Gas eruptions from Earth's volcanoes: an often deadly hazard.

Bill Evans – USGS representing many collaborators over many years

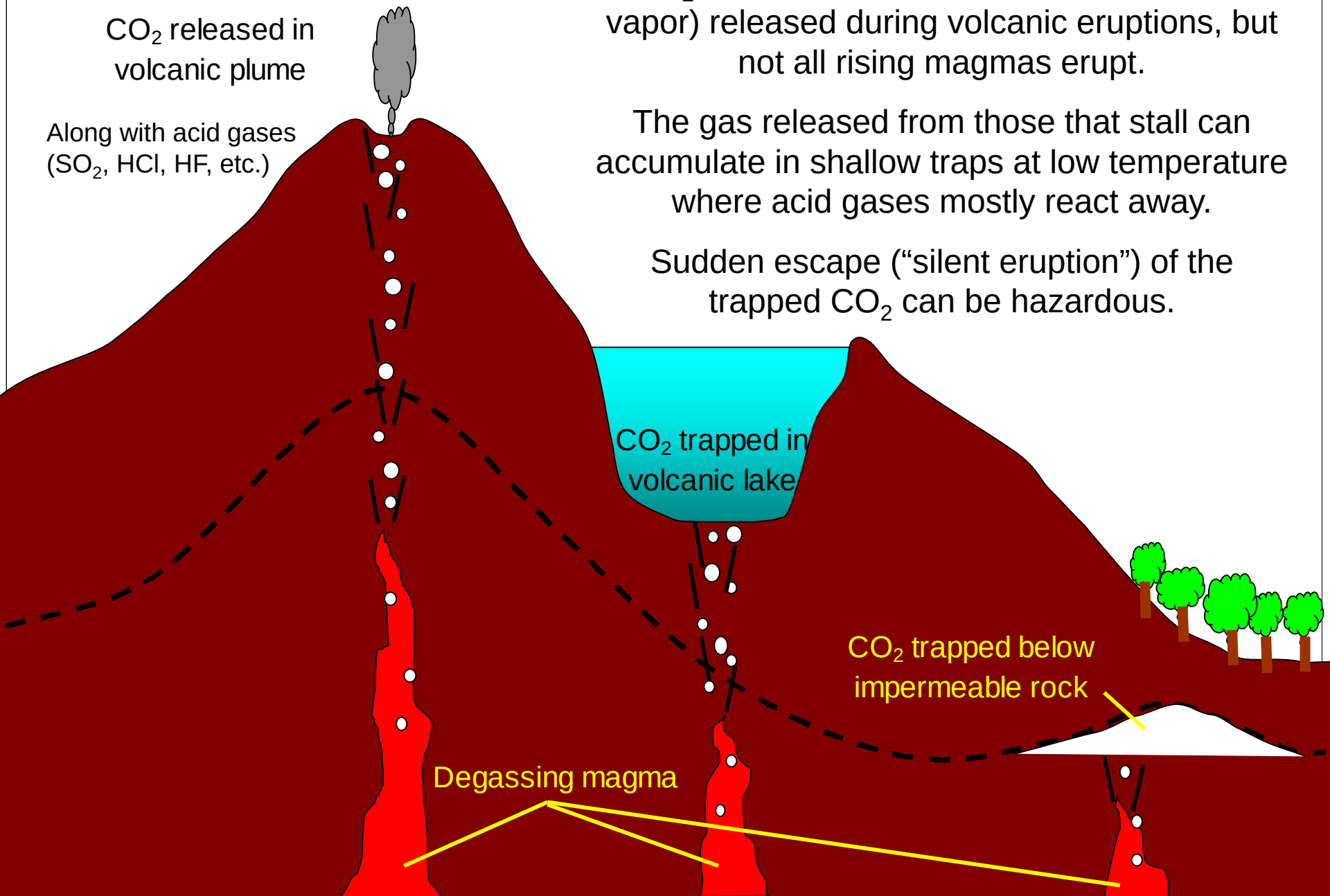
Cowboy Neal in his first teaching assignment

Wish I could get back to Texas some day!

CO_2 is the most abundant gas (after water vapor) released during volcanic eruptions, but not all rising magmas erupt.

The gas released from those that stall can accumulate in shallow traps at low temperature where acid gases mostly react away.

Sudden escape ("silent eruption") of the trapped CO_2 can be hazardous.



Examples of “silent eruptions” (large releases of magmatic gas at low temperature):

Dieng Plateau (Indonesia) 1979 – 142 fatalities

Lake Monoun (Cameroon) 1984 – 37 fatalities

Lake Nyos (Cameroon) 1986 – 1700 fatalities

Mammoth Mtn (CA) 1989-present – 4 fatalities with widespread forest mortality

*Chiginagak crater lake (AK) 2005 – widespread plant mortality

Miscellaneous others: Ukinrek maars, Shrub Mud Volcano, Yellowstone

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OK! – not all silent and not really eruptions, but very potent in terms of gas released.

Mount St. Helens 2004-2005:
100-1000 t/d CO_2 in plume

e.g.,Gerlach et al., 2008

Mammoth Mtn. 1989-present:
100-1000 t/d CO_2 diffuse emission

e.g., Sorey et al., 1998

What's the source strength?

Basaltic magma at mantle depths contains ~1 wt% CO_2

This CO_2 is virtually all lost during magma ascent into the shallow crust

Gas/magma volume ratio is >10 at surface conditions

What is the hazard?

CO_2 is invisible, odorless, and toxic at concentrations above ~10%

Its heavier than air and slow to dissipate from low-lying areas

Why are (deep) lakes a concern?

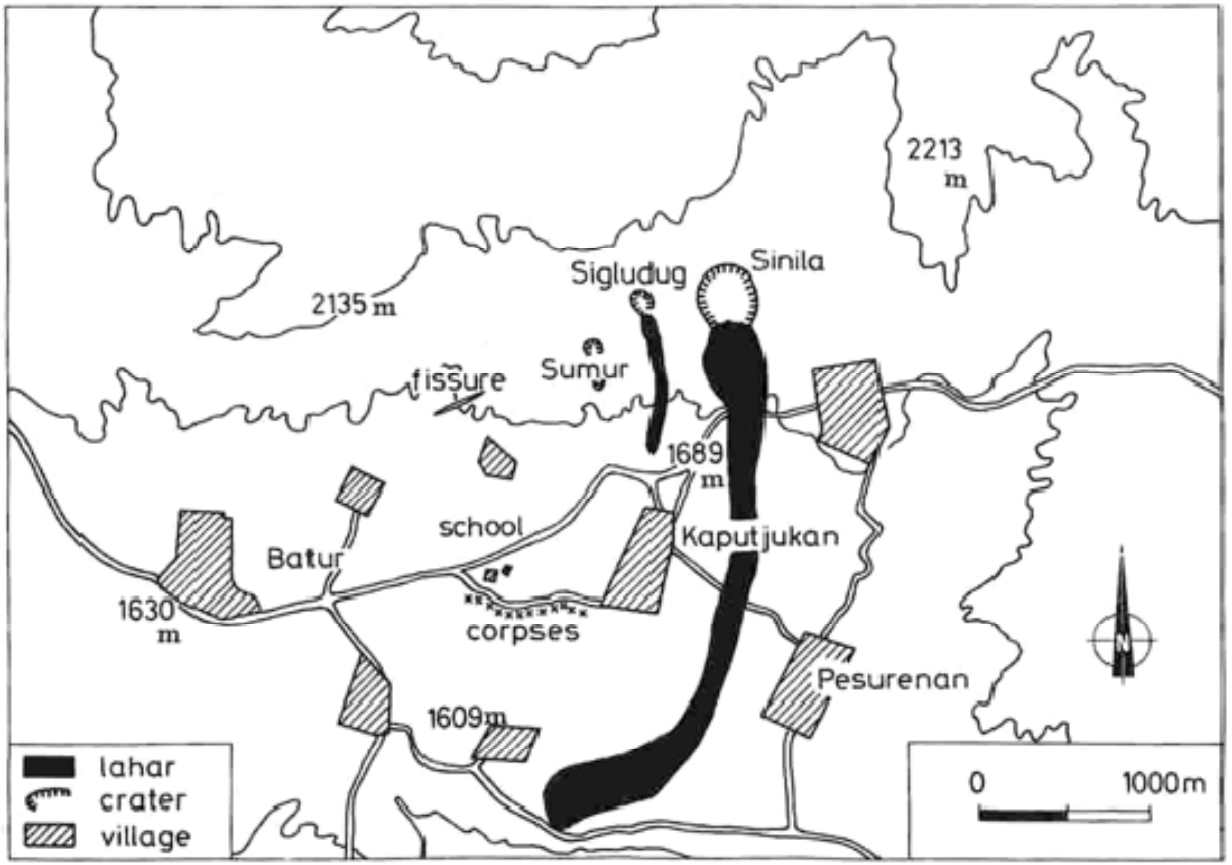
CO_2 is fairly soluble in cold water – about 1L for each atm pressure

