

THE STORY OF INTERGLACIAL PERMAFROST UNRAVELED IN FROZEN CAVES

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What is permafrost, and why should we care?

Over 10% of the Earth's land is covered in permanently frozen ground, called permafrost (Fig. 1). As humans cause the planet to warm up through climate change, permafrost will begin to thaw. What happens to it will have tremendous repercussions both locally and around the world.

Permafrost forms when the ground temperature drops below zero degrees Celsius (32 degrees Fahrenheit), freezing the water within. If temperatures the following summer aren't warm enough to thaw the ground, it stays frozen all year. When this continues for two or more years... **Voilà! You have permafrost.**

Most of the permafrost that exists today formed during the last ice age*, around 20,000 years ago, when the Earth was much colder. Ancient organic matter, like dead and decaying plants and animals, has remained frozen inside until the present day. Now, as humans cause our planet to warm, we're measuring permafrost thaw accelerating, especially at its most southern edges. As it does so, the frozen organic matter starts to break down to carbon dioxide and methane (Fig. 2). This has the potential to release vast quantities of greenhouse gases* into the atmosphere and accelerate climate change.

Scientists are worried that large-scale thawing of permafrost could release greenhouse gases into the atmosphere. This will cause further warming and increase the rate of permafrost thaw, creating what we call a positive feedback loop. This makes permafrost a tipping element—a key component of our climate which, once pushed into a new state, could cause irreversible changes to the climate system.

Permafrost

covers circa 15% of the Arctic and Subarctic of the northern hemisphere.

Permafrost belongs to the periglacial, the regions that are cold, but not covered by glaciers and ice sheets.

The Arctic

is not limited by the Arctic Circle but often defined as the region around the North Pole where the mean July temperature remains below 10°C. This region is surrounded by the 10°C July isotherm

