Mysterious Rotten-egg Smell of Lake Kauhako

A strange rotten-egg smell is coming out of Kauhako Crater Lake on Molokai's Kalaupapa Peninsula. Residents first noticed the smell in September 2011. When park rangers investigated, they found the usual green color of the lake had turned into a milky brew. The rangers concluded that an "overturning" had happened.

To get a first-hand look at this mysterious phenomenon, IPRC's **Axel Timmermann** and **Niklas Schneider** fly to Molokai in May 2012. They take along IPRC postdoctoral fellows **Pedro DiNezio** and **Malte Heinemann** and lots of equipment to study the lake's water characteristics.

A former central vent of Kauhako volcano, the tiny pond-like lake is very deep…over 240 meters. With a surface area of less than an acre, it is the lake with the largest depth-to-surface-area ratio in the world.

"Our hydrographic measurements from 2006 and 2010 have revealed a brackish oxygenated layer about several meters thick floating on top of saline anoxic water with a salinity similar to the nearby ocean," explains Timmermann. "At depth, sulfate reducing bacteria transform the sulfate of seawater into hydrogen sulfide. Something must have happened that September to make the deep layer come to the surface, belching hydrogen sulfide and turning the lake into the milky brew."

Arriving at the crater rim, the IPRC team is disappointed —not a whiff of a foul smell, and the lake glows in its usual emerald hue. Helped by ropes, they climb down the steep crater walls. It takes a good hour with all their equipment. At the lake's shore they set up their computer to record the data to be transmitted via a cable from the CTD, an instrument measuring conductivity (salinity), temperature, density, oxygen and the chlorophyll concentration. To collect data with this instrument, DiNezio and Heinemann paddle to the middle of the lake in a little rubber dingy. Lowering the more than 20-pound heavy CTD to collect systematic samples is a nearly impossible feat. The soft sides of the dingy just crumble under the heavy weight, and the vessel is leaking air. In spite of these less than optimal circumstances, they make several successful deep CTD casts.

That evening back in Kalaupapa settlement, the group sits together and studies their first data graphs on the computer screen. The data is noisy, yet they can detect a less dense, oxygenated layer of water above a colder anaerobic layer (see figure).

Next morning, heading out to the lake again, they smell from afar hydrogen sulfide…An overturning happened over night! The lake is crystal clear, but stinks hellishly. At higher concentrations, hydrogen sulfide is deadly, but undetectable to the human sense of smell. They must rely on a sensor that should beep once concentrations get poisonous.

Lowering the CTD today is much easier: **Eric Brown**, marine ecologist for the National Park Service at Kalaupapa, brought down a sturdy ocean kayak for them and a pulley system from which they lower and raise the CTD without much effort. While collecting the CTD data and taking water samples, DiNezio notices that a part of the lake is taking on a

Milky film is starting to form over the lake.

whitish, opaque hue. It's where the sunlight hits the lake. With time, the whole lake is in the sun and is turning from its crystal-clear morning state into the milky brew.

Schneider explains the events as follows: Usually, frequent rains on Lake Kauhako create a freshwater lens, several meters deep, floating on a salty layer. Because freshwater is lighter than salty water, it does not mix with the salty layer but acts as a lid. During that state, no traces of hydrogen sulfide are found at the lake's surface, and shrimp and other fresh water animals live happily in the oxygen rich lens.

During 2011, however, Kalaupapa was experiencing a very severe drought. The freshwater layer thus was not replenished but evaporated gradually. With time the surface layer became salty until its salinity differed little from the layer below. What probably began to happen last fall, when the rotten-egg smell was first noticed, was that the lid had evaporated away and the very clear, rich hydrogen sulfide water could rise to the surface, killing the creatures and filling the air with the rotten-egg smell.

From left, Pedro DiNezio, Malte Heinemann, Axel Timmermann, Niklas Schneider, and Eric Brown.

Why does the overturning continue to happen particularly during nighttime? The density of water changes not only with salinity, but also with temperature. Warm water is light and floats, while cool water is heavy and sinks. With hardly a difference in salinity, small changes in temperature due to heating during the day and cooling at night alter the density of the surface waters. This means that a lid of lighter water forms during the day and erodes with night-time cooling. The hydrogen sulfide from the interior of the lake can then come to the surface, giving the smell and crystal-clear appearance. The lid starts to form again with warming during the day, cutting off the exchange with the interior of the lake. The daylight then allows sulfur-oxidizing bacteria to break down the hydrogen sulfide near the surface and form crystalline sulfur – the substance that turns the lake milky.

The IPRC team is eager to go back to Lake Kauhako to install a continuous monitoring system that would help predict future hydrogen sulfide belching.

Story by Gisela E. Speidel based on interview with Malte Heinemann and email correspondence with Niklas Schneider, Axel Timmermann, and Pedro DiNezio.

Photos by Pedro DiNezio.

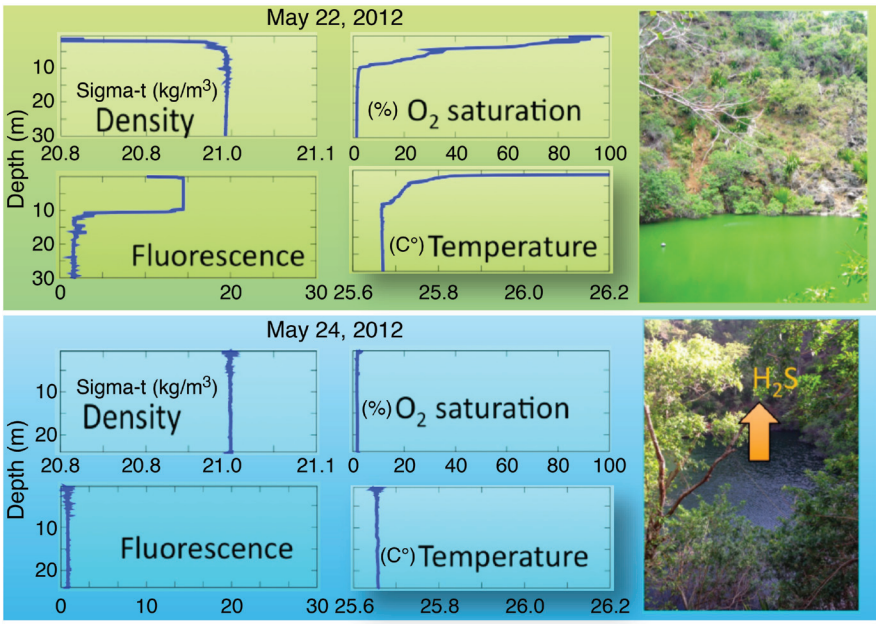

Figure. Changes in Lake Kauhako from May 22 to May 24, 2012. Green panel (May 22): vertical profiles of density, oxygen saturation, temperature and fluorescence on the day before the overturning event; photo shows green color of lake, indicating high plankton concentrations. Blue panel (May 24): same vertical profiles after the nightly overturning event. The stratification in the lake collapsed, plankton concentrations becoming very low and the lake emitting H_2S gas. (Courtesy of Axel Timmermann and Pedro DiNezio)