

KILLER LAKES

IN A REMOTE REGION OF CAMEROON, AN INTERNATIONAL TEAM OF SCIENTISTS TAKES EXTRAORDINARY STEPS TO PREVENT THE RECURRENCE OF A DEADLY NATURAL DISASTER BY KEVIN KRAJICK PHOTOGRAPHS BY LOUISE GUBB

ON THE NIGHT OF THE APOCALYPSE, Ephriam Che was in his mud-brick house on a cliff above Nyos, a crater lake in the volcanic highlands of northwest Cameroon. A half-moon lit the water and the hills and valleys beyond. Around 9 p.m., Che, a subsistence farmer with four children, heard a rumbling that sounded like a rockslide. Then a strange white mist rose from the lake. He told his children that it looked as if rain were on the way and went to bed, feeling ill.

Down below, near the lake's shore, Halima Suley, a cowherd, and her four children had retired for the night. She also heard the rumbling; it sounded, she would recall, like "the shouting of many voices." A great wind roared through her extended family's small compound of thatched huts, and she promptly passed out—"like a dead person," she says.

At first light, Che headed downhill. Nyos, normally crystal blue, had turned a dull red. When he reached the lake's sole outlet, a waterfall cascading down from a low spot in the shore, he found the falls to be, uncharacteristically, dry. At this moment he noticed the silence; even the usual morning chorus of songbirds and insects was absent. So frightened his knees were shaking, he ran farther along the lake. Then he heard shrieking. It was Suley, who, in a frenzy of grief and horror, had torn off her clothing. "Ephriam!" she cried. "Come here! Why are these people lying here? Why won't they move again?"

Che tried to look away: scattered about lay the bodies of Suley's children, 31 other members of her family and their 400 cattle. Suley kept trying to shake her lifeless father awake. "On that day there were no flies on the dead," says Che. The flies were dead too.

He ran on downhill, to the village of Lower Nyos. There, nearly every one of the village's 1,000 residents was dead, including his parents, siblings, uncles and aunts. "I myself, I was crying, crying, crying," he says. It was August 21, 1986—the end of the world, or so Che believed at the time.

All told, some 1,800 people perished at Lake Nyos. Many of the victims were found right where they'd normally be around 9 o'clock at night, suggesting they died on the spot. Bodies lay near cooking fires, clustered in doorways and in bed. Some people who had lain unconscious for more than a day finally awoke, saw their family members lying dead and then committed suicide.

Within days scientists from around the world converged on Nyos. At first, they assumed the long-dormant volcano

under its crater had erupted, spewing out some kind of deadly fumes. Over months and years, however, the researchers uncovered a monstrous, far more insidious geologic disaster—one thought to exist only in myth. Even worse, they realized, the catastrophe could recur, at Nyos and at least one additional lake nearby. Since then, a small band of dedicated scientists has returned here repeatedly in an attempt to head off tragedy. Their methods, remarkably low-tech and inexpensive, may very well work. "We are anxious to protect the people there," says Gregory Tanyileke, a Cameroonian hydrologist who coordinates experts from Japan, the United States and Europe.

IT TOOK ME nearly 24 hours to fly from New York, via Paris, to Yaoundé, Cameroon's sprawling capital. There I met photographer Louise Gubb, but this was just the start of our journey. Most people in Cameroon, a poor equatorial country the size of California, are subsistence farmers, cultivating yams, beans and other staples by hand. In a nation with 200 or more ethnic groups, languages change every few miles. Islam, Christianity and animist cults mix and recombine in peaceful confusion.

