PROGRAM facts

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Lake Nyos and Mammoth Mountain: What Do They Tell Us about the Security of Engineered Storage of CO_2 Underground?

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Introduction

Lake Nyos in the Northwest Province of Cameroon in western Africa and Mammoth Mountain in California are the sites of two well-known underground releases of carbon dioxide (CO_2) in nature, both with adverse effects. Both Lake Nyos and Mammoth Mountain are atop current or former volcanoes and the released CO_2 is volcanic in origin (sometimes referred to as magmatic origin). Molten rock (magma) far below the Earth's surface contains entrained amounts of water, CO_2, and other gases. If the magma rises toward the Earth's surface, the pressure it is under is reduced and the entrained gases begin to expand. The expansion of the entrained gases forces the magma to move faster in a spiraling effect. In fact, it is the force of expanded gases that give volcanoes most of their power. Water vapor is the primary volcanic gas, but CO_2 can account for nearly half the entrained gas in certain formations. Worldwide, volcanoes annually release 130 million tons of CO_2 into the Earth's atmosphere.

This document discusses these incidences and evaluates their implications for engineered CO_2 storage in underground formations, i.e., geologic sequestration. In summary, all hazardous releases of CO_2 from the earth — such as Lake Nyos and Mammoth Mountain — are associated with CO_2 release from magma held deep within the Earth's crust. Although much can be learned from Lake Nyos and Mammoth Mountain regarding large releases of CO_2 into the atmosphere, these situations have little relevance to potential CO_2 release from engineered storage of CO_2 in geologic formations. No known hazardous CO_2 leaks have ever been associated with leakage from a geologic formation.

Lake Nyos

Located in the West African country of Cameroon, Lake Nyos is relatively small, only about 1.6 square kilometers in area and 200 meters (m) deep. It is situated in the crater formed from the collapse of the rock channel feeding a now extinct volcano. The lake is compositionally stratified, with fresh water in the upper 50 m and heavier sodium and CO_2-rich water below that. The water below 180 m is particularly rich in these chemicals. Most of the sodium and CO_2 come from numerous sodium-bicarbonate bearing springs – derived from an underlying magma chamber – feeding into the bottom of the lake.

In August of 1986, some event – perhaps a mudslide, heavy rain, or strong wind blowing across the lake – caused the water column to be disturbed. Some of the deep CO_2-rich water moved toward the surface where it was subjected to lower pressure. The dissolved CO_2 quickly converted to CO_2 gas and rushed to the surface, starting a chain reaction of degassing the deeper water. A huge cloud of CO_2 spilled over the lake's outlet and down into the surrounding valleys. More than 3,500 animals and 1,700 people died, many in their sleep.

Controlled degassing of Lake Nyos will prevent a second catastrophic CO_2 release.

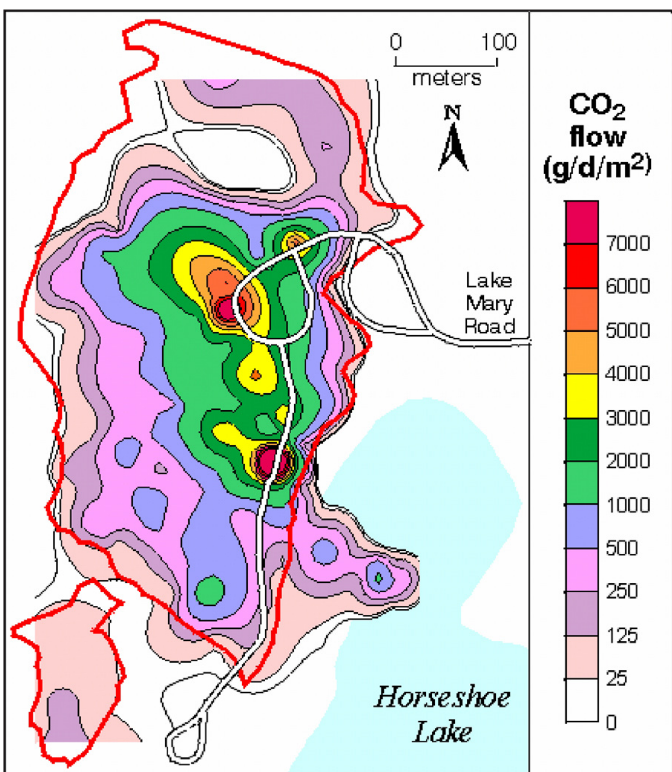
Degassing at Lake Nyos

The lake is now degassed in a controlled way to prevent a reoccurrence. The procedure involves lowering a strong polyethylene pipe to the lake bottom. Some water is pumped out at the top, and as the deep water rises through the pipe the CO_2 starts to bubble out. The gas and water then become buoyant and suck more water in at the bottom in a self-sustaining process. **http://www.mala.bc.ca/~earles/nyos-feb01.htm**

