The Physics of Fluid Oscillations in Volcanic Systems

Department of Environmental Science

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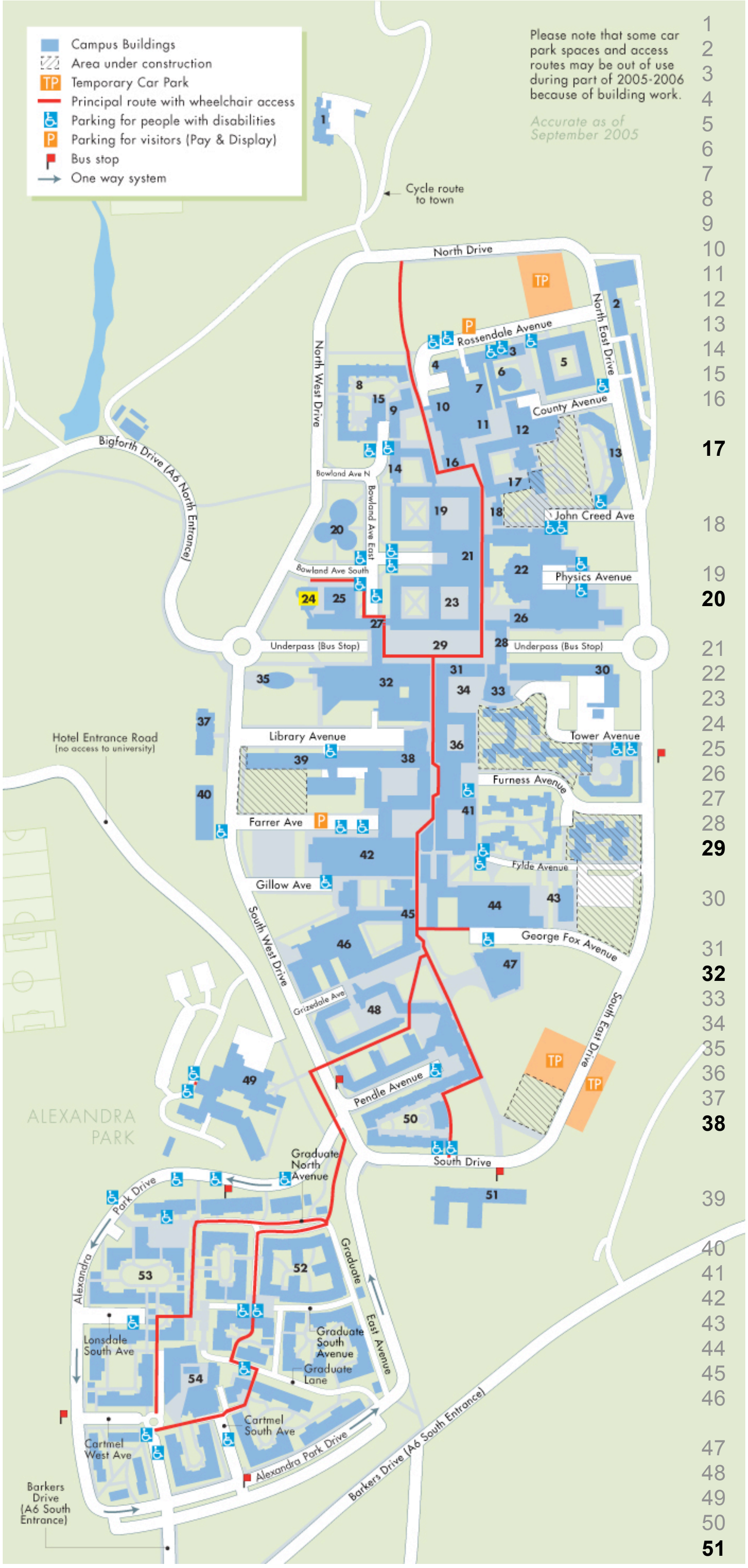
7th and 8th September 2006

Conveners
Steve Lane and Jennie Gilbert

Abstract Volume



1 Bailrigg House
2 LEC Workshops
3 County West
4 Music Building
5 County College
6 LUTV
7 Nuffield Theatre
8 Bowland Hall
9 Bowland Annexe
10 Great Hall
11 Peter Scott Gallery
12 County South
13 John Creed Building
14 ASH House
15 CETAD
16 Jack Hylton Music Rooms
17 Institute for Advanced Studies (IAS) Meeting Room 2/3
18 Institute for Cultural Research
19 Bowland North
20 Chaplaincy Centre (multi-faith)
21 Conference Centre
22 Faraday Building
23 Bowland College
24 Reception Building
25 Computer Services
26 Physics Building
27 University House
28 Bowland Tower East
29 Alexandra Square (shops and banks)
30 Central Workshops and Stores
31 Bowland Tower South
32 Library (preview)
33 Slaidburn House
34 Edward Roberts Court
35 Ruskin Library
36 Furness College
37 Pre-School Centre
38 Biological and Environmental Science Building
39 Lancaster Environment Centre
40 Health Centre
41 Fylde College
42 Sports Centre
43 Whewell Building
44 Engineering Building
45 Management School
46 Lancaster Leadership Centre
47 George Fox Building
48 Grizedale College
49 Lancaster House Hotel
50 Pendle College
51 InfoLab21 (evening meals)
52 Graduate College
53 Lonsdale College (accommodation)
54 Cartmel College and Barkers House Farm

Venue: Meeting Room 2/3, Institute for Advanced Studies.

Thursday 7th September

09:00 Welcome by Professor Trevor McMillan (Pro-Vice-Chancellor for Research)

09:10 Introduction by Steve Lane

Volcanoes in Reality

Insights from Eruption Products

09:15 Houghton, B. F., N.C. Lautze, and H. Gonnerman. Textural diversity in basaltic ejecta at Stromboli in 2002: Implications for oscillatory phenomena in Strombolian conduits. (Invited keynote)

09:45 Varley, N., J. Stevenson, J. Johnson, G. Reyes, V. Sword-Daniels, A. Corvin, K. Weber, R. Sanderson, and R. Harwood. Modelling conduit processes at Volcán de Colima, Mexico.

10:05 Taddeucci, J., P. Scarlato, D. Andronico, P. Del Carlo, R. Büttner, and B. Zimanowski. The effect of groundmass crystallization on the fragmentation of basaltic magma: Observations and experiments.

10:25 Tuffen. H. Cyclic processes during the emplacement of silicic lava: fracture, flow and valve behaviour.

10:45 *Morning coffee and discussion (IAS).*

Measurement and Interpretation of Oscillations

11:15 Garces, M. Acoustic oscillations in magma conduits. (Invited keynote)

11:45 Matoza, R., M. Hedlin, M. Garces, and D. Fee. Constraints on the source mechanism of long period events, tremor, and eruptions from simultaneous seismic and acoustic observations.

12:05 Johnson, J. B., and J. M. Lees. On the prevalence and manifestation of acoustic harmonic tremor at volcanoes.

12:25 Vergniolle, S., and M. Ripepe. Listening to fire fountains at Etna volcano (Italy).

12:45 *Buffet lunch and discussion (IAS).*

13:45 Ripepe, M., D. Delle Donne, E. Marchetti, and G. Ulivieri. Tracking explosive parameters in real-time by infrared and infrasonic records: Implication for the source dynamics. (Invited keynote)

14:15 Marchetti, E., M. Ripepe, and G. Ulivieri. Degassing dynamics at Stromboli Volcano: Insights from infrasonic activity.

14:35 Ohminato, T. Source mechanisms of moderate scale vulcanian eruptions at Mt. Asama, Japan, inferred from volcano seismic signals.

14:55 Takeo, M., T. Ohminato, and Y. Maeda. Long-period signals at Mt. Asama volcano, Japan, preceding an eruption on September 1, 2004.

15:15 *Afternoon tea and discussion (IAS).*

15:45 Nakamula, S., and M. Takeo. The frequency structure and characteristics of the deep low frequency tremor occurring in Western Shikoku. (Invited keynote)

16:15 Chouet, B., and P. Dawson. Shallow-conduit dynamics at Stromboli volcano, Italy, imaged from waveform inversions.

16:35 Aster, R., P. Kyle, W. McIntosh, C. Lucero, and B. Borchers. Very long period Strombolian eruption-associated seismic signals observed in the near field at Mount Erebus volcano.

16:55 Discussion.