After a 12-hour overland journey northwest from Yaoundé, we took the road to Lake Nyos, a washed-out dirt track winding through forested hills and passable only in a four-wheel drive vehicle. Electric power lines peter out at the dusty market town of Wum, 18 miles from the lake. As one approaches Nyos, grass grows in the road, indicating that few travelers come this way. After a final, mile-long climb through thinning bush, one emerges into an airy amphitheater of high cliffs carved into fantastical shapes surrounding the lake. At its north end, the crater's rim cants downward to a natural spillway, the waterfall Che found running dry that terrible morning. The lake is small, roughly half a square mile in area, now once again blue and tranquil. Black fishing eagles soar under a perfect sky. "Nyos," in the regional Mmen language, means "good," but in Itangikom, a related tongue, it means "to crush."

Local mythology suggests that people around Nyos have long been aware that the lake harbored destruction. Indeed, Cameroonian myths reserve a special category for lakes, which are said to be the homes of ancestors and spirits and sometimes a source of death. According to legends documented by anthropologist Eugenia Shanklin of the College of New Jersey, in Ewing, a lake may rise, sink, explode or even change locations. Certain ethnic groups decree that houses near lakes be erected on high ground, perhaps, in the collective memory, as a defense

against disaster. Che's people, the Bafmen, have lived here for hundreds of years and followed that tradition: they settled Upper Nyos. About 60 years ago, other groups began moving into the area, and they did not necessarily follow long-standing custom. Suley and her family, for instance, who are Muslims (Che is Christian), are Fulani; they settled on Nyos' lower slopes. By the 1980s, the population near the lake was several thousand and growing fast. Even some Bafmen relocated down there.

Che, an energetic man who never seems to stop smiling, walked with me around Nyos' rim, telling a story he had learned from his grandfather. Long ago, the story went, a group of villagers decided to cross Lake Nyos. One man parted the waters, much as God parted the Red Sea for the Israelites, but a mosquito bit the man on a testicle; when he swatted the insect, he lost his grip on the waters and every villager was drowned. Che pointed toward the lake with the homemade spear he often carries. "They're between those two rocks," he said, referring matter-of-factly to the ghosts of that catastrophe. "You hear them talking sometimes, but you do not see them."

The story falls under the rubric of what anthropologist Shanklin calls "geomythology"—in this case, an account of an actual disaster that would become more fantastic as it passed down the generations, eventually fading into legend. "Details shift over time, but these stories probably preserve real events," Shanklin says.

ON AUGUST 15, 1984, two years before the catastrophe at Nyos, a strangely similar incident, albeit on a smaller scale, took place at Monoun, a bone-shaped crater lake about 60 miles south of Nyos. Monoun is located in a populous area, surrounded by farms and bordered in part by a road. Just before dawn, Abdo Nkanjouone, now 72, was biking northward to the village of Njindoun when he descended into a dip in the road. Parked along the road was a pickup truck belonging to a local Catholic priest, Louis Kureayap; Nkanjouone found the priest's dead body next to the truck. Moving on, he found another corpse, a man's body still astride a stalled motorcycle. "Some terrible accident has happened," thought Nkanjouone. Sinking into a kind of trance, he became too weak to bike and continued on foot. He passed a herd of dead sheep and other stalled vehicles whose occupants were dead. Beginning to climb uphill now, he encountered a friend, Adamou, walking toward him. He says he wanted to warn Adamou to turn back, but Nkanjouone had lost the capacity to speak. As though in a dream, he shook Adamou's hand silently, and the two continued in opposite directions. Nkanjouone made it into Njindoun alive. "God must have protected me," he says. Adamou and 36 others traveling that low stretch of road at the time did not survive.

Rumors about the disaster arose instantaneously. Some said that plotters attempting to mount a coup d'état, or perhaps the government itself, had carried out a chemical attack. Conspiracy theories abound in Cameroon, where unexplained events are often attributed to political intrigues. But a few officials looked to the local geology, theorizing that the long-dor-

mant volcano under Lake Monoun had reactivated.

