VMSG

V-VMSG
Annual General Meeting

6-8 January 2021

Abstract book

CODE OF CONDUCT FOR MEETINGS AND EVENTS

The Volcanic & Magmatic Studies Group is a Special Interest Group joint between the Geological Society of London and Mineralogical Society. These learned societies are signatories to the Science Council Declaration on Diversity, Equality and Inclusion. Through their members, the Geological Society of London and Mineralogical Society have a duty in the public interest to provide a safe, productive and welcoming environment for all participants and attendees of meetings, workshops, and events regardless of gender, sexual orientation, gender identity, race, ethnicity, religion, disability, physical appearance, or career level. The Volcanic & Magmatic Studies Group has worked with the Geological Society of London and Mineralogical Society on Code of Conduct policies. These are available from https://www.geolsoc.org.uk/codeofconduct and https://www.minersoc.org/code-of-conduct.html.

The Code of Conduct outlined below specifically applies to all participants in Volcanic & Magmatic Studies Group activities, including ancillary events and social gatherings. The Volcanic & Magmatic Studies Group expects all participants -- including, but is not limited to, attendees, speakers, volunteers, exhibitors, staff, service providers and representatives to outside bodies -- to uphold the principles of this Code of Conduct.

1. Behaviour The Volcanic & Magmatic Studies Group aims to provide a constructive, supportive and professionally stimulating environment for all its members. Participants of VMSG meetings and events are expected to behave in a professional manner at all times.

2. Unacceptable Behaviour Harassment and/or sexist, racist, or exclusionary comments or jokes are not appropriate and will not be tolerated. Harassment includes sustained disruption of talks or other events, inappropriate physical contact, sexual attention or innuendo, deliberate intimidation, stalking, and photography or recording of an individual without consent. It also includes offensive comments related to gender, sexual orientation, disability, physical appearance, body size, race or religion.

3. Breach of the Code of Conduct Anyone requested to stop unacceptable behaviour is expected to immediately cease and desist. If an incident of prohibited conduct occurs either within or outside the premises during a meeting or event, then the aggrieved person or witness to the prohibited conduct is encouraged to report it promptly to a member of the Volcanic & Magmatic Studies Group Committee or meeting organizing committee either in person or via email.

Once the Volcanic & Magmatic Studies Group is notified, the committee member will discuss the details first with the individual filing the complaint, then any witnesses who have been identified, and then the alleged offender before determining an appropriate course of action. Actions in response to breaching this Code of Conduct will range from a verbal warning to immediate removal from the meeting or activity without refund of registration fee. The Volcanic & Magmatic Studies Group also reserve the right to prohibit attendance at any future meeting or other societysponsored event.

Confidentiality will be maintained to the extent that it does not compromise the rights of others.

Table of contents

Joining instructions

Once joined via the Zoom link you have received, please ensure that your microphone and video are off. You can do this through the microphone and video icons on the lower left of your screen.

To rename yourself, you can click on the three dots on your picture, or open the participants list and click on "more". Please include your first and last name, and a short affiliation.

If you would like to ask a question, you can use the raise hand feature at the bottom of the participants list menu.

Keynote: The rheology of magma and lava – upwards and onwards!

Ed Llewellin (Durham University)*

*ed.llewellin@durham.ac.uk

Magma is one of the most physically complex materials in the natural world. As a parent silicate melt moves through the magmatic and volcanic system, it decomposes into a multiphase mixture of crystals, bubbles, and liquid. The proportions and properties of the phases undergo dramatic changes in response to changes in pressure, temperature, strain, and with the passage of time. Consequently, the rheology of magma and lava is both complex and dynamic. Understanding and quantifying this rheology is, nonetheless, essential for all aspects of physical volcanology, since rheology dictates the response of magma and lava to the stresses that drive it through the crust and over the ground.

Decades of research into multiphase rheology – much of it driven by the volcanological community – has brought us to the point where rheological models that are general, theoretically-grounded, and experimentally-validated are available only for two-phase systems of low to intermediate suspended fraction. Whilst considerable progress has been made towards understanding and characterising more complex systems, there is much work left to do.

In this contribution, I will explore recent and ongoing work at the frontier of the discipline, addressing three-phase systems, highly-concentrated systems, and systems that are out of equilibrium. I will consider the role that emerging experimental and numerical technologies are playing in pushing the frontier. Finally, I will offer a personal view of the disciplinary priorities for the new decade, as we work towards a more complete and general understanding of the rheology of magma in its natural complexity.

Keynote on reservoir and emplacement processes: 3D seismic Imaging of the buried Erlend Shield Volcano

Faye Walker (University of Aberdeen)

Understanding the nature and growth of magmatic plumbing systems is fundamental to the study of igneous geology. However, although extensive study of modern shield volcanoes (e.g. Hawaii and Iceland) has provided detailed understanding of the surface processes associated with basaltic volcanism, our knowledge of the internal 3D structure of volcanic edifices and their plumbing systems is comparatively poor. We cannot observe such systems directly, and have generally relied on outcrops, seismic tomography and theoretical modelling, which are all useful but cannot provide a complete and detailed view. Here we present the first high-resolution 3D reconstruction of a subsurface shield volcano and its magmatic plumbing system in the Faroe-Shetland Basin, revealed by careful mapping using new high-quality 3D seismic data. The plumbing system comprises a large laccolithic complex which appears to have fed hundreds of radially-distributed sills, overlain by a conduit structure containing numerous stacked sills. The images give hitherto unprecedented 3D access to the sub-volcanic plumbing system of a shield volcano.

Keynote on volcanic histories: The utility of plutonic xenoliths and lavas for imaging magmatic systems

Michal Camejo-Harry (The University of the West Indies), Elena Melekhova (University of Bristol), Jon Blundy (University of Oxford), Richard Robertson (The University of the West Indies), Thomas Christopher(The University of the West Indies, Montserrat Volcano Observatory)

Volcano behaviour is ultimately a surface expression of the dynamics of magmatic systems in the underlying crust. It is now well recognised that most volcano plumbing systems are vertically extensive consisting of crystalline mushes separated by transiently interconnected accumulations of melt. Although technological advancements have made the imaging of sub-volcanic systems possible through geophysical surveys, the acquisition of such measurements is not always readily available. Petrological and geochemical observations of volcanic deposits provide an alternate and complementary means of retrospectively imaging the configuration of magmatic systems and their internal conditions. Plutonic xenoliths sample the crystalline roots of magmatic systems while lavas derive from shallow eruptible magma storage reservoirs.

We draw insights from a case study of albeit inactive volcanic island of Bequia, Lesser Antilles, an arc distinguished by unusually abundant plutonic xenoliths and diverse lava compositions. Petrographical and geochemical analyses of these rocks show widespread disequilibrium textures and broad mineral compositional ranges. Bulk compositions of xenoliths deviate from the liquid line of descent of lavas supporting a cumulate origin with varying degrees of reactive infiltration by evolved hydrous melts, preserved as melt inclusions in xenolith crystals. Volatile saturation pressures in melt inclusions indicate xenolith crystallization over a 162–571 MPa pressure range under conditions of high dissolved water contents (up to 8 wt% H2O), consistent with other thermobarometric estimates. Phase assemblages of xenoliths are consistent with published experimental data on volatile-saturated low-magnesium and high-alumina basalts and basaltic andesite from the Lesser Antilles at pressures of 200–1000 MPa, temperatures of 950–1050 °C and dissolved H2O contents of 4–7 wt%. Once extracted from mid-crustal mushes, residual melts ascend to higher levels and undergo H2O-saturated crystallization in shallow, pre-eruptive reservoirs to form phenocrysts and glomerocrysts. A complex, vertically extensive (6 to at least 21 km depth) magmatic system is inferred beneath Bequia. During eruption, ascending magmas incorporate xenoliths (mush fragments), glomerocrysts and phenocrysts from different parts of the trans-crustal magmatic system with different crystallisation histories. Studying both plutonic and extrusive samples helps to distinguish these varied crystal cargos for reconstructing the histories of volcanic systems.

VMSG

Keynote on magmatic processing in sub-volcanic systems: Beyond the crystal rim: using non-isothermal diffusion chronostratigraphy to reconstruct magma dynamics.

C.M. Petrone (The Natural History Museum)*, M. Mangler (The Natural History Museum, Durham University), S. Tommasini (Università di Firenze)

*c.petrone@nhm.ac.uk

Time-related information of pre-eruptive magmatic processes is locked in the chemical profile of compositionally zoned minerals and can be retrieved by means of elemental diffusion chronometry. However, only the timescale of the outermost rim is commonly resolved, limiting our knowledge of timescales to those directly preceding the eruption. A major obstacle is the need to accurately constrain temperatures at which diffusion occurred. This is particular difficult for multiple zoned minerals where the different compositional boundaries indicate multiple physicochemical changes of melt environments during the lifetime of a crystal.

Fe-Mg interdiffusion in pyroxenes from Stromboli and Popocatépetl are used to reconstruct the time-dependent elemental diffusion chronostratigraphies of single crystals and to discuss their implication on magma dynamics. Chronostratigraphies are reconstructed taking into account the non-isothermal nature of pre-eruptive processes via the Non-Isothermal Diffusion Incremental Step Model (NIDIS) (Petrone et al., 2016, Nat. Comm). This approach allows deconstructing the main core-rim diffusion profiles of multi-zoned crystals into different isothermal steps.

Elemental diffusion chronostratigraphy can be fully resolved for crystals that have spent their lifetime in hot storage. Under this condition, crystals will be kept at the temperature(s) of the eruptible magma(s), and diffusion timescales approximate the storage of the crystal in question in different melt environments. We argue that hot storage conditions are typical of open-conduit systems in steady-state and are driven by the regular supply of fresh hot magmas determining the constant presence of eruptible magma.

Elemental diffusion chronostratigraphy is an extremely powerful tool for obtaining time-related temporal information on the dynamics and histories of volcanic plumbing systems, providing in-depth knowledge of the magmatic system far beyond late-stage pre-eruptive processes. Combined with monitoring data and other petrological, geological, and geophysical constraints at active volcanoes, they can greatly enhance our capability to inform volcanic hazard assessments.

Keynote on media, communication and society: Lessons from the Volcanic Community to Develop Effective Alert Level Systems (ALS) for Pandemics

Dr Carina J. Fearnley

A pandemic was expected. Yet, as Mami Mizutori, Head of the UNISDR, states, ‘past warnings of a pandemic were often ignored, despite mounting evidence’. Despite urging from the UN there is no standardised pandemic alert system for viral threats that cut across borders in our increasingly interconnected world. Numerous nations have devised COVID-19 alert level systems (ALS) to protect local populations during the shift from full lockdown precaution to normality. While ALS are commonly thought of as simple ‘triggers’, to be effective they must be embedded in an extensive system of observation and communication that integrates different expert cohorts, thresholds or tipping points, communication mediums and iconography, for the provision of timely warnings to both state apparatus’ and diverse publics. ALS are used globally as a shorthand system to convey concise and clear information to a wide range of stakeholders and often follow a traffic light colour structure, or numerical order (as commonly used in military contexts), and are standardised on national or international levels. Whilst numerous ALS exist for a range of purposes it is not yet clear which ALS have been most effective for a pandemic but there have been some success stories seen in New Zealand, South Africa, and South Korea.

Yet, ALS for other natural hazards such as volcanoes are well established, providing a comprehensive series of best practice ‘lessons’ for the development of much-needed Pandemic ALS. Volcanoes have the most diverse range of ALS of any hazard, they are also one of the most frequently used ALS, and many have been reviewed and improved to enhance their effectiveness over recent decades. Clearly pandemics unfold differently to volcanic crises, with different monitoring systems in place that deal with complex sociomedical data and emerging contexts, and differing behaviours expected or required of individuals. However, these crises involve many of the same governmental organisations, industries, and deal with the same publics as the now well established ALS rely on and target. This talk provides an overview on how the lessons learned from the development and implementation of Volcano ALS can be adapted for pandemic situations by focusing on three key aspects:

1. Translation and multi-way communication is required to ensure that all involved in designing and assigning alerts understand what information is credible and relevant.

2. The decision to change an alert level is challenging as often scientists encounter difficulties in interpreting scientific data to establish what a hazard is doing, and that the decision to move between alert levels is based upon a complex negotiation of perceived political, economic, and environmental risks rather than the scientific data.

3. The standardisation of ALS is vital to convey information to a wide range of stakeholders, but they need to be designed to accommodate local contingency, while also adhering to national/international policy.

Keynote: From applicable to applied: an exploration of recent applied volcanology papers and the challenges and opportunities involved in converting research into practice

Ailsa K. Naismith (University of Bristol), I. Matthew Watson(University of Bristol), Rüdiger Escobar-Wolf(Michigan Technological University), Gustavo Chigna(Instituto Nacional de Sismología, Vulcanología, Meteorología, e Hidrología (INSIVUMEH)), Helen Murray (Thomas), Diego Coppola(Università degli studi di Torino), Carla Chun(Servicio Sismológico de Guatemala)

A major challenge of volcanological research is how to embed investigative results within policy and practice. Results from academic studies are often assessed in terms of their potential for practical impact. In particular, results are judged on how they can aid existing institutional systems in their efforts to minimize volcanic risk – efforts that include scientific monitoring of active volcanic systems and disaster risk reduction (DRR). However, the pathway from academic to practical is not always clear. A single volcano may produce events over many timescales, from rapidly-accelerating eruptions generating hazards that devastate in seconds, to processes occurring over many millions of years. Working across a variety of timescales is familiar within the discipline of volcanology, but is not necessarily familiar to institutions wanting practical results. This is just one example of the challenges in converting theory to practice.

In this talk we present our paper, Eruption frequency patterns through time for the current (1999 – 2018) activity cycle at Volcán de Fuego derived through remote sensing data, and review its potential impact as well as the challenges and opportunities involved in applying its methods and findings to the environment of study. We elaborate on this theme by exploring citing papers to identify several key areas in which applied volcanology papers can have a practical impact. These include probabilistic assessment of volcanic hazards, real-time forecasting of explosive eruptions, and understanding magmatic processes over various timescales. These papers describe specific methods within volcanological research that are likely to have practical impact, including triangulation of multiple datasets, automated detection of precursory activity, identification of sets of analogue volcanoes, and novel satellite remote sensing methods. Our overview allows us to ask further questions about translating research into practice for volcanoes worldwide. What are the specific challenges that must be overcome in order to apply volcanological research "on the ground"? How much of the responsibility for this conversion lies with us as research volcanologists? Can we identify case studies where research has been converted successfully into practice, and are these successes replicable at other volcanoes? Finally, what are some future difficulties and opportunities in reaching the ultimate goal of embedding scientific discovery within policy and practice?

Keynote on volatiles from the mantle to the atmosphere: Central American forearc volatile (He-CO2) characteristics

P.H. Barry (WHOI), D.V. Bekaert (WHOI), J. M. de Moor (Observatorio Volcanológico y Sismológico de Costa Rica (OVSICORI)), D. Giovannelli (University of Naples "Federico II"), K.G. Lloyd (University of Tennessee)

The most important physical process linking deep and shallow volatile cycles on Earth is subduction, which transports slab-derived volatiles into the mantle. During subduction, the majority of volatile-rich fluids are released from the downgoing slab due to increasing pressure and temperature. These fluids migrate through the overlying mantle wedge and crust and are ultimately released across the forearc, volcanic arc and backarc. Only the fraction of volatiles remaining within the slab upon subduction will be transported to the mantle. The efficiency of this volatile transfer to the mantle has profound implications for the nature and scale of geochemical heterogeneities in Earth's deep (i.e., mantle) interior and shallow (crustal) reservoirs. Carbon fluxes associated with arc and backarc localities are relatively well constrained in Central America, however, until recently, the forearc flux remained poorly constrained, but now it seems likely that potentially significant volatile outputs may be occurring in the forearc.

