; *How did species develop within the lake?*; *What can we learn about the future from our observations of the lake's past?*

ENDEMIC SPECIES

Species found only in a single defined place and nowhere else on the planet.

A **hydro-acoustic survey** was performed to find the best spot to drill down into the sediments. This survey showed a view of the underground sediment structures for the first time [3]. In places where the sediment structures are undisturbed, scientists can obtain

HYDRO-ACOUSTIC SURVEY

A technique that uses sound waves to create a picture of underground structures.

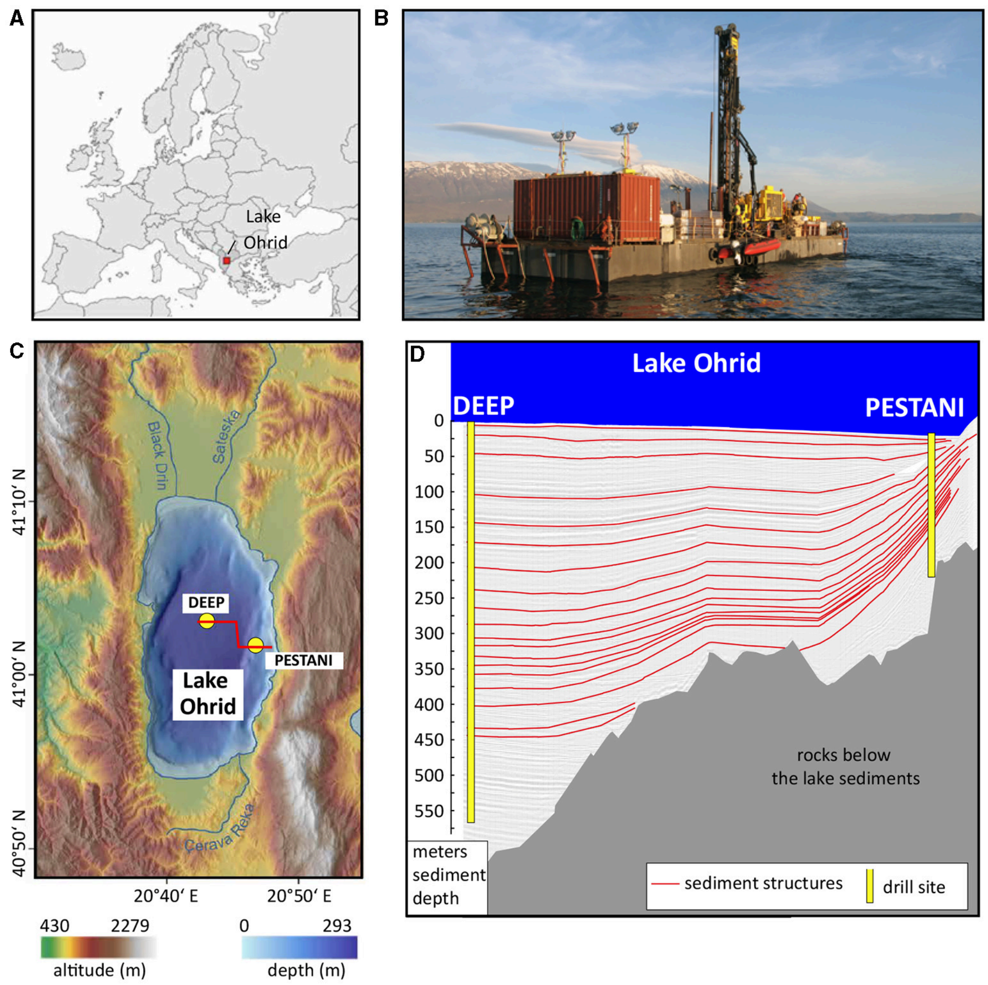

Figure 1

Figure 1

(A) Location of Lake Ohrid within Europe and **(B)** drilling platform used for recovering the lake sediments. **(C)** Map of the lake showing the location of the hydro-acoustic profile (red lines) and the drilling sites (yellow spots). **(D)** The results of the hydro-acoustic profile show undisturbed sediment structures (red parallel lines) at the drill sites DEEP and Pestani. **(A, C)** were modified from [1] and **(D)** was modified from [2].