Mammoth Mountain

Numerous small earthquakes occurred beneath Mammoth Mountain in California, United States, between May and November of 1989. Data collected from monitoring instruments during those months indicated that a small body of magma was rising through a fissure beneath the mountain. In the following year, U.S. Forest Service rangers noticed areas of dead and dying trees on the mountain. After drought and insect infestations were eliminated as causes, scientists from the U.S. Geological Survey discovered that the roots of the trees were being killed by exceptionally high concentrations of CO_2 gas in the soil. Although trees produce oxygen (O_2) from CO_2 during photosynthesis, their roots need to absorb O_2 directly. High CO_2 concentrations in the soil kill plants by denying their roots O_2 and by interfering with nutrient uptake. In the areas of tree kill at Mammoth Mountain, CO_2 makes up about 20 to 95 percent of the gas content of the soil; there is less than 1 percent CO_2 in soils outside the tree-kill areas. Today, areas of dead and dying trees at Mammoth Mountain total more than 170 acres, with a total CO_2 flux of roughly 300 tons per day.

The events at Mammoth Mountain and Lake Nyos provide examples of "lessons learned" regarding releases of extremely high concentrations of CO_2.



CO_2 Flow rates at Mammoth Mountain

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Implications for Underground CO_2 Storage

All hazardous releases of CO_2 from the earth—such as Lake Nyos and Mammoth Mountain—are associated with volcanism. No known hazardous CO_2 leaks have ever been associated with leakage from a geologic formation. The events at Lake Nyos and Mammoth Mountain do provide examples of "lessons learned" regarding release of extremely high concentrations of CO_2. The gas is buoyant underground, and under the right circumstances, will rise from underground strata and into the atmosphere. Once in the atmosphere, CO_2 is heavier than air and can gather temporarily in low-lying areas and confined spaces. Because CO_2 is an asphyxiant, high CO_2 concentrations in the soil will destroy plants, and CO_2 concentrations in the air higher than 30 volume percent are fatal to humans within minutes.

Mammoth Mountain shows us that even relatively high flux rates through the soil do not result in high-risk asphyxiation hazards for humans and animals. People still use Mammoth Mountain for recreation, but are advised not to lie face down on the ground in the tree-kill areas. Also trees and other plants will often serve as a "canary in a coal mine," alerting people of potential risks before they materialize.

Engineered sequestration projects are and will be performed only under optimal circumstances; pre-, during, and post-injection monitoring plans also will be implemented. Every project will perform a high level of due diligence activities related to reservoir characterization and monitoring leakage. The likelihood that any stored CO_2 will escape from the target formation will be very low. A large portion of any CO_2 that does escape will often be dissolved or trapped in the strata that lie above the injection site, prior to reaching the surface. Underground monitoring technologies such as three-dimensional seismic surveying will give operators years or even decades of advanced notice that CO_2 could escape the target formations. Geologic sequestration poses no additional risks beyond the daily risks currently associated with CO_2 injection in the oil and gas industries. Over 70 CO_2 enhanced-oil-recovery projects inject more than 8 million tons of CO_2 per year into oil reservoirs throughout the United States and Canada. Many of these projects have been injecting CO_2 at these levels for more than 20 years. Numerous projects also exist for enhanced coalbed-methane recovery using CO_2 injection and acid gas disposal injection; the latter involves injecting gas mixtures containing high quantities of CO_2 and hydrogen sulfide into geologic formations. The Sleipner Gas Field in the North Sea is an example of CO_2 injection into a saline formation specifically for sequestration purposes. This project has been injecting over 1 million tons of CO_2 per year since 1996. All of these projects continue to operate in a safe, effective manner with a low level of environmental safety and health risk. The risk of large, catastrophic releases of CO_2, such as occurred at Lake Nyos and Mammoth Mountain, are virtually non-existent for geologic sequestration.