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PROGRAM and ABSTRACTS

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3rd workshop on

Physics of Volcanoes

on 8 and 9 March 2017

at
Ludwig-Maximilians-Universität
(LMU) München

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Contents

Location

Ludwig-Maximilians-University Munich
Department of Earth and Environmental Sciences
Section for Mineralogy, Petrology and Geochemistry
Theresienstr. 41
80333 München

www.en.mineralogie.geowissenschaften.uni-muenchen.de/ueber_uns/directions/index.html

The workshop will take place at auditorium B052 in Theresienstr. 37/39.

www.uni-muenchen.de/funktionen/gebaeudeplaene/1001_d_00.pdf

How to get there:

- from Karlsplatz (Stachus) use Tram 27 direction Petuelring or Tram 28 direction Scheidplatz and get off at the station "Pinakotheken"

or

- from "Hauptbahnhof Nord" use the Museum-Bus line 100 (direction "Ostbahnhof") or Bus line 150 (direction "Tivolistraße") and get off at the station "Pinakotheken"

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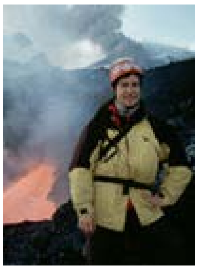

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Session conveners

Physics and chemistry of melts

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Physics of magmatic processes

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Volcano hazards and risk mitigation

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Volcano monitoring

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Keynote speaker

Volcano hazards and risk mitigation

Ali Hoshyaripour [Universität Hamburg], gholamali.hoshyaripour@uni-hamburg.de

Program

Program Physics of Volcanoes 2017

Wednesday

Time		Session	Speaker	Topic
9:00	9.00			
	9:15			
	9:30	Registration		
	9:45			
10:00	10:00	Coffee		
	10:15			
	10:30			
	10:45	Opening		
11:00	11:00	VOMO	Gaudin	High speed imaging, lightning mapping arrays and thermal imaging: a synergy for the monitoring of electrical discharges at the onset of volcanic explosions
	11:15	VOMO	Walter	Imaging and structural analysis of the Geyser field, Iceland, from underwater and drone based photogrammetry
	11:30	PIMP	Cigala	The dynamics of pyroclast ejection velocity from impulsive shock-tube experiments
	11:45	PIMP	Pena Fernandez	Effects of the Reynolds number on the starting jet
12:00	12:00	MELT	Klein	The influence of crystal size distributions (CSD) on the rheology of magma: new insights from analogue experiments
	12:15	MELT	Song	Wetting and spreading of molten volcanic ash in jet engines
	12:30	Lunch break		
	12:45			
13:00	13:00			
	13:15			
	13:30			
	13:45			
14:00	14:00	VOMO	Dietrich	Seismic investigation of the Fogo magmatic plumbing system, Cape Verde, using multi-array techniques
	14:15	VOMO	Lühr	TOMO-ETNA Experiment – first results of seismic investigation at Etna volcano
	14:30	VOMO	Zakšek	Small satellites for monitoring volcanic clouds?
	14:45	VOHA	Hoshyaripour	The Initial Fate of Sulfur and Chlorine from Eyjafjallajökull Eruption 2010
15:00	15:00			
	15:15	VOHA	Casas Ramos	In-plume gas scavenging: Insights on gas adsorption
	15:30	Coffee break		
	15:45			
16:00	16.00	Poster session		
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19:00	19:00	Voluntary dinner at Löwenbräukeller		

Thursday

Time		Session	Speaker	Topic
9.00	9:00	PIMP	Breitkreuz	The large volcanic centers in Late Paleozoic Europe: towards a better understanding of their volcanic evolution and magma genesis
	9:15	PIMP	Cimarelli	From ashes to flashes: volcanic plume electrification observation and experiments
	9:30	PIMP	Douillet	Sediment plates (lacquer peels) as a dissemination and vulgarization tool for volcanic research
	9:45	VOMO	Scharff	Dissecting the dynamics of a pyroclastic flow
10.00	10:00	VOMO	Pfanz	Volcanic CO2 and its detection by organisms
	10:15	VOMO	Wilken	Influence of ambient conditions on NOVAC measurements
	10:30	Coffee break		
	10:45			
11.00	11:00	VOHA	Müller	Deposition or not? The fate of volcanic ash aggregates
	11:15	VOHA	Steinau	Numerical modeling of volcanic ash deposits using Ash3D and HAZMAP - a comparative study
	11:30	VOHA	Passarelli	Is the seismicity swarm at long-dormant Jailolo volcano (Indonesia) a signature of a magmatic unrest?
	11:45	PIMP	Scheu	Phreatic & hydrothermal eruption dynamics: Insights from field work and lab experiments
12.00	12:00	PIMP	Schmid	The viscous to brittle transition in eruptions of clay suspensions
	12:15	PIMP	Klügel	Magma plumbing during the 2014-2015 eruption of Fogo, Cape Verde Islands
	12:30	Lunch break		
	12:45			
13.00	13:00			
	13:15			
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14:00	14:00	PIMP	Nikkhoo	Temporal evolution of the lava dome at Merapi volcano investigated through TerraSAR-X time-series analysis and boundary element modelling
	14:15	PIMP	Colombier	Vesiculation and aggregation processes during the 2014-2015 surtseyan eruption of Hunga Tonga-Hunga Ha'apai volcano
	14:30	PIMP	Rivalta	Numerical modelling of magma ascent through the crust for Etnean and Hyblean volcanism
	14:45	VOHA	Strehlow	Phreatic eruptions at Ruapehu: Occurrence statistics and probabilistic hazard forecast
15:00	15:00	VOMO	Salzer	Evaluating links between deformation, topography and surface temperature at volcanic domes: Results from a multi-sensor study at Volcán de Colima, Mexico
	15:15	VOMO	Dinger	Mechanical interaction between gas bubbles and micro-crystals in magma
	15.30	Coffee break		
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16:00	16:00	Lacquer Peels		
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18:00	18:00			
19:00	19:00			

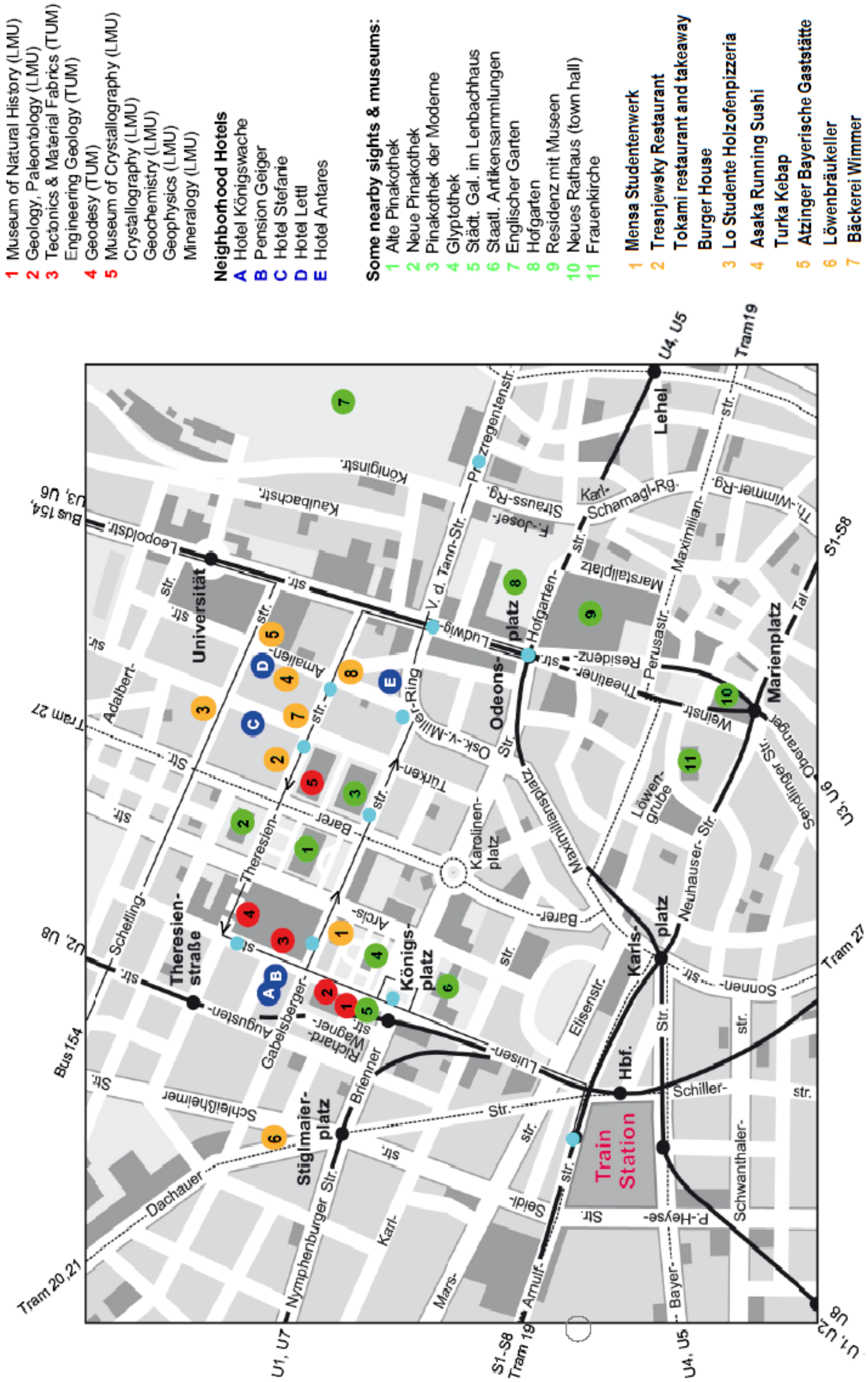
Poster session

Author		Title
Physics and chemistry of melts		
Cáceres	Francisco	Laguna del Maule magma feeding system and construction of a shallow silicic magma reservoir
Kühn	Christian	The Anahim Volcanic Belt, British Columbia - Hot-spot or not-spot?
Yilmaz	Tim	Mineralogy, chemistry and intensity of hydrothermally altered conduit rocks and their thermal expansion between 150 and 800°C (Mt Unzen, Shimabara, Japan)
Physics of magmatic processes		
Keller	Franziska	Lightning-induced melting of volcanic ash: an experimental study
Rivalta	Eleonora	Can spectral ratios help us constraining the parameters of magma reservoirs?
Wadsworth	Fabian	The permeability of magmas
Volcano hazards and risk mitigation		
Costa	Ana	Numerical modelling of collapsing volcanic edifices
Douillet	Guilhem	Deposits from the 1877 eruption of Cotopaxi volcano (Ecuador): interaction between PDCs and lahars triggered by glacier melting
Volcano monitoring		
Keicher	Viktoria	Determine volcanic SO2 plume heights from satellite observations on a global scale using meteorological wind fields
Kuhn	Jonas	Imaging trace gases in volcanic plumes with Fabry Perot Interferometers
Plank	Simon	Monitoring of volcanoes by means of satellite-based remote sensing
Strehlow	Karen	Poroelastic aquifer responses to crustal strain and their use in volcano monitoring
Tirpitz	Jan-Lukas	Ground-based and airborne measurements of volcanic gas emissions at White Island in New Zealand
Tirpitz	Jan-Lukas	LED based Quartz Enhanced Photoacoustic Spectroscopy
Warnach	Simon	Investigation of BrO in volcanic plumes: Comparing satellite data from OMI and GOME-2

Session		Convener
MELT	Physics and chemistry of melts	Christoph Helo, Kai-Uwe Hess
PIMP	Physics of magmatic processes	Jonathan Castro, Ulrich Kueppers
VOHA	Volcano hazards and risk mitigation	Bettina Scheu, Thomas Walter
VOMO	Volcano monitoring	Lea Scharff, Joachim Wassermann

Please upload your presentation at latest in the break before the session your presenting in.
Ask Kai-Uwe Hess or Ulrich Küppers.