We present He and CO_2 isotope and relative abundance data from forearc fluids of southern Costa Rica and western Panama in (n=43) water and (n=22) gas samples. These data allow us to determine the extent of tectonic, chemical and biological controls on forearc carbon outgassing. Helium isotope ($^3He/^4He$) values range from 0.3 to 8.9 R_A (where air = 1 R_A). Data reveal a clear southward increase in $^3He/^4He$, from arc volcanism-type values to the high end of the mantle range. Remarkably, "cold" seeps in western Panama display the highest $^3He/^4He$ ever reported along the volcanic arc chain bordering the Americas, hence pointing to a ^3He-rich mantle signature with no contribution from slab-derived and crustal components. Taken together, our data are most consistent with the existence of a slab window, most likely formed via subduction of a spreading ridge under western Panama7. Carbon isotopes of CO_2 ($\delta^{13}C$) vary from – 29.7‰ to +6.7‰ vs. PDVB, suggesting a variety of fractionation processes are at work in this complex region. These data are modelled to show that CO_2 loss due to calcite precipitation may be an important process, as it has been shown in Costa Rica's Nicoya Peninsula6. $CO_2/^3He$ values of the seeps are also variable and fall between 10^3 and 10^{12}, with the low values being consistent with a significant sink due to calcite precipitation. In summary, we show that 1) there is a pervasive (deep) mantle component in all forearc samples, and 2) extensive CO_2 fractionation is occurring in the low temperature forearc region.

Keynote on geophysics & monitoring: Tracking cracking during the 2018 Kilauea caldera collapse with shear wave splitting

Jessica Johnson (University of East Anglia)

The 2018 eruption of Kilauea volcano in Hawaii was unique in several ways. One of the interesting aspects was the well-recorded incremental collapse of the summit caldera over the course of three months. This collapse was accompanied by over 50,000 earthquakes. These earthquakes tell an interesting story in themselves, but we are using them to measure seismic ansiotropy using shear wave splitting at a spatial and temporal resolution that has not been achieved at volcanoes before. Preliminary results suggest that cracking of ring faults associated with the caldera collapse can be detected using shear wave splitting, and hence the timing and evolution of the deformation can be mapped in this way.

Keynote on East Africa: Volcanology of the East African Rift

Karen Fontijn (Université libre de Bruxelles)

The East African Rift System (EARS) is the natural laboratory of a continental rift, and has gradually developed over the last 10-15 My, with however early phases of magmatism recognised since ca. 45 Ma. In its present-day configuration, some rift basins are more clearly associated with magmatism than others. The Eastern Branch from northern Tanzania throughout Kenya and Ethiopia to the Afar Triple Junction, comprises a near-continuous magmatic rift segment with evidence of both on-axis and off-axis volcanism. The Western Branch, however, is marked by more discrete volcanic provinces largely concentrated in tectonic accommodation zones. Despite the dissimilarities in the rift-magmatic architecture between different rift basins, many parallels can be drawn on the rift volcanoes throughout the EARS, in terms of their magma composition and thus rheology, and in terms of their eruptive style.

This review talk will focus on the styles and products of rift volcanism that are most common across the present-day EARS and so largely focuses on the volcanoes that are considered dormant-active in the Late Quaternary and up to the present day. About a quarter of these volcanoes have had historical eruptions, and most others have evidence of geologically young eruptive products. In addition, several volcanoes along the EARS show active signs of (magmatic) unrest, and some host economically important geothermal resources, all clearly indicating the presence of active magmatic reservoirs with a potential to erupt in the future. Despite significant advances in our understanding of rift volcanism in recent years, many outstanding questions remain on the general styles and recurrence rates of activity in rift settings, as well as on the magmatic plumbing systems and controls on eruptive behaviour. In particular, at some volcanoes we find evidence for enigmatic volcanic-magmatic processes that seem typical for rift settings, and which have important implications for understanding future eruptions.

Keynote: Using satellite data to identify rainfall-triggered volcanic activity

Jamie Farquharson* Falk Amelung (University of Miami)

*jifarq89@googlemail.com

There is a clear link between heavy rainfall in volcanic environments and the potential for secondary volcanic hazards, such as the generation of lahars and other non-eruptive hazards. However, there is also mounting evidence that rainfall can be instrumental in triggering or otherwise modulating primary volcanic activity: discrete eruptions of lava, tephra, and gases. Individual case studies have revealed a link between rainfall and volcanism at Piton de la Fournaise (La Réunion), Mount St. Helens, Kīlauea (both USA), Las Pilas volcano (Nicaragua), and Soufrière Hills volcano (Montserrat), among others. Additionally, there exists a wealth of anecdotal evidence of rainfall-induced volcanism around the world, noted in bulletin reports compiled by the Smithsonian Institution's Global Volcanism Program. Are these discrete examples purely random, or are they symptomatic of a prevalent underlying link between rainfall and volcanic activity?

Previous research has typically relied upon sparse gauge data; however, satellite-based precipitation detection systems means that we can now investigate these phenomena on a near-global scale. We extract and analyse multi-decadal rainfall timeseries from satellite data to assess whether the duration and timing of annual rainfall plays a role in modulating eruption frequency at different volcanoes. By comparing observed eruption distributions over time with the theoretical probability of those distributions, we identify around three dozen volcanic systems where the eruption record appears to be strongly correlated with the wettest parts of the year.

Potential physical mechanisms have been proposed to explain such correlations at different systems: shallow-seated trigger mechanisms involve either the thermal contraction of recently-emplaced lava, fluid-induced pressurisation of the interior of a dome, or a combination of both. Deeper mechanisms involve rainfall perturbing the regional stress within or applied by the volcanic edifice in one of two primary different ways: (a) by changing the load overlying the magma chamber, or (b) by changing the threshold for mechanical failure (either prompting opportunistic dyke propagation or directly facilitating magma chamber rupture). We highlight that these mechanisms, which operate at a range of subsurface depths and are associated with time lags from hours to months, are underpinned by a single common process: the infiltration of meteoric water into the edifice.

The surest examples of rainfall-modulated volcanoes are those where eruptions are nonuniformly distributed throughout the year, correlate with the wettest parts of the year, and are characterised by a short seasonal lag time, such as Mount St. Helens and Vesuvius (Italy). We propose that the response of these two volcanoes to rainfall represent end-members of a spectrum of eruptive behaviours driven by infiltration-induced stress change within the edifice. While several volcanoes revealed by our analysis have previously been studied in this context (e.g. Piton de la Fournaise, Kīlauea, Karkar, Karangetang, Langila), many others have not. We argue for the integration of rainfall monitoring into probabilistic hazard analysis of volcanic activity: rainfall is both measurable and forecastable, so the inclusion of continuous ground- and satellite-based meteorological monitoring—in tandem with simple models of pressure transfer—could prove invaluable in providing some advance warning of these hazards.

Keynote on eruptive processes: Experimental insights into eruptive behaviour

Jackie Kendrick (University of Edinburgh), Paul A. Wallace (Université Libre de Bruxelles), Anthony Lamur (University of Liverpool), Yan Lavallée (University of Liverpool)

The frequent and, as yet, unpredictable transition from effusive to explosive behaviour is common at active composite volcanoes, yet our understanding of the processes which control this evolution is poor. The key to this catastrophic transition rests in the rheological response of the magma. Magmas are complex suspensions of crystals and gas bubbles in amorphous silicate melts, which evolve constantly during ascent due to changes in pressure and temperature that drive gas exsolution (i.e. degassing) and crystallisation. In particular, highly silicic magmas may evolve from a regime controlled by viscous flow to that where they localise strain and fragment, owing to increasing viscosity of the suspension. The tendency for non-Newtonian suspensions to localise strain ensures that in the upper conduit of many composite volcanoes, plug flow prevails. Such behaviour impacts the eruptive activity, in particular the volcano's ability to build pressure via the creation and destruction of permeable pathways.

The presence of a plug may: (1) heighten the ability for gas pressure to build below the dense magma mass, enhancing the chance of significant explosive activity; and/ or (2) favour cyclic pressure release through the development and healing of fractures resulting in periodic gas and ash explosions; and/ or (3) form permeable fractured shear zones that flank the magma column, allow degassing and favour extrusion of magma spines or lobes. Changes in magma viscosity, magma flux or overburden (e.g. due to lava dome creation/ collapse) will perturb the stability of the system in such a scenario, and can result in a shift in eruption style. To our benefit magma failure (rupture) releases characteristic seismicity, which can help us infer subsurface magmatic processes thanks to increasingly sophisticated models and a wealth of experimental data. Here we will review how laboratory experimentation, that probes the physical and mechanical properties of magmas, has illuminated the processes extant in magmatic conduits and can help us interpret the state of an eruption.

Keynote on volcanism and climate: The role of volcanism in shaping Neoproterozoic snowball Earth

Tom Gernon (University of Southampton)

The snowball Earth hypothesis remains a subject of lively debate and scrutiny among geoscientists. A now widely held view is that igneous and volcanic processes either directly or indirectly helped drive, regulate and terminate the snowball state. For example, it has been suggested that enhanced chemical weathering of large igneous provinces served as a major sink of CO_2, triggering a runaway ice-albedo feedback. Moreover, continuous volcanic arc outgassing through ice sheets has been invoked as a mechanism to overcome this ice-albedo effect, effectively melting the snowball.

Here, another important process is identified: submarine volcanism along a transient shallow mid-ocean ridge system during breakup of the supercontinent Rodinia. Chemical alteration of basaltic glass deposits along these ridges may explain why the oceans gained massive amounts of alkalinity during glaciations, culminating in the widespread deposition of cap carbonates on deglaciation. Numerical simulations demonstrate that widespread basalt alteration under near-global sea-ice cover could lead to Ca^{2+} and Mg^{2+} supersaturation over the course of the glaciation that is sufficient to explain the volume of cap carbonates deposited across the continental shelves. Furthermore, conservative estimates of phosphorus release are sufficient to explain observed P:Fe ratios in contemporaneous banded iron formations. This large phosphorus release may have fuelled primary productivity in the oceans, which in turn would have contributed to atmospheric oxygen rises associated with Cryogenian glaciations. This model provides new constraints on the geochemical and sedimentary environment in which the first multicellular animals evolved and diversified during the Cryogenian and Ediacaran Periods.

Application of the dual-band method for determining surface temperatures at Manam volcano, Papua New Guinea

Adam Cotterill* Emma Liu (University College London)

Christopher Kilburn (University College London)

Kila Mulina (Rabaul Volcanological Observatory)

Ima Itikarai (Rabaul Volcanological Observatory)

*adam.cotterill.13@ucl.ac.uk

Manam volcano, located in the western Bismarck volcanic arc, is one of the most frequently active volcanoes in Papua New Guinea. In recent decades, Manam has experienced several major eruptions, notably in 1996 and 2004-2005, that forced large-scale evacuations of the local island population. Manam remains active, exhibiting persistent degassing from two summit craters punctuated by explosive paroxysmal eruptions. Aerial observations of the South Crater from a drone overpass in May 2019 showed shallow magma close to the surface in an open-vent situation.

Satellite-based remote sensing offers a strategy for semi-continuous monitoring at remote volcanoes where ground-based monitoring infrastructure is limited. In particular, thermal anomalies (where surface temperatures are noticeably in excess of background values) can be identified routinely from multispectral imagery. In this study, we analyse a timeseries of multispectral images from the Sentinel-2 satellite to determine Pixel Integrated Temperatures (PIT) for each of Manam's two summit craters. Further, we extend our analysis to deconvolve the temperatures of each component (i.e. exposed lava and cooler crust) that contributes to the PIT using the Dual Band Method; a process that we have fully automated.

Preliminary results suggest that the PIT temperatures at both craters have remained relatively stable between June 2019 and September 2020. PIT measured in Band 11 (1.61 μm) ranged between 350-450°C and 200-285°C in Band 12 (2.19 μm). Temperature measurements of the cooler lava crust (Tc) have been achieved using the Dual Band Method. The distribution of the relationship between Tc and the area of a pixel occupied by hotter, fractured crust (fh) has previously been shown as indicator of different modes of activity. Comparing our data with published Tc vs fh distribution scenarios is an area of ongoing work.

We aim to extend the duration of our study backwards in time to span a period of elevated activity at Manam, which began with a major eruption in August 2018 and was followed by a further four major eruptions in the 10 months subsequent. Our analysis seeks to explore the relationship between the thermal properties of the summit region and eruptive activity, based on the hypothesis that the PIT is function of both the height of magma in the conduit (i.e. a proxy for gas supply rate) and the proportion of cooled crust relative to exposed lava at the surface (i.e. a proxy for overturning rate). To evaluate this relationship further in the context of volcanic outgassing, we propose to combine timeseries of temperature data with SO2 gas emission data from TROPOMI satellite measurements. This study forms part of broader, multi-parameter project focused on developing volcano monitoring and hazard communication at volcanoes in Papua New Guinea.

Modelling the Soufrière Hills Volcano; Investigating the Montserrat magmatic system with co-analysis of EDM and GPS data

Alexander Johnson* James Hickey (University of Exeter),Karen Pascal (Montserrat Volcano Observatory, University of the West Indies), Ben Williamson (University of Exeter), Racquel Syers (Montserrat Volcano Observatory)

*aj401@exeter.ac.uk

Ground deformation offers vital insight into the activity of volcanoes, as well as the characteristics of the magmatic systems that feed them. The extended eruption of the Soufrière Hills Volcano (SHV) has allowed for the development of a comprehensive multi-disciplinary monitoring network, which has aided extensive research into the magmatic system underlying the volcano. The modern network comprises GPS, strainmeters, and cheaper Electronic Distance Measurement (EDM). However, the island's EDM network has to date only being used for monitoring the SHV. Here, for the first time, we co-analyse the EDM dataset from 2010-19 with the GPS data from the same period. This study aims to delineate the modern magmatic system conditions by building 3D Finite Element Models, as well as assessing the best use of EDM data in modelling the SHV.

The island-wide deformation recorded over the past decade at the GPS network is broadly radial relative to the SHV dome, with a decreasing deformation rate. The EDM data shows line lengthening on the west and east flanks of the volcano, but minor line length shortening on the northern flank. We utilise Finite Element Modelling to model the SHV magmatic system as a single elongated prolate source after 'The transcrustal magma reservoir beneath Soufrière Hills Volcano, Montserrat: insights from 3-D geodetic inversions', (Gottsmann et al, unpublished) with 3D topography incorporated (Stinton, A., 2015). We systematically test a wide range of parameters to explore how both EDM and GPS record perturbations to the magmatic system. Our preliminary results show that variations of certain parameters to the deeper magmatic system have an impact on both EDM and GPS timeseries, while some parameters (e.g., source pressure, source depth, and source location) have a more significant effect on EDM measurements than others (e.g., source shape).

Experimental insights on the generation of tsunamis by pyroclastic flows

Alexis Bougouin* Olivier Roche [Laboratoire Magmas et Volcans, Clermont-Ferrand]

Raphaël Paris [Laboratoire Magmas et Volcans, Clermont-Ferrand]

*alexis.bougouin@uca.fr

Most tsunamis are triggered by submarine earthquakes, and warning systems are therefore mainly structured to deal with this. However, other geophysical events may generate tsunamis, such as meteorite impacts, landslides, iceberg calvings, volcanic eruptions, which make costal populations particularly vulnerable to these other sources. During explosive volcanic eruptions, the entrance of pyroclastic flows into the sea represents one of the major processes for the generation of volcanic tsunamis. However, this issue remains still poorly understood.

