CASE REPORT

Fatal Fall into a Volcanic Fumarole

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Fatalities secondary to inhalation of volcanic gases in the United States have rarely been reported. We report the deaths of 3 ski patrol members at a popular California ski resort. After a snowstorm, ski patrol members were fencing off a well-known volcanic fumarole when the snow around the vent collapsed. Two members slid into the deep hole and rapidly lost consciousness. A third member carrying oxygen descended into the hole and also lost consciousness. A fourth member affixed an oxygen mask, but still lost consciousness upon descent. The 3 initial victims expired at the scene, while the fourth victim survived. Autopsy results for all 3 were consistent with a suffocation/asphyxiation death. In the case described, the involved fumarole is a well-known source of toxic gases. Atmospheric sampling data dating back decades demonstrate that carbon dioxide levels typically range from 97% to 99%, nitrogen gas from 1% to 3%, and hydrogen sulfide from .004% to .07%. Other gases in smaller concentrations include oxygen, hydrogen, and carbon monoxide. Given the rapidity with which our victims lost consciousness and the historical data available on the Mammoth Mountain Fumarole (MMF), it is plausible that our patients suffered from acute asphyxiation, although the contribution of the directly toxic effects of the gases involved cannot be ruled out. During winter months, snow can build up and disguise volcanic vents and potentially trap toxic fumes to form dangerous, gas-filled pits. Recognition of such potential hazards is essential when working in or venturing into volcanically active areas during the winter.

Key words: gasses, fumarole, volcanic, asphyxiation

Introduction

Despite the fact that the United States is one of the most concentrated sources of volcanic activity on earth, reported fatal exposures to volcanic gases are rare. A fumarole is a geothermic vent from which volcanic gases, such as carbon dioxide, nitrogen gas, carbon monoxide, and hydrogen sulfide, are emitted. Fatalities caused by inhalation of volcanic gases in the United States have rarely been reported. We report the deaths of 3 ski patrol members at a popular California ski resort after they fell into the Mammoth Mountain Fumarole (MMF).

Case report

Shortly after a heavy snowstorm, a group of 6 ski patrol members was moving a barely visible fence protecting the boundaries of a well-known volcanic fumarole on

Mammoth Mountain, CA, when the snow around the covered vent collapsed. Two members (victims 1 and 2) slid into the 21-feet-deep hole and rapidly lost consciousness. An emergency distress call was placed and additional ski patrollers arrived with rescue equipment soon after. While others attempted to dig a rescue hole through a lower section of the vent to reach the victims, one ski patrol member (victim 3) descended into the hole with a nonrebreathable oxygen mask in hand, but lost consciousness within 30 seconds before he could affix the mask. An additional patroller (victim 4) descended partway down the hole, quickly recognized the dangers of the overwhelming fumes, called out for rescue, and affixed his oxygen mask just prior to losing consciousness.

Because of the noxious gasses emitted by the fumarole, the remaining members of the initial ski patrol party plus additional patrollers who responded to the distress call worked in brief shifts for approximately 15 minutes until a sufficiently large hole could be dug to allow access to the victims. Eventually, patrollers using

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nonrebreathable oxygen masks (one of whom was overcome by fumes and briefly lost consciousness upon exiting) successfully extracted victims 3 and 4, while victims 1 and 2 were removed soon after with the aid of fire department personnel wearing self-contained breathing apparatus.

Many of the ski patrol members involved in the rescue experienced transient nausea, vomiting, and dizziness. Victim 4 was alert and oriented soon after extraction. All symptomatic patients were admitted to a local hospital for overnight observation, but none required significant medical intervention. Pulse oximetry and carboxyhemoglobin levels were normal for all patients tested. Victims 1, 2, and 3 were all in cardiopulmonary arrest upon extraction and could not be resuscitated. Autopsies on the 3 deceased patrollers revealed pulmonary edema, enlargement of all 4 cardiac chambers, and subperiosteal hemorrhages in the areas of the petrous pyramids. These findings, combined with the history of exposure, were deemed consistent with asphyxiation deaths. Postmortem carboxyhemoglobin concentrations were not measured.

Discussion

While deaths related to acute volcanic gas exposure have been well documented in the medical literature,¹ such incidents have rarely been described in the United States.^{2,3} Our search revealed no other reports of fatalities secondary to falling into geothermic vents. In our cases, the involved fumarole, the MMF, is a well-known source of toxic gases. It is located on the north side of Mammoth Mountain, an active volcano located on the southwest rim of the Long Valley Caldera in California, where extensive emissions of carbon dioxide (CO₂) have been documented for almost 2 decades.⁴ Periodic atmospheric sampling of the MMF by the US Geological Survey (dating back to 1997) indicates that the measured levels typically found include the following: CO₂, 980 000 ppm; nitrogen gas (N₂), 10 000 ppm; and hydrogen sulfide (H₂S), 200 ppm.⁵ Other gases in smaller concentrations include oxygen (O₂), hydrogen (H₂), helium (He), and methane (CH₄) (Table).

In this event, atmospheric measurements taken 1 to 2 hours after the incident by fire department personnel revealed the following readings: O₂, 180 000 ppm; CO₂, 100 000 ppm, carbon monoxide (CO), 40 000 ppm; and H₂S, 30 ppm. Interpretation of these values is difficult, however, because of the venting that occurred during rescue efforts. Also, the elevated CO concentrations are difficult to explain because they have not been reported in prior sampling done with the MMF. Given the rapidity with which our victims lost consciousness and the his-

Table. Volcanic gas concentrations

<i>Gas component</i>	<i>Mammoth Mountain Fumarole gas concentrations [volume (%)]</i>
Carbon dioxide (CO ₂)	987 000 ppm* (98.7)
Nitrogen (N ₂)	11 000 ppm (1.1)
Oxygen (O ₂)	900 ppm (0.09)
Hydrogen (H ₂)	300 ppm (0.03)
Hydrogen sulfide (H ₂ S)	200 ppm (0.02)
Methane (CH ₄)	20 ppm (0.002)
Helium (He)	10 ppm (0.001)

*ppm indicates parts per million. Adapted from the US Geological Survey (<http://lvo.wr.usgs.gov/helium.html>).

torical data available on the MMF, it is plausible that our patients suffered from acute asphyxiation, although the contribution of the directly toxic effects of the gases involved cannot be ruled out.