19:00 *Workshop dinner, InfoLab 21 Café.*

Friday 8th September

Volcanoes in Simulation

Experimental Approaches

09:00 James, M. R., S. C. Corder, and S. J. Lane. Laboratory investigations of possible gas-slug related seismic source processes in low-viscosity magmas. (Invited Keynote)

09:30 Phillips, J. C., T. Kidd, R. S. J. Sparks, and O. E. Melnik. Cyclic variation in discharge rate during volcanic eruptions: Experimental, and theoretical studies.

09:50 Lane, S. J., J. C. Phillips, and G. A. Ryan. Cyclical volcanic processes resulting from diffusion pumping and gas venting.

10:10 Taddeucci, J., O. Spieler, and M. Ichihara. Bubbles, jumps, and fractures in an analogue experiment on volcanic conduits.

10:30 *Morning coffee and discussion (IAS).*

Numerical Approaches

11:00 Papale, P., A. Longo, M. Barsanti, M. Vassall, and D. Barbato. Numerical simulation of fluid flow oscillations in volcanic systems. (Invited keynote)

11:30 Woods, A. Some insights into the controls on basaltic eruption.

11:50 Rust, A. C., N. J. Balmforth, and S. Mandre. Elastic instabilities, roll waves and volcanic tremor.

12:10 Ichihara, M. Pressure perturbations generated by interaction of gas, liquid, and solid.

12:*30* *Buffet lunch and discussion (IAS).*

13:30 Melnik, O, A. Costa, and R.S.J. Sparks. Cyclic behaviour in lava dome building eruptions. (Invited keynote)

14:00 Costa, A., O. Melnik, and R.S.J. Sparks. Wallrock elasticity effect on magma flow in dykes during cyclic lava dome extrusion.

14:20 Neuberg, J., P. Smith, and M. Collombet. Computing synthetic seismograms from two-dimensional magma flow models.

14:40 Collombet, M., and J. Neuberg. How to consider gas loss in 2D fluid flow modeling.

15:00 *Afternoon tea and discussion (IAS).*

15:30 Kurzon, I., V. Lyakhovsky, N. G. Lensky, and O. Navon. Damping of seismic waves in a saturated bubbly magma.

15:50 Esposti Ongaro, T., A. Neri, M. Pelanti, and R. LeVeque. Shock-wave pattern and atmospheric signature of underexpanded volcanic jets: a comparative study using two numerical multiphase flow models.

16:10 D'Auria, L. Numerical modelling of gas slugs rising in basaltic volcanic conduits: Inferences on Very-Long-Period event generation

16:30 O'Brien, G., and C. Bean. Seismicity generated by gas slug ascent: a numerical investigation.

16:50 Concluding discussion.

Textural diversity in basaltic ejecta at Stromboli in 2002: Implications for oscillatory phenomena in Strombolian conduits

B.F. Houghton[1], N.C. Lautze[1], H. Gonnerman[2]
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2. Department of Earth & Planetary Sciences, Harvard University.

Ejecta collected from explosions at Stromboli in 2002 show that the shallow conduit is characterized by a complex mixture of five fluid phases. Two of these are melt, namely: 1) newly arrived melt (LD) accompanying rising gas slugs; 2) melt that has been resident during the passage of 2 or more slugs (HD). Preliminary calculations suggest a c. 2x contrast in viscosity between 1) and 2), with absolute values in the range of 2000 to 2500 and 3000 to 5000 Pa s, respectively. The melt types mingle on a fine scale during the passage of the gas slug, and during melt readjustment immediately following explosions.

The gas component in the conduit can be divided into 3 phases depending on the degree of mechanical coupling to the melt phases. The later is, of course, strongly dependent on bubble diameter: 3) small (< 1 mm) mechanically coupled bubbles in 1) and 2); 4) intermediate-sized bubbles (mm-cm) that are decoupled wrt to 2); 5) gas slugs.

While phase 5) is widely recognized as “powering” explosions at Stromboli, 4) contributes to passive degassing between explosions, whereas 3) plays an important role in influencing the rheology of the fragmenting melt. Constraints imposed by the buoyant ascent rates of the bubbles suggest that indicate that the melt in Stromboli’s shallow conduit ejected in any explosion has a range of residence times, likely spanning seconds to hours for LD magma, and hours to months for HD magma.

Collections made over time scales as short as a single explosion and as long as 24-hours considerable heterogeneity close to the magma free surface but the wide *range* of heterogeneity is preserved over considerable time scales. The dynamic balance between the 5 phases reflects shifts on the flux of gas and melt from the deeper conduit and the evolution of LD melt to HD via bubble coalescence and loss. The proportions of LD to HD do not change significantly between consecutive explosions at single vents but do vary significantly on time scales of several hours. More major contrasts are apparent between samples collected months apart during intervals of contrasting eruptive vigor. An increased flux of gas-rich magma permits continuing high or waxing intensity of eruption and vigorous mingling of melt types (e.g., September/October 2002), while an interval of decreased supply of new magma (e.g., May 2002) causing waning eruption intensity inhibits mingling and leaves to eruption of increasing quantities of texturally “mature” HD melt.

Notes

Modelling conduit processes at Volcán de Colima, Mexico

Nick Varley[1], nick@ucol.mx
John Stevenson[1], Jeffrey Johnson[2], Gabriel Reyes[3], Vicky Sword-Daniels[4], Anna Corvin[5], Klaus Weber[6], Richard Sanderson[1], Rob Harwood[1]
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2. University of New Hampshire, USA
3. RESCO, Universidad de Colima, Mexico
4. University College London, UK
5. Michigan Technical University, USA

Recent observations suggest that Volcán de Colima has entered a pre-Plinian phase. Activity has been increasing and has been almost constant since 1998. During at least the last few hundred years activity has been cyclic, each one lasting approximately 100 years and terminating in a Plinian event; the last one ended in 1913. It is critical to try and understand the complex seismicity and the relationship between the different observed parameters, and to identify the signals detectable by the monitoring network that might indicate an imminent catastrophic eruption.

The majority of activity over the past 8 years has consisted of Vulcanian eruptions of small to moderate size; the largest producing pyroclastic flows reaching over 5 km. Swarms of low frequency seismic events have been usually associated with each event. These have been examined statistically with variations observed in the magnitude-frequency relationship of each swarm and their distribution. Physical parameters, such as the ascent velocity, SO_2 flux and thermal-emission of the eruption plume, are being recorded above the crater. These are then being compared to the energy release, both seismic and acoustic to try and understand the conduit processes that lead to explosive eruptions. It is clear that small variations within the conduit system can lead to a transition between effusive and explosive activity. With frequent transitions, Volcán de Colima provides an ideal opportunity to analyse variations in the signals that can be observed and deduce relationships with changes within the conduit that influence magma ascent and degassing, such as its volatile contents or ascent velocity.

The upper edifice of Volcán de Colima is complex with several vents that can be active for both effusive and explosive eruptions. Relationships are being sought between the seismicity resulting from fluid and gas movements and the active vent for the subsequent eruption. Many events show pulses and switch between vents. A large range of both ascent velocities for ash jets and the ash contents of the column have been measured. The complexity of the relationship between these two parameters and the seismic signal is being scrutinized.

This multiparametric study will help to define the most efficient monitoring strategy for Volcán de Colima and have implications for similar andesitic volcanoes. A model of the magmatic conduit processes will help to explain the significance of different variables.

Notes

The effect of groundmass crystallization on the fragmentation of basaltic magma: Observations and experiments

J. Taddeucci, P. Scarlato (1), D. Andronico, P. Del Carlo (2), R. Büttner, B. Zimanowski (3)
(1) HP-HT Laboratory, INGV, Italy.
(2) Department of Catania, INGV, Italy.
(3) Physikalisch-Vulkanologisches Labor - Universität Würzburg, Germany.

To investigate the fluid dynamics of basaltic explosive eruptions, we use a two-fold approach: first, we analyze the texture of ash particles originated by well-characterized explosions; and second, we perform laboratory experiments to constrain the factors that control explosive processes and the corresponding ash features.

During the 2001 and 2002-03 flank eruptions of Mt. Etna (Itay), the morphology and crystallinity of juvenile, basaltic ash particles varied systematically with varying style of explosive activity: vesicular, glassy sideromelane and blocky, microcrystalline tachylite end-members of ash dominated the products of ash-poor, impulsive, single-bubble explosions (Strombolian activity) and ash-rich, jet-like explosions (ash explosions-fountains) end-members of activity, respectively. This strong relation between crystallization of magma groundmass and explosion dynamics can be explained hypothetically considering that two of the main effects of microlite growth are i) a large increase of magma viscosity, and ii) the onset of a yield strength. Both effects reduce the mobility of gas bubbles in the melt and push the magma closer to a brittle behavior, changing the way gas expansion fragments the melt.