In this objective, well-controlled laboratory experiments of fine-granular flows entering water were performed in a large-scale channel of 7x0.8x0.2 m3 at the Laboratoire Magmas et Volcans (Clermont-Ferrand, France). One of the originalities of the present setup arises from the opportunity to fluidize granular flows until impact, which ensures a suitable modelling of natural pyroclastic flows. More specifically, the fluidization process generates high gas pore pressure, which reduces the internal friction of the granular material and therefore promotes a higher mobility (e.g., long runout distance). In addition to vary the degree of fluidization (from nonfluidized to fully-fluidized), the grain properties (size, density), the flow conditions (velocity, height, volume), the slope angle of the inclined plane, and the water depth were also addressed.

Our results showed that the impact of a granular flow into water generated (i) a first large-amplitude wave which may be followed by lower-amplitude waves, and (ii) a particle-driven gravity current underwater. In the near-field region, i.e. close to the impact, the wave characteristics were mainly dependent on the mass flux and the volume of the granular flow, while the maximum water depth in the channel could be disregarded. Beyond the flow conditions, the grain properties may also affect the wave amplitude through the density and the size of grains. In particular, coarse granular flows generate lower wave amplitudes than fine granular flows, which was attributed to the ability of water to penetrate the flowing material. At sufficiently low grain size (d≈65 μm), the granular flow behaved as a nonporous flowing material, and the wave amplitude was equivalent to that generated by a water flow under the same initial conditions. This study supports the idea that ash-rich pyroclastic flows are predisposed to generate large-amplitude tsunamis.

Did the ~74ka Toba eruption cause aridity in the Eastern Mediterranean over millennia?

Alice R Paine* James U.L Baldini (Durham University), Ezgi Ünal-İmer (University of Queensland & Middle East Technical University), Fabian B. Wadsworth (Durham University), Richard J Brown (Durham University), Stacy A. Carolin (University of Cambridge), Alexander A. Iveson (Durham University), Wolfgang Müller (Goethe Universität), Tom Verniers (Durham University)

*alice.paine@earth.ox.ac.uk

Explosive volcanism is the primary natural driver of climate variability, and a growing number of studies reveal a link between volcanism and decadal-scale climate change. However, the scale and persistence of climatological perturbation following Earths largest (>M7.0) eruptions are largely unknown. This includes the eruption of Toba, Indonesia at ~74 ka BP – the largest known volcanic event of the Quaternary period. Here, we present a new geochemical record from stalagmite DIM-E3-A (Dim Cave, South Turkey) grown between 90 and 70 ka BP, and dated using U-series methods. Importantly, DIM-E3-A grew substantially closer to the Toba caldera compared to ice core records and is dated to <400 years uncertainty per data point in the presented record. Therefore, we posit that DIM-E3-A is suitable for assessing the onset and duration of climate variability during the interval either side of the ~74 ka BP eruption. Our results show evidence for an abrupt shift towards arid conditions < 200 years following the Toba eruption. This change manifests as simultaneous enrichment of trace elements that can be associated with enhanced bedrock dissolution, atmospheric dust flux, and supersaturation of dripwater with respect to calcite: all indicative of low moisture availability during stalagmite growth. The enrichment in the trace elements noted following the Toba eruption persist for > 2 kyr. Therefore, we propose that a transition to drier and cooler conditions in the Eastern Mediterranean could have resulted from inundation by volcanic aerosols, prompting a positive feedback response driving atmospheric reorganization. Taken together, findings from DIM-E3 could provide evidence for climate perturbation persisting for millennia following high-magnitude volcanism. However, geochemical change in our record also occurs in conjunction with the transition into Greenland-Stadial 20. Evidence from DIM-E3 suggests that Toba may have affected the onset and pacing of this shift, yet further work is required to constrain the relative role and impact of volcanic forcing on this abrupt climate transition in the Northern Hemisphere.

The role of fractures in lava dome instability

Amy J. Myers* Claire E. Harnett (UCD School of Earth Sciences, University College Dublin, Belfield, Dublin, Ireland)

Michael J. Heap (Institut de Physique de Globe de Strasbourg (UMR 7516 CNRS, Université de Strasbourg/EOST), 5 rue René Descartes, 67084, Strasbourg cedex, France)

Eoghan P. Holohan (UCD School of Earth Sciences, University College Dublin, Belfield, Dublin, Ireland)

Thomas R. Walter (German Research Centre for Geosciences GFZ, Telegrafenberg, 14473 Potsdam, Germany)

*amy.myers@ucdconnect.ie

Volcanic domes form when lava is too viscous to flow away from an active volcanic vent; instead, the lava accumulates into a mound consisting of a hotter, ductile core and a colder, brittle outer layer. An existing lava dome grows when new material is injected into the core of the dome, causing the outer layer to stretch and develop tensile fractures. With continued dome growth, these weaknesses can propagate to form an extensive fracture network and the dome may fail. Collapse events often generate rock falls and debris avalanches, lahars, and high-speed pyroclastic flows, endangering populations residing at the base of a volcano. Since such fractures represent potential failure planes, in this project we aim to understand the role they have in destabilising lava domes.

This project will build on the work published by Harnett et al. (2018), which demonstrates the suitability of a discrete element modelling approach to simulate dome emplacement and evolution. Specifically, this project is designed to:

i. Use high-resolution photogrammetry to characterise the possible fracture states of a dome;

ii. Establish up-scaled rock-mass properties by performing geomechanical experiments on both fractured and non-fractured samples of dome rock from prior collapses;

iii. Develop a numerical model to investigate how the presence and properties of fracture networks influence dome stability.

The model, developed using PFC, will be used to identify critical fracture states that can signify a dome collapse is likely to occur. Under the current model, parallel bonds simulate the fluid magma core and flat joints simulate the solid talus material. This project will build on this original model by incorporating discrete fracture networks into the smooth-joint model to implement dome fracturing. The new model will look to investigate the effect of a fracture network on a static dome that, when in its unfractured state, is stable under gravity. Additionally, the model will be designed such that inputs can include experimentally derived rock-mass properties. It is hoped that, by incorporating observational and experimental data into a more complex model, the dynamic evolution of fractures in a growing lava dome can be investigated and the ongoing likelihood of a dome collapse event can be assessed.

Harnett, C. E. et al., 2018. J. Volcanol. Geoth. Res., 359: 68-77.

Geochemical characterisation of the youngest explosive volcanic activity at St Kitts and Nevis, Lesser Antilles

Amy Peach* Paul Cole (School of Geography, Earth and Environmental Science, University of Plymouth)

Jenni Barclay (School of Environmental Sciences, University of East Anglia)

Michelle Harris (School of Geography, Earth and Environmental Science, University of Plymouth)

*amy.peach@plymouth.ac.uk

Saint Kitts and Nevis lie in the northern part of the Lesser Antilles island arc. To understand the potential hazards posed by Mt Liamuiga, and the other volcanic centres on St Kitts and Nevis, it is important to characterise their past activity.

Pyroclastic density currents (PDCs) of both block and ash flow, pumice rich fountain collapse type and potentially blast deposits, characterise the youngest products at both Mt Liamuiga and Nevis Peak, although subordinate fallout deposits also occur on St Kitts. We have analysed the geochemistry of youngest products at Mt Liamuiga, St Kitts and Nevis Peak in an attempt to characterise the nature of the potential triggering mechanisms for the most recent explosive eruptions.

Whole rock major element XRF data show that the youngest deposits on Mt Liamuiga, taken from the upper Mansion Series, are of two broad compositions; andesite and dacite. Samples from single PDC units on St Kitts show that the geochemistry ranges from 58.6% SiO2 to 63.2% SiO2 indicating that magma mingling was an important mechanism at St Kitts. On Nevis, samples of the Long Point deposits, a sequence of at least three PDC flow units which appear transitional between typical ‘Block and Ash flow’ deposits and ‘fountain collapse style’ deposits, have whole rock compositions ranging from basaltic andesite to dacite.

Further geochemical and petrological analysis will be used to shed light on eruptive styles, relate past activity to pre-eruptive perturbations in magma storage conditions. This information will contribute to the overall understanding of potential future volcanic scenarios on St. Kitts and Nevis.

High sensitivity of summer temperatures to stratospheric sulfur loading from volcanoes in the Northern Hemisphere

Andrea Burke* Kathryn Moore (St Andrews), Rob Wilson (St Andrews), James Rae (St Andrews), Mike Byrne (St Andrews), Helen Innes (St Andrews), Laura Crick (St Andrews), Michael Sigl (U. of Bern), Joe McConnell (Desert Research Institute), Kevin Anchukaitis (University of Arizona)

*ab276@st-andrews.ac.uk

The 540s, 1450s, and 1600s represent three of the five coldest decades in the last 2.5 thousand years. In each of these cases, the cause of these cold pulses has been attributed to large volcanic eruptions. However the source and magnitude of the volcanic forcing remains uncertain. Here, we use high-resolution sulfur isotopes in ice cores over these events to provide a novel means of quantifying stratospheric sulfate loading for these volcanic eruptions. In each case, the largest tree ring cooling is associated with an extra-tropical eruption, and the stratospheric sulfate loading of these events is substantially smaller than previous estimates (by up to a factor two). These results suggest an increased sensitivity of the reconstructed northern hemisphere summer temperature response to extra-tropical eruptions. This may be due to climate feedbacks and processes that amplify and prolong the cooling signal from high latitudes (e.g. sea ice or changes in ocean heat content).

Petrophysical characterization of volcanic ejecta to constrain subsurface lithological heterogeneities: implications for edifice stability at Piton de la Fournaise volcano (La Réunion, France)

Andrea Di Muro* Fabian Schwarzlmüller (LMU, Munich), Ulrich Kueppers (LMU, Munich), Michael Heap (IPGS, Strasbourg), Donald Dingwell (LMU, Munich)

*dimuro@ipgp.fr

Piton de la Fournaise (PdF) is an active basaltic volcano whose eruptive activity is predominantly characterized by frequent effusive to mildly explosive (Hawaiian-Strombolian) eruptions. The geologic record also preserves evidence of less frequent, major explosive eruptions, typically associated with the seaward sliding of the steep east flank. Such eruptions formed calderas that are several km in diameter and their products have been emplaced as proximal pyroclastic breccias and medial fall deposits dispersed over tens of km. Such rare yet recurrent highly explosive events at volcanoes exhibiting predominantly effusive behavior are accruing increasingly more attention in volcanology. The breccias of PdF offer the unique opportunity to sample a wide range of different lithologies covering most of the stratigraphy of the edifice. In the framework of the national project “SlideVOLC”, funded by the National Research Agency of France (ANR), a petrological and petrophysical characterization of 14 different breccia lithologies has been conducted. Petrological analysis of samples from the Plaine des Sables and Bellecombe breccias (deposits relating to the main recent explosive events related to volcano destabilization) reveal a large range of fresh to weakly altered crustal basaltic lithologies, encompassing plutonic (fine to medium grained gabbros), sub-volcanic (fine-grained dolerites emplaced in sills and dykes), and volcanic (lavas with variable vesicularity and porphyricity) units. Petrophysical measurements revealed a corresponding variability in density, porosity, P-wave velocity (dry and wet), and uniaxial compressive strength, confirming the petrophysical consequences of the lithological diversity of PdF. The large variation in P-wave velocity and strength is interpreted to be the result of the wide ranges in texture (porosity/vesicularity) and lithology. Notably, some of the dense gabbroic units that have remained intact despite likely having experienced several natural cycles of reheating are comparatively weak. Different lithologies cannot simply be distinguished solely on the basis of their physical properties. We infer that volcano instability should not be interpreted solely in terms of altered rock units. Rather, the large petrophysical heterogeneity of crustal rocks at PdF, and by inference likely at many other volcanoes, must be considered when interpreting monitoring data and assessing potential hazards related to volcano stability.

Caldera Resurgence during the 2018 eruption of Sierra Negra volcano, Galápagos Islands

Andrew Bell* Peter LaFemina (Pennsylvania State University)

Mario Ruiz (Instituto Geofísico, Escuela Politécnica Nacional)

Stephen Hernandez (Instituto Geofísico, Escuela Politécnica Nacional)

Christopher Bean (Dublin Institute for Advanced Studies)

*a.bell@ed.ac.uk

Recent large basaltic eruptions began after only minor surface uplift and seismicity, and resulted in caldera subsidence. In contrast, some eruptions at Galápagos Island volcanoes are preceded by prolonged, large amplitude uplift and elevated seismicity. These systems also display long-term intra-caldera uplift, or 'resurgence'. However, a scarcity of observations has obscured the mechanisms underpinning such behaviour. Here we combine a unique multiparametric dataset to show how the 2018 eruption of Sierra Negra contributed to caldera resurgence. Magma supply to a shallow reservoir drove 6.5 m of pre-eruptive uplift and seismicity over thirteen years, including an Mw5.4 earthquake that triggered the eruption. Although co-eruptive magma withdrawal resulted in 8.5 m of subsidence, net uplift of the inner-caldera on a 'trapdoor' fault resulted in 1.5 m of permanent resurgence. These observations reveal the importance of intra-caldera faulting in affecting resurgence, and the mechanisms of eruption in the absence of well-developed rift systems.

Lies, Damn Lies and Social Media: Themes in disinformation surrounding volcanic crises

Andrew Peck* Dr Rebecca Williams (University of Hull)

*a.g.peck-2019@hull.ac.uk

In the communicative mix surrounding modern volcanic events, disinformation is playing an increasingly prominent role, and (as with many professional scientific communities), professional geologists are yet to find a way to appropriately and definitively respond to this information. This is only exacerbated by an increase in ‘click-bait’ online media and an apparent willingness of some to report on anything appearing on a blog as an authoritative source. Here we explore the idea that modern science communications can not be seen as existing in a vacuum, and that an adversarial element now exists to communication where communications are not limited to our own professional circles but fora where everyone can take a wide voice. Examples of who “everyone” includes are drawn out, and will explore how different these open social media platforms are from more traditional forms of communication and how competitive and adversarial they can be regardless of the veracity and scientific validity of a message.

This project investigates online dis- and mis-information found on social media surrounding the 2017 Mount Agung Volcanic Crisis.

Here, exemplar dis- and mis- information are presented together with an initial mapping of these examples to an interdisciplinary taxonomy of online influence activities. This taxonomy organises the communications by the apparent intent of the author (ranging from misguided/altruistic through to informed/malicious) and their core messaging (intrinsic or extrinsic to the issue at hand). Through better understanding the authorship and origins of messaging, a response mode based on influence operations is suggested that may empower professional geologists to communicate better with their target audience. The significance between dis-information (deliberately propagated) and mis-information (accidentally/innocently propagated) is discussed.

This is not a typical geology presentation, but will be of interest to anyone who finds themselves discussing science online, or may wish to do so professionally or personally in the future.