Carbon dioxide is heavier than air and like most gases can cause asphyxiation when sufficient quantities are present. Atmospheric CO₂ concentrations of 100 000 ppm or more can rapidly produce unconsciousness and death.⁶⁻⁸ Lower concentrations may cause headache, sweating, rapid breathing, tachycardia, shortness of breath, dizziness, mental depression, visual disturbances, or tremor.⁹ The severity of the symptoms is dependent on the concentration of CO₂ and the duration of exposure. Given the historically high concentrations of CO₂ in the MMF and the layer of snow completely covering the vent opening, it is plausible that the amount of CO₂ trapped in the fumarole at the time of the incident caused the rapid loss of consciousness in the victims inside the vent as well as the symptoms experienced by rescuers in and around the vent. Additionally, because the MMF sits at an altitude of 2743 m above sea level, any relative hypoxemia experienced by those exposed could have potentially made them more susceptible to the effects of an asphyxiant exposure.

In addition to CO₂, another gas historically found in the MMF cannot be excluded as a contributing factor in the described exposures and subsequent clinical effects. Hydrogen sulfide is a foul-smelling, colorless gas that is heavier than air. The primary toxic effects of H₂S involve the inhibition of the cytochrome oxidase system, which results in cellular asphyxia, similar to the results of cyanide.¹⁰ Clinical effects associated with H₂S exposure concentrations range from mucous membrane and respiratory irritation at 50 to 100 ppm, pulmonary edema at 250 to 500 ppm, and rapid loss of consciousness and death at >500 ppm.¹¹ Although measured H₂S concentrations soon after the accident were lower than

those reported to cause serious symptoms, the snow covering the vent opening could have initially trapped H₂S in higher concentrations. As is the case with death from asphyxiation, there are no pathognomonic autopsy findings for H₂S poisoning, so it is difficult to determine if H₂S played an important role in the deaths.

With respect to the initial rescue efforts, it appears that the ski patrol members were either unaware of the significant dangers associated with fumarole gases or ignored them in an effort to rapidly aid their colleagues. Although efforts were made to utilize the available non-rebreathable oxygen masks, they were apparently ineffective in protecting the wearers. As a result of the high concentrations of toxic gases found in volcanic vents, rescue efforts inside these vents should be avoided until self-contained breathing apparatus can be utilized.

Conclusions

During winter months, snow can build up and disguise volcanic vents and potentially trap toxic fumes to form dangerous, gas-filled pits. The rescue of individuals who fall into such pits can be extremely dangerous and should not be attempted without adequate respiratory protection. Recognition of such potential hazards is essential when working in or venturing into volcanically active areas during the winter.

References

1. Hansell A, Oppenheimer C. Health hazards from volcanic gases: a systematic literature review. *Arch Environ Health*. 2004;59:628–639.
2. Stephenson R, Burr G, Kawamoto M, et al. Exposures to volcanic emissions from the Hawaiian volcanoes: a NIOSH health hazard evaluation. *Appl Occup Environ Hyg*. 1991;6:408–410.
3. Hill PM. Possible asphyxiation from carbon dioxide of a cross-country skier in eastern California: a deadly volcanic hazard. *Wilderness Environ Med*. 2000;11:192–195.
4. Sorey ML, Evans WC, Kennedy BM, Farrar CD, Hainsworth LJ, Hausback B. Carbon dioxide and helium emissions from a reservoir of magmatic gas beneath Mammoth Mountain, California. *J Geophys Res*. 1998;103:15, 303–315, 323.
5. U.S. Geological Survey. Helium Discharge at Mammoth Mountain Fumerole. Available at: <http://lvo.wr.usgs.gov/helium.html>. Accessed February 6, 2007.
6. Ikeda N, Takahashi H, Umetasu K, Suzuki T. The course of respiration and circulation in death by carbon dioxide poisoning. *Forensic Sci Int*. 1989;41:93–99.
7. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Documentation for Immediately Dangerous to Life or Health Concentrations (IDLH): NIOSH chemical listing and documentation of revised IDLH values (as of 3/1/95). Available at: <http://www.cdc.gov/niosh/idlh/intridl4.html>. Accessed February 6, 2007.
8. Manning TJ, Ziminski K, Hyman A, Figueroa G, Lukash L. Methane deaths? Was it the cause? *Am J Forensic Med Pathol*. 1981;2:333–336.
9. Flomenbaum NE, Goldfrank LR, Hoffman RS, Howland MA, Lewin NA, Nelson LS, eds. *Goldfrank's Toxicologic Emergencies*. 8th ed. New York, NY: McGraw-Hill; 2006: 1673–1688.
10. Beauchamp RO Jr, Bus JS, Popp JA, Boreiko CJ, Andjelkovich DA. A critical review of the literature on hydrogen sulfide toxicity. *Crit Rev Toxicol*. 1984;13:25–97.
11. Reiffenstein RJ, Hulbert WC, Roth SH. Toxicology of hydrogen sulfide. *Annu Rev Pharmacol Toxicol*. 1992;32: 109–134.