# Recent (2006-2013) unrest at Mammoth Mountain, California and the evolving role of magmatic $CO_2$

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Mammoth Mountain is a dacitic dome complex located on the southwestern rim of Long Valley caldera in California. In 1989, an 11-month-long seismic swarm occurred beneath Mammoth Mountain and was followed by diffuse emissions of magmatic $CO_2$ and development of associated areas of tree kill, along with increases in the ratio of $^3He/^4He$ in fumarolic gas and frequency of mid-crustal long-period earthquakes. These events are thought to be related to magma intrusion and upward migration of $CO_2$-rich hydrous fluid. Over the subsequent 20+ years, an estimated 3.5 Mt of $CO_2$ have been emitted from Mammoth Mountain. Long-term geophysical and geochemical monitoring carried out by the U.S. Geological Survey was recently augmented by a multidisciplinary geophysical, geochemical, hydrologic, and biologic research project aimed at improved understanding of the origin, transport, and environmental impacts of $CO_2$ at Mammoth Mountain. Components of this project include: (1) studies that encompass $CO_2$ solubility experiments with hydrous basaltic melt, deployment of a temporary broadband seismic network, spatio-temporal analysis of fluid-driven earthquakes, and modeling fluid flow with dynamic permeability; (2) hydrologic/atmospheric studies of fumarole and spring fluid geochemistry and soil $CO_2$ flux; and (3) biologic studies of radiocarbon in tree growth rings, soil geochemistry, microbiology, and disruption ecology. Key observations of and inferences from this work to date have included the recording of multiple lower-crustal (13-31 km depth) seismic swarms beneath Mammoth Mountain between 2006 and 2013. Based on spatio-temporal analysis, the 2009 swarm was interpreted to be driven by ascending $CO_2$-rich fluids derived from underlying magma. Solubility experiments support substantial loss of $CO_2$ from hydrous basaltic melt at these lower-crustal conditions, while hydraulic diffusivities calculated from time-depth earthquake hypocenter progression suggest transient states of high permeability suitable for enhanced fluid transport. The 2009 swarm was followed in 2009-2010 by an increase in shallow (<10 km depth) seismicity and in 2010-2011 by an increase in diffuse $CO_2$ emissions and magmatic carbon content of tree rings at the largest (Horseshoe Lake) tree kill area, as well as a rise in fumarolic $^3He/^4He$ ratios on Mammoth Mountain. Preliminary analysis of the 2011-2013 seismicity suggests northeastward migration of deep seismic swarms to directly beneath Mammoth Mountain. Further detailed analysis of earthquakes coupled with continued geochemical monitoring should elucidate the relationship between magma injection, seismicity, and $CO_2$ emission in this latest phase of activity at Mammoth Mountain.

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