# TESTING THE UPPER LIMITS

Science explorers battle the elements to drive new discoveries in extreme high-altitude laboratories

**Figure 1.** Dr. Lee Florea endures extreme conditions to research Mount Rainier's microclimates. (Photo courtesy of James Frystak)

## PROJECT BACKGROUND

For two days, hydrogeologist Lee Florea and his fellow explorers have been slowly plodding step by step to the top of Washington's Mount Rainier. Laden with up to 80 pounds of supplies and scientific gear, they watch enviously as recreational climbers cruise past them carrying half that on their path to the summit.

But there's a big difference between the two groups: when Florea and his team members reach the top, their expedition will have only begun.

They're on a quest for knowledge hidden in caves at the summit of Mount Rainier, formed by fumaroles leaking gases beneath glaciers trapped in volcanic craters. Gathering data in this hostile environment calls for scientists willing to go to the ends of the Earth—and an intrepid support team of expeditioners to get them there.

Exploring these otherworldly laboratories is more than just an adventure into the shifting depths of high-altitude ice. It's a chance to make sense of complex hydrothermal processes, advance exploration of distant icy worlds, and better understand the impacts of a changing climate.

## AN UNEXPECTED JOURNEY

When Lee Florea was in college, he had no idea he'd one day be pushing the boundaries of glacier cave research. In fact, he was majoring in physics and math when a class at Mammoth Cave sparked a passion for mapping caves. Today, he's assistant director for research at the Indiana Geological and Water Survey and a hydrogeologist at Indiana University.

In 2014, Florea was at the annual Geological Society of America meeting in Vancouver when he met an old friend who was researching Mount Rainier's summit craters.

In typical geologist fashion, his first question was, "Where do I sign up?"

As it turned out, her team had plenty of scientists and cavers, but few, like Florea, were both. So he jumped into the research and preparation for his first trip, set for the following year. It wasn't going to be easy.

"Rainier was my first true technical mountain climb," Florea says. "I'd been up a 14,000-foot peak in Colorado in summer—a trail that goes up to a pile of rocks—but nothing as serious as this."

His colleague connected him with expedition leader Eddy Cartaya, co-founder of Glacier Cave Explorers. The group is part of a nonprofit chapter of the National Speleological Society, organizing cave research expeditions on Mount Rainier, Mount Hood and Mount St. Helens. It's a herculean effort that involves collaborating with multiple organizations, including obtaining permits from the National Park Service (NPS) and funding from National Geographic.

Cartaya, known as "Glacier Cave Eddy," is a certified cave rescuer whom team members describe as someone akin to the Energizer bunny.

"That first year, I think Eddy was really concerned about me," says Florea. Before the trip, Cartaya sent him workout schedules, to-do lists and tips, like stocking up on medication to prevent altitude sickness.

"He made it seem like you needed to know what you're doing or you were going to die," Florea says.

And for good reason. Beyond frostbite and physical exhaustion, expeditioners faced risks unique to traversing glaciers atop an active volcano. From avoiding crevasses to the constant threat of avalanches, earthquakes and rockfall, the trips are not for the faint of heart.

Then there were the toxic fumes, which National Geographic photographer Tom Wood experienced firsthand. Wood was photographing cavers in the west cave and had pre-installed rescue rigging and an air monitor nearby.

"The air monitor was fine at three feet off the ground, but when I bent down to take a photo, I ducked into a $CO_2$ lake," he says. Because carbon dioxide is denser than air, in this environment it can settle into an invisible layer capable of knocking someone out in two breaths.

"Everything went gray, and I was unconscious in half a second," Wood says, adding that he luckily fell uphill, just above the layer of bad air. "It was a little scary, but if I'd needed rescue we were prepared.

**Figure 2.** Collecting water samples from Lake Adelie to establish baseline data. (Photo courtesy of FX De Ruydts)

## NO COUNTRY FOR WHINERS

Safety is a key reason why Cartaya takes extreme care to assemble such a strong team of cavers, medical professionals and high-angle rescue experts.

In addition to Florea, the team included climatologist Andreas Pflitsch of Ruhr University in Germany, who studies interactions between air flow, cave climate and the volcano's hydrothermal system. Aaron Parness and Aaron Curtis from NASA's Jet Propulsion Laboratory (JPL) also came along to test ice-drilling robots that could one day be used to explore Mars and Europa and collect microbiological samples for Penelope Boston at NASA's Astrobiology Institute.

The expedition's cave surveying and mapping team included Christian Stenner and Katie Graham, whom Wood calls "two of the best cavers in the world." Combined with Pflitsch's data, their documentation of changes in cave size could indicate not only effects from Mount Rainier's hydrothermal system, but also from climate change as a whole.

The team had roughly 100 people carrying gear up and down the mountain, but National Park Service permits allowed only twelve people to camp overnight at the summit. Everyone had to wear multiple hats. Cornelius "Woody" Peeples, for example, the team's charismatic doctor, also served as the latrine manager.

**Figure 3.** Members of the Mt. Rainier expedition team. (Photo courtesy of Tom Wood)

## A DATA ODYSSEY

The team's ascent followed the Camp Muir route, an unmarked route surrounded on both sides by glaciers. They camped briefly at Ingraham Flats, elevation 11,000 feet, then made another grueling climb up 3,300 feet of ice and established a camp in the summit crater to explore cave within the East and West Craters just below the summit.

