Understanding how volcanoes and eruptions work: Insights from observations and analogue modelling; what, how and what for ?

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Many aspects of how volcanoes and eruptions work remain incompletely understood to the extent that in most cases the character of eruptions cannot yet be anticipated. Hundreds of active volcanoes in the developing world are yet to be documented and monitored. Only 200-300 of the 1500 potentially active volcanoes have been studied and are continuously monitored with state-of-the-art monitoring techniques. Volcanology is a young and exciting science only just starting to find its marks. New insights into the mechanics of eruptions and volcanoes can come from documenting unstudied volcanoes and volcanic phenomena in the field, in the lab or by taking advantage of advances in integrated remote sensing techniques, as well as from new applications of first principles of geological fluid mechanics or cloud physics to volcanic phenomena. In the lab, the simplest possible scaled-down geological fluid dynamics experiments focus on one aspect of the phenomenon at a time that can be carried out and modelled theoretically, with predictions subsequently compared to natural observations. Such simple experiments and comparative work typically provide the most insights.

The analogue modelling approach is illustrated to show how it enables to advance understanding of the dynamics of particulate dispersal from turbulent jets, plumes or associated gravity currents in a still ambient or in a crossflow. Geological examples of such flows include deep-sea black smokers and turbidity currents, powder snow avalanches and desert dust storms, as well as flows produced by explosive volcanic eruptions. During a plinian eruption for example, a 1000C hot multiphase flow mixture exits the vent vertically at 100s m/s, entrains air and heats it up and can produce a turbulent jet developing into a buoyant plume and finally a radially-spreading gravity current intruding the cold upper troposphere or lower stratosphere, at ca.10-50km elevation before interacting with crosswinds. Eruption column gravitational instability can produce collapsing fountains and hot, ground-hugging density currents that can move kilometres to tens of kilometres before lofting and producing giant stratospheric ashclouds.

Material can be dispersed far and wide from such flows and can devastate entire regions as well as threaten international air traffic and have a short-term influence on the atmosphere-climate system (eg. Pinatubo in 1991). A simple analytical model is developed for fallout from turbulent jets and plumes and compared to analogue lab experiments to show that particle recycling is a key control on such flows and on deposition from them. Another model is developed to show that dispersal from associated gravity currents is characterised by dynamic regimes with high, intermediate and low Reynolds number settling and that this has important implications for eruption reconstruction from deposits which is the basis for hazard assessment at volcanoes. Simple flow visualization experiments show how the dynamics of interaction between explosive eruption clouds and crosswinds depends on the plume-to-crossflow characteristic velocity ratio. Strong plumes in weaker crosswinds are dominated by wind-advected gravity currents at their final rise level whereas relatively weaker plumes are dominated by a counter-rotating vortex pair and bifurcate, dispersing tracers in two directions. The relationship between deposits and advected volcanic clouds as seen from satellites can also be studied experimentally and exploited to infer key eruption parameters from deposits.

In water-rich eruptions, an eruption column accounting for water and ash particle interactions (cloud microphysics) is developed from the ATHAM numerical model. Developed through joint efforts with the Max Planck Institute for Meteorology (Hamburg), it is the first eruption column model accounting for cloud microphysics and meteorology. Volcanic cloud particle aggregation is another key poorly understood process. In water-rich clouds, pea-size dense ash aggregates form (accretionary lapilli), which we also studied through observations and measurements. A number of their features can only be accounted for if they form in a way analogous to hailstones from severe thunderstorms and a simple conceptual model for their formation is illustrated. There are analogies between the turbulent columns of water-rich eruptions and severe thunderstorms: both are rich in supercooled water and ice, are dominated by particle-particle interactions, fallout and recycling, contain hailstone-like particles growing by riming, have similar scales and emplace particles during discrete and repeated fallout events, the number of which depends on storm intensity, together with maximum hailstone size.

A focus in volcanology has been to relate deposit features to dynamic processes. We are extending this approach in a systematic way to relate the shape, size and vent distributions of entire volcanoes to explore what understanding of processes can be inverted. This effort takes advantage of near-global topographic and other remote sensing datasets which now enable to systematically quantify the morphometry of volcanoes, document and compare sizes of volcanoes or their vent distributions for the first time. This then leads us back to the lab where new analogue experiments are starting at UGhent to provide insights into controls on the geometry of particular volcano types (notably volcanic cones and cone-forming eruptions to start with), on magma ascent and on the outbreak locations of future eruptions. New insights are then applied to unstudied volcanic regions, notably across central Africa, where we survey the regions by remote sensing, carry out novel field and physical volcanology work and first explore the development of low cost hazard analyses or monitoring that can be derived with existing means in the developing world. Recent applications enabled to carry out the first assessment of hazards from lava flows at Mt. Cameroon (one of the biggest undocumented on-land lava-dominated volcano; and the most active volcano in W Africa), to document the transitional phase associated with the major change in eruptive activity from effusive to explosive and from carbonate to silicate magmas at Oldoynio Lengai (N Tanzania) and to develop semi-automated daily thermal RS monitoring of its crater, as well as discover major catastrophic events which occurred in the last thousands of years at Lengai and in the Rungwe Volcanic Province (RVP, SW Tanzania). These include major volcano collapse events at Lengai and the RVP, and Pinatubo-scale plinian eruptions in the RVP. These central Africa unstudied volcanic regions are now a major new focus of study in the new UGhent volcanology group. Objectives are to simultaneously advance scientific understanding of eruptions and volcanoes and to apply our work to anticipate hazards and contribute to poverty alleviation in the developing world.