Dissolved CO_2 *increases* water density, strengthening lake stratification.

Umbertide gas vent Italy

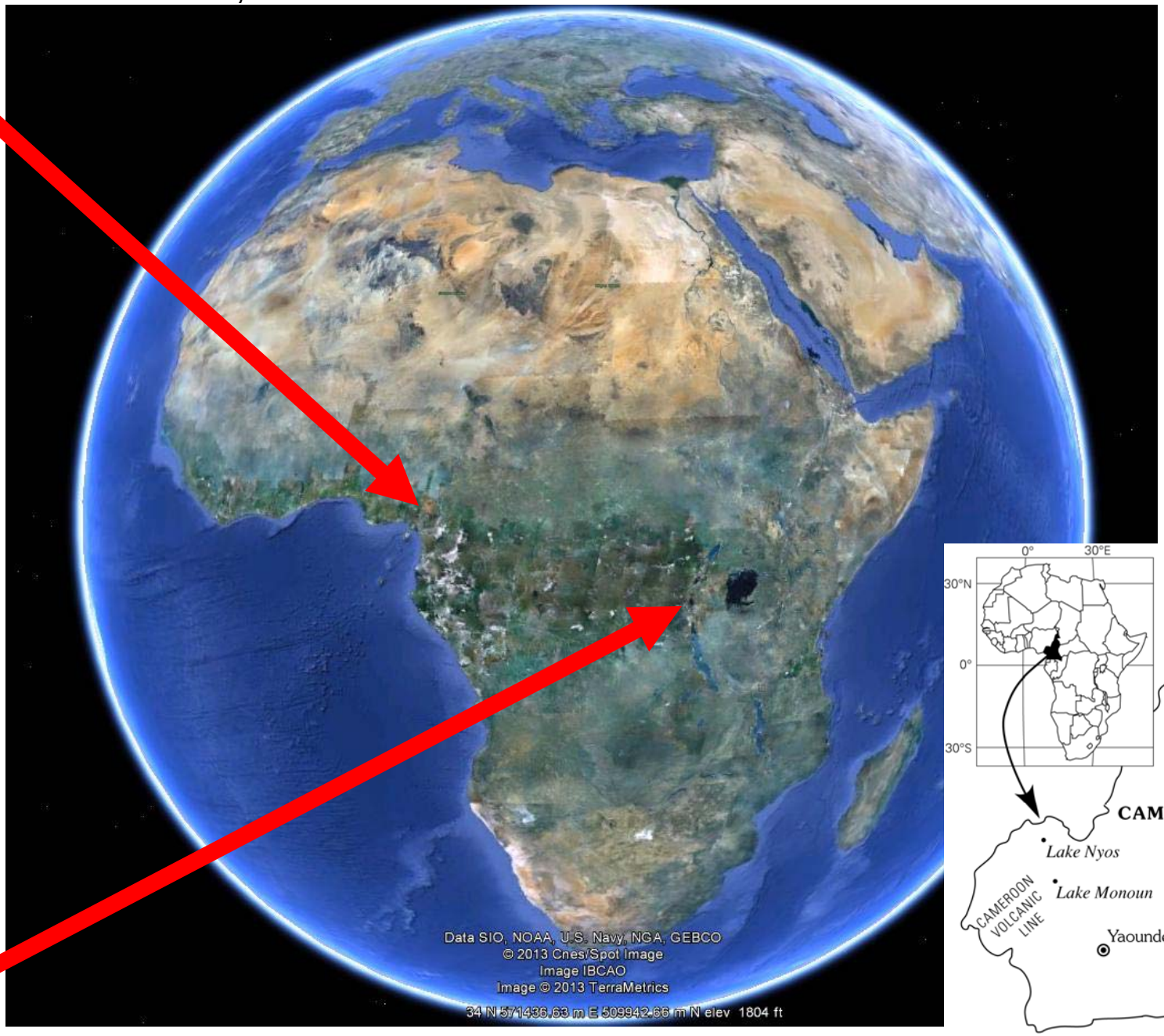
Rogie et al. 2000

Dieng Indonesia Feb 1979. This event was associated with an eruption and lahar from Sinila crater, but the cold CO_2 gas was actually emitted from a distal fissure and flowed downslope like a river, killing 142 residents fleeing Kaputjukan village on foot. A small but lethal stream of CO_2 gas flows out of this or nearby fissures to this day.