To substantiate these hypotheses, we investigated experimentally the role of groundmass crystallization on the dynamics of fragmentation of basaltic melts. First, we inductively melted large (0.5 kg) samples of Etna basalts to obtain variable crystal-melt ratios. Then, we injected compressed gas below the melt to drive fragmentation, while force, pressure, and electric field sensors monitored the experiment. Other conditions being equal, fragmentation dynamics change dramatically as a function of the amount and distribution of microlites in the melt. If sparsely crystallized, the melt reacts as a liquid, ductile behavior being reflected in the post-injection morphology of the melt, a high proportion of fluidal, sideromelane-like, particles “erupted”, and a relatively long delay between injection and fragmentation. Conversely, if microlite crystallization is extensive, brittle reaction prevails, as reflected by large cracks present in the melt, dominant blocky, tachylite-like, “erupted” fragments, and a short delay between injection and fragmentation. Finer grain size of products and stronger electrical emissions also characterize fragmentation of microlite-rich melts.

Geochemical and petrological features of sideromelane and tachylite suggest that microlite crystallization is not homogeneous in the upper conduit, but is reduced in the central part, where gas bubbles buoyantly rise, and is extensive at the margins, where slow-moving magma accumulates. Hence, other parameters being equal, we expect the flux of magma and gas and conduit diameter to primary control microlite crystallization and consequent explosion dynamics. To validate these hypotheses we are now studying ash samples collected from individual, basaltic explosions at Stromboli volcano (Italy). The large monitoring network and the continuous activity of this volcano allows us to associate the ash features with the geophysical signature of each explosion, leading to a unified interpretation of the explosive dynamics.

Notes

Cyclic processes during the emplacement of silicic lava: fracture, flow and valve behaviour

Hugh Tuffen

The emplacement of silicic lava commonly involves cycles of brittle-ductile magma deformation and gas loss at shallow levels in the conduit, lava dome or flow. Arguably, these cycles largely control observable phenomena such as shallow seismicity and degassing, whilst strongly influencing eruption mechanisms and associated hazards. The geological record indicates that such cyclic behaviour is widespread during the eruption of both glassy and crystalline lava. Two processes will be considered here: faulting in lava and degassing through tuffisite veins. In each case a summary of textural observations will be given, together with examples of recent eruptions where these processes may have occurred.

Faults in lava are small, hot hyperactive versions of tectonic faults. They are initiated by shear fracture of magma and enter a phase of repetitive stick-slip or creep-slip behaviour. If melt is abundant, faults may heal, forming viscously deformed flow bands that are cross-cut by later faults. This textural collage indicates cyclicity on two different timescales, one occurring during the lifetime of an individual fault, the other between generations of faults. Slip events cause transient changes in permeability that allow volcanic gases to periodically escape (fault valve behaviour). The cyclic behaviour may cease if changes in the strain rate or magma rheology lead to purely brittle or ductile deformation.

Tuffisite veins are commonly seen at the walls of shallow conduits and are also a valve for periodic gas release and a seismic trigger. Vein textures indicate repeated injection of a gas-ash mixture into tensile fractures that are opened by magma overpressure. When gas escapes the pressure may drop, closing the valve. If the valve were to become blocked by ash the eruptive behaviour may drastically change.

The conditions that lead to faulting in silicic magma are being investigated experimentally and it has been confirmed that faulting of high-temperature magma is seismogenic. Meanwhile, the textural record of faulting and tuffisite vein formation is being studied. A key challenge is how to quantitatively link these processes to geophysical data collected from active volcanoes and how to incorporate them into models of flow behaviour.

Notes

Thursday 11:15

Acoustic oscillations in magma conduits

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A vibrating volcanic system can be described using acoustic principles and concepts. This presentation concentrates on the classic problem of a sound source immersed at an unknown depth within a volcanic conduit of unknown shape filled with a fluid of unknown composition and phase. Although the fluid within the conduit can be excited by seismic waves, only oscillations induced by flow, volume, or phase changes within the fluid itself are discussed.

The acoustic excitation of a volcanic conduit can be posed as a propagation problem where the key specifications are fluid state (phases, composition, temperature, ambient pressure), flow Mach number, and conduit geometry. At a given temperature and pressure, and before fragmentation, the void fraction and viscosity determine the sound speed and attenuation of the fluid. Wall friction can further increase the effective viscosity and decrease the sound speed. After fragmentation, the fluid can be acoustically treated as a solid-gas mixture. The simplest conceptual acoustic model of a fluid filled volcanic conduit consists of a three-section pipe. The deepest section consists of magma with some exsolved gas (primarily CO_2), the central section would correspond to the beginning of water exsolution, producing a substantially more gas-rich melt, and the upper section would consist of a fragmented ash-gas mixture. Each transition point between the segments could be a potentially active acoustic source region. We hypothesize that infrasonic tremor, long period (LP), and explosive events observed at volcanoes with stable plumbing may correspond to the progressive excitation of the deeper to shallower sections, respectively.

In addition to affecting the sound speed and viscosity of the melt, the conduit geometry can also substantially affect the transition points by accelerating fluid flow along constrictions. As the void fraction of the magma-gas mixture increases, the sound speed can decrease drastically to values as low as 10m/s. Such frothy magmas are very unstable, as not only can they coalesce into larger structures, but fluid flow can easily approach a Mach number of unity. Such subsonic to supersonic transitions would not only produce sound efficiently, but also redefine the fragmentation depth and intensity as well as trigger a pressure readjustment along the magma column that would affect the dynamics of water exsolution.

Whether we observe these processes seismically and acoustically depends in part on how efficiently sound is transmitted to the surrounding environment. The acoustic impedance of a magma conduit will depend on its density, sound speed, and cross-sectional area as a function of depth. For a source at depth, the impedance match between the conduit and the atmosphere dictates the intensity and frequency of airborne sound. Many of these principles would also apply in the case of a horizontal conduit (such as a lava tube), where gravity becomes more relevant. Lava falls and surface gravity waves would then become candidate acoustic sources for excitation of the gas above the melt.

Notes

Thursday 11:45

Constraints on the source mechanism of long period events, tremor, and eruptions from simultaneous seismic and acoustic observations

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Volcanic processes can radiate acoustic energy both into the ground and into the atmosphere. We present data from co-located broadband seismometers and infrasonic arrays deployed near Mount St. Helens, Washington and Kilauea, Hawaii. These volcanoes represent two archetypal end members of magma viscosity. The data demonstrate the unique ability to unambiguously separate seismic and airborne acoustic signals. Infrasounds radiated from Mount St. Helens have included: 1) intermittent infrasonic long period (LP) events ('drumbeats') which mimic the waveforms and temporal sequence of their seismic counterparts; 2) pre-eruptive signals observed in the absence of seismic signals; 3) strong signals associated with three observed eruptions in which steam and ash were ejected from the dome. The infrasonic signals from the three eruptions were substantially different in character from simultaneous seismic observations. The infrasound produced by the LP events was observed to switch on and off during a timescale of a few days, while the seismic energy continued uninterrupted at the same rate and magnitude. This suggests that the LP source is variously coupled and then decoupled to the atmosphere at different times. If we assume LP events are associated with the triggering and acoustic excitation of a fluid-filled volume such as a conduit or crack, possible explanations for this transition include: 1) changes in depth of the LP triggering mechanism; 2) changes in the impedance contrast between the subsurface and the atmosphere; 3) changes in the permeability of the uppermost section of the conduit or adjacent dome material. Permeability changes at shallow depth could act as a valve controlling the mass flux and affecting the transmission of sound from the LP source region to the atmosphere. The surge in infrasonic energy observed during the eruptive events is possibly related to the removal of the capping obstruction and the consequent sudden release of gas, ash, and pressure. These signals contain information on the eruption mechanism and near-vent conditions. A phreatic eruption on March 8th, 2005 was accompanied by a strong infrasound signal and an increase in the triggering rate of seismic LP events. A less vigorous eruption on January 16th, 2005 was accompanied by a lower amplitude infrasonic signal, but almost no seismicity. The partitioning of energy into seismic and infrasonic components is markedly different for these two events. Infrasound recorded near Kilauea has included continuous tremor emanating from a disperse array of open vents and skylights, which is probably related to the transport of magma through lava tubes. The large diversity in infrasound signals, and the similarities and differences between infrasound and seismic signals, provide independent constraints on models of long period events, eruptions, and tremor.

