

Large-Scale Experiments on Volcanic Processes

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Some of the least understood and most hazardous geologic processes involve complex multiphase flows, particularly those related to explosive volcanic eruptions. These phenomena inherently involve a wide range of characteristic length and time scales, as well as processes that are coupled across those scales in a range of flow regimes. For example, a pyroclastic density current's (pyroclastic flows and surges) behavior is governed in a complex way by the interactions between individual particles ($\sim 10^{-4}$ to 10^1 meters, $\sim 10^{-1}$ to 10^1 seconds) and by turbulent mixing with surrounding air ($\sim 10^{-2}$ to 10^2 meters, 1 to 10^2 seconds). Material properties within individual flows can vary over huge ranges; for example, when ascending magma interacts with groundwater in a volcanic conduit, the viscous melt and liquid water are transformed into brittle glass and steam.

There are four ways in which scientists explore these processes: observations in real time, observations of deposits after an event, analog and scaled benchtop experiments, and analytical or numerical models. Data collection from active volcanic flows is limited by the unpredictability of the events and the dangerous conditions they produce. Even when measurements can be made, the initial and boundary conditions of the eruptive flows may be poorly constrained, limiting the physical insight that could be gained. Data measured on deposits or other eruptive products, such as individual clasts, provide important, but indirect, information on the parent processes. While analog experiments provide many insights into the flows, a fundamental difficulty with many multiphase volcanic processes is that they cannot strictly be scaled to the benchtop. Numerical modeling is of growing importance in predicting and interpreting volcanic flows but requires improved constitutive models and validation data sets.

Addressing these gaps, as well as learning about as yet undiscovered emergent behaviors, requires the development of large-scale experiments to capture the relevant regimes, length and time scales, and material properties of natural processes under controlled situations where careful measurements can be made with known initial and boundary conditions. Such a capability would be a natural follow-on to recent growth in the role of experimentation in volcanology. During the past 2 decades, researchers have conducted laboratory-scale experiments and simulations of magma fragmentation [e.g., *Alidibirov and Dingwell*, 1996; *Zimanowski et al.*,

1997; *Büttner et al.*, 2002; *Kueppers et al.*, 2006; *Alatorre-Ibargüengoitia et al.*, 2010] and particulate flows [e.g., *Chojnicki et al.*, 2006; *Girolami et al.*, 2010] and field-scale multiphase eruption simulations [*Dellino et al.*, 2007, 2010a, 2010b] and fragmentation experiments [*Kueppers et al.*, 2010]. A new large-scale experimental facility would also build on previous and ongoing experimental approaches to other Earth science relevant processes, such as debris avalanches, debris flows [*Iverson et al.*, 2010], and sediment gravity currents in water [*Garcia and Parker*, 1993; *Kneller et al.*, 1999]. Because large-scale experiments are inherently complex and costly, and the geohazards and volcanology communities are relatively small and have limited resources, it makes sense to pursue large-scale experimental capabilities with a "community use facility" approach. Such a shared facility would provide basic infrastructure, sensors, data acquisition and archiving, and engineering support while