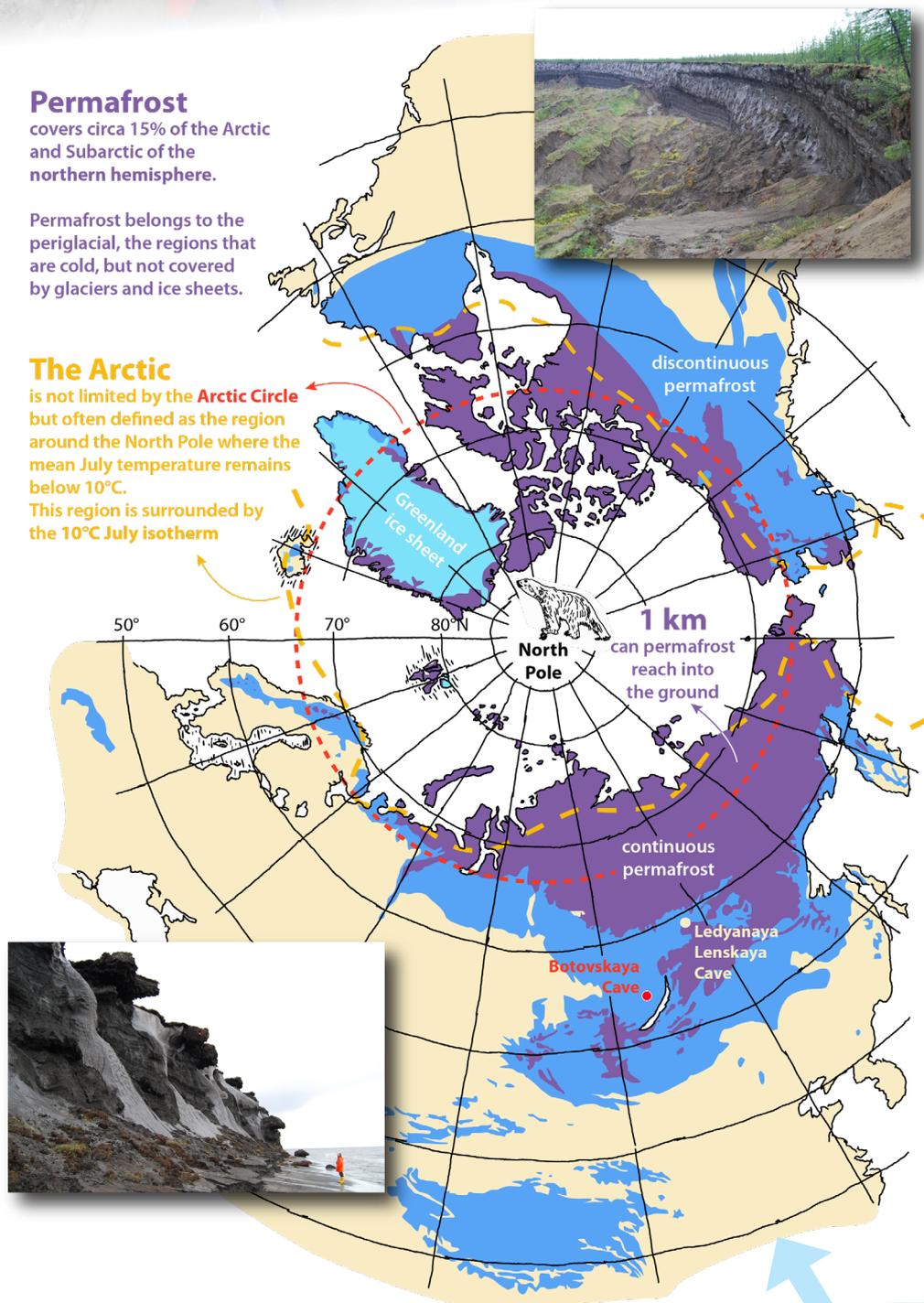


Figure 1 Permafrost is widespread in Siberia, Canada, Tibet, and northern China. We study the Lenskaya and Botovskaya caves in Siberia. This map shows a view of the Earth looking down from above the North Pole.

How are scientists using past interglacials* to predict future changes in permafrost?

Scientists look to warm periods of the Earth's history, known as interglacials, to understand how permafrost might respond to human-caused climate change in the future.

Over the past 2 million years or so, the Earth has cycled through cold and warm periods, called glacial* and interglacials respectively. We are looking at how permafrost has changed in past interglacials, when the global temperature was similar to, or warmer than, today. Sadly, we can't go back in time and check the permafrost conditions directly. So, we need somewhere in which clues as to ancient permafrost behavior are preserved to the modern day. We find such places in caves, in the form of calcium carbonate deposits known as speleothems.



Speleothems come in many forms—for example, you may have already heard about stalagmites! They form over thousands (sometimes even millions!) of years when calcium carbonate precipitates from drip water. It's the same process that sometimes causes chalky deposits (limescale) to build up on your shower and hot water pipes.



To find suitable speleothems, we travel to remote corners of Siberia and explore kilometers of caves, many of which have never been explored before.