The U.S. embassy in Yaoundé called on Haraldur Sigurdsson, a volcanologist from the University of Rhode Island, to travel to Cameroon to investigate. Venturing out to the lake several months after the incident, Sigurdsson performed an array of analyses and found no signs of a volcanic eruption. He detected no indication of temperature increase in the water, no disturbance of the lake bed, no sulfur compounds. But a strange thing happened when he hauled a water-sample bottle from the lake depths: the lid popped off. The water, as it turned out, was loaded with carbon dioxide.

That curious finding prompted Sigurdsson's recognition that, indeed, the deaths around Lake Monoun appeared to be consistent with carbon dioxide asphyxiation. Carbon dioxide is a colorless, odorless gas heavier than air. It is the normal by-product of human respiration and the burning of fossil fuels—probably the main culprit in global warming. But at high concentrations, CO₂ displaces oxygen. Air that is 5 percent carbon dioxide snuffs candles and car engines. A 10 percent carbon dioxide level causes people to hyperventilate, grow dizzy and eventually lapse into a coma. At 30 percent, people gasp and drop dead.

Carbon dioxide is also a natural by-product of geologic processes, the melting and cooling of rock. Most of the time it's harmless, surfacing and dispersing quickly from vents in the earth or from carbonated springs—think San Pellegrino water. Still, CO₂ poisonings have occurred in nature. Since Roman times, vented carbon dioxide in volcanic central Italy occasionally has killed animals or people who have wandered into topographic depressions where the heavy gas pools. At Yellowstone National Park, grizzly bears have met the same fate in a ravine known as Death Gulch.

Sigurdsson, after a few weeks, began to conclude that carbon dioxide from magma degassing deep under Lake Monoun had percolated up into the lake's bottom layers of water for years or centuries, creating a giant, hidden time bomb. The pent-up gas dissolved in the water, he believed, suddenly had exploded, releasing a wave of concentrated carbon dioxide. He wrote up his findings, calling the phenomenon "a hitherto unknown natural hazard" that could wipe out entire towns, and in 1986, a few months before the Nyos disaster, he submitted his study to *Science*, the prestigious U.S. journal. *Science* rejected the paper as far-fetched, and the theory remained unknown except to a few specialists. Then Lake Nyos blew up, killing 50 times more people than at Monoun.

WORD OF THE NYOS DISASTER spread quickly around the world. In Japan, a government official awakened Minoru Kusakabe of Okayama University at 1 a.m., inquiring if the geochemist would be willing to go at once to Cameroon. Kusakabe did not even know where the country was. French volcanologists; German, Italian, Swiss and British scientists; U.S. pathologists, geologists and chemists—all would converge on Nyos. Many departed from home so precipitously that they carried little more than a briefcase, a change of clothes and

whatever scientific instruments they could grab. Among the Americans was limnologist (lake scientist) George Kling of the University of Michigan, who, as it happens, was making his second visit to the remote location. While studying the chemistry of Cameroonian lakes for his doctoral thesis the year before, he had sampled Nyos' waters from the shore because he didn't have access to a boat. The shallow water had yielded no hints of the dangerous gas in the depths. Now, a year later, the local boy who had guided him along the lake was dead, along with nearly everyone else he had met. "I was numb," recalls Kling. "I had always dreamed of going back there, but not like this."

Arriving within days of the disaster, the scientists themselves were fearful; no one was sure what had just happened—or if it was about to happen again. The Cameroon military had buried human victims in mass graves. Thousands of cattle lay dead, their carcasses bloated and decomposing. Heavy rains fell. Only the survivors' hospitality alleviated the grimness. They took the researchers into their houses and cooked meals of corn mush over open fires. "Can you imagine that?" says Kling's research partner, geochemist Bill Evans of the U.S. Geological Survey. "These people had just lost everything, and *they* were worried about *us*."

The scientists motored out onto Nyos in inflatable dinghies to take water samples and look for clues. Once again, some assumed that an underwater volcano had erupted. But others immediately grasped that the villagers around Nyos had perished under the same conditions previously documented at Monoun—that Sigurdsson's "unknown natural hazard" was real.