Accumulated snowfall in the craters becomes packed ice to form glacial plugs 400 feet or more in thickness. Fumarole gases have melted the bottom of one of these plugs—the ceiling of a glacial cave—to form Lake Adelie, the highest-altitude lake in North America.

The first year, Florea's aim was to get baseline data from water samples collected from Lake Adelie's dripping cave walls and fumarole steam condensation. For everyone, having instruments rugged enough to withstand harsh conditions was a big concern.

"It's tough to get things accomplished up there," Florea says. He recalls how upset Pflitsch was when rockfall broke an anemometer for measuring wind speed. It had taken three people to get the anemometers to the summit, and just one worked for a few days.

Florea himself was able to get data from only one of four glass tubes used to collect fumarole gases. "You can only expect to get a fraction of the data you want back."

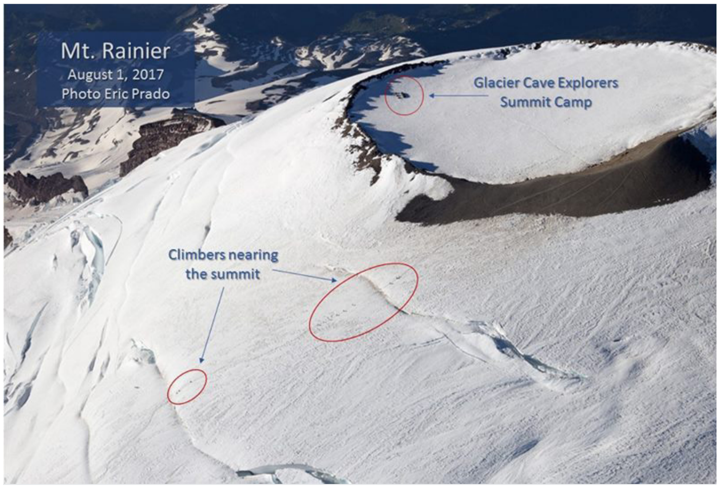


**Figure 4.** Climbers approach the summit camp of Mt. Rainier. (Photo courtesy of Eric Prado)

On the 2016 trip, Florea left behind In-Situ instruments in Lake Adelie to collect data over an entire year. He set up an Aqua TROLL 200 to record lake temperature, depth and conductivity, also suspending a Baro TROLL nearby for barometric compensation since he couldn't use a vented tube.

"Nothing is stable there," he says. "The glacier is moving, the rocks are moving, the lake level goes up and down. There's nothing to attach instruments to."

Given the constant environmental fluctuations and difficulties other team members faced with their instruments, he didn't have high hopes for his setup.

"We wished it luck, believing we'd never see it again."

In 2017, Florea returned on his third expedition. While he had no trouble retrieving the Baro TROLL, the data logger itself was lodged between two boulders in the lake, which had shifted. He didn't think he'd be able to retrieve it. But with a little ingenuity, a GoPro and a selfie stick, they were able to pry it loose.

"There wasn't a single ding or scar on the data logger, says Florea, who was shocked. "I was also afraid the lake freezing over would have burst the pressure transducer membrane on the bottom, but it didn't. It was perfectly intact."

At 14,000 feet with no way to download the data, he was left wondering for two weeks whether it had actually managed to collect any readings. What awaited Florea back at sea level was the biggest surprise of all.

"It had a beautiful, year-long set of data on it," he says. "I was just amazed."

## THE QUEST CONTINUES

Florea hasn't published his results yet, so he's hesitant to make any big conclusions. However, initial data reveal a complex interplay between precipitation, fumarole activity and lake level.

He hypothesizes that when snowfall seals off the cave entrances, air flow is reduced. Trapped fumarole gases then warm the cave, melting ice on the ceiling and raising the lake's water level. The rising temperature also melts the seal on the cave entrance, opening it up again.

"That allows cold air to circulate, which causes the temperature to drop again. It's cyclical," he says.

Freeze-thaw cycles in the ground, which relate to snowfall intensity, can also mobilize rockfall that raises water levels. What scientists need to find out, he says, is how wind speed and fumarole temperature changes affect these processes.

"We know they're not all changing temperature at the same time or rate, so there are things happening in terms of when and where volcanic heat is rising that we don't understand."

From a practical perspective, Florea says knowing how cave entrances change can inform how the NPS can protect them from damage—and protect tourists from injury. Data from these caves, which are part of the Mt. Rainier Wilderness, will help the NPS meet its management objectives to protect these rare and sensitive environments.

Florea also points out the importance of understanding the cave system's overall water balance in terms of monitoring geohazards. In addition to the water that circulates within the cave itself, some of it enters the groundwater within the volcanic edifice.

**Figure 5.** Dr. Lee Florea deploys an Aqua TROLL 200 in Lake Adelie. (Photo courtesy of FX De Ruydts)

Heated thermal groundwater can weaken the volcanic rock, contributing to landslides and glacial outburst floods.

Ultimately, expeditioners are risking their lives to answer these types of questions. For Tom Wood, who admits to losing most of his toenails on the trek back down the mountain, being part of the research is worth it.

"At the end of the day, we're helping scientists achieve some pretty important goals," he says.

Of course, getting the data is no simple task; it takes a special caliber of person to engage in this high-stakes research. Everyday people advocating for continued land access is also crucial to moving the science forward.

"It's getting harder and harder for the government to let people do this on public land." says Wood. "Support from the public is what makes these trips a reality."

Also essential is the support team backing up the researchers.

"What many don't understand is that most of us are volunteers," says Wood. "It's a great example of what people can do if you just let them.

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