Quick ref:

Williams & Krippner, 2019 https://doi.org/10.30909/vol.01.02.i-viii

Magmatic water content and the overpressure 'sweet spot'

Anna Brookfield* Dr Michael Cassidy (University of Oxford)

*anna.brookfield@pmb.ox.ac.uk

The explosivity of a volcanic eruption has a huge bearing on its destructive potential. Understanding what drives explosive vs effusive behviour is therefore a fundamental goal of volcanology. One potential driver is magmatic overpressure, which is linked to eruption triggering, ascent rate and explosivity. Here we use MELTS thermodynamic modelling to track the evolution of volatile-exsolution driven overpressure during cooling and crystallisation. Magmatic water content (wt% H2O) and XH2O (molar H2O/ (H2O+CO2) in the fluid phase) are varied for a range of natural compositions, in order to test the range of overpressures which can be generated via volatile exsolution. We find that there is a 'sweet spot' in magmatic water content and H2O-CO2 ratios at which peak overpressure occurs. The water content of the sweet spot varies for different systems, and represents a balance between low magma compressibility and high volumetric expansion. Magmas with water contents at or near the 'sweet spot' have the capacity to generate higher overpressures. In addition, we find that increasing magmatic XH2O (i.e. increasing water saturation) tends to generate higher overpressures, due to the delayed exsolution of a fluid phase in these magmas. Degassing of CO2 from a volcanic system will increase XH2O, and could provide a mechanism for increasing the peak volatile-driven overpressure and transitioning between effusive and explosive behaviour.

The Textural Record of Mixed Brittle-Viscous Deformation in a Shallow Silicic Conduit

Annabelle Foster* F.B. Wadsworth (Earth Sciences, Durham University, Durham, DH1 3LE)

M.C.S. Humphreys (Earth Sciences, Durham University, Durham, DH1 3LE)

H. Tuffen (The Lancaster Environment Centre, Lancaster University, Lancaster)

*annabelle.foster@durham.ac.uk

Silicic volcanoes can produce both the most devastating explosive eruptions on Earth, and relatively low-hazard effusive lavas. The controls on whether an explosive or effusive eruption occurs remain poorly constrained. Hrafntinnuhryggur – Obsidian Ridge – at Krafla volcano (northern Iceland) preserves the shallow conduit fill of a rhyolitic fissure eruption that fed both explosive and effusive activity at the surface. This locality offers an opportunity to constrain silicic conduit dynamics through the textures that eruptive processes leave behind, at varied depths of dissection that reach ~100 metres. Small-volume subaerial lava bodies represent the conduit-plugging fill emplaced in the waning phases of the eruption.

Here, we present the characteristic microtextures of lithofacies that occur in distinct zones across the feeder dyke and conduit-plugging lava bodies. From the outside in, these comprise: (1) variably baked and altered hyaloclastite country rock; (2) massive marginal rhyolitic obsidian; (3) flow-banded obsidian with cross cutting, variably healed fractures and mini-faults (mm-cm long, with variable offsets); (4) brecciated-and-healed rhyolitic obsidian; (5) obsidian containing variably welded tuffisite; (6) a gradation to spherulitic and lithophysae-dominated rhyolite, through to fully devitrified stony rhyolite in the conduit core.

This project focuses on examining each lithofacies in turn to constrain a conceptual model that seeks to explore the evolution and assembly of these juxtaposed textures. In the context of previous work, we favour a model in which the conduit-filling rhyolite (at this locality) represents an aggraded deposit of in-conduit marginal welding during a bypassing explosive eruption, producing a variably flow-banded deposit similar to sub-aerial welded ignimbrites. During gradational welding, lateral fractures opening to release high gas over-pressure can produce tuffisites. The textural record of repeated, transient brittle failure events likely induced localised magma vesiculation, but are followed by complete magma healing and compaction. Even limited vertical extrusion of this shallow welded plug can create overprinting signatures of marginal brecciation and viscous healing events. Beyond this case study, our project has implications for how explosive-effusive eruption transitions occur and for how degassing mechanisms can be inferred from textural studies of conduit deposits.

The role of subsurface gas localization in basaltic fissure eruptions

Ariane Loisel* Prof. Edward W. Llewellin (Durham University)

Dr. Antonio Capponi (Lancaster University)

*ariane.loisel@durham.ac.uk

Effusive basaltic eruptions are the most common form of volcanism on Earth. They produce lava flows that may destroy local infrastructure and emit toxic gas and particles that may adversely impact public health on a regional scale. Predicting the eruptive style and its evolution for basaltic volcanoes is therefore a key goal in volcanology. This requires an understanding of the multiphase flow processes that operate within the sub-volcanic plumbing system and drive transitions in style.

The aim of this PhD project is to characterise the evolving organisation of gas-driven flow patterns within basaltic feeder dyke systems, with a particular focus on the effects of volcanic outgassing via discrete vents along the fissure. Field observations of both eroded and active basaltic feeder dykes will be synthesised with laboratory analogue experiments to determine the fluid dynamics within feeder dyke systems, and their effects on eruptions. Our laboratory kit was designed to perform scaled analogue experiments reproducing bubbly flows in a 3.0 x 2.0 x 0.03 m glass-walled slot which mimics the geometry of dykes that feed most basaltic eruptions. This apparatus will allow us to explore the effects of a slot-like geometry on fluid dynamic processes within the magma, whereas previous experimental studies have usually assumed a cylindrical conduit. We present preliminary results on the ascent of gas slugs and the organization of convective flow patterns within this slot-like geometry. The project will be based on two volcanic case studies, relating these analogue experiments to past and future fissure eruptions at Piton de la Fournaise volcano (La Réunion, France) and Kilauea volcano (Hawaii, USA). Collating monitoring data from fissure eruptions with the imagery acquired during our analogue experiments will improve our understanding of the controls on the eruptive behaviour of basaltic systems. This will be developed, in collaboration with the Piton de la Fournaise Volcano Observatory and the University of Hawaii, into a conceptual framework for interpreting the underlying flow patterns within feeder dykes from real-time gas and erupted lava flux measurements.

Multidisciplinary approach to constrain the dynamics of the Altiplano-Puna magma system

Arne Spang* Tobias Baumann (University of Mainz, Germany)

Boris Kaus (University of Mainz, Germany)

*arspang@uni-mainz.de

Continuous Interferometric Synthetic Aperture Radar (InSAR) monitoring (> 25 years) has revealed a concentric surface deformation pattern centered around the summit of Uturuncu volcano above the Altiplano-Puna magma body (APMB) in the central Andes. For the past decades, several numerical studies have successfully reproduced this pattern with models of varying complexity. However, the temperature- and strain rate-dependent visco-elasto-plastic rheology of rocks, the buoyancy of magma, the effects of modelling in 3D as well as the shape of the magma body have often been simplified or neglected.

Here, we use a joint interpretation of seismic imaging, gravity anomalies and InSAR surface deformation data to constrain location, 3D shape and density of the magma body. With the help of the thermomechanical stokes code LaMEM, scaling law analysis, the neighborhood algorithm and bayesian inference, we estimate the uncertainties associated with the geometry of the mid-crustal magma body and identify the most important parameters that control the dynamics of the system.

We find that the density contrast between the APMB and the surrounding host rock must be in the range of 90 to 130 kg/m3 (2σ) to satisfy both tomography and Bouguer data. Based on that and the chemistry of eruption products, we estimate the melt content of the APMB to be on the order of 15 - 22%. We also present a 3D model that can reproduce the observed surface deformation self-consistently by buoyancy driven magma transport without the need for additional pressure sources. The flow pattern is controlled by a central rise at the top of the APMB whose geometry can be constrained with the help of the stokes code while gravity anomalies help to constrain the deeper parts of the magma body. Scaling law analysis shows that the rheology of the upper crust and the magma mush as well as the density contrast between the two are the most important parameters in the system and need to be constrained for a better understanding of the subsurface processes.

Volcanic Gas Emission Measurements from Soufrière Hills Volcano, Montserrat, using the OpenSO2 network

Ben Esse* Mike Burton (The Department of Earth and Environmental Sciences, The University of Manchester, Manchester, UK)

Matthew Varnam (The Department of Earth and Environmental Sciences, The University of Manchester, Manchester, UK)

Thomas Christopher (Montserrat Volcano Observatory, Hope Drive, Flemmings, Montserrat)

Graham Ryan (Montserrat Volcano Observatory, Hope Drive, Flemmings, Montserrat)

Carlisle Williams (Montserrat Volcano Observatory, Hope Drive, Flemmings, Montserrat)

Marlon Fergus (Montserrat Volcano Observatory, Hope Drive, Flemmings, Montserrat)

*benjamin.esse@manchester.ac.uk

Soufrière Hills Volcano, Montserrat, erupted in 1995 and has displayed several cycles of extrusive phases (characterised by increased seismic activity and a deflation signal) separated by pauses (with low seismic activity and radial extension). The last extrusive phase ended in 2010, making the current pause the longest since the eruption began. However, there is still sustained gas emission, with SO2 fluxes of roughly 150 – 400 tonnes/day, and monitoring of deformation continues to show ongoing, though slowing, extension. This raises questions about the current state of Soufrière Hills volcano and the potential for future activity.

SO2 flux measurements are the most common of volcanic gas measurements due to the typically high abundance of SO2 in a volcanic plume compared to an almost negligible background atmospheric concentration. SO2 has an absorption feature in the UV, making it possible to quantify with passive measurement of scattered UV sunlight passing through the gas plume. This led to the development of networks of scanning UV spectrometers to automatically monitor SO2 flux in real time and at moderate frequency (typically 5-10 minutes). Examples include the Network for Observation of Volcanic and Atmospheric Change (NOVAC) and Flux Automatic Measurement (FLAME) network. These networks require information of the plume altitude, direction of travel and speed to determine the flux, potentially leading to high uncertainty when not constrained well. The plume altitude and direction can be obtained geometrically when the plume is seen by multiple scanners simultaneously, however plume speeds can be more difficult to constrain.

We will present SO2 fluxes from a new scanning network deployed on Soufrière Hills Volcano, Montserrat, for 15 months (April 2019 – July 2020). This is an alternative to existing networks developed in partnership between Montserrat Volcano Observatory and the University of Manchester, named OpenSO2, which utilises a Raspberry Pi single board computer to control the scanner, handle data acquisition and analyse the spectra in real-time. The spectra are analysed using the iFit method, which does not rely on a measured reference spectrum like the typical Differential Optical Absorption Spectroscopy method used, meaning that the OpenSO2 scanner is not affected by contamination issues. We will also investigate different sources of wind speed data, including modelled wind and ground measurements, to determine the optimal solution for ongoing SO2 flux monitoring. We will discuss these results in the context of the ongoing activity at Soufrière Hills Volcano.

The abundance and origin of magmatic volatiles at Rabaul volcano, Papua New Guinea

Brendan MCCORMICK KILBRIDE* Peter Barry (Woods Hole Oceanographic Institute)

Tobias Fischer (University of New Mexico)

Emma Liu (University College London)

Margaret Hartley (University of Manchester)

Greg Holland (University of Manchester)

Romain Tartese (University of Manchester)

Caroline Bouvet de Maisonneuve (Nanyang Technological University)

Gareth Fabbro (Caraga State University)

*brendan.mccormickkilbride@manchester.ac.uk

Around our planet, hundreds of volcanoes are constantly emitting gas into the atmosphere. Over geological time, this volcanic outgassing is a key control on atmospheric composition, climate change, and planetary habitability, but how does volcanic outgassing vary, in chemical composition, in flux, and over what spatial or temporal scales? Measurements of gas emissions at active volcanoes suggest (i) a variable balance in the planetary reservoirs (e.g. mantle, subducting slab, crustal rocks) feeding outgassing, and (ii) wide disparities in outgassing flux between volcanoes. Are certain volcanoes or arcs inherently major contributors to planetary outgassing, due to the efficiency of volatile recycling in the adjacent subduction zone, unusually volatile-rich magmas, or persistent mafic recharge from depth? To address these questions, we need to combine studies of active outgassing today with analysis of volatiles in magmas sampled by past eruptions.

Rabaul is a caldera in Papua New Guinea that has been among Earth’s major outgassing sources in recent decades. Rabaul has a long history of activity, ranging from caldera-forming eruptions associated with dacitic ignimbrite and airfall deposits, to andesitic–dacitic intra-caldera vulcanian to subplinian explosive eruptions and lava flows, to basaltic eruptions from nearby extra-caldera stratocones. Recent petrological and geochemical studies suggest that the majority of Rabaul magmas originate by fractional crystallization from a parental basaltic melt, though mafic recharge and magma mingling and mixing is important in sustaining long-term volcanism, triggering eruptions and potentially feeding outgassing. Future eruptions at Rabaul pose a significant threat to regional populations and infrastructure, and further investigation of magma volatile contents, the present state of unrest, and possible signs warning of imminent eruptions are all important for monitoring and risk management.

We are offering a fully-funded PhD research opportunity at the University of Manchester in studying the magmatic volatile chemistry of the Rabaul system. We have acquired rocks and gas samples from around Rabaul caldera and will analyse rocks, minerals, and melt and fluid inclusions sampled from a diverse suite of eruptions at Rabaul. Our objective is to place constraint on the abundance and origins of volatiles in magmas sampled by eruptions of different styles, from different vents, and from different intervals in the caldera cycle. We seek to determine if recent high outgassing fluxes at Rabaul are characteristic of the volcano’s long-term behaviour or an artefact of our short period of modern observations. The petrological analyses undertaken by the student will complement ongoing monitoring and research on the chemistry and flux of volcanic gases around the caldera. The research project will also involve close partnership with Rabaul Volcanological Observatory. For more details, please contact the first author (/lead supervisor).

Textural insights into complex ascent dynamics and explosivity of a small-volume trachytic eruption on Ascension Island, South Atlantic.

Bridie V Davies* Jenni Barclay (School of Environmental Sciences, University of East Anglia, Norwich, Norfolk, NR4 7TJ, UK)

Richard Brown (Department of Earth Sciences, Durham University, Science Labs, Durham, DH1 3LE, UK)

Richard Herd (School of Environmental Sciences, University of East Anglia, Norwich, Norfolk, NR4 7TJ, UK)

Jane H Scarrow (Department of Mineralogy & Petrology, University of Granada, 18071, Granada, Spain)

*Bridie.Davies@uea.ac.uk

Small-volume trachytic eruptions are often poorly preserved or lack sufficient exposure to employ standard techniques for estimating eruption magnitude and intensity, particularly where volcanic activity is concentrated in a small area. Thus, estimates of magnitude/intensity/VEI may not correctly capture the explosive potential of these eruptions, and the hazards they pose may be underestimated. Despite being common in a range of settings and often exhibiting eruptive transitions, the dynamics of small-volume trachytic eruptions are relatively understudied compared to their calc-alkaline counterparts. The influence of high alkali content on the "reactivity" of these melts during ascent is beginning to be understood through studies of diverse juvenile clast textures and their records of rapidly evolving bubble-melt-crystal interactions(1,2).

The Echo Canyon volcanic edifice is the remnant of a 60 ka small-volume explosive-effusive trachytic eruption on Ascension Island, South Atlantic. We systematically traced changes to juvenile clast texture throughout this eruptive sequence. This allowed us to identify dominant controls on evolving bubble-melt networks, and their influence on eruptive style. We then evaluated bulk vesicularity distributions and compared them to several well-constrained eruptions show how fragmentation, outgassing pathways and explosivity changed over time.

Development of shear zones, at the peak of the eruption, as evidenced by high proportions of sheared clasts, induced coalescence, permeable outgassing, melt densification and obsidian formation. Incorporation of dense pumice clasts and obsidian fragments increased plume density and explosive degassing through tuffisite formation further reduced plume stability. Ultimately, these changes shifted the eruption towards column collapse and effusive activity. Bulk vesicularity distributions indicate that, prior to shear-induced outgassing, fragmentation was dominated by bubble-interference and rupture (3). Similarities between the bulk vesicularity distributions of these phases and that of the 1883 eruption of Krakatau suggest a transient peak-eruption intensity equivalent to a VEI 6 eruption. The broader distributions of later units suggest transient fragmentation dominated once densification was initiated. The weak bimodality of these distributions likely reflects the influx of dense clasts and secondary degassing pathway provided by tuffisite formation.