Over ensuing weeks and months, scientists would piece together the Nyos story. The crater lake is extraordinarily deep (682 feet) and rests atop a porous, carrot-shaped deposit of volcanic rubble—a subaqueous pile of boulders and ash left from old eruptions. Carbon dioxide may remain from this old activity; or it could be forming now, in magma far below. Wherever it comes from, underwater springs apparently transport the gas upward and into the deep lake-bottom water. There, under pressure from the lake water above, the gas accumulates; pressure keeps the CO₂ from coalescing into bubbles, exactly as the cap on a seltzer bottle keeps soda from fizzing.

If the lake were farther north or south, seasonal temperature swings would mix the waters, preventing carbon dioxide buildup. Cold weather causes surface waters to become dense and sink, displacing lower layers upward; in spring, the process reverses. But in equatorial lakes like Nyos and Monoun, the deep layers seldom mix with top layers; indeed, the deepest layers may stagnate for centuries.

But something must have detonated the built-up carbon dioxide that August night 17 years ago. One theory is that boulders crashing into the lake (perhaps the rockslide Ephriam Che

heard) set it off; the scientists at Nyos noted that an adjacent cliff face bore signs of a fresh rockslide. Or a fluky drop in air temperature, causing surface water to cool and abruptly sink, might have been the trigger, or a strong wind that set off a wave and mixed the layers. Whatever the cause, water saturated with carbon dioxide was displaced upward from the depths; as it rose and pressure lessened, dissolved carbon dioxide bubbled out of solution, and the bubbles drew more gas-laden water in their wake, and so on, until the lake exploded like a huge shaken seltzer bottle. (The explosion, they determined, had also brought up iron-rich water, which oxidized at the surface and turned the lake red.)

In addition, the scientists observed that a lakeside promontory had been stripped of vegetation to a height of 262 feet, presumably by a carbon dioxide-driven waterspout rocketing into the air. The explosion released a cloud of carbon dioxide—perhaps as much as a billion cubic yards, scientists estimate—that thundered over the lake's rim, hit Suley's family first and poured downhill at 45 miles per hour through two valleys and into the villages of Lower Nyos, Cha, Fang, Subum and, finally, Mashi, which is 14 miles from the lake.

Those on high ground survived. A few individuals at lower elevations, like Suley, were spared for no apparent reason. The only other survivor in her family was her husband, Abdoul Ahmadou. He had been away on business in Wum that night. When he returned, it was to join his wife in burying their dead, then to flee to a refugee camp near Wum. Amid fears that the lake could erupt again, the military ordered out most of the region's survivors, around 4,000 in all.

The scientists began making frequent return trips to Cameroon, not only to study both Nyos and Monoun but also to make the region safe for people wishing to return. Testing of the lake depths showed that the explosions had not cleared all the pent-up carbon dioxide; indeed, the gas was accumulating at alarming rates. The researchers speculated that certain layers of Monoun, if left untouched, could become saturated with carbon dioxide by this year, and Nyos, sometime after. But either lake, even short of saturation, could explode at any moment.

The researchers considered various measures, such as blowing out the carbon dioxide by dropping bombs (too dangerous); dumping in massive quantities of lime in order to neutralize the gas (too expensive); or digging tunnels in the lake bed to drain the gas-laden bottom waters (*way* too expensive). In the end, they settled on a low-tech approach: running a pipe from the lake's deepest water layer to the surface, gradually releasing the gas to disperse quickly and harmlessly in the air. In theory, such a pipe, once primed, would carry the pressurized water from the depths and shoot it into the air like a natural geyser—a controlled explosion that could be sustained for years.

But not all researchers agreed that vent pipes would work.