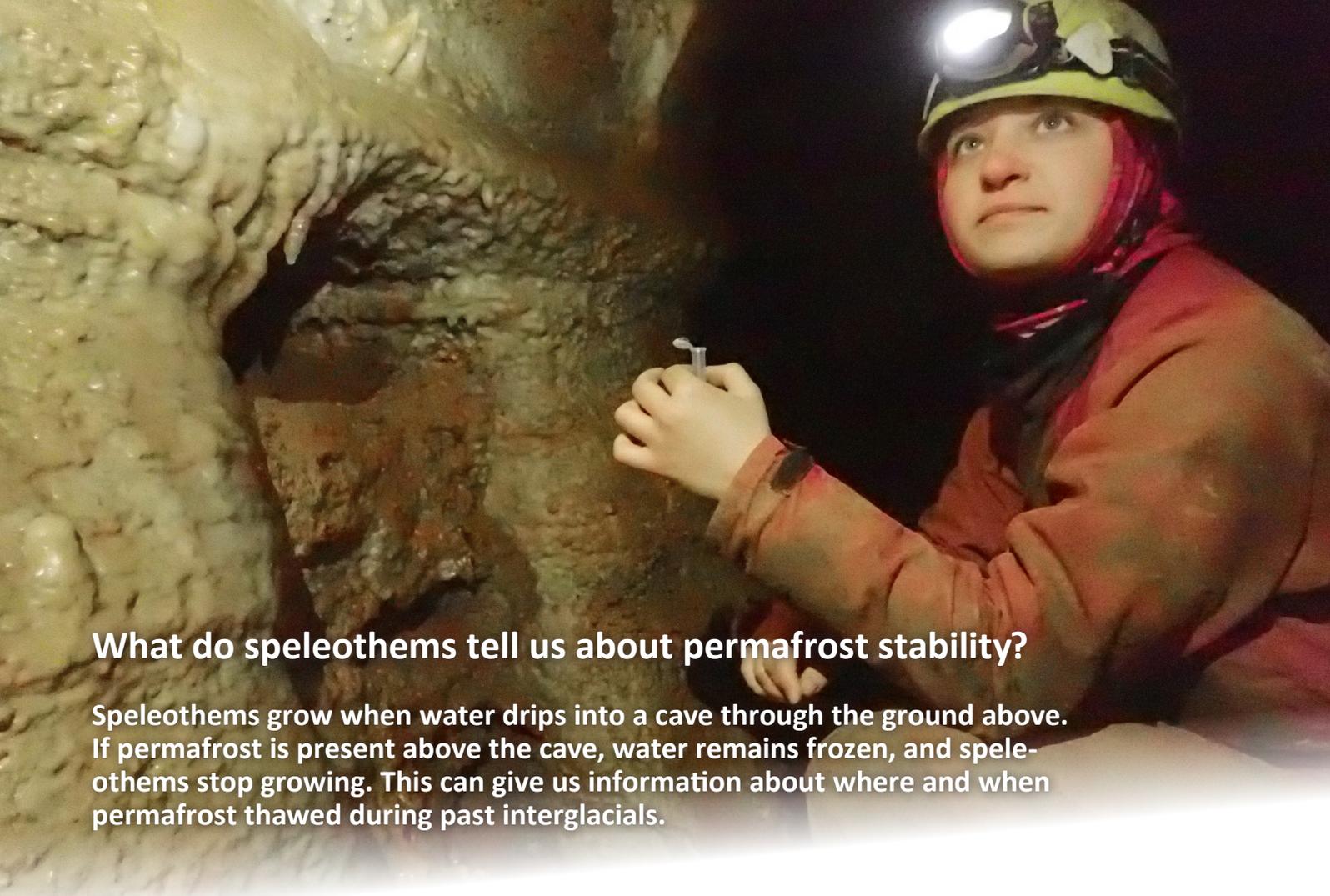


Wherever we stop, we make a fire and drink tea because it's so cold.. Sometimes we even make a sauna!



Our expeditions often take place in winter, when temperatures as low as -40°C (-40°F) turn rivers into ice roads that allow us to travel to the caves.

We also monitor environmental conditions of the cave like temperature, drip rates, and CO_2 concentration. This can help us understand the impact of specific environmental parameters (like temperature, drip rate, water chemistry, or cave ventilation) on speleothem composition as they grow.



What do speleothems tell us about permafrost stability?

Speleothems grow when water drips into a cave through the ground above. If permafrost is present above the cave, water remains frozen, and speleothems stop growing. This can give us information about where and when permafrost thawed during past interglacials.

interglacials

allow for soil growth. organic material accumulates in soggy, suboxic peat and soil

glacial permafrost

keeps huge amounts of un-degraded organic material frozen

thawing permafrost

releases greenhouse gases from fossil organic material

more greenhouse gases increase global temperature

rising temperature forces more thawing

thawing releases greenhouse gases

Figure 2

In temperate soil, microbes break down organic matter, releasing greenhouse gases*. Permafrost freezes microbes so they're unable to break down organic matter, trapping it in the ground, often for thousands of years. When permafrost thaws, microbes start breaking down fossilized organic material, releasing huge amounts of greenhouse gases.