Map


1 Museum of Natural History (LMU)
2 Geology, Paleontology (LMU)
3 Tectonics & Material Fabrics (TUM)
Engineering Geology (TUM)
4 Geodesy (TUM)
5 Museum of Crystallography (LMU)
Crystallography (LMU)
Geochemistry (LMU)
Geophysics (LMU)
Mineralogy (LMU)
Neighborhood Hotels
A Hotel Königswache
B Pension Geiger
C Hotel Stefanie
D Hotel Lettl
E Hotel Antares
Some nearby sights & museums:
1 Alte Pinakothek
2 Neue Pinakothek
3 Pinakothek der Moderne
4 Glyptothek
5 Städt. Gal. im Lenbachhaus
6 Staatl. Antikensammlungen
7 Englischer Garten
8 Hofgarten
9 Residenz mit Museen
10 Neues Rathaus (town hall)
11 Frauenkirche
1 Mensa Studentenwerk
2 Tresnjewsky Restaurant
Tokami restaurant and takeaway
Burger House
3 Lo Studente Holzofenpizzeria
4 Asaka Running Sushi
Turka Kebap
5 Atzinger Bayerische Gaststätte
6 Löwenbräukeller
7 Bäckerei Wimmer
8 Bäckerei Kistenpfennig
Universität
Theresien-straße
Königs-platz
Stiglmaier-platz
Odeons-platz
Karolinen-platz
Karls-platz
Marienplatz
Lehel
Hbf.
Train Station

Abstracts talks

The large volcanic centers in Late Paleozoic Europe: towards a better understanding of their volcanic evolution and magma genesis

Christoph Breitkreuz[1], Raymundo Casas García[1], Marcel Hübner[1], Alexander Repstock[1]

[1] Institut für Geologie und Paläontologie, Bernhard-von-Cotta-Str. 2, TU Bergakademie Freiberg, 09599 Freiberg, cbreit@geo.tu-freiberg.de

Numerous volcanic centers were active during Carboniferous to Lower Permian (c. 325 to 290 Ma) in Europe. Among these, the Athesian Volcanic Group (N Italy), various centers in the Saar-Nahe Basin and in the NE German Basin and Poland, the Halle Volcanic Complex, the North Saxony Volcanic Complex and systems in the eastern Erzgebirge stand out for their size and complexity (Benek et al. 1996, Awdankiewicz 1999, Lorenz and Haneke 2004, Breitkreuz et al. 2007, Geißler et al. 2008, Hoffmann et al. 2013, Wilcock et al. 2013, Schmiedel et al. 2015, Walther et al. 2016, and references therein). Most of these late- to post-Variscan complexes are dominated by crystal clast-rich ignimbrite sheets (35 to 58 vol %, Repstock et al. under revision).

Currently we focus on volcanic and subvolcanic centers in eastern Germany and in the border region to the Czech Republic, in cooperation with the geological surveys of Saxony-Anhalt, Saxony and Czechia, with the GFZ Potsdam and the University of Wroclaw. Limited natural outcrops, many active and abandoned quarries, and literally thousands of exploration wells allow for an excellent, locally 3d, insight into these extended magmatic systems. We attempt to reconstruct the volcanic and magmatic evolution applying volcanic facies analysis, petrophysical measurements, whole rock and mineral geochemistry, U/Pb dating on zircon, and measurement of isotope ratios.

The thick and extended welded ignimbrite units of the Rochlitz and Wurzen Volcanic Systems in the Lower Permian North Saxony Volcanic Complex are being interpreted as caldera fill. Presence of exotic mafic fiamme, the mineral assemblage and geochemical pattern suggest that magma mixing and mingling was important during the Wurzen evolution. Caldera margin features and the presence of central, NW-SE-trending subvolcanic bodies suggest pyroclastic fountaining from large fissures as the principal eruption mechanism. This, and geo-barometric calculations suggest relatively deep seated magma chambers. In contrast, the mid-Carboniferous eastern Erzgebirge volcanic centers are associated with high-level intrusions: the Tharandt Wald caldera with the Niederbobritzsch pluton, and the Altenberg-Teplice Volcanic Complex with the Schellerhau and Zinnwald granitoids.

With this contribution we want to call attention to the existence of these important magmatic centers on our doorstep. Presenting data of our work in progress we hope to stimulate discussion about magma genesis, the reasons for abundance and size of these systems and their relevance for the understanding of (post-)Variscan geotectonics.

Awdankiewicz M (1999) Volcanism in a late Variscan intramontane trough: Carboniferous and Permian volcanic centres of the Intra-Sudetic Basin, SW Poland. Geol Sudet 32:13–47

Benek R, Kramer W, McCann T, Scheck M, Negendank JFW, Korich D, Huebscher HD, Bayer U (1996) Permo-Carboniferous magmatism of the Northeast German basin. Tectonophys, 266: 379-404

Breitkreuz C, Kennedy A, Geissler M, Ehling B-C, Kopp J, Muszynski A, Protas A, Stogue S (2007) Far eastern Avalonia: its chronostratigraphic structure revealed by SHRIMP zircon ages from Upper Carboniferous to Lower Permian volcanic rocks (drill cores from Germany, Poland and Denmark). Geol Soc Amer Spec Pap, 423: 173-190

Geißler M, Breitkreuz C, Kiersnowski H (2008) Late Paleozoic volcanism in the central part of the Southern Permian Basin (NE Germany, W Poland): Facies distribution and volcano-topographic hiati. Int J Earth Sci 97: 973 - 989

Hoffmann U, Breitkreuz C, Breiter K, Sergeev S, Stanek K, Tichomirowa M (2013) Carboniferous-Permian volcanic evolution in Central Europe - U/Pb-ages of volcanic rocks in Saxony (Germany) and northern Bohemia (Czech Republic). Int J Earth Sci, 102: 73–99

Lorenz V, Haneke J (2004) Relationship between diatremes, dykes, sills, laccoliths, intrusive-extrusive domes, lava flows, and tephra deposits with unconsolidated water-saturated sediments in the late Variscan intermontane Saar-Nahe-Basin, SW Germany. Geol Soc London Spec Publ 234: 75–124

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Schmiedel T, Breitkreuz C, Görz I, Ehling B-C (2015) Geometry of laccolith margins: 2D and 3D models of the Late Paleozoic Halle Volcanic Complex (Germany).- Int J Earth Sci, 104: 323-333.

Walther D, **Breitkreuz C**, Rapprich V, Kochergina Y, Chlupáčová M, Lapp M, Stanek K, Magna T (2016) The Carboniferous Schönfeld–Altenberg Depression on the NW margin of the Bohemian Massif (Germany/ Czech Republic): volcanosedimentary and magmatic evolution.- J Geosci 61,4

Willcock MAW, Cas RAF, Giordano G, Morelli C (2013) The eruption, pyroclastic flow behaviour, and caldera in-filling processes of the extremely large volume (>1290 km^3), intra- to extra-caldera, Permian Ora (Ignimbrite) Formation, Southern Alps, Italy.- J Volc Geotherm Res 265: 102–126

In-plume gas scavenging: An Insight on gas adsorption, ash-surface chemistry and the role of water

Ana S. Casas[1], Fabian Wadsworth[1], Paul Ayris[1], Corrado Cimarelli[1], Donald B. Dingwell[1]

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In-plume gas scavenging-processes are well known to occur in large volcanic eruptions, where, over the range of plume conditions (temperature and gas composition) and physicochemical ash-surface properties, volcanic gases (mainly SO_2, HCl, and HF) can be sequestrated by the occurrence (alone or combined) of three processes: (1) salt deposition, (2) adsorption, or (3) acidic liquid condensation on the ash-surface. Several studies have sought to constrain the diffusion-driven mechanisms through which scavenging occurs, the optimal temperatures for efficient scavenging, and the likely reaction products formed. Here we bolster these datasets with new high-resolution experimental work.

Our current project additionally seeks to identify the role of water vapour in gas scavenging processes using a time- and temperature- series of experiments with well-characterized ash samples, for which, particle size distribution, surface area, and bulk chemistry were constrained. These samples will be exposed to various hydrous and anhydrous gas atmospheres with proportions of some plume-relevant gas mixtures (SO_2, SO_2-H_2O) at high temperatures (200 to 800 °C) for various time series (1 to 60 min.) in the Advanced Ash-Gas Reactor (AGAR) available at the LMU chemistry laboratory.

Post-experimental samples are analyzed by standard leachate techniques. We show that a diffusion-controlled sequestration mechanism will be strongly temperature dependent proportional to the diffusivity of the mobile species. In complex mixtures of gases, which could result in the diffusion of more than a single species, it remains to be tested whether simple diffusion models can yield average sequestration volumes. This will be tested explicitly using simple diffusion time scaling laws. Future work should target the additional combined effects of HCl, SO_2 and H_2O in more realistic complex volcanic atmospheres.

The dynamics of pyroclast ejection velocity from impulsive shock-tube experiments

Valeria Cigala[1*], Ulrich Kueppers[1], Juan José Peña Fernandez[2], Jacopo Taddeucci[3], Jörn Sesterhenn[2], Donald B. Dingwell[1]

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[3] INGV Rome, Italy
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During explosive volcanic eruptions gas and particle mixtures are ejected at various range of velocities. This variability is a direct consequence of complex interaction between physical and chemical parameters, which consequently constitute the boundary conditions for a certain eruption. However, boundary conditions are often difficult to characterize entirely on the field and so scaled and controlled laboratory experiments come in hand. We investigated the control of physical boundary conditions on the dynamics of pyroclast ejection performing shock-tube experiments focusing particularly in the near vent region, also called gas-thrust, for the case of impulsively released gas-pyroclast mixtures (i.e. unsteady eruptions). We varied the following experimental conditions: 1) tube length, 2) vent geometry, 3) gas-particle ratio, 4) initial temperature and 5) particle size distribution, while initial overpressure was kept constant at 15MPa. We repeated each set of conditions at least three times for statistical reproducibility. Finally, we tested the reproducibility of a fragmentation depth model at our experimental conditions. We observed a positive correlation of velocity with 1) diverging vent walls and 2) temperature and a negative correlation with 1) starting tube length and 2) particle size. Moreover, we found that gas-particle ratio strongly affects the temporal evolution of particle ejection velocity. Our conclusions stress the importance of scaled and repeatable laboratory experiments for a better understanding of volcanic phenomena and therefore volcanic hazard assessment.

From ashes to flashes: volcanic plume electrification observation and experiments.

Corrado Cimarelli[1] and the Volcanic Lightning Team (VoLT)

[1] Earth and Environmental Sciences, Ludwig-Maximilians-Universität München (Germany)

Ash-rich volcanic plumes inject large quantities of aerosols into the atmosphere and are often associated with intense electrical activity with generation of volcanic lightning. Volcanic lightning can be remotely detected in adverse weather conditions to monitor volcanic plumes. In addition electrical discharges associated with explosive eruptions may provide crucial information on the dynamics and structure of the plume as well as on the mass eruption rate and cargo of erupted fine ash. We adopt a twofold approach to advance our understanding of plume electrification by performing multi-parametric observation of volcanic lightning at active volcanoes and by replicating volcanic lightning in particle-laden jets generated in the lab.