a complete record of the lake's history (Figure 1D). A team of about 30 scientists from several countries, along with professional drillers, drilled the lake's sediments in 2013. The deepest drill hole (DEEP site) reached 569 m below the lake floor, in the center of the lake [2, 4]. All sediments deposited since the lake's formation were recovered there. Drilling produces long cylinders of sediment called **cores**. Sediment cores were opened lengthwise and analyzed to study sediment layers (Figure 2A). Sediment samples were sent to researchers around the world for detailed analysis. They analyzed the size of sediment grains as well as the elements, minerals, and evidence of living things to understand sediment formation and past environmental conditions.

CORES

Cylindric-shaped pieces of rocks or soil which can be retrieved by drilling into the Earth's underground.

HOW AND WHEN DID LAKE OHRID FORM?

Dating of old sediments in lakes is challenging. One way to do so is to use known past environmental events, like volcanic eruptions. Eruptions can leave ash deposits that make their way to the sediment.

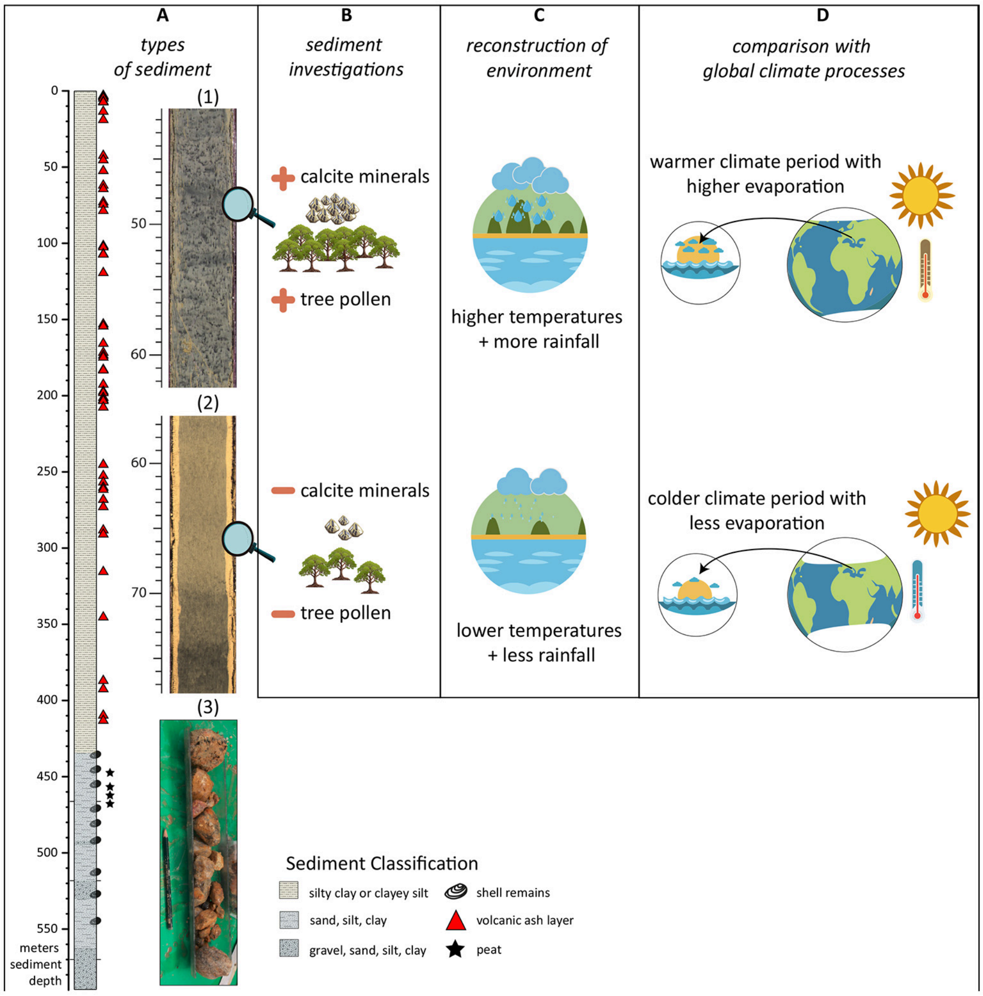

Figure 2

Figure 2

(A) The sediments drilled in Lake Ohrid have different grain sizes, volcanic ash, shells and peat layers. Pictures (1–3) show different types of sediments. Before the lake formed, coarse grained sediments from ancient rivers were deposited (picture 3). When a bigger lake formed, the sediments became more fine-grained (pictures 1–2). The sediments revealed information about the past environmental and climatic conditions. If sediment investigations showed higher (lower) amounts of calcite minerals and tree pollen **(B)**, the local environment experienced more (less) rainfall and higher (lower) temperatures when the sediments were deposited in the lake **(C)**. **(D)** Shows the global climate during these times.

The exact composition of an ash layer in the sediment can reveal which volcanic eruption it came from. If scientists know the date of that eruption, they can use that info to date the sediment layers. The sediment record from Lake Ohrid contained 16 layers of ash from known, dated volcanic eruptions [5]. Another event that can be used for dating is a change in Earth's magnetic field. Such events were identified in the Lake Ohrid sediments, which provided additional information on the age the sediment. More age information came from variations in sediment composition. All age information was combined to calculate a specific age for each sediment depth [4].