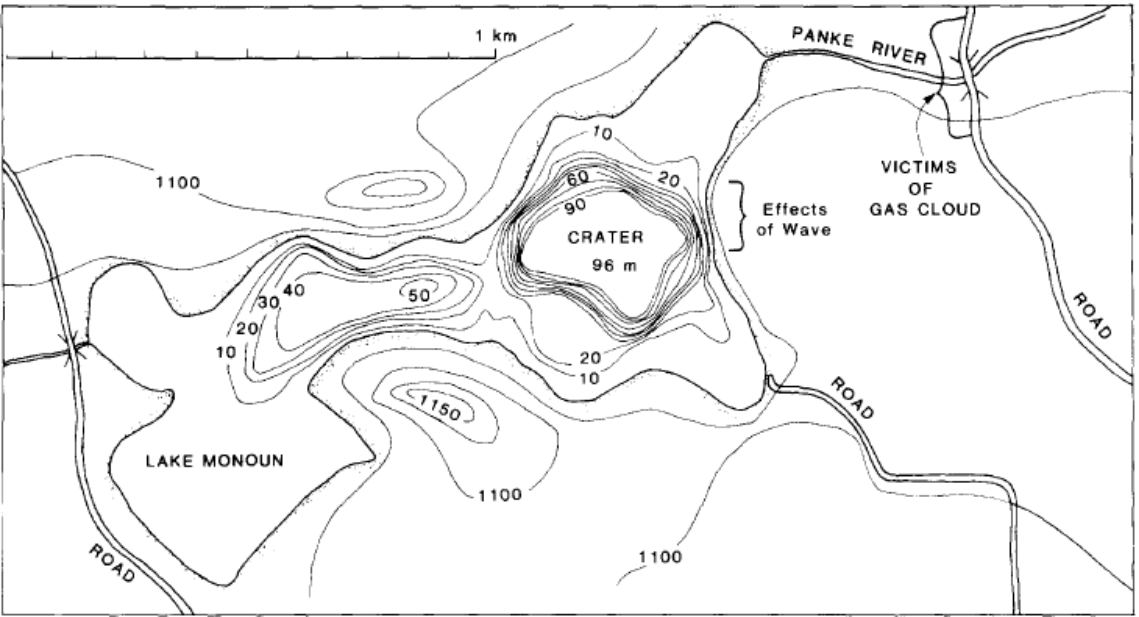
From Le Guern et al. 1982

Lakes Nyos and Monoun, Cameroon Volcanic Line



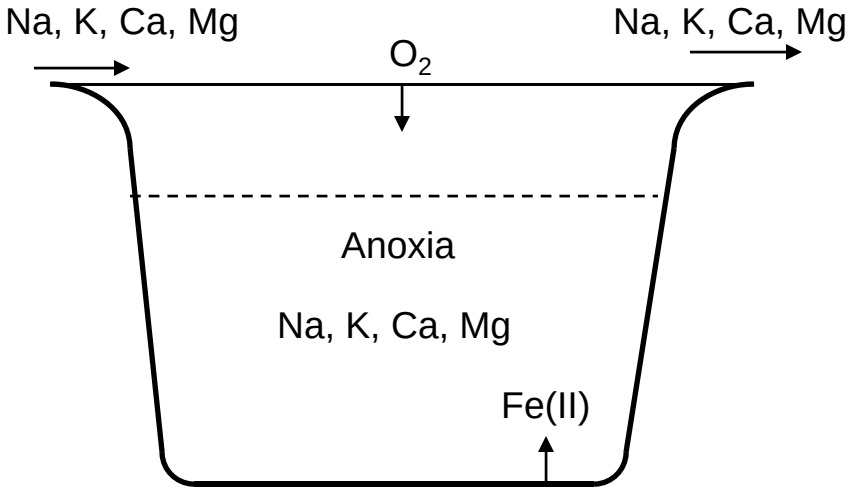
Lake Kivu, East African Rift

Lake Monoun August 1984. Gas release occurred at night and cloud drifted eastward along the Panke River. 37 people travelling by foot or by vehicle were killed in the pre-dawn hours when they entered the gas cloud at the bridge. Cloud dissipated in the morning winds revealing a red-colored lake and evidence of large waves. Investigated 7 months later by Sigurdsson and Devine. Lake occupies volcanic maar. Fresh landslide scar at lake's edge. Deep lakewater samples retrieved to the surface literally exploded with CO_2 gas bubbles. No evidence of volcanic eruption. Gas and water samples collected.



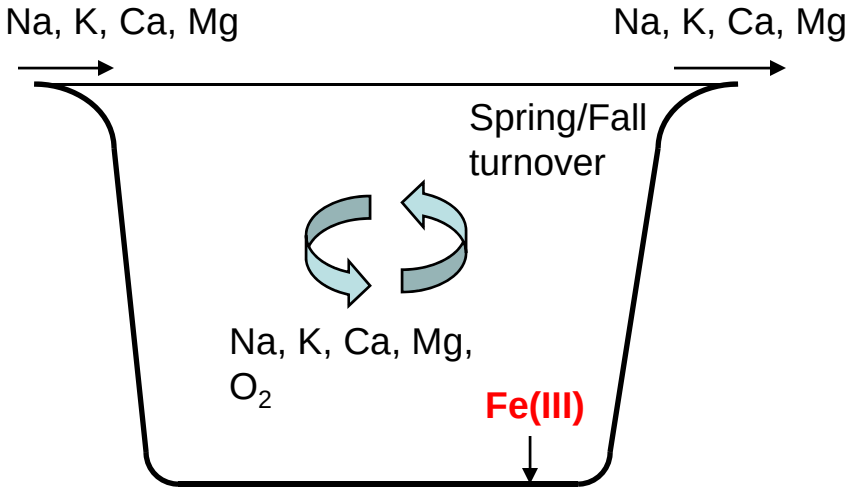
Sigurdsson et al. 1987

Possible causes:	**Pros:**	**Cons:**
The gas was derived from a volcanic eruption through the lake (CO_2, SO_2, H_2S, HCl, etc).	Local Holocene volcanism Victims were blistered	Reactivated maar? Plants were unharmed SO_4 <1 mg/L; CL <4 mg/L
The gas was derived from decaying organic material in the sediments (CO_2, CH_4).	Lush vegetation River inflow Deep water anoxic	Only 2% CH_4 in gas ^{14}C-CO_2 only 10% modern
The gas was magmatic CO_2 that had built up over decades/centuries in the deep stratified lake (CO_2)	CO_2-rich lakewater Kivu analog No “acid gas” components $\delta^{13}C$-CO_2 = -7‰ PDB Ferrous bicarbonate chem 600mg/L Fe in bottom water	Skin blistering?