The potential for small-volume trachytic melts to reach high explosivities, produce PDC deposits and undergo multiple explosive-effusive transitions has implications for our understanding of volcanic hazard, particularly in remote ocean island settings like Ascension. Shear, melt densification, and obsidian and tuffisite formation exert a strong influence on plume stability and are key drivers of explosive - effusive transitions. Through systematic examination of clast textures in their stratigraphic context, we provide further evidence of the complex interactions facilitated by trachytic melts. Finally, we highlight the explosive potential of these small-volume eruptions, where traditional magnitude/intensity measures cannot be applied.

References:

1- Shea et al., (2017); doi: 10.1007/s00445-017-1106-z

2- Deniel et al., (2020); doi: 10.1007/s00445-020-01420-5

3- Mueller et al., (2011); doi: 10.1016/j.jvolgeores.2011.04.006

Modelling magma plumbing systems: a multidisciplinary approach

Caitlin Chalk* Dr Janine Kavanagh (University of Liverpool)

*c.m.chalk@liverpool.ac.uk

Magma plumbing systems are responsible for transporting magma from deep chambers towards the Earth's surface. Understanding the dynamic processes of magma transport is vital for interpreting volcanic field data, and ultimately for predicting whether or not an eruption will occur. Naturally, magma plumbing systems cannot be observed in the field, and it is only possible to examine ancient solidified intrusions that are revealed years of erosion. Experimental and mathematical models are therefore essential to gain insight into the complex and dynamic processes of magma transport as it occurs. Small-scale, analogue experiments – representing the injection of magma into host rock – allow for the direct observation of magma plumbing systems as they develop. Mathematical and numerical models can be employed to simulate plumbing systems at a much larger scale, and provide insight into the underlying physical processes of magma transport. However, these models make several key assumptions (such as a simplified magma flow profile) that have been challenged by the results of analogue models (e.g. Kavanagh et al. 2018). What's more, the results of numerical models are rarely compared with those of experiments. In this presentation I will talk about my new postdoc position where I will investigate magma plumbing systems with a combination of experimental and numerical models. This multidisciplinary approach is expected to bring significant advantages to models of magma transport, and bridge the knowledge gap between direct field observations and subsurface dynamic processes.

TROPOMI-PlumeTraj measurements of the April 2020 eruption of Piton de la Fournaise

Cat Hayer* Mike Burton (Uni of Manchester)

*Catherine.hayer@manchester.ac.uk

Piton de la Fournaise volcano erupted continuously from 2nd to 7th April 2020. The eruption plume from each day was captured by the Sentinel-5P instrument, TROPOMI.

TROPOMI is a polar-orbiting hyperspectral UV spectrometer, providing global daily coverage, and flying within the A-Train constellation of satellites. Its nadir resolution of 3.6 x 5.6 km is a massive improvement over previous generations of satellite spectrometers and has led to a step change in our ability to monitor and measure small and medium sized gas emissions from volcanoes around the world.

Data from 1st to 8th April 2020 were analysed using the PlumeTraj analysis toolkit which uses the HYSPLIT trajectory model to produce back trajectories from each pixel and assign an injection altitude and time and a measurement altitude to each pixel. This allows the column density of SO2 to be corrected for altitude, one of the major sources of uncertainty within satellite retrievals, so producing an accurate estimate of the emitted SO2 mass. This mass, combined with the injection time, produces an SO2 emission flux timeseries.

PlumeTraj allows for sub-daily measurements from a single satellite image, meaning it was possible to determine that the emission was continuous throughout the eruption, with some pulsatory behaviour visible in the timeseries.

The analysis showed that there were regularly two plumes, one at around 2 km and a higher plume between 4 and 6 km. The maximum SO2 mass, measured on 6th April, was 18.1 [+0.9/-0.7] kt.

Using dyke textures to reconstruct flow history

Ceri Allgood* Llewellin, Edward W. (Durham University), Humphreys, Madeleine C. S. (Durham University), Brown, Richard J. (Durham University), Vye-Brown, Charlotte (BGS)

*ceri.allgood@durham.ac.uk

Basaltic eruptions are the most common form of volcanism on Earth, spawning lava flows that can pose a significant hazard to property and essential infrastructure. These eruptions are typically fed by dykes – planar conduits that supply magma to eruptive fissures at the surface. Usually, basaltic eruptions initiate with effusive activity along the entire length of a fissure, before activity localises into discrete vents that can feed long-lasting lava flows. By examining the textures of phenocrysts and vesicles in exposed, solidified dykes, this project aims to develop a new tool for interpreting dyke flow patterns and their relation to eruptive activity. An improved understanding of how magmatic flow patterns evolve to localise fissure eruptions could increase understanding of the temporal and spatial distribution of volcanic hazards produced by this style of eruption.

Within an active dyke, elongated, rigid phenocrysts align with their long axis parallel to the flow, or – where collisions are prevalent – they stack in a manner indicative of flow direction. In addition, the degree of preferred orientation in a population of phenocrysts is related to the velocity gradient within the flow. An underlying principle of this project is that dykes cool and solidify inwards from their margins, leading to magma progressively accreting against the dyke wall. Consequently, a sequence is produced from the oldest textures at the margins, to the youngest textures in the dyke centre. An analysis of phenocrysts across the widths of dykes should therefore provide a time series showing changes in flow conditions throughout the dyke's emplacement.

The links between magma flow and resulting textures will be investigated through a mix of fieldwork and analogue experiments. A phase-change fluid (such as paraffin wax) carrying rigid particles will be passed through a chilled slot, allowing material to accrete against the walls. By establishing a relationship between phenocryst orientations and marginal accretion, subsequent measurements of phenocrysts across the widths of dykes could provide a new tool for unravelling their flow history.

Bulk rock geochemistry of a swarm of orangeite dykes intersecting the Western Limb of the Bushveld Complex: major and trace element abundances, and radiogenic isotope compositions

Charlie Compton-Jones* Hannah Hughes (University of Exeter), Jens Andersen (University of Exeter), Grant Bybee (University of the Witwatersrand), Judith Kinnaird (University of the Witwatersrand)

*cc715@exeter.ac.uk

The Western Limb of the Bushveld Complex hosts a vast, recently documented swarm of orangeite dykes that are significantly younger (177-132 Ma; Hughes et al., in prep.) than the c. 2.06 Ga Bushveld lithologies they intrude. Orangeite dykes are hybrid igneous rocks that form from very low-degree partial melting deep within the sub-cratonic lithospheric mantle (SCLM) and upon ascent entrain foreign material (mantle and crustal xenoliths and xenocrysts). Thus, they can be used to probe the composition of and processes within the ancient lithospheric mantle. Whereas similar orangeite dyke swarms typically span < 10 km, the considerable size of this swarm (> 50 km along strike and ~10 km wide) and number of closely-spaced dykes offers a unique opportunity to investigate the Kaapvaal SCLM on an unprecedented spatial scale. In this contribution we present the petrology, bulk rock major and trace element abundances, and radiogenic isotope compositions of the dykes.

The dykes are commonly bifurcating, up to a few metres thick, and are often composed of 'bands' representing multiple magma pulses. The dykes vary in compositions and textures but are commonly composed of olivine macrocrysts and phlogopite. Olivine macrocrysts (2–10 mm) are partially or entirely serpentinised, and phlogopite forms euhedral (micro)phenocryst laths (generally < 1mm, but up to 10 mm) as well as a main groundmass constituent.

The bulk rock Mg# ranges from 65 to 88, within the range of regional ultramafic lamprophyres and orangeites, and the dykes have major element compositions similar to the coeval Kaapvaal orangeite dyke swarms, Star and Swartruggens (Coe et al., 2008). Trace element abundances of the Bushveld orangeites are less consistent with Kaapvaal orangeite variability, displaying greater ranges in concentrations of certain elements (e.g. La, Th, Ba) despite being generally relatively depleted in these elements. Further depletion is present for Nb leading to extreme lithophile element ratio values (e.g. Ba/Nb and La/Nb), greatly exceeding that observed in the Star and Swartruggens orangeite dykes. Decoupling exists with respect to certain trace elements (e.g. Nb, Th, Gd) and specific trace element ratio pairings (e.g. La/Yb vs. Gd/Yb and La/Nb vs. Th/Nb), revealing two discrete sub-groups with indistinguishable major element concentrations displaying trace element trends not previously observed in global orangeite studies.

Radiogenic isotope compositions of the orangeites typically confine to global orangeite variability, with radiogenic Sr compositions (87Sr/86Sri of 0.70642 to 0.70787) and unradiogenic Hf compositions (εHfi of -18.3 to -8.3). Initial Nd compositions are generally unradiogenic (εNdi of -11.6 to -9.0), conforming to those of global orangeites, however three samples display elevated Nd (εNdi of -5.4 to -0.4) and plot in a similar Sr-Nd compositional space to Kaapvaal transitional kimberlites.

Using the trace element variations and radiogenic isotope compositions we aim to investigate the geochemistry of the mantle source regions tapped by the orangeites and whether we can identify changes in source characteristics on a swarm (and dyke?) scale.

References:

Coe, N. et al. (2008) Cont. Min. Pet. 156(5). 627-652.

Hughes, H.S.R. et al. (in prep)

How do crustal processes affect the behaviour of chalcophile elements in continental arcs?

Clara Matthews Torres* Eleanor S. Jennings (Birkbeck University London)

Chiara M. Petrone (Natural History Museum London)

Hilary Downes (Birkbeck University London)

Frances E. Jenner (The Open University)

*c.matthews-torres@nhm.ac.uk

Chalcophiles are a suite of 'sulfur loving' elements consisting of both metals and non-metals, many of which are highly sought after (e.g. Cu and Au). These economically important elements are commonly mined from sulfide rich porphyry ore deposits found along active continental arcs. However, the distribution of these chalcophile rich deposits appear to be sporadic across arcs. The manner and extent to which chalcophile element distribution and movement is affected by magmatic processes, such as sulfide saturation, magnetite fractionation and magma mixing remains unclear. This study aims to understand the processes governing the enrichment and depletion of chalcophile elements in a continental arc setting, with a particular focus on how the quantity of sulfur degassed during different volcanic episodes affects chalcophile element concentrations.

Two representative arc volcanoes have been chosen for this study. Popocatépetl, Mexico, is an active stratovolcano well known for its explosive behaviour and degassing of large quantities of sulfur. Given the relationship between chalcophiles and sulfur, this is an ideal location for study. Similarly, Santorini in Greece is a dormant volcano with a history of sulfur degassing. However, most striking is the region of extensional faulting in which Santorini lies, the role of which in local chalcophile element behaviour is not well studied, making this an interesting comparative location.

Samples will be studied using a combination of petrographic and analytical techniques including mass spectrometry to look at major, trace, volatile and chalcophile elements within and around melt inclusions. Data will be used to model crustal and mantle processes in order to trace magmatic evolution, enrichment and the ultimate fate of chalcophile elements within the continental arc setting.

Seismic Activity in the South Shetland Islands, Antartic Group: A Tectonic or Magmatic triggering?

Daniel Basualto Alarcón* Daniel Basualto Alarcón [Departamento de Ingeniería en Obras Civiles, Universidad de la Frontera], Cesar San Martin [Facultad de ingeniería y Ciencias, Departamento de Ingeniería Eléctrica, Universidad de la Frontera], Edgardo Casanova [Centro de Investigación GAIA, Universidad de Magallanes]

*daniel.basualto@ufrontera.cl

Tectonic or volcanic source? is the eternal question when we try to understand the processes that trigger seismic swarms in an active volcanic framework. The uncertainty increases if there is an incomplete geophysical network that allows real-time monitoring of seismic activity and deformation linked. This monitoring is critical if we want to understand potentially destructive geological phenomena such as earthquakes or eruptions, and their possible effects (landslides and tsunamis). In order to anticipate and suggest possible scenarios, researchers must promote resilience among the affected inhabitants. A thorough seismic analysis by the IRIS Global Network (JUBA) located in King Jorge Island (https://www.iris.edu/app/station_monitor/#Today/AI-JUBA/webicorder/AI-JUBA|11321172) has recorded seismicity triggered by active faults, with an impulsive arrival of Primary (P) and Secondary (S) waves, followed by surface waves. Compressive and extensive polarities, added to the different arrivals of the Δ(S-P) body waves (2.1sec to 3.7sec), support the coexistence of several seismic sources located close to each other (Φ≈25km, http://ds.iris.edu/seismon/zoom/index.phtml?rgn=S_Atlantic). Chilean official reports available on the website (https://www.inach.cl/inach/?page_id=29047 "MEV004-20201012_EstrechoBransfield-MonteSubmarinoOrca") suggest a volcanic source that triggers the swarms, classified as: volcano-tectonic (VT). However, since the beginning of the seismic crisis 08-28-2020 until 11-06-2020, the day with the highest magnitude recorded (Mw:6.0), the artificial intelligence automatic analysis and classification developed by the Engineering Group from the Universidad de La Frontera, Araucanía_Region, Chile (FONDEF-Project:N°ID19/10397) has only classified tectonic events (≈70,000) clustered in many swarms. The system has not identified earthquakes related with a volcanic source triggered by magmatic fluids such as Hybrids (HB), Long Period (LP) or Tremor (TR); therefore, we do not have evidence of volcanic activity until 06th November. One of the arguments that justifies the absence of volcanic earthquakes is the lack of nearby stations and the remoteness of the JUBA station from the most likely source, the Orca volcano (25km). Due to the complexity of analyzing seismicity just with a station (JUBA), it was decided to compare the data with other volcanic monitoring networks to suggest that signals >40μm (LP and TR) should be recorded at distances like >25 km, but this has not been recorded. This work also considered a second assumption, the JUBA station would be installed on a rocky basement (Paleogene lavas-flows, Kraus [2005]), that had a low noise level. This assumption is based on the ability to record earthquakes with <1μm in amplitude, and by the type of rock that has been exposed as a result of the current retreat that the glacier has suffered next to the Carlini Base. Finally, considering the large number of earthquakes, their magnitudes> Mw: 5.0 and the elapsed time (71 days), it is suggested that the seismicity recorded up to 06-11-2020 have mainly of tectonic origin. This information allows to prioritize possible scenarios, as it is discussed in the document: "Complementary Information, written in Spanish" (https://www.inach.cl/inach/?page_id=29047 "Informe_Técnico_actividad_tectonica_Islas_Shetland_del_Sur") which raises the possibility of this seismic crisis end with an earthquake that affects critical infrastructure of the Antarctic bases is proposed. We cannot dismiss that this earthquake triggers a volcanic activity in a new phase of this crisis.

Volumetric and compositional evolution of El Negrillar, one of the largest monogenetic volcanic field in the Central Andes, Chile.