Sediment data provided unique information on the age and origin of Lake Ohrid [2, 4]. Hydro-acoustic data suggest that the formation of Lake Ohrid started with a narrow valley. The lowermost sediments obtained by drilling documented the earliest phase of the lake, which began around 1.9 million years ago (Figure 2). The sediments consisted of small, rounded rocks and smaller gravel, which indicated that a river drained the valley. Toward the top, finer-grained sediments and occasional layers of plant material called peat were found, along with shell remains. This tells us that the narrow valley eventually widened, and a series of small ponds formed in the valley. Fossil algae and specific compositions of minerals suggested that these ponds were partially connected, but they existed for only a short time. The valley continued to widen, and at 1.36 million years ago, a permanent, larger lake developed and has existed since then [2, 4]. Now we know that Lake Ohrid is 1.36 million years old!

PAST CHANGES IN MEDITERRANEAN RAINFALL PATTERNS

The sediments of Lake Ohrid are a natural record of 1.36 million years of environmental change. Natural records of similar age are extremely rare. The sediment compositions tell us that the climate varied over time [4]. Changes in amounts of some minerals, such as calcite, as well as variations in the amount of tree pollen, are related to the amount of rainfall. Looking for these changes in the sediments can help us determine past rainfall patterns. The data suggest that rainfall increased during specific warm periods (Figure 2). During these periods, the position of the Earth relative to the Sun caused the planet to receive more solar energy during summer. This warming period increased the temperature of the Mediterranean Sea, leading to increased evaporation and moisture in the atmosphere. Thus, more clouds formed and increased the rainfall over Lake Ohrid.

HOW HAS BIODIVERSITY EVOLVED IN LAKE OHRID?