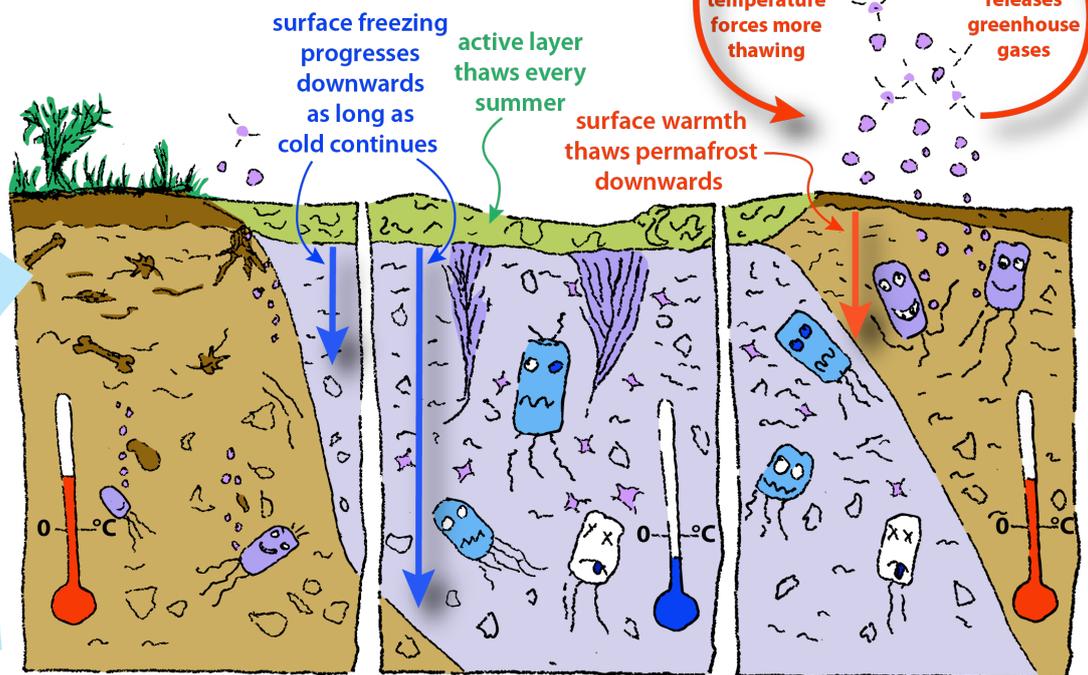
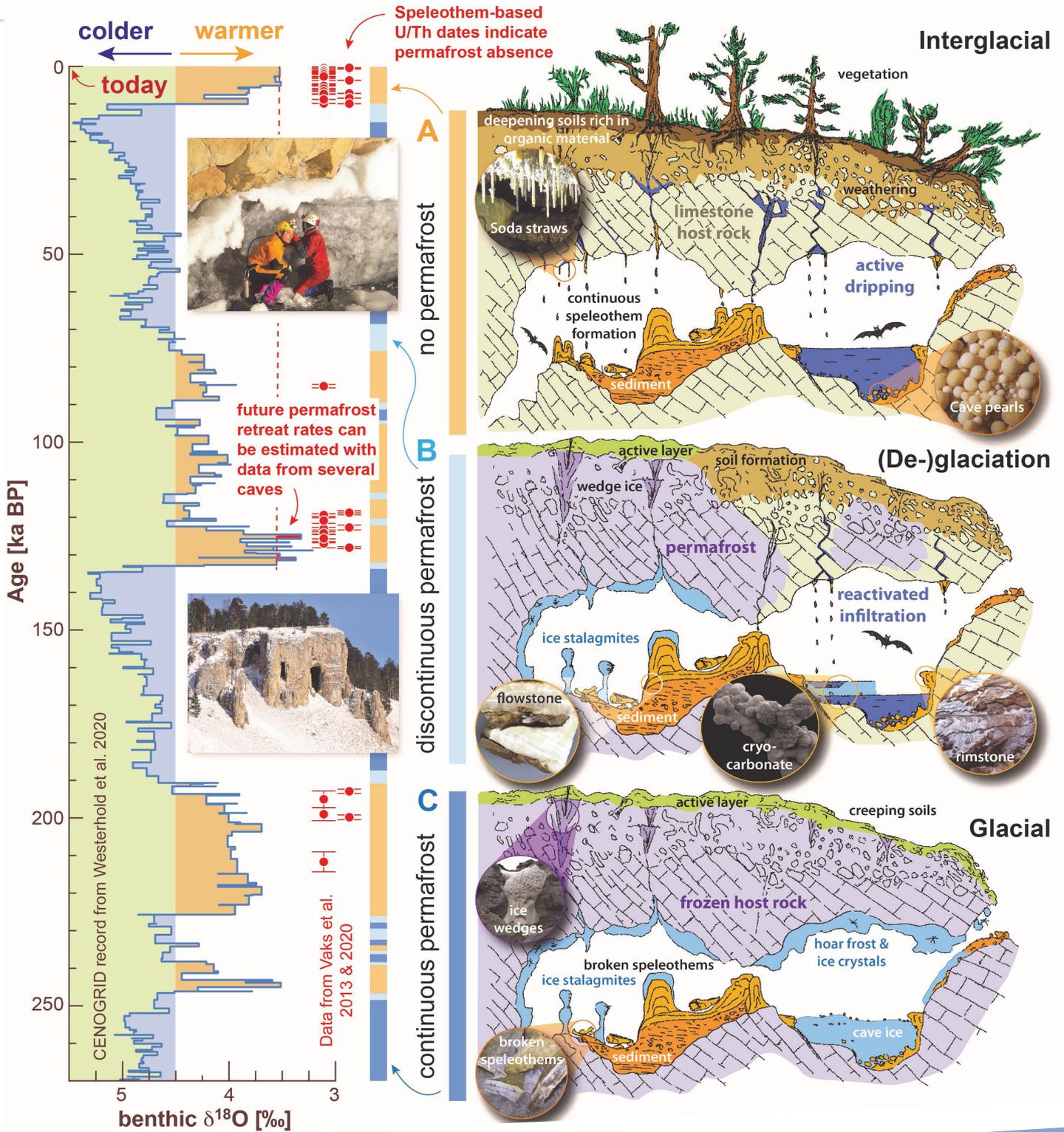