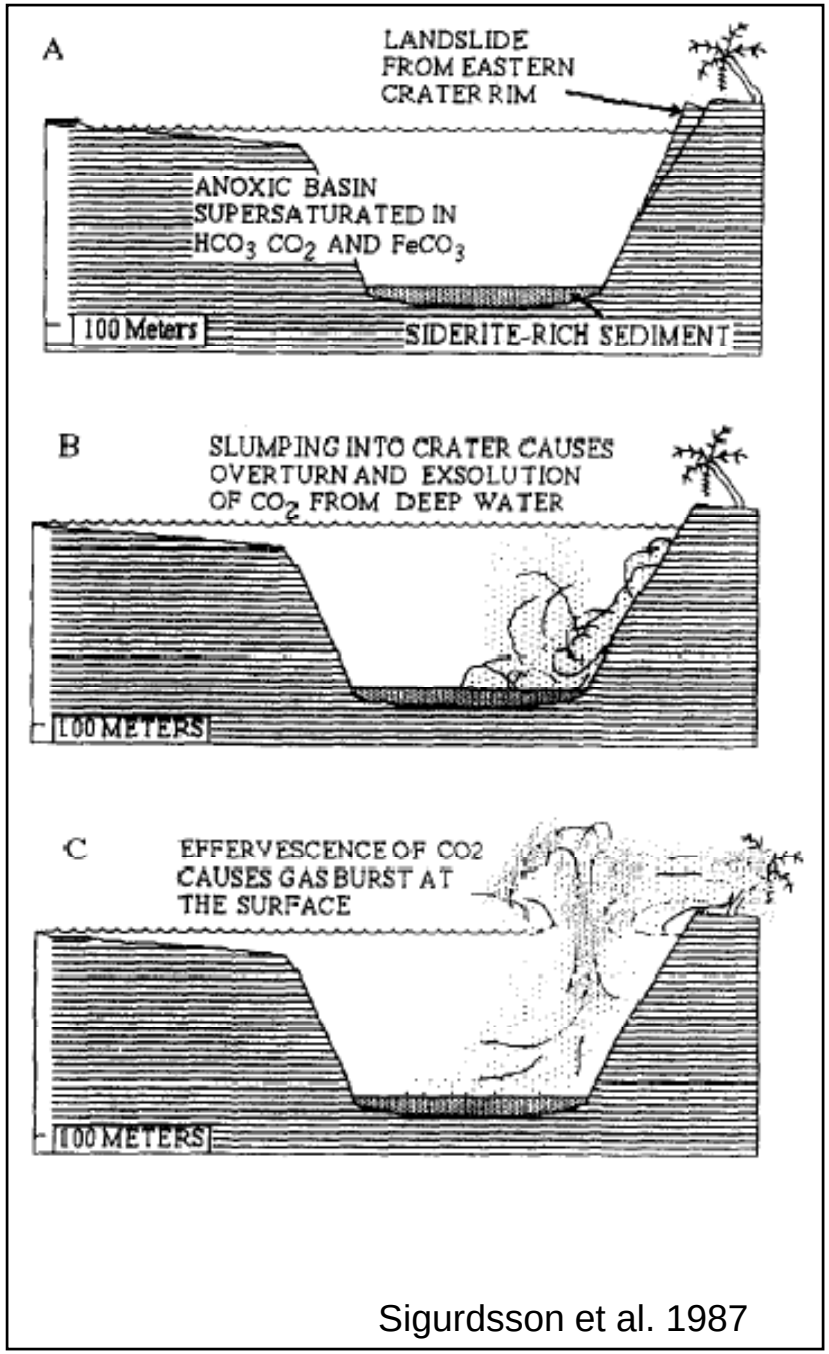


Ferrous iron bulds up during stratification

Perennial stratification is called meromixis



Ferric iron precipitates out during turnovers



Sigurdsson et al. 1987

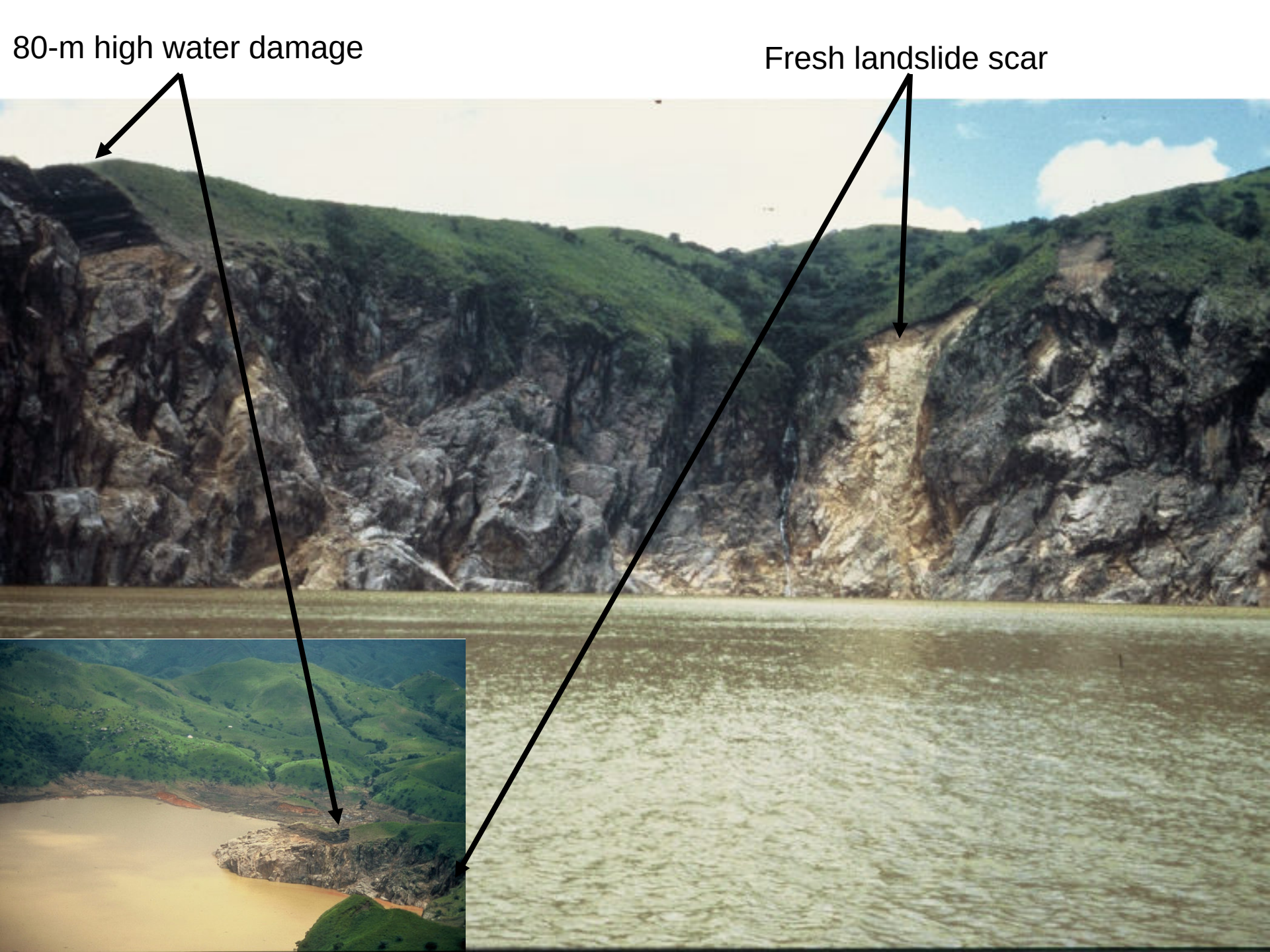
Lake Nyos August 1986: Gas released at night; major wave damage; 1700 fatalities, some as far as 25 km from the lake; survivors describe burning eyes, lips, sinuses, smells of gunpowder and rotten eggs before losing consciousness – some for 36 hours


No dead cattle 100 m above lake


Skin damage not like heat or acid burns


Painless, only epidermis affected


Only ferric iron ppt in surface water


80-m high water damage
Fresh landslide scar

Lake Nyos outlet

No vegetation damage in areas most impacted by the gas.

No detectable Cl or SO_4 (<1 mg/L) in lake water.

No excess sulfur in tissues of the victims.

Lake known to be >200 m deep from old survey (Hassert, 1912).

Lake could hold 1-1.5 km^3 of CO_2.

<u>From boat:</u>

Lake 210 m deep

Cool (<25°C) to bottom

Water below 10 m depth clear (no suspended sediment)

Water samples retrieved to surface “explode” with gaseous CO_2 (same as at Lake Monoun).

Possible causes:	**Pros:**	**Cons:**
The gas was derived from a volcanic eruption through the lake (CO_2, SO_2, H_2S, HCl, etc).	Local Holocene volcanism Victims were blistered Sulfurous odors	Reactivated maar? Plants were unharmed SO_4 <1 mg/L; CL <1 mg/L
The gas was derived from decaying organic material in the sediments (CO_2, CH_4).	Lush vegetation Stream inflow Deep water anoxic	Only 0.2% CH_4 in gas ^{14}C-CO_2 only 2% modern ^{14}C-CH_4 41% modern
The gas was magmatic CO_2 that had built up over decades/centuries in the deep stratified lake (CO_2)	CO_2-rich lakewater Monoun analog No “acid gas” components $\delta^{13}C$-CO_2 = -5‰ PDB $^3He/^4He$ = 5 R_A Ferrous bicarbonate chem 100mg/L Fe in bottom water	Skin blistering? Sulfur smell? Feeling hot, burning eyes?

Skin blistering?

Medical doctors/pathologists identify some cases of skin loss as likely due to necrosis in people lying motionless for up to 36 hours.

They also found literature describing blisters in patients rendered comatose by carbon monoxide.

No medical reports of CO_2–induced blistering, but Indonesian doctor who examined Dieng victims describes similar blistering.

Sulfur smell?