Effects of impulse lightning discharges on volcanic ash analogues are also presented.

Vesiculation, fragmentation and aggregation processes during the 2014-2015 eruption of Hunga Tonga-Hunga Ha'apai volcano

Mathieu Colombier[1], Manuela Tost[2], Shane Cronin[2], Bettina Scheu[1], Kate Dobson[3], Kai U Hess[1], Tim Yilmaz[1], Donald B Dingwell[1]

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[2] School of Environment, University of Auckland,
[3] Department of Earth Sciences, Durham University

Surtseyan eruptions are shallow emergent subaqueous explosive volcanic eruptions. Conditions of water-magma interaction along with magma ejection rates and its gas/expansion conditions control eruption styles during progressive emergence of the volcano.

In order to better assess the effect of water on processes such as vesiculation, fragmentation, cooling or aggregation, we studied the textural and morphological properties of ash, lapilli and bombs from the deposits of the 2014-2015 surtseyan eruption of Hunga Tonga-Hunga Ha'apai volcano, Tonga. We assessed the fragmentation and aggregation mechanisms by analysing aggregates by X-ray micro-computed tomography and 2D textural analysis using BSE images at SEM. We also qualitatively measured the vesicularity, vesicle connectivity, permeability and vesicle size distributions of juvenile lapilli and bombs from the deposits by Helium pycnometry, X-ray micro-computed tomography using Avizo 9.2 software and SEM using FOAMS software to infer the vesiculation processes.

Aggregates are ubiquitous in the deposits and most of these are armoured lapilli consisting of a juvenile lapillus coated by fine ash. 2D and 3D images reveal that the rims of the core lapilli are heavily cracked. These cracks lead to autobrecciation of the outer rim leading to jigsaw fit textures. Furthermore, the coated ash and the host lapilli have similar textures and we propose that the autobrecciation partly contributed to the ash coating. We interpret these cracks as the result of thermal granulation due to rapid cooling at the melt-water interface, confirming that the water played an important role in the cooling, fragmentation and aggregation processes during this surtseyan eruption.

The bombs show gradual textural variations with increase of vesicle size and degree of coalescence from rim to core. These textural variations are also observed in the lapilli. The vesicle connectivity in the lapilli and bombs covers a wide range from fully isolated to completely connected. Vesicle connectivity and permeability increase strongly with vesicularity. The percolation threshold, that is the critical vesicularity corresponding to the onset of connectivity and permeability due to system-spanning coalescence is estimated at around 0.2-0.4 and is lower than for scoria from fire fountaining and strombolian eruptions. These variations of connectivity and permeability with vesicularity are likely to reflect post-fragmentation vesiculation interupted at different stages by quenching in water. The link between vesiculation and cooling will be further constrained using heat transfer equations and geospeedometry.

This study exemplifies the diverse influence water-magma interaction can pose on the vesiculation, fragmentation and aggregation processes for instance in the role of thermal granulation during this surtseyan eruption.

Analysis of volcano-related seismicity to constrain the magmatic plumbing system beneath Fogo, Cape Verde, by (multi-) array techniques

Carola Dietrich[1], Ingo Wölbern[1], Bruno Faria[2], Georg Rümpker[1]

[1]Institute of Geosciences, Goethe-University Frankfurt, Germany
[2]National Institute of Meteorology and Geophysics, Cape Verde

Fogo is the only island of the Cape Verde archipelago with regular occurring volcanic eruptions since its discovery in the 15th century. The volcanism of the archipelago originates from a mantle plume beneath an almost stationary tectonic plate. With an eruption interval of approximately 20 years, Fogo belongs to the most active oceanic volcanoes. The latest eruption started in November 2014 and ceased in February 2015.

This study aims to characterize and investigate the seismic activity and the magmatic plumbing system of Fogo, which is believed to be related to a magmatic source close to the neighboring island of Brava. According to previous studies, using conventional seismic network configurations, most of the seismic activity occurs offshore. Therefore, seismological array techniques represent powerful tools in investigating earthquakes and other volcano-related events located outside of the networks. Another advantage in the use of seismic arrays is their possibility to detect events of relatively small magnitude and to locate seismic signals without a clear onset of phases, such as volcanic tremors.

Since October 2015 we have been operating a test array on Fogo as part of a pilot study. This array consists of 10 seismic stations, distributed in a circular shape with an aperture of 700 m. The stations are equipped with Omnirecs CUBE dataloggers, and either 4.5 Hz geophones (7 stations) or Trillium-Compact broad-band seismometers (3 stations). In January 2016 we installed three additional broad-band stations distributed across the island of Fogo to improve the capabilities for event localization.

The data of the pilot study is dominated by seismic activity around Brava, but also exhibit tremors and hybrid events of unknown origin within the caldera of Fogo volcano. The preliminary analysis of these events includes the characterization and localization of the different event types using seismic array processing in combination with conventional localization methods.

In the beginning of August 2016, a "seismic crisis" occurred on the island of Brava which led to the evacuation of a village. The seismic activity recorded by our instruments on Fogo exhibits more than 40 earthquakes during this time. Locations and magnitudes of these events will be presented.

In January 2017 the pilot project discussed here will be complemented by three additional seismic arrays (two on Fogo, one on Brava) to improve seismic event localization and structural imaging based on scattered seismic phases by using multi-array techniques.

Mechanical interaction between gas bubbles and micro-crystals in magma

Florian Dinger[1,2], Nicole Bobrowski[1,2], Stefan Bredemeyer[3], Santiago Arellano[4], Ulrich Platt[2,1], Thomas Wagner[1]

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[2] University of Heidelberg, Germany
[3] GEOMAR, Kiel, Germany
[4] Chalmers University of Technology, Gothenburg, Sweden

The magnitude of volcanic gas emissions from low viscosity magmas is controlled by many factors. The buoyancy driven ascent of gas bubbles in the volcanic conduit is one of them. During the ascent the bubbles may collide with micro-crystals, slide along the crystal faces, and finally leave the crystal at the crystal tip. We investigate the mechanical consequences of this interaction in a static volume of magma assuming constant pressure, temperature and chemical composition and neglecting thermodynamic processes between bubbles and crystals. Explicitly, we focus on tabular crystals whose extensions are about one order of magnitude larger than the bubbles. The mechanical interaction changes the motion of both the bubbles and the crystals. The buoyancy force of the bubbles results in a torque on the crystal which ultimately orients the long axis of the crystal to the vertical direction. On the other hand, bubbles change their ascent path and velocity if they slide along a crystal face. This change in the bubble motion may have two opposing impacts on the magnitude of volcanic emissions: First, the reduced ascent velocity results in a bubble accumulation and thus enhanced bubble coalescence rate in the proximity of crystals. Second, the crystals align the bubbles in rise channels starting at the crystal tips while no bubbles access the magma volume immediately located above the crystal cross section, which we call "crystal shadow". Now, volatile degassing from supersaturated magma is a diffusive short-distance process which accelerate in the proximity of pre-existing gas bubbles. We thus infer that the orientation of the crystals influences the bulk volatile degassing rate and thus the volcanic gas emission rate due to the crystal shadow.

The mechanical model suggests that all crystals get erected by the bubble-induced torque within time periods in the order of weeks to months. This has to be compared to the crystal nucleation rate in order to obtain a steady state distribution of the crystal orientation. Anyway, crystal orientation is also, and potentially much stronger, influenced by the general magma convection. Accordingly, for the second part of our investigation - a crystal-induced variation of the volcanic gas emissions - we assume a random crystal orientation. We investigate a quantisation of the crystal-induced changes in volcanic gas emissions and its dependency on crystal size and distribution. Finally, we investigate the impact of a periodic variation of the crystal orientation, as exerted by e.g. a Earth tidal forcing.

Sediment plates (lacquer peels) as a dissemination and vulgarization tool for volcanic research

Guilhem Amin Douillet[1], Mélanie Bouysson[2], Ulrich Kueppers[1], Célia Mato[3], Benjamin Bernard[4], Donald Bruce Dingwell[1]

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Sediment plates (lacquer peels) are cross-sections of loose sediments that are artificially hardened in the field so that a thin slice of the outcrop is extracted and transported in the lab. An epoxy resin applied to the surface of an outcrop is sucked into the sediment by capillary forces. The differential uptake driven by the grain size of individual laminae highlights lamination and cross stratification to a degree not otherwise observable, and the original organization of grains is preserved. This permits fine scale, fundamental research on boundary layer and PDC sedimentation, but also represents a unique opportunity for outreach and illustration of real PDC deposits to people that would otherwise not have access to field outcrops.

A set of sediment plates was produced in the cross-stratified deposits of the 2006 pyroclastic density currents from Tungurahua volcano (Ecuador). Twelve sections of 3 m length were extracted from 5 dune bedforms, representing about 50 m^2 of outcrops. Individual plates are 50 cm wide, between 1 and 2 m high, and 0,5 cm thick. The plates were consolidated and prepared for exhibition in Munich.

The sediment plates were used in various occasions for communication and vulgarization:
-An afternoon was devoted to their observation and scientific analysis during a volcanology short-course in Munich (MELTS, GLASSES, MAGMAS),
-The plates were used to illustrate volcanology classes with bachelor students, and
-The plates are exposed as a special exhibition in the mineralogy museum "Reich der Kristalle" in Munich during the summer 2016.

We present our feedbacks on the value of such a dataset for science dissemination, the method to produce them, and open a discussion on how to improve their use. The sediment plates from Tungurahua are available for presentation, and we encourage other researchers, museums and teachers to contact us about further possibilities for synergy.

High-speed imaging, thermal imaging and lightning mapping arrays: a synergy for the monitoring of electrical discharges at the onset of volcanic explosions

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Because it is observed in a large number of ash-rich volcanic eruptions and it produces electromagnetic waves that can be detected remotely, volcanic lightning is being increasingly studied, for the purpose of using it for the detection and monitoring of ash plumes. However, it features several peculiarities linked to the presence of gas jets and ash, preventing direct comparison with well-studied thunderstorm lightning, in particular in the earliest stages of the plume development.

In order to better constrain the electrical activity of young volcanic plumes, we took part to a multiparametric field campaignat Sakurajima (Japan) in 2015. The set-up included: i) a lightning mapping array (LMA) of VHF antennas recording the electromagnetic waves produced by lightning at a sample rate of 25 Msps; ii) a thermal camera (25 fps, 1.5 m pixel size, 800 m field of view) continuously recording the plume and allowing the estimation of its main source parameters (volume, rise velocity, mass eruption rate); and iii) a visible-light high speed camera (5000 frames per second, 0.5 m pixel size, 300 m field of view) shooting short movies (approx. duration 1 s) at different stages of the plume evolution, showing the location of discharges in relation to the plume.

The complementarity of these three setups is demonstrated by comparing and aggregating the data at various stages of the plume development. In the earliest stages, the high speed camera spots discrete small discharges, that appear on the LMA data as peaks superimposed to the continuous radio frequency (CRF) signal. At later stages, flashes happen less frequently and increase in length. The correspondence between high speed camera and LMA data allows to define a direct correlation between the length of the flash and the intensity of the electromagnetic signal. Such correlation is used to estimate the evolution of the total discharges within a volcanic plume and while the superimposition of thermal and high speed videos allows to contextualize the flashes location with respects to the plume features and dynamics.