Figure 3

A During a warm interglacial, permafrost thaws and drip water enters the cave, allowing speleothems to grow. With a warmer climate, the soil deepens, and vegetation returns. This causes chemical changes in a speleothem as it grows that we can use to reconstruct past environmental conditions! Looking at past warm intervals when permafrost thawed (e.g. 125,000 years ago) can help us predict if/when permafrost might thaw in the future.



B At the beginning and end of glaciations, discontinuous permafrost forms in some sections of the cave, stopping speleothem growth, while thawing in others, allowing water to infiltrate. Speleothems can tell us about the timing of ground freezing and thawing. Cryo-carbonates form when calcium carbonate precipitates out of (re-)freezing water. Sampling multiple caves, we can also establish the speed of permafrost thaw.

C During glacials the cave “hibernates”. Permafrost surrounds the cave, water stops flowing, and ice often accumulates inside.

Understanding the conditions under which permafrost thaws

We can look at the chemical composition of a speleothem to give us clues as to the timing and environmental conditions of past interglacials.

Speleothems can be dated accurately using a technique called radiometric dating. This allows us to determine when permafrost was absent from above the cave.

As speleothems grow they incorporate tiny amounts of radioactive uranium isotopes.* These decay over thousands of years. As they decay, the concentration of uranium within the speleothem decreases. Uranium decays into thorium and lead, increasing the concentration of these “decay products” over time. By measuring the ratio of uranium to thorium or lead, we can determine when the speleothem formed. This tells us when permafrost around the cave started to thaw.

Atoms come in heavy and light forms that we call isotopes. The different isotopes within a speleothem give us further clues as to the environmental conditions—how warm or wet it was, for example—when permafrost thawed. We hunt for tiny bubbles of water trapped in the speleothem as it grows. The number of heavy oxygen isotopes found in the water changes with the precipitation conditions when it was trapped.

The concentration of noble gases dissolved in the water depends on temperature. So, we can measure them and estimate the temperature of the water when it was trapped. We can combine this by looking at the way that carbon and oxygen are bonded together within the speleothem. This changes as the cave warms and cools. So, we can use it to estimate the temperature at which speleothems formed—even if that’s millions of years ago!

We can measure many other speleothem properties to learn about the past. As speleothems form, tiny traces of chemicals are deposited in the calcium carbonate. Their quantities change with environmental conditions like rainfall, vegetation, and even the number of wildfires! We can measure these in the lab to build up a detailed picture of environmental conditions when the speleothem formed.



Radiometric dating is conducted in ultra-clean labs. We have to wear space-age bunny suits, so we don't contaminate our speleothem samples!



We measure the chemical and isotopic composition of speleothems on machines called mass spectrometers.

In this way we can infer the timing and environmental conditions of permafrost thaw at different locations. This allows us to reconstruct permafrost shifts in response to warming and helps us predict what might happen to permafrost as anthropogenic warming continues in the future.