Notes

Thursday 12:05

On the prevalence and manifestation of acoustic harmonic tremor at volcanoes

Dr. Jeffrey B. Johnson (University of New Hampshire)
Jonathan M. Lees (University of North Carolina)

Seismic harmonic tremor is extended duration ground motion manifested by a stable fundamental frequency and often accompanied by peaked integer overtones. Such seismicity is a common feature of many volcanic systems and is often associated with acoustic harmonic tremor (sometimes referred to as 'chugging') that is radiated into the atmosphere. Simultaneous sampling of the seismo-acoustic wavefield at many volcanoes have indicated a conjoint seismo-acoustic source with identical fundamental frequencies evident in both data streams. Diverse models have been invoked to explain harmonic tremor sources include resonating fluid volumes, propagating cracks, and constricted flow through conduits. The seismic tremor that is associated with intense acoustic radiation suggests a source mechanism that extends well up into the upper portion of a volcanic conduit.

This presentation provides a survey of seismo-acoustic observations made at a variety of andesitic volcanoes including Karymsky, Sangay, Tungurahua, and Reventador. Statistical comparison of occurrence frequency and tremor envelope are provided for the four sites. Differences in fundamental modes at the different systems and the evolution of these fundamental modes ('gliding') are shown in the context of the concurrent volcanic activity. Spectral characteristics including the amplitudes and number of integer overtones are related to the specific impulse response at each volcano. Finally, the evolution of energy partitioning between seismic and acoustic wavefields and the potential significance of this parameter is summarized.

Notes

Listening to fire fountains at Etna volcano (Italy)

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Eruptive episodes from the 2001 eruption of Etna volcano show a series of Strombolian explosions, which may lead to a fire fountain at the vent. Insights into fire fountain formation is provided by a close comparison between episodes leading to fire fountains (13/07/2001) and those solely with Strombolian explosions (4/07/2001). Because visual observation shows that Strombolian explosions are the consequence of bursting large bubbles at the top of the magma column, the measured sound wave for each explosion is modelled by the bubble vibration at the surface. The best fit between measured and synthetic waveforms gives the bubble radius (5 m), length (8 m) and overpressure (0.39 MPa). The time sequence of each episode show the evolution of the number of bubbles, their gas volume and overpressure, giving a total gas volume of $7.4\text{x}10^7$ m^3 per episode.

Such large bubbles fill most of the space available in the conduit, hence are slugs. The thickness of the lateral film around a bubble is estimated at 0.5 m for a magma viscosity of 30 Pa.s, giving a conduit radius of 5.5 m and an upward velocity of 3.7 m/s. The Reynolds number, based of the bubble nose, is around 3000. Therefore a bubble develops a long turbulent wake, whose maximum length is 6 times the slug length. Such long wakes are not steady and periodically form and detach from the slug bottom. Small bubbles accumulate into the wake as the bubble rises upwards from the depth of the reservoir towards the surface.

Comparing the intermittency between explosions (several tens of seconds) with the combined length of a slug and its wake suggests that fire fountains results from merging several slugs and their wake together just below the surface. This is in excellent agreement with videos from fire fountains at Etna.

Although not all the eruptive episodes show a transition from Strombolian explosions to fire fountains, each episode can be interprated as resulting from the withdrawing, by coalescence, of a foam layer accumulated in the reservoir. The few days intermittency between eruptive episodes results in re-building the foam to its maximum stable height, giving a gas flux in the reservoir of $2.7\text{x}10^{-2}$ m^3/s. Such a gas flux is obtained by rising small bubbles with diameters between 0.2 and 0.7 mm, gas volume fractions between 0.1 and 1 % and assuming a reservoir area of 10^6 m^2.

Notes

Tracking explosive parameters in real-time by infrared and infrasonic records: Implication for the source dynamics.

M. Ripepe, D. Delle Donne, E. Marchetti, and G. Ulivieri
Dipartimento di Scienze della Terra, via G. La Pira, 4 - 50121 Firenze

Explosive activity generates seismic, infrasonic, and thermal transients which provide different prospective on the complex source process. Each signal reflects peculiar aspects of the explosive source, but once combined together they offer additional constraints on the source dynamics. Seismic transients are inferred to reflect the triggering source mechanisms of the explosions, while infrasonic and thermal transients should result from a more shallow process linked to the gas overpressure and gas/fragments velocity. We show how the onset between infrasound and thermal waveforms can be used to track changes in the explosive mechanism giving information on the position of the magma free-surface (or fragmentation level) in the conduit, the gas volume and overpressure, and the gas jet velocity.

The time differences between seismic, infrasonic and thermal emission measured at Stromboli volcano are not stable in time and variations cannot be related uniquely to large fluctuations in the path differences between seismic and infrasonic travel times. Rather they should reflect a specific explosive dynamics that involves changes in the velocity of the magma stream within the conduit (for example, the pressure front of the expanding gas magma fragments mixture inside the conduit above the explosion).

Thermal imagery produced by the explosions can be used to estimate in real-time the quantity of the ejected gas-fragments, gas jet velocity and to track changes in the explosive activity of the system. We have developed a real-time image acquisition and processing to analyze the imagery acquired by a FLIR A20 thermal camera. Thermal imagery are acquired at 2 frames per second at a distance of ~450 m from the craters. Real-time processing allow us to estimate, the bulk volume, the maximum height reached, and the velocity of the ejected volcanic matter for each explosion.

The integrated use of these parameters with infrasound and seismic signals provides the constraints for experimental and numerical models inferring on the source mechanisms driving the explosive activity.

Notes

Degassing dynamics at Stromboli Volcano: Insights from infrasonic activity

E. Marchetti, M. Ripepe, and G. Ulivieri
Dipartimento di Scienze della Terra, via G. La Pira, 4 - 50121 Firenze

Explosive activity at Stromboli is generally explained as the result of large gas slugs that, on reaching the uppermost portion of the conduit, explode when their overpressure is no more compensated by the external pressure. This gas bursting of the magma column generates infrasonic transients. Infrasound at Stromboli consists on transients related to explosions and on small amplitude intermittent pulses associated with “active” over-pressurized degassing of the magma column.

Degassing of a magmatic system is generally understood as a quasi-steady “non-explosive” passive mechanism, when the slow exsolution process allows the continuous compensation of the gas pressure. In contrast infrasound indicates that degassing can occur also in over-pressurized condition, associated to the bursting of small gas pockets at the magma free-surface. This intermittent release of gas induces in the atmosphere small (< 0.1×10^5 Pa at the source) infrasonic pulses and occurs almost regularly every ~1-2 s. This degassing feature of the magma column represents the “over-pressurized” and “discrete” counterpart of the continuous degassing of the magma column.

The permanent small aperture 5-element infrasonic array at Stromboli is monitoring in real-time both explosions and degassing providing position, over-pressure and occurrence of the source and revealing the complex and complete behavior of the magma column.

Log-linear amplitude distribution of infrasonic data shows 2 different trends of decay suggesting that degassing and explosions are driven by a different gas dynamics. Moreover, infrasound location indicates that over-pressurized degassing is active only in one vent at once. Location of the puffing is stable in a single vent over hours-to-days periods, or it can shift from vent to vent with smooth or abrupt transitions. The stability in the position of the puffing within the crater terrace is suggesting that the over-pressurized gas bubble flow is following only one preferential segment of the feeding conduits at once. The stable location of the bursting bubbles, however, may change from time to time and without any apparent evidence or trigger mechanisms, leading to a sharp change in the rising path of gas bubbles.

This gas bubble behavior seems to be consistent with experimental and numerical studies on the flow of particles and drops at pipe bifurcations. In the experiments, gas bubbles and particles are rising in the pipes following trajectories coinciding with the branch with the highest gas flux. Over-pressurized gas bursting could thus reflect higher gas flux regimes in the conduit and it will indicate where the gas flux is more localized within the volcanic system. Accordingly infrasonic monitoring on an active volcanic systems would not only help to detect this activity but also to track changes in gas flux regime.

Notes

Source mechanisms of moderate scale vulcanian eruptions at Mt. Asama, Japan, inferred from volcano seismic signals

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Mt. Asama is one of the most active volcanoes in Japan. During the Asama 2004 volcanic activity, five moderate summit eruptions occurred. All of these eruptions were vulcanian type and seismic signals accompanying the eruptions were recorded by up to 8 broadband stations around the volcano. The results of the waveform inversions assuming a point source show that the force system exerted at the source region is dominated by vertical single force components. The source depths of the single force are shallower than 200m from the bottom of the summit crater, and the order of magnitude of the single forces is 10^{10}-10^{11}N. In the source time history of the vertical single force component, two downward forces separated by 5-6 s are seen. Between these two downward forces, an upward force component is also seen. The initial downward force probably corresponds to the sudden removal of a lid capping the pressurized conduit. Contrary to the origin of the initial downward force, the origin of the following upward force and the latter downward force is not clear.