The Initial Fate of Sulfur and Chlorine from Eyjafjallajökull Eruption 2010

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The climatic impacts of volcanic eruptions are essentially linked to the quantity and composition of the volcanogenic volatiles that reach the upper troposphere and beyond. Although volcanic degasing determines the initial flux of SO_2 and HCl, significant fractions of these volatiles can be scavenged by adsorption onto ash and hydrometeor surfaces within eruptive plume and cloud. In other words, the chemical interaction of gases, aerosols and ash during atmospheric transport plays a major role in the fate and impacts of volcanic gases. A fundamental understanding of this chemical transport system is therefore a vital requirement to better comprehend the impact of volcanism on climate system.

Volatile scavenging on volcanic ash and hydrometeor surfaces has been studied previously in independent experimental and modeling studies. Here we present, for the first time, the combination of numerical modeling and laboratory measurements to study the chemical transport of volcanic ash and gases. The numerical model takes into account the gaseous and aqueous chemistry as well as the gas-aerosol partitioning within a fully-coupled scheme. In other words, it is capable of modeling the changes in the gas, liquid and solid phase separately as well as the interactions between phases. The model is used to simulate the chemical aging of the Eyjafjallajökull eruption plume, Iceland, 2010.

The results compare very well with the properties of the ash samples that are measured during leaching experiments. For instance, the model satisfactorily reproduces the halogen and sulfur scavenging by ash as a function of residence time in the eruption cloud. By furthering our understanding of the initial fate of volcanic volatiles, this study lays the ground for the future modeling and laboratory investigation dealing with the impacts of volcanism upon the environment and climate system.

Magma storage during the 2014-2015 eruption of Fogo (Cape Verde Islands)

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The latest eruption of Fogo (Cape Verde Islands), one of the world's most active oceanic island volcanoes, occurred from 23 November 2014 to 8 February 2015. It produced lava flows and tephra of basanitic composition, as well as minor phonotephrite at the early and late phases of the eruption. Zoned phenocrysts and mingled lavas in some samples indicate a magma mixing event that may have initiated the eruption. We have carried out thermobarometric investigations of a suite of samples to place constraints on the depths of pre-eruptive and syn-eruptive magma storage and transport. The samples cover all main stages of the eruption; their dates of emplacement have been determined from the date of incandescence of each sample site in high-resolution thermal infrared emissivity maps collected by satellite instruments (Landsat-8 OLI and EO-1 ALI) during the eruption. The compositions of clinopyroxene phenocrysts and coexisting groundmass indicate equilibrium pressures of 540-740 MPa (90% of data; average 640 MPa), equivalent to ca. 19-25 km depth, within the uppermost mantle. We suggest that this range indicates the depths of a magma reservoir system from which the eruption was fed. Our data show little inter-sample variation and no systematic changes during the course of the eruption. In contrast, fluid inclusions in clinopyroxene phenocrysts indicate a well-defined shallower depth range of 250-340 MPa (90% of data; average 300 MPa), equivalent to ca. 9-13 km depth. This data is interpreted to reflect a section of lateral magma flow within the lower oceanic crust, plausibly in a short-lived storage subsystem that became filled prior to eruption during the months of precursory seismic activity. The bimodal depth distribution of our data shows complete overlap with thermobarometric data from the preceding 1995 and 1951 eruptions, which suggests that similar magma storage systems and pathways in the uppermost mantle and lower crust are repeatedly used.

The influence of crystal size distributions (CSD) on the rheology of magma: new insights from analogue experiments

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Knowing the flow properties, or *rheology*, of magma is of great importance for volcanological research. It is vital for understanding eruptive and depositional features, modelling magma flow rates and distances, interpreting pre-eruptive volcanic unrest and earthquakes, and ultimately predicting volcanic hazards related to magma motion. Despite its key role in governing volcanic processes, magma rheology is extremely difficult to constrain in time and space within a natural volcanic system, because it is dependent upon so many variables. Therefore, both analogue and experimental studies of permissible yet simplified scenarios are needed to isolate different rheological influences.

Despite significant progress in understanding the rheological properties of silicate melts and two-phase mixtures (e.g., melt+crystals), as well as the impact of the volume fraction (e.g. Pinkerton & Stevenson 1992, Caricchi *et al.* 2007, Mueller *et al.* 2010) and shape (Mueller *et al.* 2011) of crystals on magma rheology, the effect of the crystal size distribution (CSD) is still poorly constrained. A highly disperse CSD (i.e., a great variety of different crystal sizes) leads to a much more efficient packing of crystals in a flowing magma which predominantly controls the rheological behavior of magma in a sheared particle Accounting for, or neglecting, the size distribution of crystals can therefore make a considerable difference in magma flow models.

We present the results of systematic rheometric experiments using multimodal analogue particle suspensions of well-defined size fractions of micrometer-sized glass beads in silicone oil as magma-analogue material. Starting with simple bimodal distributions (i.e. particles of two distinct sizes), the complexity of the samples' particle size distribution has been successively increased and evaluated towards tetramodal distributions (four distinct size fractions). Statistical values of the given suspensions have been calculated and controlled by image analyses either way to analyze multimodal Gaussian distributions with varying variance ('broadness') as well as with varying skewness ('tailed distributions'). This dataset of analogue experiments is the first of its kind and compared to theoretical and numerical approaches.

TOMO-ETNA Experiment –, first results of seismic investigation at Etna volcano

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The TOMO-ETNA experiment, as part of the European Union project "MEDiterranean SUpersite Volcanoes (MED-SUV)", was devised to image the crustal structure beneath Etna by using state of the art passive and active seismic methods. Activities on-land and offshore are aiming to obtain new high-resolution seismic images to improve the knowledge of crustal structures existing beneath the Etna volcano and northeast Sicily up to the Aeolian Islands. In a first phase (June 15 - July 24, 2014) at Etna volcano and surrounding areas two removable seismic networks were installed composed by 80 Short Period and 20 Broadband stations, additionally to the existing network belonging to the "Istituto Nazionale di Geofisica e Vulcanologia" (INGV). So in total air-gun shots could be recorded by 168 stations onshore plus 27 ocean bottom instruments offshore in the Tyrrhenian and Ionian Seas. Offshore activities were performed by Spanish and Italian research vessels. In a second phase the broadband seismic network remained operative until October 28, 2014, as well as offshore surveys during November 19 -27, 2014. Active seismic sources were generated by an array of air-guns mounted in the Spanish Oceanographic vessel "Sarmiento de Gamboa" with a power capacity of up to 5.200 cubic inches. In total more than 26.000 shots were fired and more than 450 local and regional earthquakes could be recorded and will be analyzed.

For resolving a volcanic structure the investigation of attenuation and scattering of seismic waves is important. In contrast to existing studies that are almostly based on S-wave signals emitted by local earthquakes, here air-gun signals were investigated by applying a new methodology based on the coda energy ratio defined as the ratio between the energy of the direct P-wave and the energy in a later coda window. Scattering caused by heterogeneities removes energy from direct P-waves that constitutes the earliest possible arrival to any part later in the seismic wave train. As an independent proxy of the scattering strength along the ray path, the peak delay time of a direct P-wave is measured which is well correlated with the coda energy ratio. As a result the distribution of heterogeneities around Etna could be visualized as the projection of the observation in directions of incident rays at the stations. Increased seismic scattering could be detected in the volcano and east of it. The strong heterogeneous zone towards the east coast of Sicily supports earlier observations, and is interpreted as a potential signature of the eastward sliding volcano flank.

Deposition or not? The fate of volcanic ash after aggregation processes

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In the course of explosive volcanic eruptions, large amounts of ash are released into the atmosphere and may subsequently pose a threat to infrastructure, such as aviation industry. Ash plume forecasting is therefore a crucial tool for volcanic hazard mitigation but may be significantly affected by aggregation, altering the aerodynamic properties of particles. Models struggle with the implementation of aggregation since external conditions promoting aggregation have not been completely understood; in a previous study we have shown the rapid generation of ash aggregates through liquid bonding via the use of fluidization bed technology and further defined humidity and temperature ranges necessary to trigger aggregation. Salt (NaCl) was required for the recovery of stable aggregates, acting as a cementation agent and granting aggregate cohesion. A numerical model was used to explain the physics behind particle aggregation mechanisms and further predicted a dependency of aggregation efficiency on liquid binder viscosity.

In this study we proof the effect of viscosity on particle aggregation. HCl and H_2SO_4 solutions were diluted to various concentrations resulting in viscosities between 1 and 2 mPas. Phonolitic and rhyolitic ash samples as well as soda-lime glass beads (serving as analogue material) were fluidized in the ProCell Lab® of Glatt Ingenieurtechnik GmbH and treated with the acids via a bottom-spray technique. Chemically driven interaction between acid liquids and surfaces of the three used materials led to crystal precipitation. Salt crystals (e.g. NaCl) have been confirmed through scanning electron microscopy (SEM) and leachate analysis.

Both volcanic ash samples as well as the glass beads showed a clear dependency of aggregation efficiency on viscosity of the sprayed HCl solution. Spraying H_2SO_4 provoked a collapse of the fluidized bed and no aggregation has been observed. This is accounted by the high hygroscopicity of H_2SO_4. Dissolving $CaCl_2$ (known to be a highly hygroscopic salt) in de-ionized water yielded comparable results without observable aggregation. In case of successful aggregation, concentration of salts has been found to be in the range of published values. We conclude that non-hygroscopic salt crystal precipitation from an aqueous liquid interacting with the glass phase in volcanic ash is a very efficient way to produce cohesive ash aggregates that can survive external forces acting during transport and sedimentation. Our parameterization of ash aggregation processes shall now be implemented in ash plume dispersal modelling for improved and more accurate ash distribution forecasting in the event of explosive volcanic eruptions.

Temporal evolution of the lava dome at Merapi volcano investigated through TerraSAR-X time-series analysis and boundary element modelling

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The eruptive activity of Merapi volcano in Indonesia is characterized by gradual dome growth, continuous degassing and intermittent explosions. The major hazards associated with Merapi volcano are lava dome collapse, pyroclastic flows, and lahars. The last catastrophic dome collapse at Merapi volcano, in 2010, has been followed by a three-year-long period of dome growth and a series of explosions and minor pyroclastic flows. The strongest explosion, which occurred in November 2013, has formed a major fissure splitting almost the entire dome.

We use Radar imagery data, acquired by the German TerraSAR-X satellite, to calculate displacement time-series. The data, which was acquired in SPOT mode in ascending and descending configurations, spans the edifice of Merapi volcano over the period of time from early 2012 to mid-2015. We form interferograms by applying the SBAS method to the data and produce displacement maps and time-series at unprecedented spatial resolution and detail. We apply the principal component analysis (PCA) method to the time-series and remove the periodic components associated with the dry and wet seasons. Combining the time-series from both ascending and descending viewing geometries we estimate the east-west and vertical components of the deformation. The displacement time-series reveal significant uplift and outward horizontal displacements on the steep-sided upper edifice of Merapi volcano.

Using the boundary element method and an analytical solution for triangular dislocations, we are able to simulate the deformation field associated with arbitrary pressurized cavities under realistic topography of a volcano. We use this forward modelling tool in a non-linear optimization scheme and invert the displacement time-series for the unknown parameters of the deformation source. We compare the parameters of the deformation source to the configuration of the major fissure, which splits the dome, as well as to tectonic trends proposed in the region. This study highlights that structural configurations that might dominate eruptive periods of the volcano, are similarly relevant even during apparent periods of quiescence. The results have significant implications for early warning and hazard assessment associated with the Merapi dome collapse. Our analyses form a basis for integrating physical, geological and geodetic observations in a more sophisticated model of the plumbing system and eruptive processes at Merapi volcano.