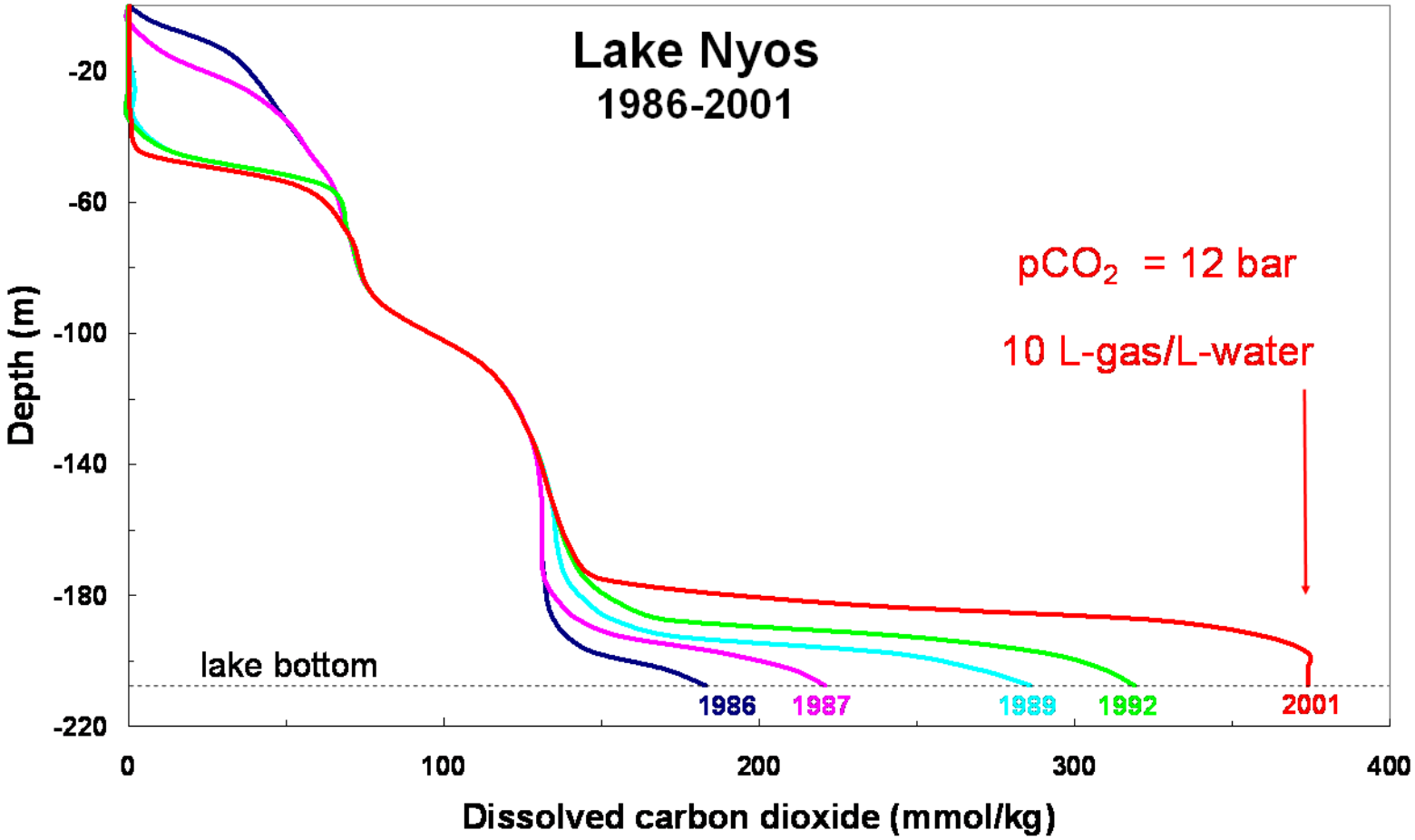
People cannot smell CO_2, but can smell H_2S at ppb levels. Trace H_2S may have been present.

Medical doctors/pathologists find study describing olfactory hallucinations during exposure to CO_2.

Feeling hot, burning eyes?

Some survivors felt cold – possibly fear, physiological response involved.

CO_2 causes burning of eyes and nasal passages after an initial delay of about 30 seconds of exposure (cannot tell you how I know this).

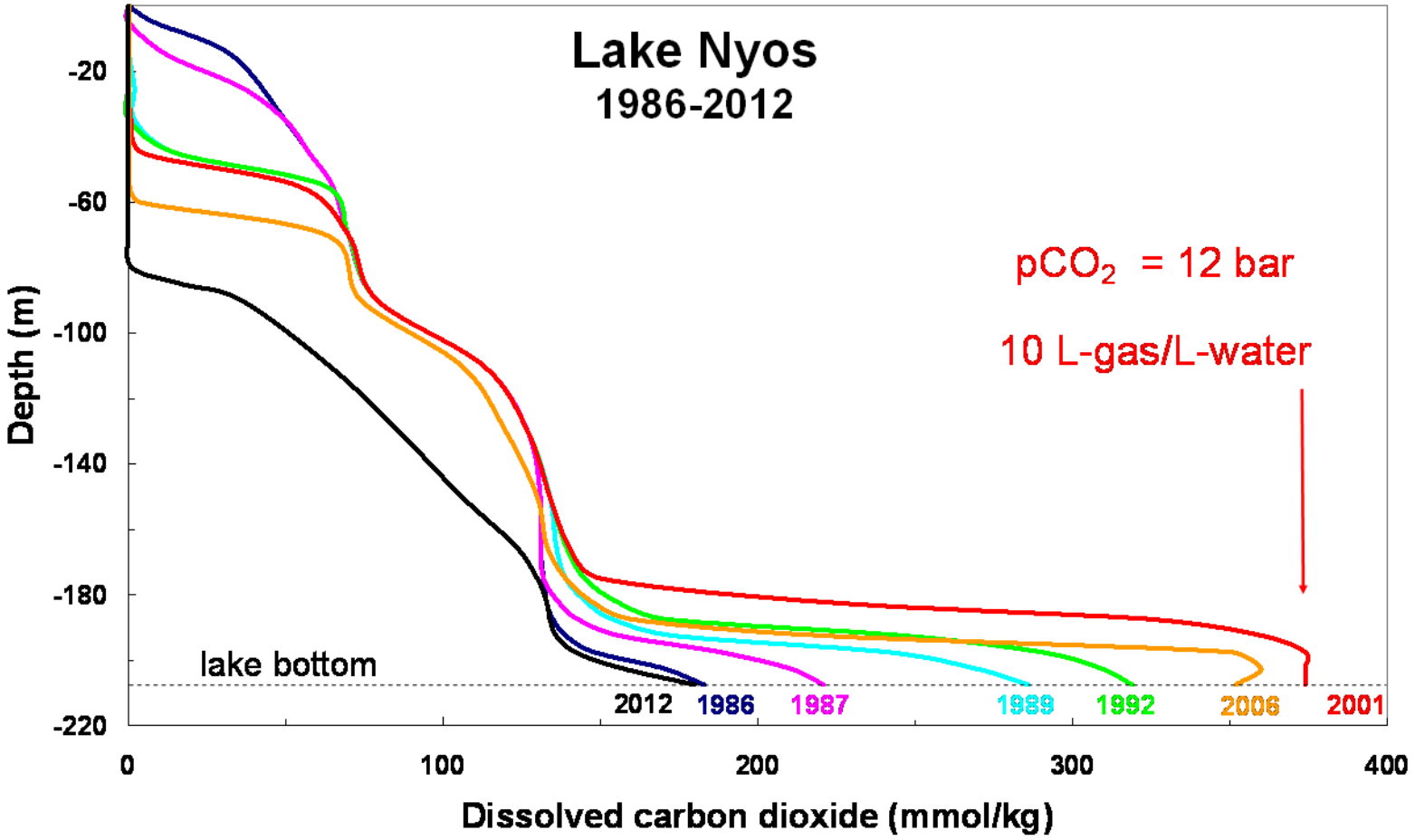


The steady build-up of CO_2 in bottom water at Lake Nyos following the 1986 disaster convinced remaining skeptics of the hazard associated with the gas dissolved in the lake, allowing mitigation efforts to begin. This involves suspending a long pipe vertically from an anchored raft, and "priming" the upflow by pumping up gas-rich bottom water far enough to allow bubbles to form. At this point, the upflow becomes self-driven and the pumps are no longer needed. Permanent pipes were installed in 2001 at Lake Nyos and 2003 at Lake Monoun. Thanks Tina Neal and US-OFDA!

French engineers led by Michel Halbwachs oversee pipe assembly on the shore of Lake Nyos.