In order to clarify the origin of the upward single force component, we investigated the possibility of the vertically extended force system. We conducted grid search for the best source combination of two point sources of single force components. The best solution was obtained when we put one of the two point sources of single forces near the top of the conduit and put the other 2000m below the first one. The residual of the waveform match and the corresponding AIC value are better than those obtained when we assumed only one point source of single force components. The source time history of the upward single force at the top is slightly different from that for the one-point-source case (no lower source), although the rest of the characteristics of the time history was essentially the same. The source time history of the vertical single force of the lower point source is similar to that of the top point source but has the opposite sign except for the very beginning. These characteristics suggest that the lower source is exerted so that the total momentum of the system is preserved. According to the lid-removal model, the initial downward force does not require the compensating upward force. However, the rest of the forces, both upward and downward components, require their counterparts in order to preserve vertical total momentum.

One possible explanation for the upward force is the drag force due to viscous magma moving upward in the conduit. When magma in the conduit obtains upward linear momentum, the rest of the earth must obtain downward linear momentum. This model suits the result that is obtained assuming two point sources.

Notes

Long-period signals at Mt. Asama volcano, Japan, preceding an eruption on September 1, 2004

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Mt. Asama, which is one of the most active volcanoes in Japan, is an andesitic volcano located in the centre of the country. The summit elevation is 2560m above sea level, and the size of the active summit crater is 450m in diameter and 150m in depth. At 11:02 (GMT) on 1 September 2004, a moderate-sized vulcanian eruption occurred for the first time in the last 21 years. From 14-18 September, a continuous stromblian explosion emitted volcanic ash. The volcanic activity seemed to have subsided thereafter, except for moderate-sized vulcanian eruptions occurring on 23 September, 29 September, and 10 October, and some small-scale eruptions afterwards which became smaller and smaller with time. The last moderate-sized eruption occurred on 14 November, and since then no eruption has occurred up to now.

We operate dense seismic and geodetic networks around Mt. Asama, and reveal a clear magma plumbing system around Mt. Asama. Magma intrusions occurred several times beneath the western flank of Mt. Asama, forming a WNW-ESE directed zone with 1 km below sea level. The eastern end of this zone connects a narrow vertical pathway extending right under the summit crater, which erupted in 2004.

Two broadband seismographs had been installed at the east and the west crater rim, but both were broken by the first eruption on September 1. Before the eruption, long-period seismic signals with unique waveforms had been frequently observed at these summit stations at least since September 5, 2002. These unique signals can be categorized in 3 types: an impulsive waveform with a dominant period up to 10 sec and repetitive outgoing initial motions from the vent, a long-period tremor followed by a short-period earthquake, a long-period tremor with pointed antinodes. The particle motions suggest that the sources are located at a relatively shallow depth of one to two hundred meters, just beneath the crater from which the summit eruptions occurred.

The activity of the unique impulsive signals had been synchronized with the activity of volcanic earthquakes until the last ten days of July 2004. Then, the activity of the unique signals had gradually decreased, and no signal has been observed since August 24, 2004, even though the number of normal volcanic earthquakes kept on increasing until the first eruption. When the trends of the unique signals and the normal volcanic earthquakes started separation, a sudden ground extension was detected by the GPS measurement. The following speculation is a likely scenario explaining the excitation of the impulsive signals. Taking into account the characteristic impulsive waveforms, the cause of these signals would be a sudden pressure increase due to vaporization of subterranean water running into the upper part of the vent. The sudden intrusion of magma under the western flank of Mt. Asama triggered a magma raise into the upper part of the vent. After that, the reservoir of subterranean water around the vent had been dried up gradually by increasing temperature due to the magma raise, and the unique signals had diminished gradually.

Notes

The frequency structure and characteristics of the deep low frequency tremor occurring in Western Shikoku

Sho Nakamula and Minoru Takeo.

The continuous seismic tremor called the deep low-frequency tremor (LFT) was found very recently in the Southwest Japan fore-arc, along the subducting Philippine Sea Plate (Obara, 2002). The source depths are about 30 - 40km, at the lower part of the crust. The same kinds of tremor events are also found in the Cascadia region, in which the subducting plate is very young, as well as the Southwest Japan (e.g. Rogers and Dragert, 2003). In the Cascadia region, tremor events are accompanied with deep slow slips, which are detected by the observation of GPS. So in this region, the tremor events are called as episodic tremor and slip (ETS). Recently, the relation between LFT and slow slip is also actively discussed in the case of Philippine Sea Plate.

Previous studies about the LFT mainly dealt with the temporal and spatial distribution of the LFT events. The causes of the LFT and the slow slip that is associated with the LFT activities are thought to be related with fluids from the subducting plate. However, the physical mechanism of the tremor associated with fluids is not clear. Extremely small amplitudes of the tremor make the onsets detection very difficult and even the hypocenter locations become inaccurate.

Not only the continuous tremor, the isolated tremor events that have short time duration have also occurred in the Southwest Japan. In the case of isolated events, we can detect the S phase for some station, and so we can determine the hypocenter location more precisely than the continuous tremor events. However, the relation between continuous tremor and isolated events has not yet been proved.

Since little information is available about the physical process of the LFT, we should not suppose a priori assumption before analysis as long as possible. In this sense, we use the theory of KM_2O-Langevin equations developed by Okabe et al. for the analysis. This theory is based on the fluctuation-dissipation theorem that is one of the principles of the statistical physics. The advantage of using this theory is that we require no prior information about the data and do not have to define any parametric models before analysis. The matrix functions which characterize the time series are extracted directly from data itself, checking the stationary property of the data.

We obtained the discrete spectrum in complex frequency space which characterize the LFT signal by the method of “Average Dissipation Spectrum (ADS)" based on the theory of KM_2O-Langevin equations. Several peaks existed from 1.3Hz, 1.75Hz, 2.3Hz, 2.8Hz, 3.2Hz, 3.8Hz, 4.3Hz in the dominant frequency range 1-5Hz of the LFT, at intervals of about 0.5Hz. The decay rate of the LFT is about 0.2. This characteristic frequency structure will be the help to understand the physical properties of the LFT events. We also applied this method to the isolated events and the same type of the frequency structure was obtained. This means that both the isolated events and continuous tremors are caused by the same physical mechanism.

Notes

Thursday 16:15

Shallow-conduit dynamics at Stromboli volcano, Italy, imaged from waveform inversions

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Modeling of VLP seismic data recorded during explosive activity at Stromboli in 1997 has imaged the top 1 km of the plumbing system at this volcano. Two distinct conduit structures have been identified, each representative of explosive eruptions from two different vents located near the northern and southern perimeters of the summit crater. The main branch of conduit activated during eruptions at the northern vent is composed of a northeast-striking dike dipping 72° northwest, and extending from the crater floor down to a depth of 160 m below sea level, where the conduit features an abrupt corner. Below this depth, the imaged conduit consists of a northeast-striking dike dipping 40° southeast. A subsidiary dike segment branches off the main conduit at elevations near 480 m. This latter segment strikes approximately north and dips 52° west. The surface trace of the main dike bisects the northern vent, while that of the subsidiary segment extends down the northwest flank and intersects the main dike trace 170 m northeast of the northern vent. A similar analysis carried out for eruptions at the southern vent images an uppermost conduit geometry composed of a northeast-striking dike dipping 54° northwest, intersecting a west-striking dike dipping 56° north. At 520 m elevation the two dikes merge into a sub-vertical dike striking northeast. At a depth of 220 m below sea level the conduit then features a second, more abrupt corner leading into a sub-horizontal fracture. The processes associated with eruptions involve volumetric changes marking a cycle of pressurization-depressurization-repressurization of the conduit, which may be viewed as the result of a piston-like action of the magma associated with the disruption of a gas slug transiting through this complex plumbing geometry. Accompanying the volumetric conduit response induced by the pressure transients are dominantly vertical force components with magnitudes 10^9 N representing the motion of the liquid mass disturbed by the passage of the slug.