Is the seismicity swarm at long-dormant Jailolo volcano (Indonesia) a signature of a magmatic unrest?

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Magmatic unrests are challenging to detect when there is no close monitoring network and little knowledge about the volcano. Observable parameters like seismicity, deformation, temperature and gas emission can be reliable indicators of ongoing volcanic unrest caused by magma movements. Jailolo volcano is a Holocene volcano belonging to the Halmahera volcanic arc in the Northern Moluccas Islands, Indonesia. Global databases of volcanic eruptions have no records of its eruptive activity and no geological investigation has been carried out to better assess the Jailolo past eruptive activity. In November 2015 an energetic seismic swarm started around Jailolo region and lasted until late February 2016 with four earthquakes with M>5. The normal fault focal mechanisms of these four events clearly depart from the regional strike-slip tectonic regime. However, no geophysical monitoring network was available around Jailolo volcano during the seismic sequence. We obviated the lack of monitoring last summer by installing a dense multi-parametric monitoring network with 36 seismic stations, 6 GPS and 2 gas monitoring stations around Jailolo volcano.

We revised the focal mechanisms of the larger events and used single station location methods in order to exploit the little information available at the time of the swarm activity. Migration of hypocenters and inversion of the local stress field derived by focal mechanisms analysis may indicate magma migration at shallow depth as the source of the 2015-2016 seismicity swarm. Data from our dense network confirms an ongoing micro-seismic activity underneath Jailolo volcano but there are no indication of new magma intrusion. Our findings seem to indicate of a magmatic unrest occurred at Jailolo volcano and call for a revision of the hazard assessment of the Jailolo volcano.

Effects of the Reynolds number on the starting jet

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The Reynolds number is a dimensionless parameter, comparing inertia and viscous forces. Volcanic eruptions have commonly Reynolds numbers based on vent diameter in the range Re = 106 – 1011. This indicates that viscosity plays a negligible role for the big scale vortices. Since small scale vortices depend on viscosity, the Reynolds number may be inferred from the relative size of vortices. Direct numerical simulations of jets are limited to about Re=104, while this is typically the lower limit for analog experiments at athmospheric pressures. The biggest effect of the Reynolds number in a free jet are the relative size of the Kelvin-Helmholtz vortices and the Kolmogorov length scale to the nozzle diameter. This is indeed related to the radiated acoustics due to turbulence (turbulent mixing noise). We generated free jets with a large range of Reynolds numbers using numerical simulations and experiments and we show the effects on the fluid flow and on the acoustics. With this "know how" we can face the inverse problem of measuring the acoustics of a volcanic eruption and retrieve the Reynolds number.

Geogenic CO_2-degassing and its effects on environment and organisms

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The geogenic CO_2 emitted from magma chambers or seismic structures degasses and influences organismic life on the earth`s surface. It irritates (8-10% CO_2) or kills most animals (15-20%), yet some soil-specific animals (collembolan, nematodes) survive [1]. Plants are not that sensitive and some species transiently tolerate CO_2 concentrations even as high as 100%. Mofette areas are characterized by bare soil, if CO_2 fluxes are extremely high. Surrounding these extreme CO_2-spots, specific vegetation occurs, showing adaption to hypoxic and acidic soils [2,3]. Several distinct plant species are even indicative for mofette fields and hint to the presence of CO_2 gas (mofettophilic plants). Sedges and rushes growing azonally in mofette areas hint to geogenic carbon dioxide emissions. Additionally, a special mofettophobic vegetation type occurs. These plants border degassing areas and cannot grow on soils with a CO_2 concentration higher than 2-3%. Aside from changes in species composition, plants occurring within mofettes reveal differences in habitus and growth. They stay smaller, have less and smaller leaves, and a reduced number of flowers and seeds. Furthermore, most species show a reduced photosynthetic ability, while chlorophyll and nutrient content are lower than in control plants. Soil fungi react to enhanced CO_2 emission with a reduction of species number.

It would be interesting to check whether specific organisms can be used as indicators to forthcoming eruptive events.

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Numerical modelling of magma ascent through the crust for Etnean and Hyblean volcanism

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A fraction of the volcanic activity on Earth occurs intraplate, challenging our models of melting and magma transfer to the Earth's surface. A prominent example is Mt. Etna in Sicily, whose location is not adequately explained by current models, being Mt. Etna offset from the proposed melt source below the Malta Escarpment. Moreover, the earlier Hyblean volcanism, to the South of Etna, remains unexplained. Here we simulate crustal magma pathways in eastern Sicily, accounting for regional tectonics and crustal decompression due to the deepening of the Malta Escarpment. Our models show that both the Hyblean and Etnean volcanism may have been fed by a melt pooling region below the Malta Escarpment and that the migration of volcanism over time may stem from the crustal stress history of Eastern Sicily. Accounting for crustal stresses may explain intraplate volcanism and its wandering.

Evaluating links between deformation, topography and surface temperature at volcanic domes: Results from a multi-sensor study at Volcán de Colima, Mexico

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Active volcanoes often display cyclic behaviour with alternating quiescent and eruptive periods. Continuously monitoring volcanic processes such as deformation, seismicity and degassing, irrespective of their current status, is crucial for understanding the parameters governing the fluid transport within the edifice and the transitions between different regimes. However, mapping the deformation and details of fluid escape at the summit of steep sloped volcanoes and integrating these with other types of data is challenging. Here we present for the first time the near-3D surface deformation field derived from high resolution radar interferometry (InSAR) acquired by the satellite TerraSAR-X at a degassing volcano dome and interpret the results in combination with overflight infrared and topographic data. We find that the results strongly differ depending on the chosen InSAR time series method, which potentially overprints the true physical complexities of small scale, shallow deformation processes. We present a new method for accurate mapping of heterogeneities in the dome deformation, and comparison to the topography and precisely located surface temperature anomalies as derived from overflight infrared images. The identified deformation is dominated by strong but highly localized subsidence of the summit dome. Our results highlight the competing effects of the topography, permeability and shallow volcanic structures controlling the degassing pathways. On small spatial scales compaction sufficiently reduced the dome permeability to redirect the fluid flow. High resolution InSAR monitoring of volcanic domes thus provides valuable data for constraining models of their internal structure, degassing pathways and densification processes.

Dissecting the dynamics of a pyroclastic flow

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The idea to use Doppler radar to measure the dynamics of density currents was first applied in glaciology, where a pulsed Doppler radar participated in a full-scale snow-avalanche experiment in Norway (Schreiber et al., 2001). A similar experiment in volcanology, producing a full-scale pyroclastic density current and to record a multitude of physical parameters with Doppler radar has not been conducted, yet.

Pyroclastic density currents, however, do occur at several volcanoes worldwide and we were extremely lucky to record the dynamics of one pyroclastic flow that occurred on Nov. 21, 2014 at Volcán de Colima, Mexico, with a Doppler radar. The chance that a PDC travels exactly toward the radar is very low and so it is no wonder that the PDC of Nov. 21, 2014 is unique in our data set from March 2014 to July 2015. During this time several PDCs occurred at Volcán de Colima. This is known from seismic data and eye-witness reports. However, none of them appears in the Doppler radar data, although the associated volcanic activity at and above the crater is clearly visible.

The Doppler radar measures tephra velocities and provides an estimate of the amount of material inside the probed volume (radar beam). Because the radar beam is roughly parallel to the volcano's topography (it follows the terrain at 100-200m height), and the radar was recording activity in 600m long distance intervals along the radar beam (i.e. along the topography), we can infer, among other variables, the flow velocity and approximate run-out distance of this pyroclastic flow.

Phreatic & hydrothermal eruption dynamics: Insights from field work and lab experiments

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Steam-driven (phreatic and hydrothermal) eruptions are amongst the most common and most diverse eruption types on earth. Heating and/or decompression leads groundwater or hydrothermal fluids to rapidly flash to steam triggering these types of eruptions. Their diversity arises from the variety of (1) rock types and host rocks that can be involved, (2) ways to seal possible degassing pathways, (3) alteration type and degree of depending on the composition of volcanic gases and the hydrothermal fluids, and finally (4) P-T conditions possible. In addition steam-driven eruptions are very difficult to predict in terms of timing and magnitude bearing important consequences, especially in densely populated regions. Despite of their hazard potential, steam-driven eruptions have so far been neglected by the field of experimental volcanology.

Field studies revealed first insights into the eruption dynamics, for instance based on detailed mapping of the deposits / ballistic strew field of a hydrothermal eruption. The main lithology types identified for an eruption were then used for rapid decompression experiments mimicking hydrothermal explosions under controlled laboratory conditions. Experimental studies of this kind facilitate better constraints on the ejection characteristics of ash as well as ballistics and their associated hazard. Furthermore they shed light on the energy conversion and partitioning during hydrothermal explosions.

The viscous to brittle transition in eruptions of clay suspensions

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The research is motivated by the early 2013 activity of White Island, New Zealand, which was characterized by frequent small phreatic activity through a fine grained mud rich shallow crater lake. Field observations demonstrate that the small eruptions were driven by bubble-burst events. Additionally, during the ongoing eruption, water vigorously evaporated, causing a shift in rheology of the crater lake liquid-solid suspension. Yet, the effect of water content on the eruptive behaviour of clay-bearing liquid suspensions is poorly understood.

Here we investigate the influence of the solid to water ratio of the clay material erupted on the eruption characteristics. Kaolin was used as an analogue for the clay and was mixed with water in different proportions. We conducted experiments with different kaolin/water mixtures held at 120°C, in which they were decompressed from 2-4 bars to ambient conditions in a few milliseconds. During an experimental eruption, the velocity of the ejected material decreased, resulting in shifts in behaviour. Based on our experimental observations we established five different regimes that depend on the particle velocity relative to the gas velocity, and on the kaolin to water ratio of the mixture.

In all experiments and for all kaolin to water ratios, regime 1 is one in which particles are ejected rapidly in an expanding high velocity gas jet. In the liquid-dominated system (low kaolin to water ratios), the jet phase evolves to the ejection of elongate fluidal structures (regime 2) and then to discrete droplets (regime 3) as the ejection velocity wanes. Contrastingly, in the solid-dominated system, the jet phase (regime 1) transitions to a mixed solid-fluid structures (regime 4) and then to individual angular ejecta (regime 5). On the basis of high speed image analysis, we establish a phase diagram separating these regimes based on kaolin/water mixing rations and the ejecta velocities observed. The dominant transition between fluidal and solid-like behaviour is a viscous to brittle transition and occurs between a kaolin mass fraction of 0.48 and 0.65, which is consistent with previous observations of the liquid and plastic rheological limits, respectively. We find that a Stokes' number balances the timescale of flow with the timescale of particle motion opposing flow. We suggest that the transition from regime 1 to regime 2 occurs when the relative velocity between the ejected material and the gas phase increases and the Stokes' number exceeds 1, leading to decoupling and shear-stresses at the ejected fluid interfaces. A capillary number characterizes the transition from elongated liquid structures (regime 2) to individual droplets (regime 3) in the liquid-dominated system when the relative velocity drops to a value at which surface tension can restore the droplets to spherical.

Our results emphasize that the different rheology of muddy material exhibit different characteristic eruption styles and offers a way to classify them.