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Geologist Samuel Freeth of the University of Wales, among others, speculated the process might set off a new explosion by spurting cold, dense bottom water onto the surface of the lake; the water would sink and create turbulence below. Even the researchers who advocated venting were worried, says Michel Halbwachs, an engineer from France's University of Savoy, who would design and install most of the equipment: "We were in an area [of science] little known and dangerous."

Using seed money from the European Union and private sources, a team headed by Halbwachs tested garden-hose-diameter pipes in Nyos and Monoun in 1990, then progressively larger pipes in 1992 and 1995. The experiment worked: the gas began venting. Halbwachs and coworkers were jubilant. Then the money ran out. The Cameroon government said it could not afford the \$2 million to \$3 million for permanent degassing installations. International aid agencies—more used to reacting to natural disasters than preventing them—did not grasp the concept. Kling, Kusakabe and others lobbied oil companies, governments and other organizations to pay for venting. Finally, in 1999, the U.S. Office of Foreign Disaster Assistance (OFDA) came up with \$433,000 for a permanent pipe to be installed at Nyos.

By January 2001, the researchers had assembled rafts and piping at the site. Attached to a raft in the middle of the lake, a 5.7-inch-diameter pipe reached 666 feet to the deepest water layer. The Cameroon military provided emergency oxygen tanks for all workers in case of a rogue carbon dioxide release. After everyone retreated to distant high ground, Halbwachs pushed a remote-control button to activate a pump that primed the pipe. Within seconds a 148-foot spray shot into the sunlight at 100 miles per hour, and the small crowd let out a cheer. The degassing of Lake Nyos had begun.

But with 5,500 tons of carbon dioxide still pouring into the lake annually, one pipe barely keeps up; Kling and Evans estimate it may take more than 30 years before enough dissolved carbon dioxide can be vented to make the lake safe. Five pipes, the researchers say, might do the job within five or six years—but so far funding has not materialized. The venting of the lake cannot happen too quickly, as far as locals are concerned. Families have begun drifting back into nearby hills, siting their compounds in high passes but venturing down to the forbidden zone by day. "You can't keep people out forever," says Greg Tanyileke of Cameroon's Institute for Geological and Mining Research. "We need to go faster."

LAKE MONOUN sits in steamy low country, surrounded by dozens of miniature, dormant volcanic cones. The area was not evacuated after the disaster in 1984; the nearby village of Njindoun alone has 3,000 residents. Yet, as at Nyos, carbon dioxide levels have been building up for years. The U.S. OFDA and the French government have pledged money to vent the lake, and preparations for installing the first pipe were begun earlier this year, as I looked on this January.

Plans call for the installation of three pipes in Monoun, which could render the lake safe in only three years. The lake

is smaller and shallower than Nyos, but continuing buildup had made Monoun more volatile. Some 210 feet down, carbon dioxide had reached 97 percent saturation. At that depth, says Kusakabe, if the layer were stirred up by only three feet, the water could start bubbling and trigger an explosion. His colleague, Bill Evans, advised caution: "Let's not go splashing around too much out there," he tells me.

Sections of pipe and other components were stacked by the lake and under military guard when photographer Louise Gubb and I arrived. A team headed by Kusakabe was eager to start, but locals made it clear that first it was necessary to contact the lake spirits. "Man can build machines, but machines can betray man," said Njindoun elder Mamar Ngouhou. "We must move slowly."

The next morning, a crowd assembled at the shore. Under a tree, several shamans stirred a blackish green paste in a ceremonial bowl and then, carrying cornstalks and an ancient wooden gong, led a solemn procession to the water. The head priest, Amadou Fakueoh Kouobouom, beat the gong while crying out to ancestors. On the lake, men in fishing canoes tossed offerings of fruit, salt and palm oil into the water. Kouobouom dipped his forefingers into the paste, and people lined up to lick it off. (The foreigners balked until a young man whispered, "This will prevent harm from coming to you on the lake.") Then came Muslim prayers; most villagers are also followers of Islam. A feast of rice and smoked fish ensued. Finally, a live ram was carried to the water; an Imam cut its throat and held the knife in the slit until the blood stopped flowing. Only after this four-hour ceremony was it time to proceed.