Notes

Thursday 16:35

Very long period Strombolian eruption-associated seismic signals observed in the near field at Mount Erebus volcano

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Mount Erebus is an approximately 1 My old polygenic stratovolcano lying within the Terror Rift (local crustal thickness of approximately 18 km) near boundary between cratonic east and extended west Antarctica. The persistently active summit region hosts a long-lived lava lake and erupts a highly chemically evolved tephriphonolite from a diverse set of vents. An incessantly convecting lava lake, eruptive, and lava flow activity are confined to a multiple vent inner crater with a diameter of several hundred meters that can be readily observed with diverse instrumentation across a wide range of azimuths and at ranges as close as a few hundred meters.

Erebus lava lake eruptions are impulsive, resulting from the explosive decompression of simple large gas slugs up to 10 meters in diameter. Due to stable conduit system geometry and self-reconstructing pre-eruptive conditions, accompanying seismograms are highly characteristic, producing repeatable signals across a bandwidth between many 10’s of seconds and 10’s of Hz. Near-field broadband seismic observations of lava lake eruptions show distinct oscillatory very-long-period (VLP) energy between 30 and 5 seconds period associated with gas and magmatic transport. VLP energy precedes, accompanies, and follows lava lake eruptions, but prolonged (10s of seconds) ash-rich eruptions from a nearby active vent do not produce VLP signals. Lava lake eruptions remove the upper few 10s of meters of the conduit system, and VLP signals terminate as the system reestablishes gravitational equilibrium through a surging refill process that takes several minutes. Moment tensor inversion suggests a combination of couple and single forces, but model resolution issues are significant. Variations in pre-eruptive (gas slug ascent) VLP and SP signals, along with video and infrasound analysis, suggest multiple regions for slug growth associated with differing ascent and/or emergence characteristics, and that the characteristic eruptive styles of the summit vents are strongly associated with enduring and diverse vent geometries.

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Notes

Laboratory investigations of possible gas-slug related seismic source processes in low viscosity magmas

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Seismic data collected at basaltic volcanoes include long-period (LP) and very-long-period (VLP) events, whose sources are usually described in terms of dynamic fluid processes occurring within the magma. At such low magma-viscosity volcanoes, bubbles of exolving volatiles rise, expand and coalesce with relative ease. In many cases, these processes culminate in the generation of rapidly ascending gas slugs, capable of violent expansion as they approach the liquid surface. Although the masses of gas involved are insufficient to excite ground motions, the associated liquid accelerations can result in significant momentum changes. We summarise the results of experiments aimed at characterising the processes, pressures and momentum exchanges involved during slug ascent under a variety of conditions.

Under standard laboratory conditions, the ascent and burst of gas slugs is a relatively quiescent process. For example, slugs rising ~2 m in a 5-cm-diameter tube produce pressure transients of <400 Pa and exert negligible forces on the apparatus. Two scenarios investigated change this: firstly, increasing the pressure gradient within the liquid column to values similar to the volcanic case (by decreasing the ambient pressure on the liquid surface) and secondly, incorporating a region of tube expansion within the apparatus, such as would be envisaged at degassing activity through a lava lake.

To characterise the pressure gradient to which an ascending slug is exposed, we define the 'slug expansion potential' as the ratio of the slug source pressure (magmastatic + ambient surface pressure) to the ambient surface pressure. The investigated range was 1.1 to 1.2×10^4, corresponding to ambient surface pressures between 10^5 and 10 Pa and covering values applicable to volcanic cases (e.g. an expansion potential of ~50 for slugs sourced at a depth of ~200 m). Two regimes of slug burst behaviour were observed. When the expansion potential is low, gas slugs behave in a near-static fashion, i.e., slug pressure approximates the hydrostatic pressure. Bursting is dominated by surface tension effects and little or no acoustic signal is generated. In contrast, at high expansion potentials, equilibrium slug expansion cannot be achieved and slug pressures are significantly greater than static. During burst, a spray of liquid droplets is produced, accompanied by significant pressure signals in the overlying gas. Large, rapid pressure changes occur within the liquid and stimulate the apparatus into resonant oscillation.

However, the forces generated are in the opposite direction to, and interpreted to be smaller than, those measured at Stromboli during Strombolian explosions (Chouet et al., 2003). Consequently it is thought that additional processes must be responsible for the VLP's recorded, and further experiments have been carried out to investigate slug flow through flared conduits. When gas slugs larger than a critical size ascend into section of significantly increased tube diameter, they become suddenly disrupted into smaller slugs or bubbles. This process produces systematic transient pressure changes that vary with initial slug size, liquid depth, tube diameter, and liquid viscosity. Where slug ascent is not dominantly controlled by liquid viscosity, these pressure transients excite oscillations within the fluid column, the remaining portions of the gas slug and the apparatus as a whole. In contrast to interpretations of comparable volcano-seismic data, where vertical downwards forces are usually assumed to be the result of mass accelerating upwards, our experiments indicate that within flared conduits they can be the result of the rapid deceleration of small volumes of downwards-flowing material. We also illustrate the influence of conduit geometry, not only on initiating flow pattern change, but in coupling generated fluid pressures to the surrounding medium and hence determining the form and location of recorded single forces.

Notes

Cyclic variation in discharge rate during volcanic eruptions: Experimental, and theoretical studies

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Large variations in discharge rate are common in andesitic dome-forming eruptions. We present an experimental and theoretical investigation of viscous flow through a heated elastic chamber connected to a cooled rigid conduit. Sugar syrup was pumped through the system, and the discharge rate, temperatures and pressures were measured. At low chamber pressures, the discharge rate showed a marked initial fluctuation before reaching a steady-state value where the input to the chamber is equal to the output. The hot syrup is initially strongly cooled in the conduit; as a consequence the conduit fluid has high viscosity and conduit resistance, so that the initial discharge rate is much lower than the eventual steady-state discharge rate. The pressure increases in the chamber and the fluid in the conduit progressively decreases in viscosity as it warms the conduit walls. Consequently the discharge rate sharply increases, reaches a maximum well above the steady-state discharge rate and then declines back to steady-state conditions. At higher chamber pressures, mathematical models predict that discharge rate will show continuous cyclicity, the period of which depends on the chamber elasticity and the change in viscosity with temperature. This behaviour is investigated experimentally and compared with mathematical models which use the experimental parameters as input, and the combined experimental and theoretical study is compared with detailed observations of lava dome growth at the Soufriere Hills Volcano, Montserrat.

Notes

Cyclical volcanic processes resulting from diffusion pumping and gas venting.

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Large gradients in magma rheology, permeability, crystallinity and volatile supersaturation with both height and time in a volcanic conduit have a strong effect on the evolution of volcanic eruptions. We discuss a process of diffusion pumping and gas venting that could establish itself in the presence of such gradients, and investigate whether this mechanism could explain tilt cycles observed at the Soufriere Hills volcano (SHV), Montserrat, West Indies.

The behaviour of a rapidly decompressed solution of gum rosin and di-ethyl ether (GRDEE) was investigated as a possible analogue to magmatic processes in this part of a volcanic system. The experimental method generated expanding foam that flowed within a self-generated conduit of higher-viscosity degassed foam. The foams comprised of three distinctive regions: a flow cap with a high apparent viscosity and a yield stress mirroring the rheological heterogeneity believed to exist in volcanic conduits, a flow body with a lower apparent viscosity and the source region. The experiments were logged over longer timescales (usually 1000 s) than previous similar studies (up to three seconds). Results show cyclical pressure changes that have a superficial resemblance to tilt cycles measured at SHV by Voight et al., 1998. Our interpretation invokes diffusive bubble growth in supersaturated gum-rosin beneath a periodically yielding and venting foam plug as a possible source of the laboratory pressure cycles.

A model describing the experimental pressure-cycle behaviour was developed for the volcanic situation in an attempt to explain tilt-cycles observed at the Soufriere Hills volcano. Magma volatile supersaturation is required to drive volatile diffusion in the hypothetical pressure cycle model. Microlite crystallisation of anhydrous magmatic phases is thought to be the best candidate for a mechanism to generate this supersaturation. We also model the dynamics of the motion of the foam/degassed-magma plug resulting from pressurisation due to volatile diffusion and resisted by viscous drag against the conduit walls. We find that for magmatic system parameters at SHV, the model predicts timescales of motion in accord with observations from tilt cycles, suggesting that periodic 'slipping' of a viscous plug in response to conduit pressurisation may be a plausible mechanism for generating tilt cycles.