Wetting and spreading of molten volcanic ash in jet engines

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A major hazard presented by volcanic ash to jet engines is linked to the wetting and spreading of molten ash droplets on engine component surfaces. Here we study the evolution of the wettability and spreading of volcanic ash during rapid heating to 1039-1451°C. We observe that temperature strongly influences the wetting propensity and spreading rate of ash. The data highlight a transition from heterogeneous to homogeneous wetting regime above 1272°C. We infer that both viscosity and microstructural evolution are key controls on the attainment of wetting equilibrium of molten volcanic ash.

Numerical modeling of volcanic ash deposits using Ash3D and HAZMAP - a comparative study

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There are many different but similar approaches to modeling the transport of tephra in the atmosphere caused by volcanic eruptions and its deposition. Apart from the framework (Eulerian or Lagrangian) and the fundamental physical principles (Conservation of mass, energy and momentum) chosen to obtain the governing equation, numerical models also differ in the way they solve these equations. Simplifying assumptions can be made to reduce a three dimensional problem to two dimensions and therefore make it possible to solve the governing equation analytically. Additionally, the computation of settling velocities utterly relies on empirical equations for which numerous algorithms exist. Volcanic ash transport and deposition models (VATDMs) usually deploy a number of different algorithms to choose from. Source terms either take the complex dynamics inside the plume into account or just describe the mass distribution inside the column with height. This study compares the two eulerian, mass conservative models Ash3d and HAZMAP; Ash3d being a fully numerical, three dimensional model and HAZMAP a semi-analytical, two dimensional model. They were used to model the deposits of different scenarios for a Laacher See Volcano (Eifel Volcanic Field, Germany) re-eruption. Simulations have been carried out using the same 1-D wind sounding for HAZMAP and Ash3d as well as a 3-D meteorological data set for Ash3d only. To quantitatively compare the deposits modeled by the three different configurations a normalized distance is calculated for the difference between two different runs respectively.

Phreatic eruptions at Ruapehu: Occurrence statistics and probabilistic hazard forecast

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Phreatic eruptions, although posing a serious threat to people in crater proximity, are often underestimated and have been comparatively understudied. The detailed eruption catalogue for Ruapehu Volcano (New Zealand) provides an exceptional opportunity to study the statistics of recurring phreatic explosions at a crater lake volcano. We performed a statistical analysis on this phreatic eruption database, which suggests that phreatic events at Ruapehu tend to cluster. This is possibly linked to an increased heat flow during periods of a more shallow-seated magma column. The averaged, absolute probability for a phreatic explosion to occur at Ruapehu within the next month is about 10%. However, the frequency of phreatic explosions is significantly higher than the background level in years prior to magmatic episodes.

Combining clast ejection simulations with a Bayesian event tree tool (PyBetVH) we perform a probabilistic assessment of the hazard due to ballistic ejecta in the summit area of Ruapehu, which is frequently visited by hikers. Resulting hazard maps show that the absolute probability for the summit to be affected by ballistics within the next month is up to 6%. The hazard is especially high on the northern lakeshore, where there is a mountain refuge.

Our results contribute to the local hazard assessment as well as the general perception of hazards due to steam-driven explosions.

Imaging and structural analysis of the Geyser field, Iceland, from underwater and drone based photogrammetry

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The Haukadalur thermal area, southwestern Iceland, is composed of a large number of individual thermal springs, geysers and hot pots that are roughly elongated in a north-south direction. The Haukadalur field is located on the eastern slope of a hill, that is structurally delimited by fissures associated with the Western Volcanic Zone. A detailed analysis on the spatial distribution, structural relations and permeability in the Haukadalur thermal area remained to be carried out. By use of high resolution unmanned aerial vehicle (UAV) based optical and radiometric infrared cameras, we are able to identify over 350 distinct thermal spots distributed in distinct areas. Close analysis of their arrangement yields a preferred direction that is found to be consistent with the assumed tectonic trend in the area. Furthermore by using thermal isolated deep underwater cameras we are able to obtain images from the two largest geysers. Geysir, name giving for all geysers in the world, and Strokkur at depths exceeding 20 m. Near to the surface, the conduit of the geysers are near circular, but at a depth the shape changes into a crack-like elongated fissure. In this presentation we discuss the structural relationship of the deeper and shallower parts of these geysers and elaborate on the conditions of geyser and hot pot formations, with general relevance also for other thermal fields elsewhere.

Influence of ambient conditions on NOVAC measurements

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The measurement of magnitude and composition of volcanic gas emissions allow insights in magmatic processes as well as the impact of volcanoes on the atmospheric chemistry. Therefore the Network for Observation of Volcanic and Atmospheric Change(NOVAC) has been installed monitoring the SO2 and "BrO" emissions of 30 volcanoes using scanning UV-spectrometers. The volcanic gas emissions are retrieved from the recorded spectra by applying Di_erential Optical Absorption Spectroscopy (DOAS). While NOVAC records an outstanding amount of gas emission data, the drawback of this automatically operating network is a limited accuracy and precision compared to manual measurements. For accurate retrievals, it is mandatory to _nd a Frauenhofer reference spectrum (FRS) which was recorded under similar conditions (e.g., instrument temperature, atmospheric conditions). Ideally, this FRS is recorded with the same instrument in close time proximity, however this is not always possible. We present an analysis of the impact of di_erent external parameters on the DOAS _t quality when evaluating spectra using a FRS recorded, for example, on a di_erent day. Based on our _ndings, an algorithm is introduced which automatically recommends for each plume spectrum a recorded FRS which optimises the accuracy. We show previous data from Tungurahua volcano in Ecuador and compare them to data created with the FRS with optimised accuracy.

Use of space-borne full-frame cameras for 3D reconstruction of volcanic clouds

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The lack of high-quality information on eruption source parameters constraints the quality of prediction of volcanic clouds dispersion. An important source parameter is the vertical geometry of the cloud, especially the Volcanic Cloud Top Height (VCTH). Because of well-known uncertainties of currently operational methods, photogrammetric methods can be used to improve VCTH estimates. But even photogrammetric methods have difficulties because appropriate instruments are lacking. Here we propose an application of full-frame cameras that are available on the new generation of small satellites. A full-frame camera makes a 2D image in a fraction of a second and it does not require a satellite to move, as a typical push-broom sensor does. Having enough of cameras in the vicinity, it is possible to reconstruct a volcanic cloud in 3D using methodology Structure from Motion (SfM). The presented work is just a pre-study of the forthcoming Telematics Earth Observation Mission (TOM). TOM is a forthcoming German Earth observation (EO) satellite mission that will be launched as a formation of three satellites in 2019. We simulated the observations of TOM using the photos of 2009 Sarychev Peak eruption (see 3D reconstruction: https://skfb.ly/SN8J). The photos have been made by astronauts on the International Space Station, as a part of the NASA program Crew Earth observations. The estimated VCTH values are a bit larger than already published estimates.

Abstracts posters

Correlations of BrO/SO2 and CO2/SO2 degassing

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The composition of volcanic gases gives hints on processes occurring in the Earth's interior, in particular on magma composition and on degassing processes. The study of pairs of gaseous components in volcanic plumes, which have different solubility in melt is an important tool to gain insights into processes related to volcanic plumbing systems. In this context, the BrO/SO_2 ratio is a proxy for the Br/S ratio. The advantage of the BrO/SO_2 pair is that - for both species nearly continuous data acquisition (during daytime) is possible and relatively easy using a remote sensing technique, the Differential Optical Absorption Spectroscopy (DOAS).

Some studies using the remote sensing DOAS method have already shown that the BrO/SO_2 ratio, variations occur between weeks to months before volcanic activity changes (e.g. Bobrowski and Giuffrida, 2012, Lübcke et al., 2013, Wahrnach 2016). It has also been already proposed that the variations of BrO/SO_2 are relatively close correlated to CO_2/SO_2 variations. A possible explanation may be that the heavier halogen bromine could be much less soluble in the magma than sulfur and therefore causing a similar temporal variation like the CO2/SO2 ratio. There might be also other reasons for the above mentioned observation, which once understood might make the BrO/SO2 ratio a decent tracer for CO2/SO2 ratios and therefore eruption forecasts. However, not much data have been presented so far.

We will present CO_2/SO_2 and BrO/SO_2 data acquired simultaneously at Mt Etna volcano (Italy) during various field campaigns as well as close to continuous measurements taken by semi-permanent installed stations. Data presented are from a ten year period, 2006-2016. Beyond this temporal variation we will also show a spatial comparison of BrO/SO2 and CO2/SO2 data taken on number of volcanoes distributed worldwide. The similarities (positive correlations) of the two ratios as well as the differences and their possible causes will be discussed.

Laguna del Maule magma feeding system and construction of a shallow silicic magma reservoir

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Laguna del Maule Volcanic Field is composed by at least 130 basaltic-to-rhyolitic eruptive vents, distributed in 500 km^2, that erupted more than 350 km^3 of lavas and pyroclasts since Pleistocene in the Chilean Andes. It has captivated attention because of its current high accelerated uplift suggested to be formed by a growing shallow rhyolitic magma reservoir beneath the zone of deformation. Studying six Holocene post-glacial andesitic-to-rhyolitic lavas and one dome that partially overlap the ground-inflation zone, we determined the architecture and steps of construction of the magma feeding system that generated its post-glacial effusive volcanism. Further we suggest a possible origin for the rhyolitic magma that generated the ring of rhyolites encircling the lake and remain active causing the uplift.
Mineral chemistry and textures suggest the same provenance of magma for the studied units, as well as complex magmatic history before eruptions. Similar temperatures, pressures, H_2O and fO_2 conditions for amphibole crystallisation in first stages indicate a common ~17 km deep original reservoir that differentiated via in-situ crystallisation. The chemistry of the amphiboles present in all not-rhyolitic units shows trends that indicate a temperature domain on their crystallisation over other thermodynamic parameters such as pressure, water activity or chemistry of co-crystallising phases. All this supports a mush-like reservoir differentiating interstitial magma while crystallisation occurs.
P-T conditions for amphibole crystallisation indicate that only amphiboles from rhyodacites show a non-adiabatic decompression that give rise to a polybaric and polythermal evolution trend from ~450-200 MPa and ~1030-900 °C. In addition, unbuffered fO_2 conditions were calculated for rhyodacite amphibole crystallisation upon cooling from melts with rather constant H_2O contents. We propose that a large part of these rhyodacite amphiboles were formed during a non-adiabatic magma ascent similar to that expected for within-reservoir convective plumes that interact with surrounding cooler and more differentiated melts. Rhyolites appear to be unrelated to the evolution of rhyodacitic magma because they crystallised under buffered and less oxidizing conditions. This along with plagioclase patterns is in agreement with inputs of slightly hotter rhyolitic magma with no significant chemical difference that formed a zone of rhyolitic magma accumulation. This is consistent with the absence of mafic enclaves in the studied rhyolites.
However, eruptions of andesitic-to-rhyodacitic lavas were triggered by injections of different more primitive magma batches into a mush-like reservoir stalled at different depths. Likewise, ascent of magma from a deeper to a shallower level would also be conducted by a more primitive magma recharge as it is suggested by the presence of mafic enclaves and complex zonation and textures of plagioclases in these lavas. Here constant input of hotter and more primitive magmas enables the system to remain active in time. In the case of the rhyolitic units, the silicic reservoir receives constant input of the extracted interstitial rhyolitic magma from a deeper level of the mush-like reservoir.

Numerical modelling of collapsing volcanic edifices

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The flanks of Oceanic Volcanic Edifice's (OVEs) can occasionally become unstable. If that occurs, they can deform in two different modes: either slowly along localization failure zones (slumps) or catastrophically as debris avalanches. Yet the physics of this process is incompletely understood, and the role of factors such as the OVE's strength (viscosity, cohesion, friction angle), dimensions, geometry, and existence of weak layers remain to be addressed.