45-m high fountain driven solely by gas exsolution

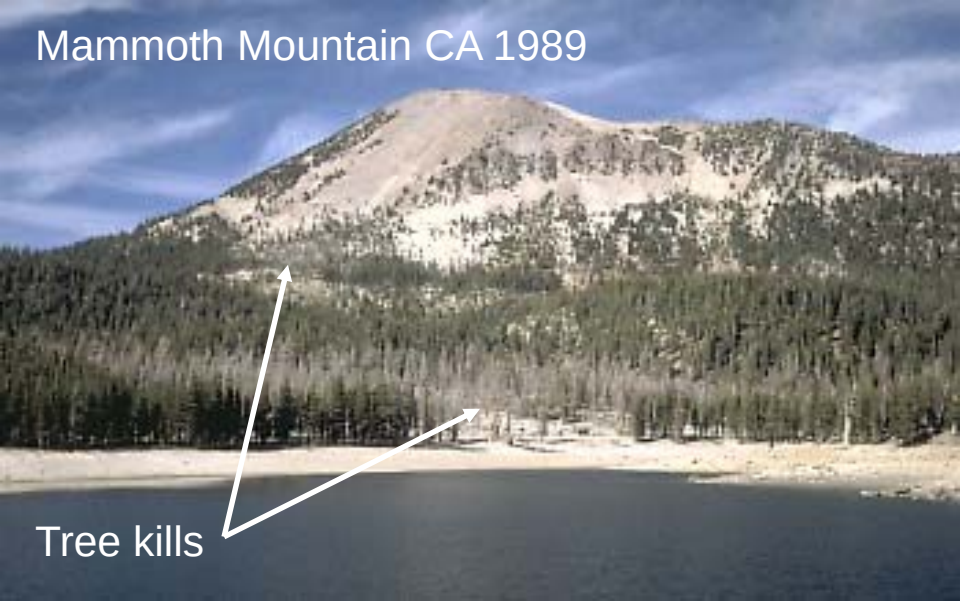
Nyos 2001



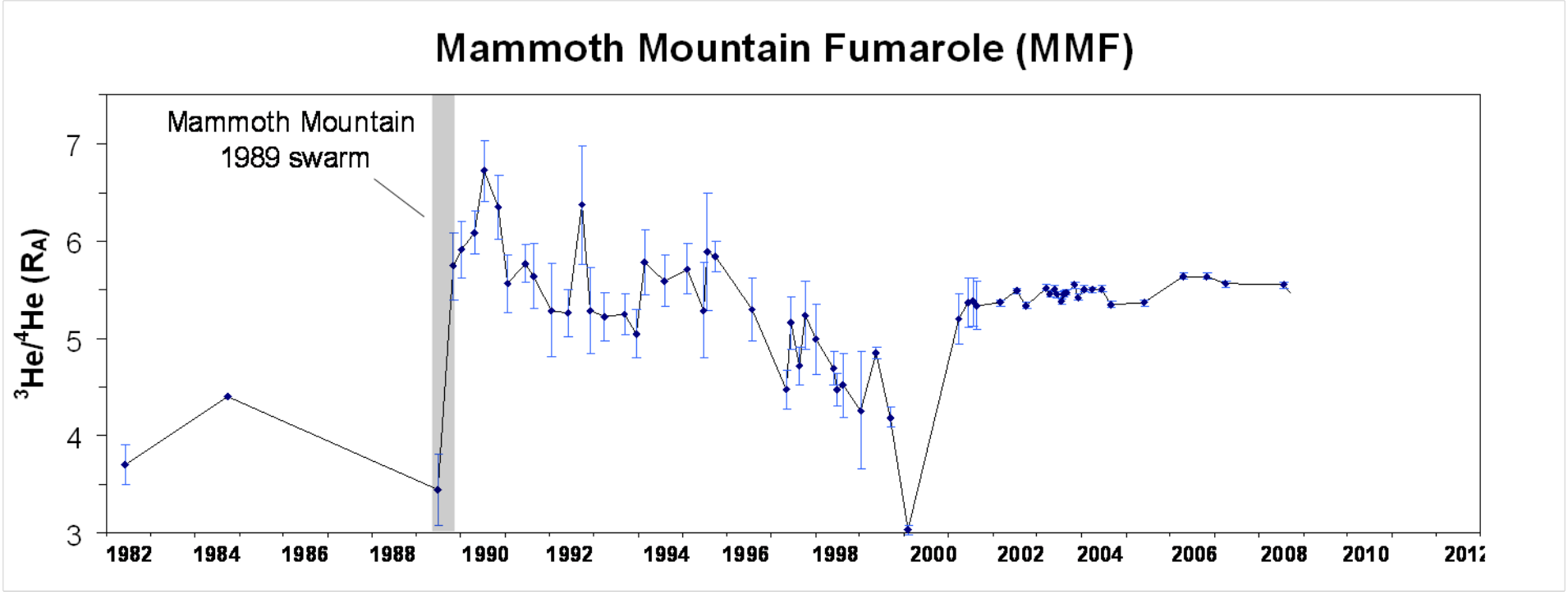
The strong density stratification allows the water column to be degassed from the bottom up, as water layers are sequentially removed – much like dealing cards from the bottom of a deck. Lake Nyos now contains much less gas than in 1986, and with three pipes running, will be completely degassed in a few more years. The smaller Lake Monoun is now completely degassed.


Nyos 2012
Kling Photo


Mammoth Mtn CA 1989



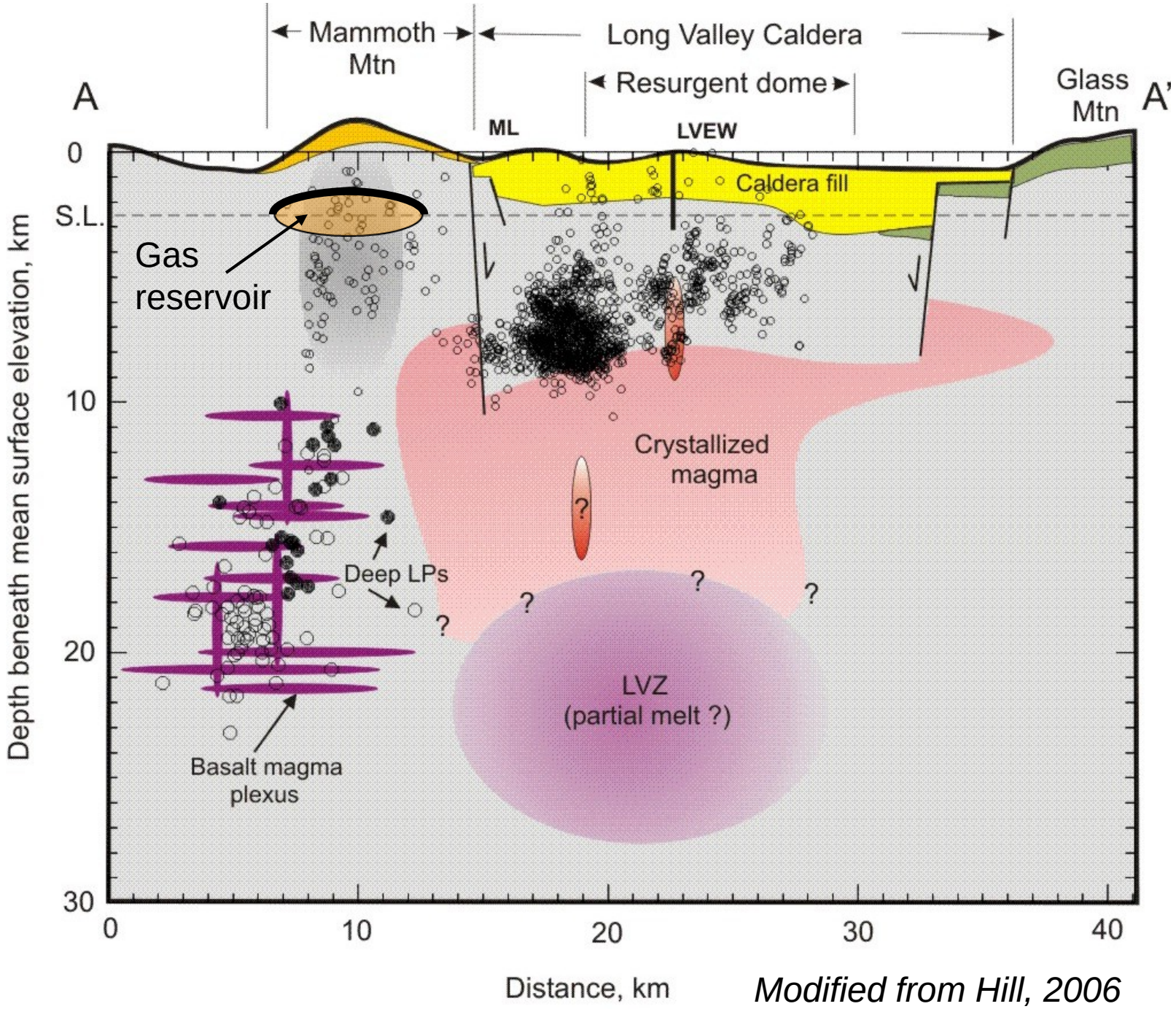
Mammoth Mtn is a dormant volcano, but in a volcanically active area. It experienced an earthquake swarm in 1989, followed by an outpouring of cold CO_2 through soils at a dozen areas around its flanks and increased $^3He/^4He$ ratios at a fumarole near the summit. High concentrations of CO_2 in the soils killed the tree roots, resulting in widespread forest mortality (Farrar et al, 1995; Sorey et al, 1998).