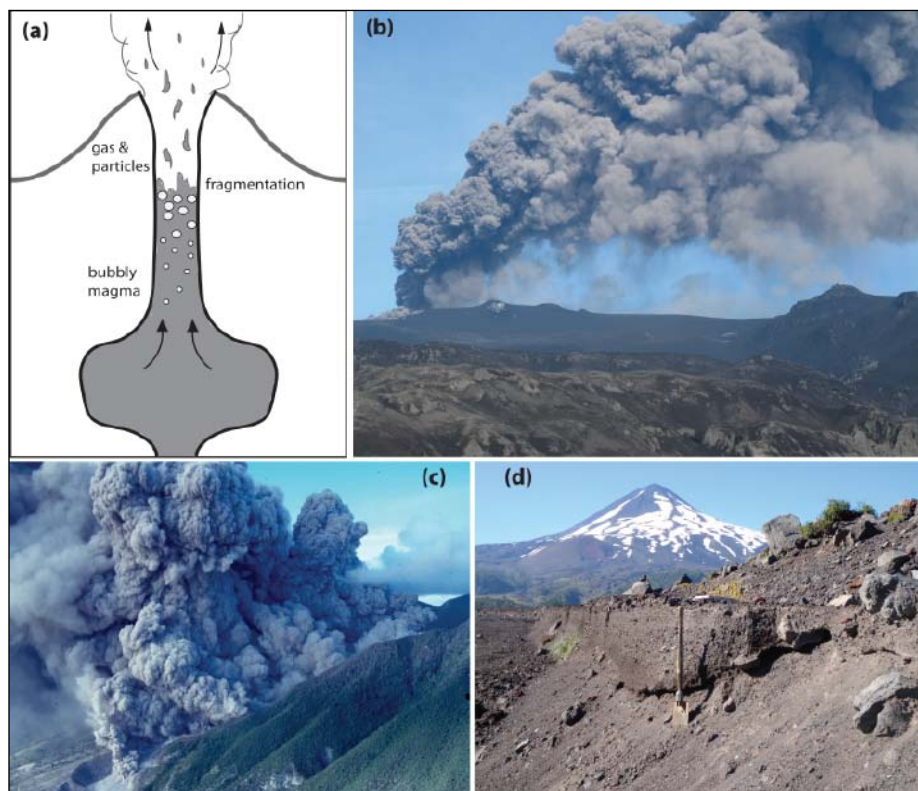


Fig. 1. (a) Schematic illustration showing subsurface ascent and fragmentation of magma driven by magmatic volatiles. (b) Eruption column from 2010 activity at Eyjafjallajökull volcano, Iceland. (c) Small pyroclastic density current produced by lava dome collapse at Soufrière Hills volcano, Montserrat (courtesy of E. Calder). (d) Debris flow (lahar) deposits related to 2008 activity at Llaima volcano, Chile.

promoting independent use by multidisciplinary teams.

Volcanic processes involving multiphase flow fall into four main categories: (1) the subsurface environment, where exsolved volatiles form bubbles that can interact with melt in complex ways and where magma can fragment explosively due to the growth and expansion of those bubbles (Figure 1a) and/or due to interaction with externally derived water; (2) eruption columns, where erupted materials interact with the atmosphere and are dispersed downwind (Figure 1b); (3) pyroclastic density currents (PDCs) that travel over the surrounding terrain, causing extreme damage and complex deposits (Figure 1c); and (4) mass failure and flow of volcanic edifice and remobilized eruptive deposits by debris avalanche and debris flow mechanisms (Figure 1d).

Subsurface Volcanic Processes

Before erupting, magma ascends, fragments, and accelerates through the shallow volcanic feeding system. Important topics in this region include bubble dynamics, magma fragmentation (whether driven by magmatic volatiles or by explosive interaction with external water), the interaction of the flow with surrounding rocks, and the formation of the resulting geologic structures (e.g., diatremes).

Many experimental studies have been conducted with both analog materials and real magmas to elucidate these processes, but these have been limited mainly to scales of centimeters to decimeters. There are several drivers for moving to larger scales (meters), including the need to reduce wall effects, replicate natural velocity gradients and profiles, allow full evolution of processes such as bubble coalescence, develop steady state fragmentation flows from significant reservoir volumes, and mimic natural geometries under dynamic conditions.

Eruption Columns and Tephra Dispersal

Eruption columns consist of both inertia- and buoyancy-driven high-speed flows of volcanic gas and particles in the atmosphere. The dynamics of volcanic plumes are strongly controlled by exit velocities and vent geometry and by the interaction of the plume with the atmosphere (e.g., entrainment and wind shear). These parameters control plume height, gravitational collapse, and associated particle dispersal and deposition.

Important questions regarding eruption column dynamics that could be answered by a large-scale experimental facility fall into three categories: (1) differential velocity between particles (tephra) and gas, which ultimately may be critical to understanding turbulent energy and scales in multiphase plumes as well as particle sedimentation and resulting deposit characteristics; (2) better

characterization of turbulence in multiphase flows, which strongly affects atmospheric entrainment and plume stability (for impulsive, pulsing, and sustained behaviors); and (3) the effects of jet overpressure, which controls large-scale plume morphology and dynamics and can be closely related to vent geometry.

PDCs

PDCs can be generated by a range of phenomena, including the collapse of eruption columns, lateral blasts, and gravitational failure of lava domes. Four key issues motivate large-scale experiments: (1) The interaction between the two main zones of PDCs, the basal avalanche and the overlying dilute portion, is not understood or quantified experimentally but is critical to predicting inundation and damage areas; (2) near-bed effects, such as shear stress, development of pore overpressure, and interaction with and erosion of topography, are also critical; (3) sources of unsteadiness within PDCs are important but poorly constrained and documented; and (4) particle-particle and particle-gas interactions over a range of particle and flow length scales must be understood, as they play a key role in generating and modulating internal friction.

The volcanology community relies heavily on the characteristics of PDC deposits to develop hazard and risk assessments; however, much of volcanologists' interpretation of features such as bed forms is borrowed from the classical sediment transport literature that focuses on shallow, clear water flows. One goal of large-scale experiments is to enable researchers to constrain the dynamic conditions under which various bed forms are developed in the flows.

Debris Avalanches, Debris Flows, and Lahars

Debris avalanches, debris flows, and lahars are highly concentrated mass flows consisting of a sediment mixture with a broad particle size range, which may include a fine-grained matrix. For studies of pure debris flows, it is possible to use the experience derived from existing large experiments as summarized by Iverson *et al.* [2010]; however, many issues remain unresolved for these flows and their more dilute transformations. New experiments are required to better constrain how the boundary conditions, flow and sediment bulk-ing, and substrate topography influence the mobility and total runout of debris flows and how these may transform both flow process and deposit character down flow. An additional important issue to be considered is flow dilution due to interaction with standing water bodies or flowing streams. However, experimental studies of this process will be feasible only if the time and length scales of an experiment are sufficiently large compared to the time scale for entrained water to be distributed through the flow.