Notes

Bubbles, jumps, and fractures in an analogue experiment on volcanic conduits

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During an eruption, fast expansion of bubbles may impose a dramatic change in the rate and mode of deformation of the enclosing magma, specially when gas bubbles cannot escape from a relatively viscous liquid phase. To investigate how viscoelastic magma may respond to the deformations induced by bubble growth, we performed experiments on the diffusion-driven expansion of bubbles in a viscoelastic magma analogue. In the transparent, high-pressure section of a shock-tube apparatus we saturated with gas Argon a sample of shear-thinning silicon polymer. On sudden decompression, the sample becomes supersaturated, vesiculates, and deforms. Experimental variables include saturation pressure and duration, and shape and lubrication of the high pressure chamber. To monitor the experiments we used a normal and a high speed camera. In addition, in selected runs we applied one pressure transducer to the base and one to the top of the chamber. During the experiments, the following processes occurred: 1) nucleation, growth, and coalescence of bubbles; 2) expansion and flow of the sample; 3) formation and healing of fractures; 4) escape of gas from the sample. 1) Bubble growth in the experiments controls both flow and fracturing, and is consistent with physical models of magma vesiculation, with initial homogeneous nucleation, a growth phase, and later extensive coalescence. 2) We observed three phases of sample expansion, controlled by the interplay between bubble expansion, wall-friction, and gas escape though a permeable foam. At the beginning of the experiment, the sample flows smoothly. At some time, the flow head starts to oscillate with a frequency similar to the travel time of the shock waves across the length of the shock-tube, suggesting that pressure fluctuations cause fluctuations in the expansion of the porous sample. Other jumps in the flow coincide with the opening of fractures. 3) Two types of fracture forms in the sample: i) sharp fractures along the uppermost rim of the sample, and ii) fractures pervasively diffused throughout the sample. Rim fractures open when shear stress accumulates and strain rate is highest at the margin of the flow, while pervasive fractures originate when wall-friction retards expansion of the sample, causing pressure to build-up in the bubbles. When bubble pressure overcomes wall-friction and the tensile strength of the porous sample, fractures open with a range of morphologies. Both types of fracture open normally to flow direction, and both may heal as the flow proceeds. 4) We observed gas escape from the sample only towards the end of the experiment, when gas pockets rise within the highly-porous sample or along the chamber walls. However, combined measurements on sample expansion and cracking show that the development of pervasive fractures allows substantial amounts of gas to escape from the sample also before the generation of a permeable network of coalesced bubbles.

Notes

Numerical simulation of fluid flow oscillations in volcanic systems

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Numerical simulations of pre-sin-eruptive volatile-rich magma in magma chambers and volcanic conduits are performed as controlled experiments in the frame of parametric investigation. The role on the overall dynamics of some relevant physico-chemical parameters that define the computed system is studied focusing on the occurrence of fluctuations in pressure, stresses and velocity of the bubbly flow. These fluctuations can be related to seismic, acoustic and deformation signals observed on the Earth surface.

The physico-mathematical model describes the time-dependent, 2D thermo-fluid dynamics of a compressible-to-incompressible homogeneous multiphase, multi-component mixture made of liquid in equilibrium with an H_2O+CO_2 gas phase at local P-T-composition conditions.

The physical properties of the mixture are allowed to vary according to the local pressure, temperature, and composition conditions adopting appropriate constitutive equations from the literature. H_2O-CO_2-liquid equilibrium is computed by modeling the non-ideal thermodynamic behavior of multicomponent gas-silicate liquid systems [Papale et al., 2006].

Magma density is calculated through the Lange [1994] equation of state for the liquid phase, real gas properties, and standard mixture laws for multiphase fluids. VTF-like parameterizations for the viscosity of liquids having composition similar to those in the numerical simulations are employed [Giordano and Dingwell, XXXX; Misiti et al., 2006]. Undeformable gas bubbles are allowed to affect mixture viscosity as in Ishii and Zuber [1979] and Papale [2001]. Inter-diffusion between magmas of different compositions is accounted for through Fick's law.

The numerical method is based on an original finite element formulation by Hauke and Hughes [1998]. This consists in a space-time discretization with Galerkin least-squares and discontinuity capturing terms, which allow a high level of numerical stability. With respect to the original formulation, the numerical model is extended to fully account for multi-component fluids, making it particularly suitable for the investigation of processes involving chemical change and phase transitions.

Parametric studies performed to assess the roles on the volcanic processes of different system geometries, magma composition, volatile contents, and chamber feeding conditions, show the generation of fluid oscillations over a large range of frequencies from much less than 1 up to about 10 Hz, covering the range of observed oscillations for fluid flow-related volcanic processes. These oscillations involve the velocity and stress fields, as well as the fluid pressure. Understanding the relationships between these computed oscillations and those characterizing signals measured at active volcanoes from seismic and deformation surveillance networks should allow in the near future a much more in-depth comprehension of the processes occurring below the Earth's surface, and a more confident evaluation of the short term volcanic hazard.

Notes

Friday 11:30

Some insights into the controls on basaltic eruptions

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We present some new quantitative models which provide some insights into the controls on the style of eruption of basaltic magma, including fire-fountaining, strombolian bursts and lava flow activity. We also use the model to illustrate some of the mechanisms by which transitions between these styles of behaviour may arise during the evolution of an eruption. We also extend the modelling to illustrate some of the transitions in behaviour of lava lake systems, and illustrate the principles with some simple laboratory experiments.

Notes

Elastic instabilities, roll waves and volcanic tremor

Rust, A. C., N. J. Balmforth and S. Mandre

The detection of long-period seismic signals including tremor, has become an increasingly important tool in forecasting volcanic eruptions. However, the physical mechanisms for the generation of these oscillations remain poorly understood. We explore theoretically, numerically and experimentally the feasibility of generating tremor by fluid flow through cracks or conduits in elastic rock. Two mechanisms for flow-induced vibrations are considered: destabilization of elastic modes by the fluid flow and interfacial waves. We solve governing equations for deformation in both the fluid and the solid, and match stresses in the two materials at their interface, allowing the conduit thickness to vary with both time and position. The corresponding experiments involve air flow through a slit cut in a gelatine block. We also gain insight into tremor by studying related problems of flow-induced vibrations in elastic membranes and slabs as well as the development of roll waves on shallow fluid flows.

We suggest that the flow-induced waves result from a supercritical, convective instability. The excitation of elastic modes is not feasible for volcanic tremor as a length scale on the order of kms is required to generate a 1 Hz signal. We conclude that flow-induced vibration is only a viable mechanism for volcanic tremor for rapid fluid flow through long narrow cracks, and probably is not responsible for most volcanic tremor.

Notes

Friday 12:10

Pressure perturbations generated by interaction of gas, liquid, and solid

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At an eruption, pressure perturbations in the volcano are observed as crustal deformation, seismic signals, and acoustic waves. Their sources are considered to include various interactions among elastic solid (ambient rocks), viscous liquid (magma), and compressible fluid (gas). Numerical experiments are conducted for simple systems consisting of these three components. Focus is put on processes to increase magma pressure following to decompression. Two types of decompression are assumed: one is penetration of seismic wave from a distant source, and the other is degassing. For given decompression, pressure-change in magma and bubble expansion is calculated. It is demonstrated that rapid pressure increase is generated by partial breakage of bubble wall.

The present work is inspired by two previous studies. One is Nishimura (2004), which presented pressure recovery in magma chamber by bubble expansion and emphasized the important effect of interaction among the three components (rock, magma, and bubbles). The other is Tameguri et al. (2004), which presented that an earthquake associated with an eruption at Suwanosej-jima volcano, Japan, is explained by a shallow mild decompression source and a following deeper strong compression source. In the present work, it is shown that the effects of interaction among the three components are more variable and may explain the source processes that generated the seismic waves.

Notes

Cyclic behaviour in lava dome building eruptions

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Lava dome eruptions are commonly characterised by large fluctuations in extrusion rate with cyclic behaviour on time-scales ranging from hours to decades. Such behaviour has been recognised worldwide, at Bezymianny volcano (Russia), Merapi (Java), Santiaguito (Guatemala), Mt St Helens (USA), Mt Unzen (Japan), and Soufrière Hills volcano (Montserrat), among others. Cyclicity provides an opportunity to test new models leading to improved understanding of the dynamics of complex magmatic systems.