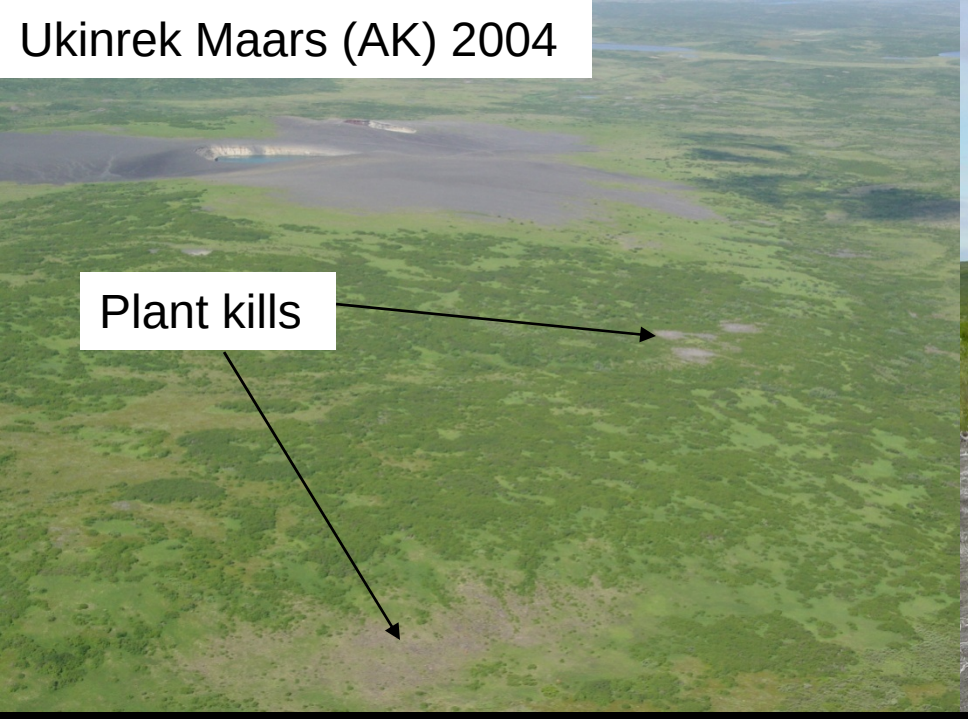
Mammoth Mountain Totals

- CO_2 discharged diffusely from soils: 300-500 t/d
- CO_2 (DIC) discharged by cold springs: 55 t/d
- About 4 Mt of CO_2 discharged from Mammoth Mtn since 1989.

Would need to degas 0.1 km^3 of basalt containing 1% CO_2.
Observed inflation of Mammoth Mtn only ~0.01 km^3.