Here we perform numerical simulations to study the interplay between viscous and plastic deformation on the gravitational collapse of an OVE (diffuse deformation vs. localization of failure along discrete structures). We focus on the contribution of the edifice's strength parameters for the mode of deformation, as well as on the type of basement.

Tests were performed for a large OVE (7.5 km high, 200 km long) and either purely viscous (overall volcano edifice viscosities between 10^{19}-10^{23} Pa.s), or viscoplastic rheology (within a range of cohesion and friction angle values). Results show that (a) for a strong basement (no slip basal boundary condition), the deformation pattern suggests wide/diffuse "listric" deformation within the volcanic edifice, without the development of discrete plastic failure zones; (b) for a weak basement (free slip basal boundary condition), rapid collapse of the edifice through the propagation of plastic failure structures within the edifice occurs.

Tests for a smaller OVE (4.5 km by 30 km) show that failure localization along large-scale listric structures occurs more readily for different combinations of cohesion and friction angles. In these tests, high cohesion values combined with small friction angles lead to focusing of deformation along a narrower band. Tests with a weak layer underlying part of the volcanic edifice base show deformation focused along discrete structures mainly dipping towards the distal sector of the volcano. These tests for a small OVE constitute a promising basis for the study of a currently active slump in the SE flank of Pico Island (Azores, Portugal).

Deposits from the 1877 eruption of Cotopaxi volcano (Ecuador): interaction between PDCs and lahars triggered by glacier melting - Northern drainage

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Cotopaxi volcano is an active composite stratovolcano situated in the densely populated Ecuadorian Andes, 50 km South of the capital Quito. In 2001, a preoccupying seismic crisis occurred, with several subsequent peaks in seismic activity. In summer 2015, weak ash clouds were emitted affecting the population to the west and northwest of the volcano. The activity has decreased to relatively low levels since then, yet a major event could occur in the future.

This study focuses on the deposits of the 1877 eruption, the last one producing pyroclastic density currents (PDCs). As a consequence of the summital ice cap, eruption can trigger widespread and dangerous lahars. Here, we document the deposits of lahars and PDCs and their interactions on one drainage of the northern flank of the volcano.

Using photogrammetry from drone images (processing with Pix4D), precise ortho-photos (pixel size < 5 cm) and Digital Elevation Models (DEMs) were produced. We also compare maximum thickness estimates of PDC lobes and levees between eye-estimates, GPS measures, laser distance-meter and the high-resolution DEM (differences in the order of 5-20 %).

Surface morphologies can be classified in 6 groups: 1) Lobes with abundant cauliflower-bombs; 2) Cauliflower-bomb-rich levees; 3) flat, lithic rich and cauliflower-poor fans; 4) flat sheets including large amounts of lithic blocks covering topography; 5) thin, lithic-rich levees; 6) flat, cauliflower-bomb-rich lobes on subhorizontal slopes with aureoles of irregular, flat protuberances of small lithic blocks.

Most lithic-rich features seem to result from lahars, whereas cauliflower-rich lobes and levees are emplaced by hot PDCs. Of particular interest are the flat, cauliflower-rich lobes that appear to be PDCs that flowed within -and sinked into- the contemporeanous, still uncompacted and water-rich lahar deposits in local depressions.

Stratigraphically, it seems that on the northern flank, the basal deposit and first flows were PDC-triggered lahars. They were followed by a series of at least four PDC lobe clusters, and several lahar generations. A refined deposit map is created, which narrows the width of PDC deposits. Further fieldwork including all flanks is needed to construct a full map, increase our understanding of the eruption chronology and of glacier-eruption interactions in general.

The Anahim Volcanic Belt, British Columbia - Hot-spot or not-spot?

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Alkaline magmatism occured in the Anahim Volcanic Belt (AVB) of western British Columbia (Canada) from the late Miocene to the Holocene. Manifestations include dyke swarms, plutons, complex shield volcanoes and cinder cone fields, with erupted magmas ranging from basalts to trachytes and rhyolites (and their peralkaline differentiates). A linear decrease in rock ages from west (~15 Ma) to east (~7,200 BP) along the belt has been proposed to result from a small mantle plume underlying the area, creating a hot-spot track on the overriding North American plate that parallels the better-known Yellowstone hot-spot track in the northwestern United States. Geochemical data remain ambiguous, however; while an influence from the nearby Cascadia subduction can be ruled out, the existing data do allow for both a mantle plume as well as continental rifting as possible volcanotectonic controls. Isotope ratios and trace element/REE patterns of mafic AVB lavas strongly suggest a mantle source, and also allow to differentiate AVB lavas from co-extensive and partially coeval plateau basalts of the Chilcotin group. While other volcanotectonic controls may have contributed to and facilitated the formation and ascent of melts of the individual volcanic centres comprising the AVB, the hot-spot theory provides the best explanation for the linear decrease of rock ages along the belt.

Determine volcanic SO_2 plume heights from satellite observations on a global scale using meteorological wind fields

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Satellite observations nowadays provide the global monitoring of volcanic plumes via sulphur dioxide (SO_2) that is injected into the Earth's atmosphere. In turn, SO_2 may lead to the formation of sulphate aerosols that can influence climate via direct and indirect radiative effects. The quantitative retrieval of SO_2 requires an accurate plume height estimate in order to constrain total amounts for such events.

However, especially for volcanic eruptions the vertical SO_2 profile is typically unknown because of the initial conditions (e.g. individual explosions over an extended time period may lead to different gas layer altitudes). In recent years, satellite observations helped to improve global SO_2 estimates, but still large uncertainties exist. Passive satellite remote sensing instruments in the UV/vis spectral range for example offer the opportunity to observe the location of a plume in two dimensions, but information about the corresponding height is limited. To gain further information about these plume profiles is not only interesting for the quantitative interpretation of satellite observations, but also in itself (e.g. to assess the radiative effect of volcanic plumes).

Here, we present first results for a newly developed and systematic approach using the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) in combination with data for selected volcanic SO_2 plumes originating from different volcanoes. The main plume information retrieved by the satellite (i.e. plume location and observation time) are used as initial input parameters in order to estimate the plume's profile at the time of the measurements. The resulting trajectories can be used to constrain the eruption time and height. First comparisons show that retrieved results are in good agreement with direct local observations and reports. While the algorithm has been so far only applied to data from the second generation Global Ozone Monitoring Instrument (GOME-2), it may be generally applied to data from other satellite instruments like OMI or the upcoming TROPOMI (Sentinel-5 precursor) instrument.

Lightning-induced melting of volcanic ash: an experimental study

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Lightning discharge in ash plumes is a common but to-date still poorly studied phenomenon related to explosive volcanic eruptions.

In 2015, Genareau et al. found evidence of glass spherules and glass aggregates in ash deposits of two explosive eruptions (Eyjafjallajökull, 2010 & Mt. Redoubt, 2009) where volcanic lightning was highly observed. They hypothesized that the extreme heat released during the lightning discharge (potentially > 30,000 K) leads to the transformation of volcanic ash particles into glass spherules and linked them to short-term melting processes similar to fulgurite forming processes.

In order to systematically investigate the potential impact of lightning on air-suspended ash, a new experimental setup was designed. The Volcanic Lightning Simulator (VLS) is based on a 400 Amp arc welder which generates an electric arc between two opposing electrodes. Ashsized sample material is then blown into the established lightning arc, and a certain proportion of the injected silicate glasses and/or minerals is melted due to the high temperatures in and around the plasma channel.

In a first set of experiments natural ash samples from Sakurajima volcano (Japan), subdivided into distinct grain fractions ranging from 36 µm to 300 µm, were used to qualitatively examine morphological changes of the particles. The experiments successfully yield spherule and aggregate textures similar to those encountered by Genareau et al. (2015).

In further experiments, chemically homogenised phonolitic glass, originating the Laacher see Tephra (Eifel, Germany), was subjected to the electric arc. Electron microprobe analyses display vaporisation of volatile phases (e.g. Cl, SO3) whereas in reverse a relative enrichment of stabile elements (e.g. SiO2, CaO) proceeds.

Imaging trace gases in volcanic plumes with Fabry Perot Interferometers

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Within the last decades, progress in remote sensing of atmospheric trace gases revealed many important insights into physical and chemical processes in volcanic plumes. In particular, their evolution could be studied in more detail than by traditional in-situ techniques.

A major limitation of standard techniques for volcanic trace gas remote sensing (e.g. Differential Optical Absorption Spectroscopy, DOAS) is the constraint of the measurement to a single viewing direction since they use dispersive spectroscopy with a high spectral resolution. Imaging DOAS-type approaches can overcome this limitation, but become very time consuming (of the order of minutes to record a single image) and often cannot match the timescales of the processes of interest for volcanic gas measurements (occurring at the order of seconds).

Spatially resolved imaging observations with high time resolution for volcanic sulfur dioxide (SO_2) emissions became possible with the introduction of the SO_2-Camera. Reducing the spectral resolution to two spectral channels (using interference filters) that are matched to the SO_2 absorption spectrum, the SO_2-Camera is able to record full frame SO_2 slant column density distributions at a temporal resolution on the order of < 1s. This for instance allows for studying variations in SO_2 fluxes on very short time scales and applying them in magma dynamics models. However, the currently employed SO_2-Camera technique is limited to SO_2 detection and, due to its coarse spectral resolution, has a limited spectral selectivity. This limits its application to very specific, infrequently found measurement conditions.

Here we present a new approach, based on matching the transmission profile of Fabry Perot Interferometers (FPIs) to periodic spectral absorption features of trace gases. The FPI's transmission spectrum is chosen to achieve a high correlation with the spectral absorption of the trace gas, allowing a high selectivity and sensitivity with still using only a few spectral channels. This would not only improve SO_2 imaging, but also allow for the application of the technique to further gases of interest in volcanology (and other areas of atmospheric research).

Imaging halogen species would be particularly interesting for volcanic trace gas studies. Bromine monoxide (BrO) and chlorine dioxide (OClO) both yield absorption features that allow their detection with the FPI correlation technique. From BrO and OClO data, ClO levels in the plume could be calculated.

We present an outline of applications of the FPI technique to imaging a series of trace gases in volcanic plumes. Sample calculations on the sensitivity and selectivity of the technique, first proof of concept studies and proposals for technical implementations are presented.

DLR's FireBird mission monitoring the 2014/15 Holuhraun fissure eruption

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This study focuses on the analysis of imagery of the first satellite of DLR's FireBird mission, the Technology Experiment Carrier TET-1, for monitoring of volcanic eruptions. As study site the Icelandic Holuhraun fissure eruption, which started in late August 2014, is selected.

With its mid-wave infrared channel, TET is ideally suited for the detection of high temperature events such as lava flows. In addition, the combination of the mid and long-wave infrared channel of TET enables the estimation of the kinematic temperature and the area of high temperature events.

First, the hotspot detection rate of TET is analyzed against the one of the Moderate Resolution Imaging Spectrometer (MODIS). Second, the area of the lava field detected by TET is compared with high spatial resolution optical (Landsat) and synthetic aperture radar (SAR) imagery (TerraSAR-X and Sentinel-1). Third, the lava temperature estimated from the TET datasets is compared with temperature values derived from Landsat-8 nighttime imagery. Finally, a comparison of the fire radiative power (FRP) derived from TET and from MODIS data is performed, showing the superiority of TET regarding the detectable maximum temperatures.

Can spectral ratios help us constraining the parameters of magma reservoirs?