We will give a review of existing models that explain different timescales of cycles on lava dome building eruptions. It is clear that no single model can explain all ranges of observed timescales. Short-period pulsations (hours) are a consequence of shallow conduit processes, years to decades timescales are controlled by pressure evolution inside a magma chamber, even longer timescales reflect evolution of supply rate of fresh magmas from feeding systems. An intermediate timescale of an order of several weeks was observed on Mt St Helens (USA) and the Soufrière Hills volcano (Montserrat),

We develop a model for magma flow in dykes, which predicts intense pulsations of magma extrusion for the case of a constant source pressure or constant magma supply rate into the dyke. The period time scale is determined by the elastic deformation of the dyke walls and the length-to-width ratio of the dyke. The dyke acts like a volumetric capacitor, storing magma as pressure increases and then releasing magma in a pulse of extrusion. For a well-documented test case, cyclic extrusions with time-scales of a few weeks are predicted for dykes 300 –500 m long and 3-6 m wide, and these match observations. The model explains the sharp onset of tilt pulsations and seismic swarms as well as associated short-lived explosions.

Notes

Wallrock elasticity effect on magma flow in dykes during cyclic lava dome extrusion

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Many lava-dome building eruptions show complex non-periodic pulsatory activity. Previous studies modelled the ascent of magma along the conduit from the chamber using a general set of transient 1-D transport equations for a constant cylindrical cross-section of the conduit, accounting for degassing induced crystallization kinetics, gas exsolution and viscosity increase due to crystal growth. Here we generalised the model to the flow geometry represented by an elliptical dyke with major and minor semi-axes changing with depth. Quasi-static elastic deformation of the dyke is accounted by an analytical solution that couples cross-section area with the conduit overpressure. The model predicts intense pulsations of magma extrusion for the case of a constant source pressure. The period time scale is determined by the elastic deformation of the dyke walls and the length-to-width ratio of the dyke. The model is applied to the description of cyclic activity on the Soufriere Hill volcano, Montserrat. In particular we were able to reproduce oscillations with a period of 30 to 50 days that were observed at Montserrat. Moreover we also present some results about effects of conductive heat loss from the conduit walls that were incorporated by using a simple semi-analytical 1D heat transfer model that is able to approximate satisfactory results obtained from a more complex computational 2D model.

Notes

Friday 14:20

Computing synthetic seismograms from two-dimensional magma flow models

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The characteristics of volcanic seismic signals depend strongly on the physical parameters of the medium in which they are generated and propagate. Particularly low-frequency seismic signals obtain their frequency characteristics through the geometry and the contrast of elastic parameters across the magma-country rock interface.

In a two-dimensional finite element approach we employ the compressible Navier-Stokes equation to model the flow of a magmatic mixture of crystals, gas and melt through dykes and conduits of varying geometries, properties and boundary conditions to determine the set of physical parameters relevant for the generation and propagation of seismic waves in such a medium. Flow modeling aspects include solubility and diffusion of gases, gas loss through permeability of magma and country rock, the effects of melt temperature and bubble deformation on melt and magma viscosity, respectively. The seismic wave generation and propagation is based on a finite difference method accounting for seismic damping, topography and stratigraphy in a wide frequency range.

Notes

How to consider gas loss in 2D fluid flow modeling

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Previous 2D fluid flow modeling showed that a possible trigger mechanism for low frequency events could be the brittle failure of the melt near the conduit walls. This brittle failure mechanism requires both high strain rates and viscosity due to cooling at the conduit walls. Since the amount of gas inside the volcanic conduit influences several fundamental parameters of the magma flow such as viscosity and velocity, it has a direct impact on physical processes occurring in the conduit, and therefore also on the depth of the brittle failure. Our study is dealing with both gas loss and anisotropic permeability of the magma related to the bubble shape.

Notes

Damping of seismic waves in a saturated bubbly magma

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We examine the dynamics of pressure waves in bubbly magmas. This effect is important for modeling the interaction of seismic waves with magma-filled conduits and for the possibility that such conduits may act as resonators and sources of low-frequency earthquakes. Wave propagation in bubbly magma was examined by combining the theory of Commander & Prosperetti (1989) for acoustic waves in bubbly liquids with the theory of Navon & Lyakhovsky (1998) for the dynamics of bubble growth. **Here we present several end-member analytical solutions for the propagation of seismic waves through a saturated bubbly magma.**

Assuming an incompressible melt we derived analytical solutions for the Q-factor; these solutions exhibit the following behavior. When mass flux between bubbles and melt is negligible, damping increases with increasing frequency. If mass transfer is allowed, the opposite effect occurs: damping decreases with increasing frequency. At very low frequencies, when bubbles and melt closely approach equilibrium damping becomes negligible. Collier et al. (2006) obtained a numerical solution for an incompressible melt; **the complex behavior exhibited in their numerical solution is explained by the new analytical solutions obtained in this study.**

Accounting for melt compressibility, we derived an additional set of analytical solutions and obtained a new numerical solution. At low frequencies these solutions are similar in their behavior to those we obtained for the incompressible case. However, above a certain frequency the trend of the analytical no mass flux solution and the numerical solution are inversed and damping decreases with increasing frequency.

Our results show that damping of seismic waves in a saturated bubbly magma is at maximum in the frequency range of Low-Frequency earthquakes.

Notes

Friday 15:50

Shock-wave pattern and atmospheric signature of underexpanded volcanic jets: a comparative study using two numerical multiphase flow models

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The structure and dynamics of underexpanded volcanic jets have been investigated by means of transient, two-dimensional, multiphase flow simulations with two different numerical codes. The results obtained with the two methods are comparable and show that the decompression of the volcanic mixture within the volcanic craters is driven by the complex pattern of oblique, reflecting shock-waves. The jet formed during the explosion results therefore to be strongly influenced by the crater shape and particularly by the crater opening angle.

Numerical results also describe the propagation in the atmosphere of a spherical pressure wave generated at the vent by the explosive source. The signature of the atmospheric perturbation marks the initial stage of the column formation and can be related to the mixture injection conditions.

Notes

Numerical modelling of gas slugs rising in basaltic volcanic conduits: Inferences on Very-Long-Period event generation

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The volcanological interpretation of Very-Long-Period (VLP) seismic signals recorded at Stromboli and other basaltic volcanoes needs a realistic physical model of their origin. In recent years, the quantitative analysis of broadband waveforms recorded at Stromboli through source function inversion (Chouet et al. 2003), furnished information about the forces acting on the volcanic conduit during the VLP events occurrence. These data are precious constrains to any model of the VLP source. For instance VLP source functions at Stromboli, have shown that previous models (as the foam collapse) are not able to explain the magnitude of observed volumetric variations. Analogue modelling has shown that a reliable model for VLP event generation is the transit of a large gas slugs through a widening in the volcanic conduit (James at al. 2006). Numerical modelling is also needed for simulating a wider range of conditions and for a deeper understanding of these phenomena.

The numerical modelling of a two-phase gas-magma system in 3D, in inertia-dominated conditions is not simple. Taking into account effects of surface tension, joining and splitting of bubbles is a hard computational task for standard methods of Computational Fluid Dynamics. We propose a new method based on the finite-difference solution of the mass and momentum conservation equations and of an advection-diffusion equation for the fluid composition. The chemical equilibrium between the two phases is modelled using a Ginzburg-Landau free energy function. This function allows the formation and the preservation of stable interfaces among the magma and the gas bubbles by acting on the diffusion processes and the mechanical pressure tensor. There in no needing of special constraints or boundary conditions on bubble interfaces. The method has been implemented for 3D modelling, using MPI based parallel computing. We will show example of simulations of gas slugs rising in simple models of magma filled dikes, showing how synthetic VLP source functions can be retrieved and compared with observed ones.

Notes

Friday 16:30

Seismicity generated by gas slug ascent: a numerical investigation

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Seismic signals span a continuum from ultra-long period events with dominate periods of 100s of seconds through very-long period events to long period (LP) events, in addition volcano-tectonic signals. It is now well established that low frequency events and tremor are linked to fluid flow through cracks and conduits. This makes them useful in accessing the internal state of the volcanic plumbing system. To date, little work has been done to develop numerical models that include multi-phase fluids and the mechanical interaction with the surrounding rock including the complex internal structure of the volcano. To investigate the role played by gas slug ascent as a potential volcanic source mechanism we apply a discrete numerical method for multi-phase fluid flow which includes the mechanical coupling of a multi-phase fluid-rock system. The mechanical coupling of a multi-phase fluid-rock system allows us to model the seismicity caused by the pressure perturbations generated by the gas slug. We perform simulations of a fluid conduit embedded inside an elastic solid employing different conduit geometries and fluid parameters and examined the associated seismicity. Our conclusions from the simulations indicate that the fluid viscosity, which controls the bubble rise time, is the dominant control on the frequency of the seismicity. Also, the conduit width plays an important role in the bubble rise time and hence the period of the seismic waves.

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