The Japanese technicians leaped up, wrenches and screwdrivers at the ready, and began fastening together two small rafts to support monitors and a vent pipe. A 15-man team wrestled the rafts into the water. Kling and Evans motored out in a dinghy and gingerly suspended instruments for measuring carbon dioxide and temperature. Later that day, the two American scientists drove to the spot where the first victims of the Monoun explosion had fallen. The team had installed a solar-powered carbon dioxide detector, equipped with a loud siren and marked with a hand-painted skull and crossbones sign and instructions to flee if the alarm sounded. They were pleased that it was still working. Three weeks later, engineers headed by Halbwachs finished installing the first pipe for Monoun. It has worked well so far.

THE COUNTRYSIDE around Lake Nyos was beautiful but eerie. At a nearby spring, one of several fed by deep lake waters, carbon dioxide bubbled up. A dead hawk lay in a mud puddle next to a dead mouse, both apparently asphyxiated. Out in the woods, white cattle appeared suddenly like ghosts, then melted into the bush silently, their owners nowhere to be seen. We slept on a lakeside promontory, millions of stars overhead, amid cricket songs and the barks of baboons. It was the dry season; farmers on the heights were torching the bush to prepare for planting. At night great rings

of land-clearing fires burned above the lake.

One morning we visited what was left of Lower Nyos, now mostly impenetrable brush. Along the dirt road, the foundations of a few mud-brick houses were still visible. Lines of trees marked the edges of what had once been yards. In the center of the former marketplace lay a large pile of rotting shoes. After the disaster, soldiers had buried the bodies in mass graves, whose locations were quickly lost in the rapidly revegetated bush country. That was a nearly unbearable loss: here, people routinely bury family members in the front yard so they can serve them meals, ask their advice and take comfort from their presence.

Survivors have overcome great challenges. On the day of the Nyos disaster, Mercy Bih was on her way to Wum, carrying about \$100—a considerable sum in Cameroon—to buy supplies for her 26-member extended family. All her relatives were killed. She was 12. She returned the groceries and was reimbursed the \$100, which she saved. Now 29 and the mother of two, she's the proprietor of the Lake Nyos Survival Good Faith Club, a four-table restaurant in Wum serving cold beer and the best grilled mackerel for miles. "I was lucky," she says. "Some people got left with nothing."

Though the Cameroon military had driven out most of those who had not fled the area on their own, Che, living on high ground, was allowed to remain, along with his wife and children, who had also survived. However, his uncle's seven children had been orphaned by the disaster, and tradition required Che to adopt them all, bringing his brood to 11. Che's income has been boosted by the foreign scientists working in the area, who pay him to measure lake levels and guard equipment, among other things.

As for Halima Suley, she and her husband now have five youngsters born to them since the tragedy. Just before dawn one morning, we hiked up to Suley and Ahmadou's new compound, located in a narrow pass above the lake. As a cooling breeze sprang up, we glimpsed thatched huts and cattle fencing coming into view. Out back, Ahmadou milked the cows; the herd numbers only 40 now. Suley greeted us in the family's perfectly swept yard with her children—from 15-year-old Ahmadou to 2-year-old Nafih. Suley made sweet tea with fresh milk and cradled the little one. "I'm no more thinking about the disaster," she says. "I have more children. I'm thinking about the children I have now." She smiled. "The only problem is a lack of cattle to feed them and to pay for them to go to school."

Ahmadou says, "If I think about what I was, what the family was, I can go crazy. So I try not to. We are believers. Your children can survive you, or you can survive your children—it is all in the hands of God." He says he appreciates the scientists' work. "When we feel their presence, we are much more peaceful, because we think something is being done." But, he admits, "When they leave, we live in fear."