Daniela Parra Encalada* Daniela Parra (Parra, D.) [Department of Geology and Centro de Excelencia en Geotermia de los Andes (CEGA), Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile]

Camila Loaiza (Loaiza, C.) [Department of Geology, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile]

Patricia Larrea (Larrea, P.) [Department of Geology and Centro de Excelencia en Geotermia de los Andes (CEGA), Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile]

Sergio Salinas (Salinas, S.) [Facultad de Ingeniería, División de Ingeniería en Ciencias de la Tierra, Universidad Nacional Autónoma de México, Ciudad Universitaria, C.P. 04510 Coyoacán, Ciudad de México, Mexico]

Benigno Godoy (Godoy, B.)[Department of Geology and Centro de Excelencia en Geotermia de los Andes (CEGA), Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile]

Petrus Le Roux (Le Roux, P.) [Department of Geological Sciences, University of Cape Town, Rondebosch 7700, South Africa]

Pablo Grosse (Grosse, P.) [CONICET and Fundación Miguel Lillo, Miguel Lillo 251, 4000 San Miguel de Tucumán, Argentina.]

*danielaparraencalada@gmail.com

El Negrillar is a monogenetic volcanic field located in the Central Volcanic Zone (CVZ) (latitude 14° to 28°S). This field is placed within The Altiplano-Puna Volcanic Complex (APVC; latitudes 21° -24°S) which was mainly formed by four high dacitic-to-rhyolitic magmatic pulses, and hosts basaltic-andesitic monogenetic volcanism erupted in the last 1 Ma (Godoy et al., 2019). The number and distribution of mafic centers along the arc front of the CVZ suggests that the rise of these magmas is structurally-controlled on a lithospheric scale, which provides paths for rapid magmatic ascent (e.g. Van Alderwerelt et al., 2017).

El Negrillar is located at the southern boundary of the APVC, made up of more than 25 eruptive centers distributed over ~168 km2. It is divided into three zones according to spatial distribution of centers, related to the Socompa volcanic debris avalanche deposit (DAD): 1) Northern El Negrillar (NEN) located to the NE of the DAD, 2) Central El Negrillar (CEN), adjacent to the eastern border of the DAD, and 3) Southern El Negrillar (SEN), to the SW of the DAD. The NEN contains nine volcanic vents, with one to five lava flows emitted; the CEN contains eight volcanic vents that emitted between two to seven lava flows each; and the SEN zone consists of nine volcanic vents, with one to six lava flows emitted respectively. All these flows are mainly characterized as blocky lava flow morphologies.

The magma volumes emitted by the CEN and SEN were calculated using a 12 m resolution TanDEM-X Digital Elevation Model with the ArcGIS(c) surface difference tool, after reconstructing the pre-volcanic topography in these areas. In both sectors, we estimated a total volume of vents, and the volume of each recognized flow. Both zones show similar emitted volumes, with 2.49 km3 for the SEN and 2.25 km3 for the CEN, comprising a total emitted volume of ~4.74 km3. These preliminary calculations position El Negrillar field as one of the most voluminous monogenetic systems in the CVZ.

According our preliminary geochemical data and previous data by Hoffmann (2011) the erupted magmas from the NEN are trachyandesites, andesites and dacites, the CEN range in composition from basaltic andesites to dacites with 57 - 65 wt.% SiO_2, whereas the SEN are trachyandesites with 60 wt.% SiO_2. Overall, these monogenetic volcanoes exhibit more mafic compositions than the evolved polygenetic volcanoes that characterize the Central Andes. These less-evolved magmatic products might provide information on deep magma generation processes, something not quite common within an area dominated by evolved compositions.

References

Godoy, B., ... & Menzies, A. (2019). Linking the mafic volcanism with the magmatic stages during the last 1 Ma in the main volcanic arc of the Altiplano-Puna Volcanic Complex (Central Andes). Journal of South American Earth Sciences, 95, 102295.

Van Alderwerelt, B. M. E. D. R. (2017). Diverse monogenetic volcanism across the main arc of the central Andes, northern Chile.

Hoffmann, C. (2011). Petrografía y Geoquímica de los conos del campo Negro de Aras. Undergraduate Thesis.

Eruptive History of Corbetti Caldera, Ethiopia

David Colby* David M. Pyle (Department of Earth Science, University of Oxford)

Karen Fontijn (Department of Geosciences Environment and Society, Université Libre de Bruxelles, Belgium)

Tamsin A. Mather (Department of Earth Science, University of Oxford)

Abate Assen Melaku (College of Natural Sciences, Addis Ababa University, Ethiopia)

Million Alemayehu (College of Natural Sciences, Addis Ababa University, Ethiopia)

Gezahegn Yirgu (College of Natural Sciences, Addis Ababa University, Ethiopia)

*david.colby@pmb.ox.ac.uk

Corbetti is the southernmost and one of the largest calderas within the Main Ethiopian Rift. Erupting predominantly crystal-free, homogenous peralkaline rhyolites, Corbetti has shown a diverse range of eruptive styles since a caldera-forming eruption ~178 ka [1-4]. The most recent explosive activity has focused around Urji and effusive activity centred around Chabbi, the two main post-caldera edifices. Presently, over a quarter of a million people live within 30 km of the caldera, therefore understanding the magnitude and style of past eruptive activity is critical to feed into efforts delimiting future risk.

Observations from a 3-week field campaign, in addition to pre-existing data [1, 2] has led to the production of a detailed account of activity at Corbetti and the compilation of a composite stratigraphy incorporating pre- and post-caldera deposits from Urji and Chabbi. This work recognised multiple potential ignimbrites and PDC deposits associated with large-scale eruptions which have not previously been documented. Multiple phases of activity have been identified which indicate that Corbetti has continued potential for large-scale Plinian eruptions and the generation of widespread PDCs. This work will continue to be built upon through geochemical investigation of deposits and intermediate crystalline lithics found within PDC deposits which will help aid our understanding of the evolution of peralkaline magmas.

References:

[1] Fontijn, K. et al. (2018) J. Volcanol. Geotherm. Res. 356: 90–113

[2] Hutchison, W. et al. (2016) Nat. Commun. 7:1–12

[3] Rapprich, V. et al. (2016) J. Volcanol. Geotherm. Res. 310:159–171

[4] Martin-Jones, C. M. et al. (2017) Geology 45: 1127-1130

Vesuvius, and the birth of modern volcanology

David Pyle* Emma Watts (University of Southampton)

Fay Amstutz (University of Oxford)

Monica Price (Oxford University Museum of Natural History)

Duncan Murdock (Oxford University Museum of Natural History)

*david.pyle@earth.ox.ac.uk

Vesuvius is continental Europe's most active volcano. From 1631-1944, it was persistently active, and switched in style between mild degassing, lava effusion, and vigorous eruption. Violent eruptions between 1767 and 1822 caught the attention of many interested observers, savants and natural historians, and paved the way for the establishment of the first permanent volcano observatory and the emergence of volcanology as a discipline. The rich legacy from this time – of physical samples, and written and visual records – opens up new opportunities for the forensic analysis of these past eruptions, and allows us to test ideas about the behaviour of persistently active volcanoes.

Introducing FTIR analysis of pumice + various research opportunities in Japan

Iona McIntosh* Dr Samuel J Mitchell (Edge Hill University, UK)

Dr Isobel Yeo (National Oceanography Centre Southampton, UK)

*i.m.mcintosh@jamstec.go.jp

Fourier Transform Infra Red spectroscopy (FTIR) is a versatile analytical technique whose geological applications include analysis of dissolved volatiles (H2O and CO2) in volcanic glasses. A notable advantage of FTIR for volatile analysis is that it can quantify water species, i.e. how much water is present as water molecules (H2Om) vs dissociated hydroxyl groups (OH). This water species information can be used to calculate cooling rates and glass transition temperatures and - crucially - to identify glasses affected by 'secondary hydration' after eruption and deposition.

Recent FTIR developments - the use of a species-dependent 3500 molar absorptivity coefficient, and application of FTIR imaging detectors - now enable successful reconstruction of glass volatile contents prior to secondary hydration, and analysis of vesicular glasses like pumice. With reference to submarine eruptions including the shallow 2019 pumice raft eruption in Tonga, deep 2012 eruption of Havre volcano, and late Quaternary eruptions of Oomurodashi volcano, Japan, I will highlight how FTIR analysis can provide new insights into a range of volcanic processes.

I will also introduce the range of research funding opportunities offered by the Japan Society for the Promotion of Science (JSPS) which may be of interest to the VMSG community, particularly PhD students and early career researchers. These include the JSPS Summer Program (an 8-week fully funded placement at a relevant Japanese institute) and independent postdoctoral fellowships spanning 1 to 24 months. Benefits of research in Japan include forming new international collaborations and access to state of the art analytical facilities, not to mention as many volcanoes as your heart could desire!

Flash Presentation - Edward McGowan

Edward G. McGowan* N/A

*emgowan1@hotmail.co.uk

I am a first year PhD student at the University of Leicester. My main area of research interest is in caldera explosive eruptions and investigating the pyroclastic deposits they produce. For my PhD project I shall be investigating the vent migrations and subsidence patterns produced during the collapse of Scafell caldera, an ancient volcano located in the English Lake District, using a combination of field observations and geochemical analysis.

I have also been conducting some exciting research into virtual volcanoes found within commercial video games. The aim of this project is to see how volcanic features and aspects are portrayed within video games that have been designed primarily for entertainment and not scientific accuracy. From this we hope to determine how we could use this form of media as an entertaining way of educating the public about volcanology.

A search for Olivine-hosted Melt Inclusions in the active Central CAVA Volcanoes Arenal and Cerro Negro to explore the degassing of basaltic systems.

Eilish Brennan* Prof Adrian Jones (Department of Earth Science,UCL)

*eilish.brennan.16@ucl.ac.uk

Volatiles are key drivers for volcanic eruptions. Primitive melt inclusions (MIs) record valuable information about pre-eruptive melt volatile concentrations but finding good MI candidates can be challenging. When found, MIs provide unique information on the volatile budgets of individual magmas enabling the reconstruction of magmatic pathways and degassing budgets. This study has targeted suites of olivine phenocrysts for MIs from a cluster of currently active Central American Volcanic Arc (CAVA) volcanoes. The studied area includes Arenal in northern Costa Rica and Cerro Negro in northern Nicaragua, as the two distinct endmembers. Both volcanoes have shown activity over the last two decades. In the region of interest, the slab geometry has a distinct steep nature, compared to the average of the CAVA, at a maximum of 64º and an extensively thinner crust at 25km (Syracuse & Abers, 2006). Therefore, these central CAVA volcanoes should be indicative of the high partial melting regime, deep mantle source and high volatile fluxes.

Raman spectroscopy confirmed the main, expected volatile phases, H2O and CO2, as well as indicating the presence of additional gaseous CH4, HCl, CO and SO2. The presence of CH4 suggests

the interaction of a deep mantle source from the steeply dipping slab beneath. FTIR results showed the segment of the CAVAs had higher magma H2O concentration in the front arc ~6.91wt% H2O at Cerro Negro. The Cerro Negro magmas are thought to represent end-member compositions formed by high degrees of mantle melting under particularly high fluid flux from the subducting Cocos Plate, perhaps related to deep dehydration of serpentinites from deep extensive bend faulting (Portnyagin et al., 2014). For the back-arc region, of Arenal, lower concentrations are expected, ranging from 1-3wt% H2O. Previous studies did, however, see ranges up to 7wt% H2O (Anderson, 1979). We repeated this upper limit with an average of 6.33wt% H2O and a range of 3.85 to 9.93 wt% H2O. The range in volatile content could be explained by the intermittent explosivity of activity at Arenal allowing new batches of the volatile-rich melt to accumulate. SEM/EDs data showed Arenal had a primary oxide composition of the whole rock closer to the groundmass than MIs suggesting they formed from an already matured melt. Cerro Negro has a higher partial melt which is less mature and has a higher volatile content. The trend of increasing degassing and decreasing oxide content of the MIs to glass defines a robust trend of magma fractionation from depth to surface, especially seen at Cerro Negro. To the extent which a short project can allow, this showed that lavas sampled at Cerro Negro volcano consistently define more primitive compositions, whereas lavas sampled at Arenal volcano are more evolved, and both these volcanoes are driven by magmas melted from a volatile-rich source in the upper mantle showing a strong correlation to prior studies. The degassing extent was not determined, as EMPA of the volatile content of the glass was not completed to make this applicable for modelling.

Accounting for Thermal Resorption of Bubbles in Experiments and Eruptions

Eleanor Dunn* Ed Llewellin (Durham University)

Fabian B. Wadsworth (Durham University)

Madeleine C.S. Humphreys (Durham University)

*mjqk56@durham.ac.uk

The growth of bubbles drives volcanic eruptions and plays a major role in determining eruption style. Consequently, understanding bubble growth processes is essential for forward modelling of volcanic eruptions, and for interpretation of vesicular eruptive products. Decompression experiments at high temperature and pressure have been widely used to investigate bubble growth processes. However, most studies neglect bubble resorption that occurs during the quench process as water solubility increases with decreasing temperature. Resorption may alter final textures, so accounting for this process is important for interpretation of experimental products.

This project aims to quantify the extent to which bubble resorption during cooling/quenching modifies the syn-experimental textures. We will apply a numerical model that captures bubble growth and resorption processes over arbitrary pressure-temperature pathways to published datasets. Our analysis includes (1) studies that explicitly consider resorption and (2) studies that do not consider resorption. We use (1) as a calibration step in order to validate our model approach and we use (2) to test the extent to which experimental studies may have been over-printed by thermal resorption processes. We restrict our analysis to experiments in which crystal content remains low, in line with the assumptions of the numerical model, and to studies that give sufficient experimental details to allow accurate modelling. The model will be used to investigate the influence of resorption on various experimental and natural scenarios, including repeated cycles of decompression, quenching and heating, post-eruptive expansion of bubbly pyroclasts, and post-emplacement cooling-driven resorption in pyroclasts.

The numerical model will indicate conditions under which thermal resorption must be accounted for in the interpretation of experimental results. This research will also demonstrate that the numerical model can be used as a tool to design experiments that minimise the effect of resorption. Finally, we anticipate that the model will allow the effect of resorption to be ‘removed’ from both experimental and natural samples, supporting more meaningful interpretation of textures.

Lost in Translation? Exploring the journey from press releases to news articles and mainstream media during volcanic crises, and its impact on public perceptions.

Elena Jones* Natasha Dowey (University of Hull)

Rebecca Williams (University of Hull)

Lewis Holloway (University of Hull)

*elena.jones-2017@hull.ac.uk

During a volcanic crisis, effective communication between volcano observatories, local government, civil defence authorities, the media and the public is crucial in ensuring the safe management of the situation. A breakdown in this chain of communication may lead to unsafe behaviours, mistrust of authorities, economic impacts, anxiety, or at worst, fatalities (see Williams and Krippner, 2019). Over the past 100 years, various stakeholders have made progress in volcanic crisis communication, but the 21st century presents significant challenges (Fearnley et al. 2017).

The world in which we communicate has changed rapidly in recent years; information from official bodies can be posted, shared, translated, re-interpreted and disseminated rapidly via online news outlets and social media. Widespread use of the internet means crises communications must now be fast paced and sustained, pushing the limits of those working in internal communication (Driedger et al., 2008). The modern drive of journalism to create different angles and interesting 'stories' can lead to conflicting comments from multiple sources, which could cause public doubt about how well a hazard is being monitored and managed (McGuire et al, 2009).

This project aims to better understand how the 'translation' of press releases by the mainstream media impacts the behaviours and perceptions of the local and global community during a volcanic crisis.

To achieve this aim, the project will focus on two research questions:

1. How is the language used in volcanic crisis press releases variably 'translated' into mainstream media?

2. How is this language viewed and interpreted by the general public, and what impact does it have on perceptions of volcanic hazards, risk and uncertainty?