Although several theories have been proposed to explain the long runout distances of debris avalanches, such as dynamic or acoustic fluidization, elastic release of energy, and pore fluid mobilization, no general consensus has been achieved on which may be most important and under what conditions. Laboratory experiments, which are essentially "inertialess," have provided vital information on the frictional, brittle kinematics of the debris avalanche body, but no modeling has yet examined either processes at the base or fragmentation within the mass where inertial forces will play an important role. The objective of these large-scale experiments would be to observe, in a controlled environment, basal processes that could be related to low friction and to characterize the textures and structures produced by each possible process. Because, at a large scale, it may not be feasible to achieve strain rates able to induce fragmentation of natural material, a synthetic analog material would be researched and used.

Testing New Remote Sensing Technologies

It is anticipated that there will be an exciting feedback between large experiments and remote sensing technology. New ground-based remote sensing techniques are obtaining detailed information on particle velocities and concentrations in eruptive fountains, as well as on gas concentrations and velocities. However, it is extremely difficult to test emerging technologies on real eruptions because of their hostile environments and uncertain timing and their poorly constrained initial and boundary conditions. Large-scale experiments provide opportunities to test new technologies in a controlled and scheduled environment, with multiple sensors for cross checking and without necessarily having to engineer the technique for field portability. At the same time, these new techniques will be extremely useful in gathering data from the experiments and increasing the diversity of data that can be used in analyzing flow physics.

The Path Forward

A user facility to enable large-scale experiments would not only advance scientists' fundamental understanding and ability to forecast hazardous volcanic processes but would also help to usher in a highly collaborative and interdisciplinary way of conducting research for the volcanology community. A 700-acre experimental site, known as the Experimental Campus for Large Infrastructure Protection, Sustainability, and Enhancement (ECLIPSE), already exists near Buffalo, N. Y. The ECLIPSE campus is being used for studies on issues such as seismic design of full-scale highway bridges and the structural resilience of construction components when exposed to extreme processes such as blasts and fires. The campus will include a geohazards field station, which will be a user facility for addressing a range of natural hazards but with an initial focus on volcanic

processes. A workshop aimed at defining the scientific priorities and functional design for the geohazards field station was held near Buffalo on 17–19 September 2010; the scientific issues described above are a product of the workshop.

To build upon the momentum developed during the workshop, an executive committee for the geohazards field station has been formed. This committee consists of researchers from across the community who are committed to the development of the facility. A virtual site has been established on <http://vhub.org>, a new online collaboration hub for volcanology research and risk mitigation. Here, interested researchers can see workshop presentations and a more detailed version of this report and can participate in an online discussion that will increase input from the wider community. Ongoing discussions will define the infrastructure and instrumentation that is needed to allow the individual research priorities to be addressed while providing maximum flexibility. Some features are already in place, such as adequate access, power, water, a machine shop, and a high-speed computer network. Additional infrastructure will focus on specific classes of experiments that correspond to the problems listed above. More details on the infrastructure concepts can be found at <http://vhub.org>.

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NEWS

Proposed Budget for U.S. Geological Survey: A Mixed Bag of Increases and Cuts

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Under the Obama administration's proposed fiscal year (FY) 2012 budget, the U.S. Geological Survey (USGS) would receive \$1.1 billion, a scant \$6.1 million more than the 2010 enacted budget. Within the agency, which is part of the Department of the Interior (DOI), some key initiatives slated for new or increased funding include the National Land Imaging Program, the USGS portion of the America's Great Outdoors Initiative, and DOI Climate Science Centers. However, the request also includes \$89.1 million in program reductions and the elimination of some programs. With Congress currently considering a budget continuation resolution to fund the federal government

through the end of the current fiscal year, 2011, USGS faces possible additional cuts.

Decisions regarding funding cuts in the administration's request were not necessarily the Survey's first choices for reductions, USGS director Marcia McNutt explained at a 14 February budget briefing. During administration budget planning, "the usual question that comes down is, 'Where do you have programs that are nonperforming or off-mission?' We said we have no programs that are nonperforming, we have no programs that are off-mission," she noted.

"We put up a lot of possible places where cuts could be made, all of them painful," she said, noting that the administration wanted the Survey to continue doing some federal government tasks that are not part of

the agency's core mission because USGS—which is a science agency with no regulatory responsibilities—is considered "an honest broker" for those activities.

With cuts necessary, though, McNutt said the USGS leadership team came up with reductions across the entire agency, so the pain of budget reductions was spread out. McNutt said the agency-wide effort in examining and dealing with budget cuts is an example of the strength of the agency's recent realignment and restructuring. "Since we are dealing with our problems and our science on an interdisciplinary basis," she said, "it does allow us, when we do take these cuts, to figure out how we can accommodate program reductions also on an agency-wide basis."

The budget request "aligns well" with the Survey's recent restructuring around six broad themes: climate and land use change; core science systems; ecosystems; energy and minerals, and environmental health; natural hazards; and water, McNutt said. "Going from our old structure to the new structure," McNutt said, "we chose to keep all our programs intact, so all our programs simply were moved, not necessarily all in