Modified from Hill, 2006

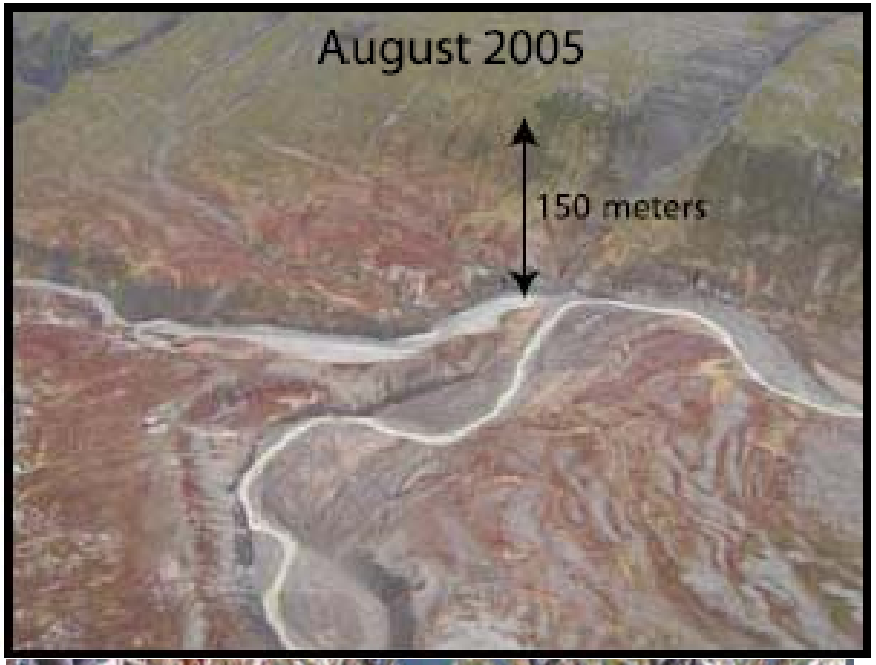

Ukinrek Maars (AK) 2004
Plant kills


44 t/d CO_2


Shrub Mud Volcano (AK) 2004

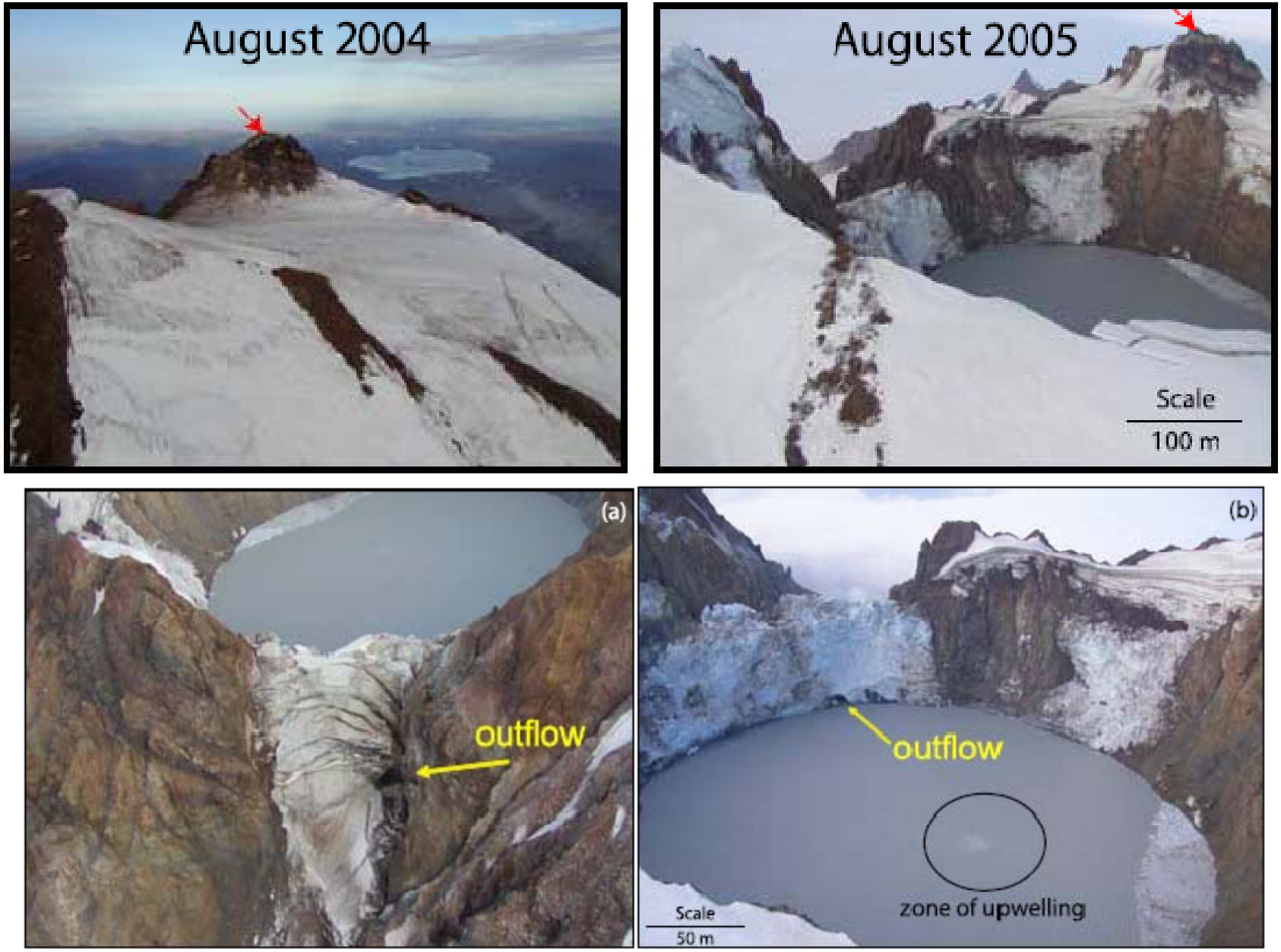

~10 t/d CO_2

Chiginagak crater lake AK 2005



Schaefer et al. 2008

Chiginagak crater lake AK 2005



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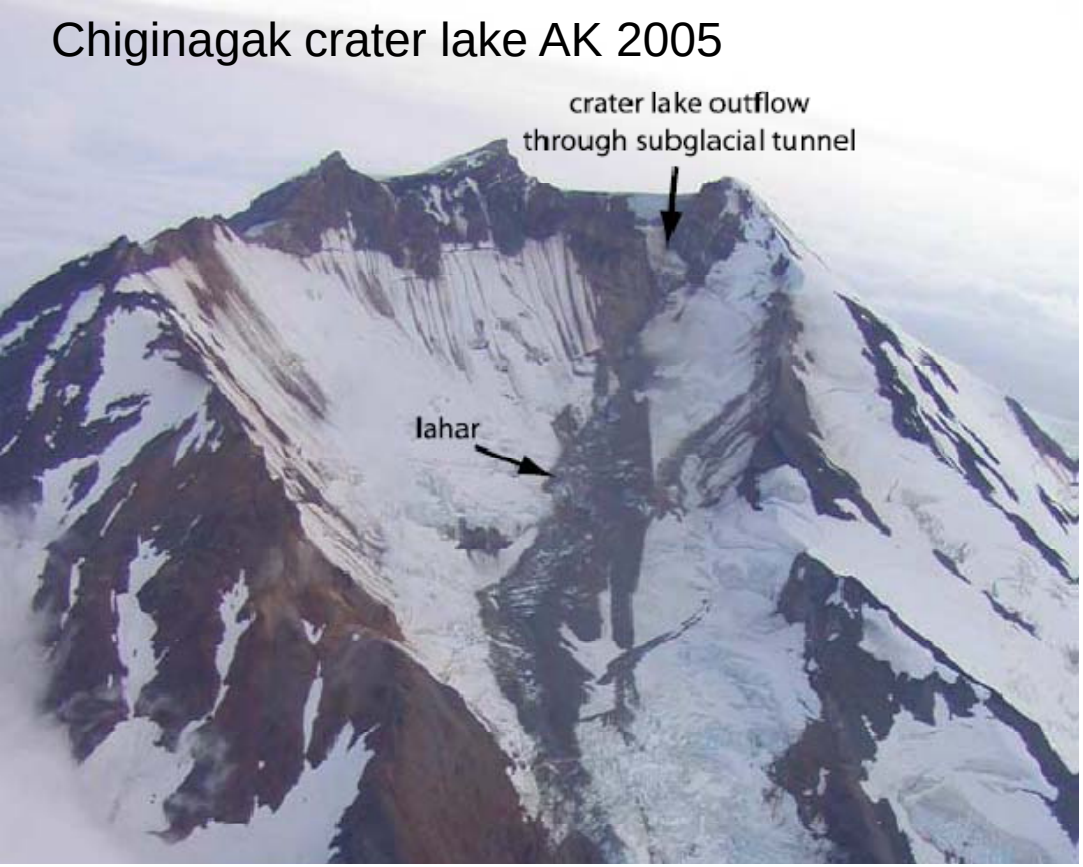
Chiginagak crater lake AK 2005

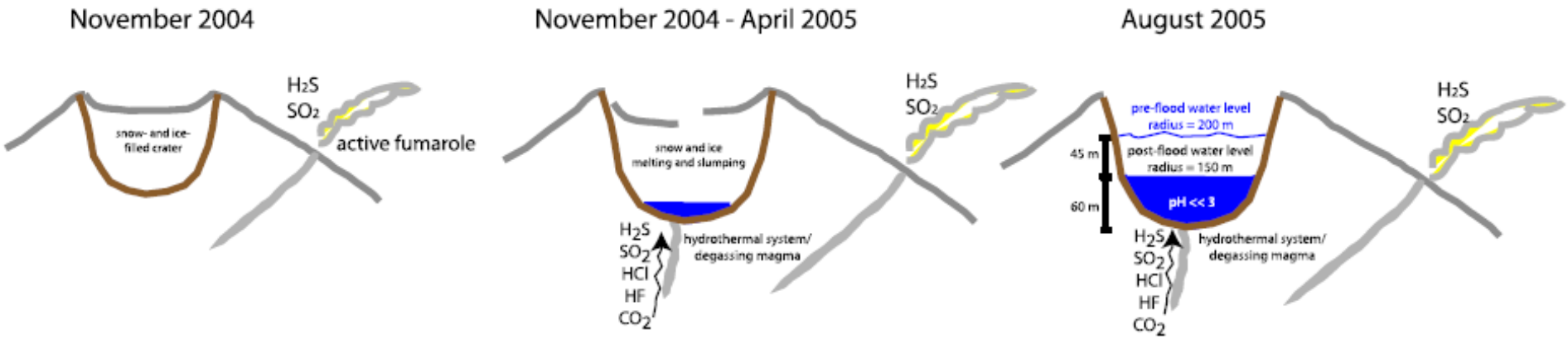


Increased upflow of gas and heat (from an intrusion?) quickly melted the summit snow and ice, creating a 100-m deep crater lake.

Breaching allowed the top 45 m to burst out through a tunnel in the ice.

The violent escape of this water, which contained sulfur gases in addition to CO_2, created an acid aerosol that flowed as a cloud down the drainage.

Vegetation was harmed when this aerosol soaked the foliage.



Schaefer et al. 2008

Summary:

Magmatic gases (mainly CO_2) can accumulate at low temperature in various crustal traps.

Sudden gas releases are rare but certainly occur.

Gas emission rates from crustal traps can rival those of volcanic eruptions.

Release at low temperature can produce a dense cloud with asphyxiation hazard.

Gas disasters can occur without volcanic or magmatic unrest (like lahars).

..but the events can shed light on magmatic processes (e.g., Mammoth Mtn.).

The events have had an impact beyond the field of volcanic hazards – for example in engineered CO_2 sequestration plans.

Annual global CO_2 emission from volcanoes:
~0.26 gigatons

Annual anthropogenic CO_2 emission:
~35 gigatons

from Gerlach, 2011

Lava flow from Mt Cameroon blocking traffic January 2001