One of the most exciting questions in biology is what drives the evolution of new species and the disappearance (extinction) of existing species. Fossils of tiny algae from the sediments of Lake Ohrid can help scientists answer these questions [1]. Formation and extinction of species can be directly compared with the rate of environmental changes recorded in the sediments. This made it possible to determine the effects of these environmental events on the evolution of the lake's species. The fossil record shows that new species evolved within a few thousand years after the lake's formation, indicating a very rapid **adaptation** of these new species to the Lake Ohrid ecosystem (Figure 3). However, during the early, shallow phase of the lake, environmental conditions like temperature, water level, and nutrients changed very rapidly. As a result, many new species died out as quickly as they emerged. Once the lake reached stable, deep water conditions, **species richness** stabilized (Figure 3C). This stability was achieved by two processes. First, fewer new habitats were created as the lake stabilized, so the evolution of new species also decreased (Figure 3D). Second, the extinction rate decreased as the size and depth of the lake increased, protecting organisms from environmental changes (Figure 3E). These new findings could explain the extremely high species richness in Lake Ohrid.

ADAPTION

Ability of an organism to change to new conditions.

SPECIES RICHNESS

Number of species present in a specific area or ecosystem.

Figure 3

(A) Shows three intervals (gray shapes) of the evolution of Lake Ohrid during the past 1.7 million years (Ma). The basin was first characterized by rivers and small ponds (A1). Starting about 1.4 Ma ago, a larger lake developed (A2, A3). **(B–E)** Show how species developed after a permanent lake had formed and slowly got deeper. Microfossils found in the sediments show that new species evolved and died out rapidly in the shallow lake (A2). As the lake deepened, speciation and extinction rates became very similar and remained similar over a long period of time (A3). Figure based on [1–3].

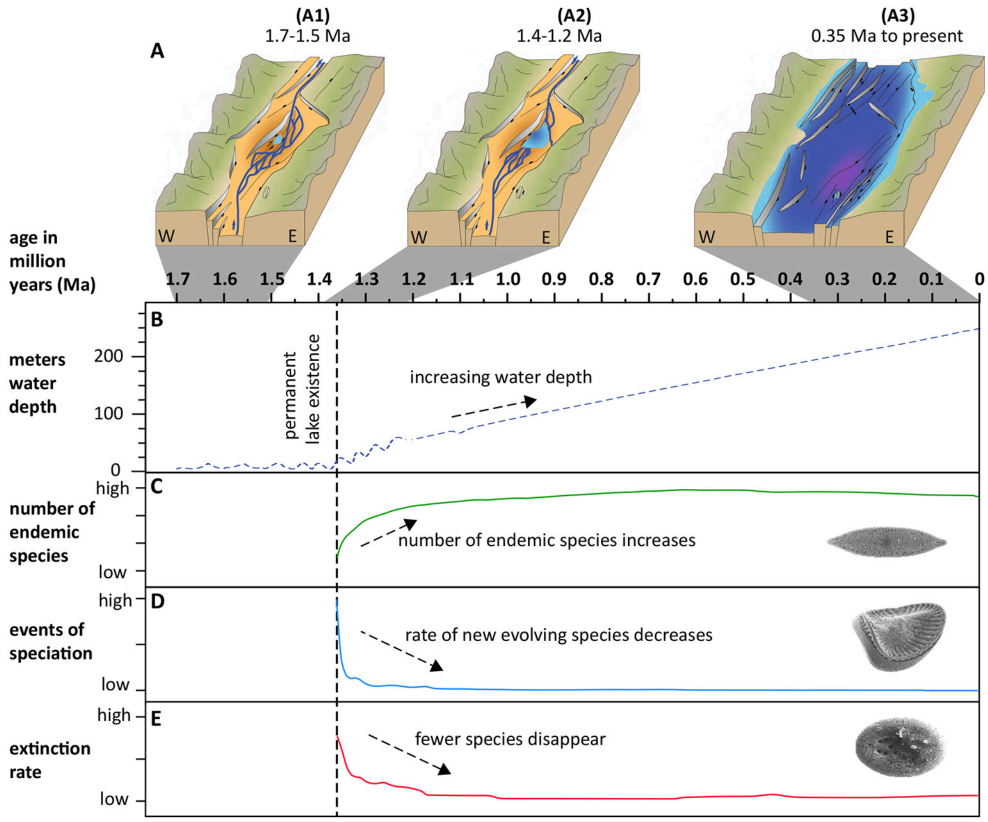

Figure 3

WHAT HAVE SEDIMENTS TAUGHT US ABOUT THE FUTURE?