This project will use two methodologies. Firstly, press releases and their associated media be analysed to assess how information becomes translated and adapted. The communication of volcanic crisis information will be categorised and compared across different countries, languages, types of volcanism, and types of media, using recent case studies (e.g. Hawaii 2018 and Agung 2017). The second stage will investigate the impact of the translation/adaption of press releases by various media channels on public perceptions. Two focus groups will be carried out to provide a comparison; one group will read materials from the original press release and the other from social media/news articles. Both groups will then answer the same set of questions, allowing for critical comparison.

This research will develop understanding of the power of modern communication to influence the public during volcanic crises. It will provide insights into how press releases are translated, with the potential to provide important learnings for the organisations that create and distribute them.

References

Bird et al. (2012) Australian Journal of Emergency Management. (1)

Driedger et al. (2008) USGS Professional Paper 1750.

Fearnley et al. (2017) https://doi.org/10.1007/11157_2017_28

McGuire et al. (2009) https://doi.org/10.1016/j.jvolgeores.2009.02.019

Williams and Krippner (2019) https://doi.org/10.30909/vol.01.02.i-viii

Modelling eruptive events in distributed volcanic fields

Elisabeth Gallant* Lawrence Cole [unaffiliated], Chuck Connor [University of South Florida], Paul Wetmore [University of South Florida], Danielle Molisee [University of South Florida], Amy Donovan [Cambridge], Rory Walshe [Cambridge], Julie Morin [Cambridge]

*eg604@cam.ac.uk

We present a new approach for modelling vent opening source parameters to better assess hazards related to distributed volcanism. Proximal hazards associated with the opening of a new vent include ground deformation, seismicity, gas emissions, and (potentially) spatter (impact within ~100m of the source). Distal hazards may include lava flows and tephra dispersal (impact may be 10's of km from the source). We refer to the entirety of an eruption and all associated distal hazards as an eruptive event. Traditionally, each eruptive vent within a distributed system has been used to calculate the most likely source location for the next eruption. While this is an appropriate method for modelling proximal hazards, it may incorrectly model the source locations for these distal hazards because the equal weighting of points ignores the fact that most of the volume erupted during an event is sourced from a small number of vents (e.g., the most recent eruption at Kīlauea hosted an impressive 24 individual fissures, but the overwhelming majority of the lava effused from a single cone). Another way to think about this is that vent opening models address direct hazards at the surface, whereas event opening models capture deeper processes associated with magma generation and ascent. For this reason, we assert that event models are more appropriate for integration with additional hazard forecasts (such as lava flows or tephra dispersal modelling). We take the next step by identifying the inter-dependence of volcanic vents with hierarchical clustering algorithms to link dependent volcanic vents in time and space to define the source locations for volcanic events. The Craters of the Moon (USA), Yucca Mountain (USA), and Pali-Aike (Chile-Argentina) distributed volcanic fields are used to illustrate the strengths and weaknesses of this approach on examples with varying dataset completeness.

Controls on the spatial distribution of health impacts arising from the 2014-2015 Holuhraun eruption

Elizabeth Sheilah Blanchard* Jazmin P. Scarlett (1. School of Geography, Politics and Sociology, Newcastle University, Claremont Road, Newcastle Upon Tyne 2. Independent Researcher)

*elizabeth.blanchard1999@outlook.com

Gases released during fissure eruptions are known to adversely impact the health of nearby populations. Recent work however, has hypothesised that more complicated interactions (i.e. other than the simple distribution of pollutants), must be considered when investigating the controls on the spatial distribution of health impacts related to fissure eruptions. Several potential variables associated with the spatial distribution of eruption-induced health impacts have been investigated to identify the main controls during the 2014-2015 Holuhraun eruption in Iceland. Consideration has been given to differences in SO2 concentrations, aerosol optical depth (as a proxy for ground based atmospheric particulate matter with a diameter of less than 2.5 micrometres), financial income and population size between Icelandic postcodes. Variables have been statistically and graphically compared with medical records, including visits to Primary Health Care Centres, and visits to Emergency Departments throughout the country with a particular focus on those linked with individual respiratory issues. Results highlighted, contrary to previous research, that during the Holuhraun eruption, the distribution of pollutants did not have the most significant correlation on the spatial distribution of health impacts. Instead, the spatial distribution, was most strongly associated with population characteristics and the nature of the environment within the postcode. Future research will need to consider whether the patterns identified are correct, or if slow onset of eruption-triggered health impacts are responsible for the apparent lack of correlation with the distribution of pollutants. Meteorological data should also be studied to assess whether a connection to health impact spatial distribution can be identified.

Tracking subducted CO_2 into the shallow mantle wedge using halogens and trace elements

Elliot Carter* Brian O'Driscoll (University of Manchester, UK), Ray Burgess (University of Manchester, UK), Patricia Clay (University of Manchester, UK), Marguerite Godard (Université Montpellier, France), Romain Lafay (Université Montpellier, France), Emma Bennett (Cardiff University, UK), Fatma Kourim (Academia Sinica, Taiwan), Hélène Balcone-Boissard (Sorbonne Université, France),Oman Drilling Project Science Team

*elcarter@tcd.ie

Recent research suggests that much of the CO_2 released by deep decarbonation in subduction zones may be focused along the slab-wedge interface into the forearc [1]. Quantifying the carbon budget of subduction zones and the origins of CO_2 in arc magmatism therefore requires an understanding of the lateral trenchward mobility of CO_2-rich slab fluids. Fully-carbonated peridotites overlying the basal thrust of the Oman Ophiolite attest to CO_2-rich fluids fluxing the shallow mantle wedge which may be the result of trenchward migration of CO_2 from deep in the subduction zone or, alternatively, from shallow expulsion of fluids. In order to distinguish between these possibilities it is necessary to identify the sources of fluids during carbonation.

Interlayered carbonated peridotites and serpentinites, the basal thrust, and the underlying metamorphic sole of the Oman Ophiolite have recently been sampled by diamond wireline coring as part of the Oman Drilling Project (ICDP Expedition 5057). Eighty four samples from the ~300 m long core have been analysed for their major, trace and volatile element characteristics. A subset of 6 samples spaced across a carbonation reaction zone has been closely studied by electron-probe element mapping and analysed for their whole-rock halogen abundances (F, Cl, Br, I) by pyrohydrolysis. In-situ halogen abundances were measured for each of these samples in serpentine (n=95) and carbonate (n=104) by secondary-ionisation mass spectrometry (SIMS). This unique dataset allows us to interrogate the metasomatic history of the lowermost Oman mantle section in detail.

Our data reveal multiple episodes of high and low temperature metasomatism. Normalised rare-earth element abundances are heterogeneous between the carbonated peridotites, as are the abundances of typically immobile trace elements including Ti, Al and Co. These features suggest that, pre-carbonation, the mantle section underwent a phase of high temperature fluid infiltration similar to that which resulted in amphibole-lherzolites elsewhere in Oman [2].

Patterns of enrichment in fluid-mobile elements suggest that, following high-temperature infiltration, there were two episodes of CO_2-rich metasomatism. This is confirmed by mineral halogen abundances which form two arrays at high and low F/Cl. Linking these SIMS data with petrographic observations indicates that the higher F/Cl fluids were later and that they derive from the metamorphic sole lithologies.

In-situ serpentine and bulk carbonate heavy halogen compositions lie along a single tight array, suggesting formation by fluids with a common origin. The serpentine endmember of this array is dissimilar from compositions in the wider literature, but can be explained by fractionation of fluid during carbonation, reducing CO_2/H_2O and Br/Cl. Modelling this process suggests that the initial carbonating fluid composition was CO_2-rich and Cl-poor, inconsistent with shallow expulsion of sedimentary pore fluid. However, deeper decarbonation reactions in the slab could have plausibly supplied this high CO_2/Cl fluid. This suggests that much of the CO_2 released from the slab beneath the proto-Oman ophiolite was focussed into the forearc mantle. This has important implications for the CO_2 budget of subduction zones through Earth history.

[1] Barry et al. (2019) Nature 568; [2] Khedr et al., (2014) Gondwana Res. 25.

What is the permeability of magma mush?

Eloise Bretagne* Fabian B. Wadsworth (Department of Earth Sciences, Durham University, Durham, U.K.)

Katherine J. Dobson (Department of Civil & Environmental Engineering, University of Strathclyde, Glasgow, U.K.)

Jérémie Vasseur (Department of Earth and Environmental Sciences, Ludwig-Maximilians-Universität, Munich, Germany)

Jason P. Coumans (Department of Earth Sciences, Durham University, Durham, U.K.)

*eloise.bretagne@durham.ac.uk

The extraction of melt from a mush in a magma reservoir is of wide interest. All models for melt extraction from a mush require knowledge of mush permeability, and yet this remains poorly constrained. This permeability is typically calculated using the Kozeny-Carman model or variants thereof, which require a priori knowledge of the microstructural geometry. Such models are not calibrated or tested for packs of crystals of a range of shapes found in natural mush piles, leading to the potential for oversimplification of complex natural systems.

Essentially, a magma mush with minimal crystal-crystal intergrowth is composed of packed crystals where the pore space is filled with interstitial melt. Therefore, this can be studied as a granular medium. We use numerical methods to create domains of closely packed, randomly oriented cuboids in which we keep the short and intermediate axes lengths equal (i.e. square cross section) and vary the long axis magnitude. Our synthetic 'crystals' therefore cover the range from oblate to prolate, passing through a cubic shape. We supplement these with 3D numerical packs of spherical particles in cubic lattice arrangements or random arrangements. For the sphere packs we use various polydispersivity of sphere sizes. The permeability of all of these pack types is calculated using a numerical simulation (both LBflow and Avizo-based algorithms) with imposed periodic boundary conditions. The preliminary results suggest that the permeability of a granular medium scales with the specific surface area exclusively, without requiring prior knowledge of the geometry and size distribution of the particles.

We suggest that the model toward which we are working will allow magma mush permeability to be modelled more accurately. If our approach is embedded in existing continuum models for mush compaction and melt extraction, then more accurate estimates of melt accumulation rates prior to very large eruptions could be found.

The Twitter Response to the 3rd of June 2018 Eruption of Volcan de Fuego, Guatemala

Emily Aspinall* N/A

*qk18833@bristol.ac.uk

Modern society is dominated by the internet and social media, with 3.96 billion active social media accounts worldwide, and with that figure expected to rise exponentially in the coming decade; whether we like it or not, social media permeates into our lives daily. However, when it matters can social media platforms such as Facebook and Twitter provide efficient communication of risk to communities threatened by volcanoes. Many Geological Institutes now have a social media presence to better engage, inform and educate the general public. Social media platforms also can disseminate vital information on a developing volcanic event. Conversely, Social media has also created a platform for the spread of misinformation and malicious content, which during a volcanic crisis can unduly influence and endanger communities. The eruption of Volcán de Fuego on June 3rd, 2018, was a catastrophic disaster where social media played both a positive and negative role in the disaster. Both INSIVUMEH and CONRED issued warnings via social media of the ensuing catastrophe, to varying degrees of success. To further complicate the situation, misinformation spread across social media resulted in avoidable fatalities.

Understanding basaltic Plinian activity at the Las Sierras-Masaya caldera complex, Nicaragua

Emily C Bamber* Fabio Arzilli (University of Manchester)

Mike Burton (University of Manchester)

Margherita Polacci (University of Manchester)

Giuseppe La Spina (University of Manchester)

Mattia de' Michieli Vitturi (INGV Pisa)

Margaret Hartley (University of Manchester)

Maurizio Petrelli (University of Perugia)

Danilo Di Genova (University of Bayreuth)

Jonathan Fellowes (University of Manchester)

*emily.bamber@postgrad.manchester.ac.uk

Basaltic volcanism is the dominant type of volcanic activity on Earth. Basaltic volcanoes produce a diverse range of explosive activity, from effusive eruptions to mildly explosive eruptions and paroxysms. However, highly explosive basaltic Plinian activity also occurs, ejecting several km3 of tephra into the atmosphere, with a large impact on the local environment and climate. Explosive Plinian eruptions arise from the brittle fragmentation of magma within the conduit during magma ascent. Although the low viscosity of basaltic magma should preclude its fragmentation, with increasing magma viscosity and under high strain rates, the potential for magma fragmentation increases, and also the possibility of a highly explosive, hazardous eruption.

The Las Sierras-Masaya caldera complex, Nicaragua, has exhibited diverse explosive behaviour through time. The active crater of Masaya caldera currently hosts a lava lake and produces degassing and mildly explosive activity. However, Masaya caldera has produced 3 basaltic Plinian eruptions in the past 6000 years, including the Masaya Triple Layer (2.1 ka) eruption, which ejected a total tephra volume of 3.4 km3. The older Fontana Lapilli (60 ka) eruption produced a maximum tephra volume of 3.8 km3. However, despite this variation in explosivity, erupted products of the Las Sierras-Masaya caldera complex show geochemical homogeneity through time, raising further questions on the cause of the explosive-effusive transition of this volcanic system.

We present a petrological investigation into the Masaya Triple Layer eruption, examining major element chemistry, volatile concentrations and microtextures. We combine our petrological data with rheological and thermodynamic models to determine the pre- and syn-eruptive conditions which may have promoted the increased explosivity of this eruption. We find that moderate pre-eruptive storage temperatures of 1080-1100°C, a low initial H2O concentration of ~2 wt.% and rapid syn-eruptive crystallisation of microlites within the conduit were conditions which favoured the increased explosivity of the eruption. Comparable conditions have been determined for the Fontana Lapilli eruption and the 122 BC Plinian eruption of Etna, Italy, suggesting that there may be a common set of physico-chemical magmatic conditions which favours highly explosive Plinian eruptions at basaltic volcanoes.

Rapid metal pollutant deposition from the volcanic plume of Kīlauea, Hawai'i

Emily Mason* Evgenia Ilyinskaya (University of Leeds), Penny E. Wieser (University of Cambridge), Lacey Holland (University of Hawai'i at Mānoa), Emma J. Liu (UCL), Tamsin A. Mather (University of Oxford), Marie Edmonds (University of Cambridge), Rachel C. W. Whitty (University of Leeds), Tamar Elias (Hawaiian Volcano Observatory, United States Geological Survey), Patricia A. Nadeau (Hawaiian Volcano Observatory, United States Geological Survey), David Schneider (Alaska Volcano Observatory, United States Geological Survey), James B. McQuaid (University of Leeds), Sarah E. Allen (University of Bern), Clive Oppenheimer (University of Cambridge), Christoph Kern (Cascades Volcano Observatory, United States Geological Survey), David Damby (California Volcano Observatory, United States Geological Survey)

*em572@cam.ac.uk

Long-lived basaltic volcanic eruptions are a globally significant source of environmentally-reactive 'metal pollutant' elements such as Cd, Pb, and Se. The 2018 eruption of Kīlauea, Hawai'i produced exceptionally high discharge of metal pollutants, and was an unprecedented opportunity to track them from vent to communities more than 200 km downwind. We found that lower tropospheric concentrations of all elements decreased to less than 10% of the source within 40 km of downwind transport. However, volatile metal pollutants (e.g., Se, Cd, Pb) were depleted up to100 times faster than refractory species (e.g., Mg, Fe) over this initial distance, demonstrating that volatility is an important control on the atmospheric behaviour of elements. At Kīlauea, the rapid wet deposition of complexes containing volatile metal pollutants, with their high environmental reactivity and potential toxicity, may place disproportionate environmental burdens on populated areas close to active vents, and lessen the impacts on far-field communities. These results have implications for assessing hazards from volcanic emissions, and for understanding the geographic scale and intensity of environmental and health impacts associated with episodes of basaltic volcanism.