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In this study we apply the spectral ratio technique to a volcano with known large-scale magmatic reservoirs in the crust, in order to search for spectral anomalies at stations above the magmatic reservoirs. We analyze spectral ratios in the seismograms from regional and teleseismic earthquakes as well as from ambient seismic vibrations. A technique is developed to automatize the processing and to retrieve statistical measures, uncertainties and to assess the robustness of possible spectral peaks.

The application to the Lazufre volcanic complex in the Central Chile in South America clearly retrieves robust anomalies of peak spectral ratios of vertical components at stations above the center of the magmatic reservoir, assumed in about 9 km depth. The size of the elliptical anomaly is exceeding 40 km in diameter in its long axis and its strength correlates with the distance to the center of the magmatic reservoir. We interpret the spectral ratio anomaly as either be related to a resonance of the magmatic reservoir itself, or be related to the reverberation of waves between the reservoir and the surface.

The application to Etna volcano in Sicily, Italy, indicates two broad peaks of spectral ratios. The anomaly is not as pronounced as for the Lazufre volcanic complex in Chile, and the peak frequencies at Etna volcano are higher. This indicates either a smaller size of the reservoir or an impedance contrast at more shallow depth. The correlation of peak strength with the distance from the volcanic centre is not clear.

Poroelastic aquifer responses to crustal strain and their use in volcano monitoring

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Due to their poroelastic nature, aquifers respond to crustal strain with changes in pore pressure and groundwater flow patterns. Well water level changes associated with volcanic unrest can therefore be interpreted as a result of hydrological responses to crustal deformation, and so could provide important constraints on the subsurface processes causing this strain.

We developed numerical models that simulate crustal deformation due to different volcanic strain sources and the dynamic aquifer response. The models are applied to two case studies. The first concludes that pre-eruptive well level changes at Usu volcano (Japan) in 2000 were induced by the pressurization of both the magma chamber and a large, shallow hydrothermal system. The second case study simulates water level changes in the Belham valley on Montserrat, 2004-2006. In this case, the aquifer responds to both gradual and rapid transient strain sources associated with the eruption of Soufrière Hills Volcano (Montserrat): repeated lahar sedimentation leads to an increasing sediment load and thereby rising aquifer pressures, while a dome collapse induced a short-term water level drop.

The presented models are a significantly improved tool for the interpretation of well level signals in volcanic areas that can provide valuable constraints for volcanic strain sources and thereby complement other monitoring systems.

LED based Quartz Enhanced Photoacoustic Spectroscopy: A cost effective Solution for in-situ Detection of Volcanic Sulfur Dioxide?

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Volcanic gas measurements, particularly of sulfur dioxide (SO_2) play an essential role for the examination of volcanic degassing processes. In the field application, in-situ instruments are frequently affected by harsh environmental conditions and the high corrosivity of volcanic gas species, making such measurements laborious, expensive, and frequently unreliable.

Sensors for volcanic SO_2 based on quartz enhanced photoacoustic spectroscopy (QEPAS) use the fact, that SO_2 is the dominant absorber of UV-radiation around 300 nm wavelength. Thus the amount of radiation absorbed by the sample gas depends only on its SO_2 content. Since the absorbed radiation is converted to heat, illumination by a pulsed light source causes the temperature and thus pressure of the sample gas to oscillate and to emit an acoustic wave. A small resonant 32.8 kHz quartz tuning fork (as it is used in any quartz clock) serves as a microphone to detect the signal intensity and to determine the SO_2 concentration. Typically, large and expensive laser systems are used as light sources.

We are developing a cost effective, mobile, and potentially ultra-compact QEPAS instrument using commercially available UV light emitting diodes, which we expect to be sufficient to reliably detect typical volcanic plume SO_2 abundances at useful detection limits (<1 ppm).

Ground-based and airborne measurements of volcanic gas emissions at White Island in New Zealand

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Quantitative understanding of volcanic gas emissions has twofold relevance for nature and society: 1) Variation in gas emission and/or in emitted gas ratios are tracers of the dynamic processes in the volcano interior indicating its activity. 2) Volcanic degassing plays an important role for the Earth's climate, for local sometimes even regional air quality and atmospheric chemistry.

In autumn 2015, a campaign to White Island Volcano in New Zealand was organized to perform ground-based as well as airborne in-situ and remote sensing gas measurements of sulfur dioxide (SO_2), carbon dioxide (CO_2) and bromine monoxide (BrO). For all three gases the ratios and total emission rates were determined in different plume types and ages. An overview over the data will be presented with focus on the two most notable outcomes:

1) The first determination of the BrO/SO_2 ratio in the White Island plume and a minimum estimate of the volcano's bromine emission rate; two of many parameters, which are important to assess the impact of volcanic degassing on the atmospheric halogen chemistry.

2) In-situ SO_2 data was very successfully recorded with the PITSA, a prototype of a portable and cost-effective optical instrument. It is based on the principle of non-dispersive UV absorption spectroscopy and features different advantages over the customary electrochemical sensors, including a sub second response time, negligible cross sensitivities to other gases, and inherent calibration. The campaign data demonstrates the capabilities and limitations of the PITSA and shows, that it can be well applied as substitute for conventional electrochemical systems.

The permeability of magmas

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Magmas contain pore spaces that are thought to become pressurized in shallow volcanic interiors, leading to explosive eruptive activity. Often these pore spaces are interconnected such that the mass of gas contained within them can escape. The gas escape timescale is proportional to the magma gas permeability, which is therefore a first order constraint required to understand the propensity of magma to fragment explosively. We provide such constraint using a wide range of techniques to measure and to calculate magma permeability. First, we divide porous magmas into two geometrical end members; (1) vesicular magma in which the pore space is envisaged as overlapping bubbles, and (2) granular magma in which the pores are envisaged as the space between overlapping particles. In both cases we derive models for high and low porosity regimes for first principles. Next, we create purely numerical samples of randomly overlapping spheres to test whether these theoretical models well describe idealized systems of overlapping "bubbles" and overlapping "particles". Once we've established the efficacy of the theoretical underpinning of magma permeability problems, we measure the gas and water permeability of a range of idealized laboratory samples in both the bubble and the particle geometry. These real data agree with the numerical data and support the use of the theoretical models. By way of a discussion point, we finally propose a Darcy outgassing time for magma, which can be used with constraints of permeability to compare with outgassing signals at active volcanoes or with inter-eruptive interval lengths that are thought to be the times in which volcanoes release their gas overpressure. Such Darcy timescales can be coupled with dynamic models for the evolution of magma porosity to show for how long outgassing channels can be open in a wide range of scenarios.

Investigation of BrO in volcanic plumes: Comparing satellite data from OMI and GOME-2

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It has been repeatedly shown in the past by measurements from the ground and from space that volcanic plumes contain widely varying amounts of bromine monoxide (BrO). The relative amount of BrO in a volcanic plume, i. e. with respect to sulphur dioxide (SO_2), is mainly affected by degassing composition as well as chemical processes, but the reasons for the variation is still not fully understood. Our study aims at obtaining a better understanding of bromine emissions from volcanoes.

The high spatial resolution of current satellite instruments such as OMI (13x24 km^2) and GOME-2 (40x80 km^2), and particularly that of future instruments like TROPOMI (3.5x7 km^2) allows to resolve the volcanic plume of eruptive events and makes. The combination of the high spatial resolution and the global coverage of satellite instruments make it possible to study the spatial variability of trace gases in a large number of volcanic plumes from a large number of volcanoes.

In this study, we investigate the BrO and SO_2 distribution as well as the BrO/ SO_2 ratio within volcanic plumes observed by OMI since 2007. We apply a plume detection algorithm which uses the retrieved SO_2 column for plume identification.

These data obtained from OMI measurements are compared to plumes identified from GOME-2 data. Differences in the number of identified plumes and the degree of agreement regarding the retrieved spatial distribution of BrO and SO_2, as well as the calculated BrO/ SO_2 ratio between plumes observed by both instruments, are discussed. Differences are mainly attributed to the differences between the two instruments with respect to spatial resolution and overpass time (GOME-2 at 9:30, OMI at 13:30 local time).

Mineralogy, chemistry and intensity of hydrothermally altered conduit rocks and their thermal expansion between 150 and 800°C (Mt Unzen, Shimabara, Japan)

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Investigations were carried out on hydrothermally altered coherent dacitic dykes samples from (USDP-4) drill core at Mt Unzen stratovolcano (Shimabara/Japan). Hydrothermal alteration was studied using optical hot-cathodoluminescence, XRF, XRD, EMPA, C-O-isotope and SEM. These investigations led to insights concerning chemistry, mineralogy, and intensity of alteration as well as the origin of carbonate-precipitating fluids as well as textural characteristics of the occurring replacement features in the magma conduit zone. Additionally, we performed thermal expansion experiments using a NETZSCH® DIL 402C.

The occurrence of the main secondary phases such as chlorite, pyrite, carbonates, and R1 (Reichweite parameter) illite-smectite indicate a weak to moderate propylitic to phyllic hydrothermal alteration. The dacitic samples of the dykes show different hydrothermal alteration features: (i) carbonate pseudomorphs after hornblende as well as core and zonal textures due to replacement of plagioclase by R1 illite-smectite as well as kaolinite group minerals, (ii) colloform banded fracture fillings and fillings in dissolution vugs, and (iii) chlorite, kaolinite group minerals as well as R1 illite-smectite in the groundmass. Late chlorite veins crosscut precipitates of R1 illite-smectite as well as kaolinite group minerals.

Carbonates in fractures and in pseudomorphs after hornblende comprise iron-rich dolomite solid solutions ("ankerite") and calcite. These carbonates show different luminescence (bright orange, reddish orange, weak orange and no luminescence) controlled by Mn/Fe ratios in which Mn acts as an activating element and Fe as a quenching element. Isotopic values of $\delta^{13}C_{VPDB}$ range from -4.59 to -6.17 (± 0.6‰) and $\delta^{18}O_{VSMOW}$ values from 6.05 to 10.18 (± 0.5‰) indicate a geothermal origin for the carbonate formation. The chlorite-carbonate-pyrite index (CCPI) and the Ishikawa alteration index (AI), applied to the investigated samples show significant differences (CCPI=52.7–57.8; AI=36.1–40.6) indicating their different degree of alteration. Weakest conduit alteration, which was obtained in samples C16-1-5 and C13-2-5, correlates with the alteration degree of the pristine dome rocks. Highest CCPI value was determined for sample C14-1-5 and the highest AI value was determined for sample C15-2-6. The degrees of alteration do not indicate highest alteration of the samples C8-1-2 and C8-2-1 from the older dykes.

The linear thermal expansion coefficient α_L of the dome material is ~5 $*$ 10^{-6} K^{-1} between 150°–800°C and only shows increasing values of up to ~25 $*$ 10^{-6} K^{-1} around the alpha-beta-quartz-transition (573°C). In contrast, α_L of the hydrothermal altered conduit samples starts to increase around 180° and reaches ~15 $*$ 10^{-6} K^{-1} at ~400°C. This effect is controlled by the water contents of clay minerals of the kaolinite group and R1 illite-smectite. Furthermore, conduit samples show significant increases of α_L between 500 and 650°C of up to ~130 $*$ 10^{-6} K^{-1}, which is generated by the breakdown of chlorite, iron-rich dolomite solid solutions, calcite, and pyrite. High linear thermal expansion coefficients of the hydrothermally altered conduit rocks can induce thermal stress acting on the surrounding host rock and therefore promotes cracks, which may lead to edifice instability.