CLIMATE MODELS

Computer calculation of how the climate and its parameters behave according to several factors, such as temperature, rainfall, or wind.

BUFFER CAPACITY

The ability to maintain stable conditions, even under changing external conditions, which is helpful to protect living things.

Scientists use **climate models** to make predictions about future climate change. These climate models need a good understanding of the ocean and atmosphere processes involved. We can learn about these processes by studying sediments which tell us about how these processes influenced the climate of the past. Information from Lake Ohrid sediments showed that the environmental causes of extreme precipitation in the past were similar to modern processes. This is important to know because it is difficult to understand how future precipitation will change based on the current climate models. Information about the change in precipitation is of great interest to the people living around the Mediterranean Sea because the winter rainfall of this region affects the types of plants that can grow there. The Lake Ohrid's sediments also allowed us to study how life developed after its formation. Once Lake Ohrid was established as a permeant lake, its high **buffer capacity** protected species from many natural environmental changes, such as climate change. However, the increasing human activities in and around Lake Ohrid threaten this balance. An imbalance could cause many of the lake's endemic species to go extinct.

In summary, studying the sediments of Lake Ohrid uncovered past environmental processes from which we can learn how the climate system changed and how the environment has responded to these changes. This helps us to prepare for future changes and to develop plans to protect the environment.

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ORIGINAL SOURCE ARTICLE

Wagner, B., Vogel, H., Francke, A., Friedrich, T., Donders, T., Lacey, J. H., et al. 2019. Mediterranean winter rainfall in phase with African monsoons during the past 1.36 million years. *Nature* 573:256–60. doi: 10.1038/s41586-019-1529-0

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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.

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JULIA, AGE: 12

Julia is a 12 year old student at Fairfield Wood Middle school. She enjoys learning about the world. Her passion is music and she plays several instruments, writes songs, and jams with her friends. She loves her dog Joy that never refuses a hug.

MOMO, AGE: 11

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

AUTHORS

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Niklas is a geologist at the University of Cologne. He is particularly interested in volcanic ash layers that document past explosive volcanic eruptions to study volcanic histories. He also uses volcanic ashes to date sediments and to link sedimentary records containing the equivalent ash layers to understand the timing of environmental change. He enjoys being outdoors—either exploring new sedimentary records or spending time and going hiking with his family. When at home, he enjoys cooking for his family and friends. *n.leicher@uni-koeln.de

BERND WAGNER
Bernd is a geoscientist at the University of Cologne. He studies sediments from lakes all around the world, from Greenland in the north to Antarctic lakes in the south. The sediments of these lakes tell the history of the lakes and their environments over up to millions of years. He likes traveling, cycling, sailing, and being in nature.

THOMAS WILKE
Thomas is an evolutionary biologist at the Justus Liebig University Giessen. He uses molecular, ecological, and modeling approaches to study speciation and extinction events in isolated ecosystems such as ancient lakes, springs, coral reefs, and brackish-water lagoons. He enjoys scuba diving, hiking with his dog, and being inspired by nature every single day.

SEBASTIAN KRASTEL
Sebastian is a marine geophysicist at Kiel University. He mainly studies underground structures of sediments in the oceans to analyse geohazards and sediment transport processes that shape the structure of the seafloor. To do this, he uses various acoustic systems such as a variety of echo sounders. The same systems can also be used in lakes, and so lakes became another area of interest for Sebastian. When he is not at sea or on a lake, Sebastian enjoys playing team handball, cycling, and hiking. He is also a youth team handball coach.