How to assemble felsic magma before eruption

Emma Rhodes* Abigail Barker (CNDS, Uppsala University)

Steffi Burchardt (CNDS, Uppsala University)

Dave McGarvie (Lancaster University)

Tobias Mattsson (Stockholm University, University of St Andrews)

Tobias Schmiedel (Uppsala University)

Erika Ronchin (Sapienza University of Rome)

Taylor Witcher (Uppsala University)

*emma.rhodes@geo.uu.se

Knowledge of the structures and dynamics within sub-volcanic plumbing systems are a prerequisite to interpreting geophysical signals at active volcanoes. One particular research question regards the assemblage of larger volumes of felsic magma at shallow levels prior to eruption. The Neogene felsic Reyðarártindur Pluton presents a shallow level analogue to the modern day rift zone plumbing systems and is at present exposed due to ca. 2 km of glacial erosion. In order to build a model for the pluton's development, we (1) characterized the volume, shape and structure of the magmatic body, and (2) investigated the relationships of the different magmas and considered the structure of the deeper magmatic source. For this purpose, we undertook detailed field mapping, 3D structural modelling and geochemical analysis of the pluton.

3D modelling shows a complex shape characterised by flat roof segments which are offset in blocks with steep walls. A minimum volume of 2.5 km3 was calculated to -50 masl. The pluton roof is pervasively intruded by dykes originating from the pluton. In three locations, the pluton roof displays depressions, which are associated with magmatic breccias and conduit-like features. The pluton is all felsic in composition and can be separated into four geochemically related, but texturally and compositionally distinct groups: The Main Granophyre (69.9 to 77.6 wt.% SiO2), Granite Enclaves (69 to 72 wt.% SiO2), Quartz Monzonite Enclaves (63 to 65.2 wt.% SiO2), and the River Matrix (67 to 72 wt.% SiO2). The dominant magma is the Main Granophyre, while the exposure of the River Matrix, Quartz Monzonite and Granite Enclaves are restricted to the Reyðará River Mixing zone, which is the lowest exposure of the pluton. All of the Reyðarártindur samples have metaluminous, tholeiitic signature and low Fe/Ca ratio typical of rift zone rhyolites.

Varieties of the Main Granophyre magma were emplaced first and accompanied by mixing and mingling within sills emplaced at different topographical elevations. Subsequently distinct magma batches forming the Granite Enclaves followed by Quartz Monzonite Enclaves intruded into the base of the pluton, likely as radiating sills or pillows. Mixing between the Main Granophyre and the enclaves produced the River Matrix. Vertical growth of the pluton was likely accommodated by floor subsidence into the deeper source reservoir. Mingling among magmas with quartz monzonite to granite composition likely contributed to conduit formation and eruption, evidenced by the mixed compositions within the conduits.

Reyðarártindur intruded during a period of high volcanism coinciding with the initiation of the Northern Rift Zone around 7 to 8.5 Ma. Comparison to the geochemical signatures of modern day felsic volcanics reveals a signature similar to developed rift zone central volcanoes such Kerlingafjöll or Krafla. The structure of Reyðarártindur therefore provides an example of how larger volumes of felsic magma can accumulate at shallow levels and give rise to eruptions in a rift zone volcano.

Mantle sources of Icelandic flank and rift zones: Forward modelling of a heterogeneous mantle to recreate trace element signatures

Emma Waters* Margaret Hartley (University of Manchester)

Oliver Shorttle (University of Cambridge)

David Neave (University of Manchester)

Ray Burgess (University of Manchester)

Alison Pawley (University of Manchester)

Sæmundur Halldórsson (University of Iceland)

*emma.waters@manchester.ac.uk

The Icelandic mantle is lithologically and chemically heterogeneous. Depleted anhydrous peridotite, harzburgite, pyroxenite and primitive mantle material are all components of the Icelandic mantle. Pyroxenite is proposed as recycled oceanic lithosphere but the spatial structure of this component remains uncertain [1].

Basaltic melts supplied to Iceland vary between tholeiitic in the active rift zones and intermediate to alkali basalts in the flank zones. We have collected melt inclusions from the Snæfellsnes and Oræfajökull flank zones and Miðfell (Western Volcanic Zone) to transect the Icelandic mantle and investigate heterogeneity across the mantle plume.

We utilise REEBOX Pro software [2] to model the melting of a three component upper mantle beneath Iceland containing anhydrous lherzolite, harzburgite and pyroxenite. Further melt mixing between the melts produced from REEBOX and primitive mantle melts is then conducted. Modelled compositions are compared to those measured from melt inclusions to find acceptable fits. Matched compositions are used to infer the role of differing mantle lithologies in the production of melts in each sample area.

Miðfell possesses two distinct trace element trends within its melt inclusions. Firstly an incompatible trace element (ITE)-depleted signature derived from purely melting of anhydrous peridotite at shallow depths in the mantle. The second moderately ITE-enriched signature is derived from mixing anhydrous peridotite melts (20-70%) with pyroxenite-derived melts (10-20%) produced at greater depths and primitive mantle melts (35-70%).

Enriched signatures from Oræfajökull involve a similar scenario to the enriched signatures of Miðfell, with a greater contribution from the pyroxenite-derived melts (up to 30%). Snæfellsnes melt inclusions possess the most ITE-enriched compositions. These enriched compositions are derived from melting pyroxenite and peridotite at the same mantle depth (67-92 km) and mixing these melts to produce a bulk melt composition. The mixed melts are majorly comprised of pyroxenite-derived melts. The proportion of pyroxenite-derived melts in the mixed composition reduces moving towards inland Iceland.

Pyroxenite is an important lithology involved in the mantle source of both plume-influenced Icelandic melts (Miðfell and Oræfajökull) and non-plume-influenced melts (Snæfellsnes). The greatest contribution from pyroxenite-derived melts is seen in the Snæfellsnes flank zone, far from the influence of the deep-seated mantle plume. The role of different mantle lithologies in melt generation differ across Iceland and within melts involved in a single eruption (Miðfell).

[1] Shorttle et al (2014) EPSL 395, 24-40

[2] Brown and Lesher (2016) G3 17 3929-3968

Evolution of the Alu-Dalafilla and Borale volcanoes, Afar, Ethiopia

Emma Watts* Dr Thomas Gernon (University of Southampton), Dr Rex Taylor (University of Southampton), Dr Derek Keir (University of Southampton, University of Florence), Dr Melanie Seigburg (University of Southampton), Dr Carolina Pagli (University of Pisa), Dr Anna Gioncada (University of Pisa).

*e.j.watts@soton.ac.uk

The Danakil depression marks a progressive change from continental rifting in Afar to seafloor spreading further north in the Red Sea. Extension and volcanism in this incipient spreading centre is localised to the ~70-km-long, 20-km-wide active Erta Ale volcanic segment. Here, we combine remote sensing and major element geochemical analysis to determine the structure and composition of three volcanoes on the Erta Ale Volcanic Segment: the Alu dome, the Dalafilla stratovolcano and the Borale stratovolcano. We investigate the evolution and compositional variation within and between these volcanic complexes. Our results show that most flows are sourced from scoria cones and fissures, representing in total 15 phases of volcanism that occurred within four major eruptive stages, most likely occurring in the last 80 thousand years (kyr). The first stage represents large-scale fissure volcanism, comprising submarine basaltic phases. Stage two involves basaltic fissure volcanism around Alu. The third stage is dominated by trachy-andesite to rhyolitic volcanism from the volcanic edifices of Alu, Dalafilla and Borale and the fourth by a resumption of small-scale basaltic/trachybasalt fissure systems. Geochemical modelling indicates a paucity of crustal assimilation and mixing within the sub-volcanic magmatic system. Spatial analysis of volcanic cones and fissures within the area indicate the presence of a cone sheet and ring faults. The fissures are likely fed by sills connecting the magma source with the volcanic edifices of Alu and Borale. Our results reveal the cyclic nature of both eruption style and composition of major volcanic complexes in rift environments, prior to the onset of seafloor spreading.

Sulphur in basaltic explosive eruptions from Okataina (Aotearoa New Zealand)

Ery Hughes* Geoff Kilgour (GNS Science), Heidy Mader (University of Bristol), Jon Blundy (University of Oxford)

*ehughes@caltech.edu

The behaviour of sulphur in igneous systems is more complex than the other major volatile components (H_2O and CO_2) because sulphur can occur in multiple oxidation states (from S^{6+} to S^{2-}), species (e.g., SO_4^{2-}, SO_2, FeS, H_2S, etc.), and phases (gas, silicate melt, immiscible sulphide liquid, solid anhydrite) at magmatic conditions. Volcanic SO_2 emissions can lead to both local and global changes in the environment and climate, such as the poor air quality associated with the 2018 Kīlauea eruption (Hawaii); the haze and associated environmental effects across Europe and beyond from the 1783–1784 Laki eruption (Iceland); and global cooling of almost 1 °C in the northern hemisphere following the 1991 Pinatubo eruption (Philippines). Environmental impacts from basaltic magmas are typically associated with long-lived, fissure eruptions (e.g., Kīlauea and Laki mentioned above and flood basalts) but short-duration, highly-explosive basaltic eruptions can also generate significant SO_2 emissions. We have measured high sulphur contents (2000–4000 ppm S) in melt inclusions from basaltic magmas from Okataina, Taupō Volcanic Zone (Aotearoa New Zealand). These basaltic magmas generated a wide range of explosive eruption styles and span a range of sizes, from Strombolian to Plinian. Hence, the eruption of Okataina basalts may lead to significant environmental impacts at a range of spatial scales.

We use our new thermodynamic model to understand the behaviour of sulphur in Okataina basaltic magmas by constraining the conditions that generate such high melt sulphur concentrations. We find that the magma must have been oxidised (ΔNNO 0 to +2) to avoid sulphide-saturation and must have had low initial total volatile concentrations to avoid vapour-saturation; otherwise, the melt sulphur concentration would not have increased during progressive crystallisation. These conditions match our MELTS modelling (ΔNNO+1 and ~2 wt% H_2O initially) and volatile concentration measurements of melt inclusions (e.g., ~2 wt% H_2O initially) in addition to literature whole rock Fe^{3+}/Fe_T measurements (ΔNNO 0 to +3) [1]. Using erupted volumes from deposit mapping [2,3] and our melt inclusion sulphur concentrations, we calculate that the Rotokawau (3.44 ka) and Tarawera (1886 C.E.) eruptions released 7–12 Mt SO_2 each. This is equivalent to 30–50 % of the annual volcanic SO_2 emissions globally today [4] released in each eruption. The Rotokawau eruption likely only had local environmental effects as the eruption columns were only 5–8 km high [2]. Conversely, the Plinian-intensity eruption column/s from Tarawera reached ~28 km high [3] and there is evidence for cooling in the southern hemisphere in the 1–2 years after the eruption [5,6].

References: 1 Nairn (2002), 2 Beanland (1989), 3 Walker et al. (1984), 4 Carn et al. (2017), 5 Picas and Grab (2020), and 6 Harvey et al. (2020).

3D diffusion of water in melt-inclusion-bearing olivine phenocrysts

Euan J. F. Mutch* Megan Newcombe (University of Maryland, College Park, USA)

*ejfmutch@umd.edu

Rapid diffusion of hydrogen (as H+ ions) through the olivine crystal lattice can help and hinder the interpretation of volatile concentrations in the crystal record. Rapid diffusive re-equilibration obscures the melt inclusion record, but it can also be an exciting chronometer that can track magmatic processes that occur hours to even minutes before eruption, such as final magma ascent. Many studies often use spherical or 1D models to track melt inclusion dehydration that fail to account for complex geometries, diffusive anisotropy and sectioning effects. We have developed a finite element 3D diffusion model for H+ in olivine using FEniCS. The model includes physical domains for a spherical melt inclusion and the surrounding host olivine. The boundary between these domains accounts for olivine-melt partitioning behaviour and ensures conservation of flux, whilst an external degassing boundary condition can be imposed to simulate magma ascent.

We combined 2D versions of our model with a Nested Sampling Bayesian inversion to invert for uncertain parameters such as anisotropy, partition coefficient, decompression rate, temperature and initial water content using 1D observations of water profiles in olivine measured by SIMS from the 1977 eruption of Seguam volcano, Alaska. We find that the diffusive anisotropy of H+ can be quite high in Fe-bearing olivine, with diffusion being 20-30 times faster along the [100] direction than the [001] and [010] directions. We also find that individual crystals can have different initial water contents and decompression rates, which highlights the power of our 2D inversion method to explore the natural variance of ascent histories in single eruptions.

We then use our 3D model to examine the fidelity of the water content of melt inclusions based on inclusion size, position, crystal size, diffusive anisotropy in olivine, olivine-melt partition coefficients and for different magma decompression rates. Our model is one of the first to account for the natural shape of olivine, and to include the diffusive properties of both olivine and melt. We find that some 1D approximations (e.g. those that assume the crystal is symmetrical around the melt inclusion) may overestimate melt inclusion water loss during ascent when the inclusion is not located centrally along the [100] axis.

Our model is also novel in that multiple melt inclusions can be modelled in a single crystal. We find that the presence of multiple melt inclusions can buffer the water composition of inclusions in the centre of the crystal. This ‘shielding’ effect may have important implications for estimating magma storage depths or primary water compositions. By reducing uncertainties associated with crystal morphology and sectioning we hope to better reconcile short-term petrological and geophysical observations.

Deciphering the coupling between tephra plumes and lava fountains at Mount Etna, Italy

Eveanjelene Snee* Wim Degruyter (Cardiff University), Costanza Bonadonna (University of Geneva), Simona Scollo (Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo), Eduardo Rossi (University of Geneva), Valentin Freret-Lorgeril (University of Geneva)

*sneee@cardiff.ac.uk

Over the last decade, Mount Etna, Italy, has undergone over 50 paroxysmal eruptions. These events are characterised by sustained basaltic tephra plumes that are coupled to lava fountains and pose a hazard to both local communities and the wider region. In particular, the associated tephra fallout can cause damage to local infrastructure as well as disrupt regional airspace. It is therefore necessary to develop models of eruptive behaviour that can be used in hazard assessment. However, unlike their silicic counterparts, the dynamics of basaltic tephra plumes remain poorly understood. In particular, how these plumes control tephra dispersal and the subsequent field deposits require further investigation. We use numerical modelling to decipher the relationships between eruption source parameters, plume dynamics and field deposits for five paroxysmal events that occurred between 2011 and 2013. We use a one-dimensional double integral plume model that captures the interaction of a hotter inner core (i.e., the lava fountain) with the surrounding tephra plume, whilst also allowing for particle fallout and interaction between the two plume regions via entrainment. By using a Monte-Carlo approach, we determine the range of initial mass flow rates (MFRs) at the vent that could have resulted in both the observed plume height and the lava fountain height. The changes of the MFR with height is recorded and compared to the MFR derived from analysis of the field deposit. For the selected case studies, the modelled MFR at the top of the lava fountain, rather than that at the vent, matches the field-derived MFR more closely. Additionally, the difference between the modelled MFR at the vent and the MFR derived from the field deposit increases as the extent of coupling between the lava fountain and tephra plume decreases. Indeed, as the coupling decreases, the amount of erupted material at the vent that reaches the top of the plume also decreases, reducing the amount of tephra made available for transport in the atmosphere. These results demonstrate that the degree of coupling between the lava fountain and the plume has direct implications on tephra dispersal and sedimentation.

Magmatic Processes in the East African Rift System: Insights from a 2015-2020 Sentinel-1 InSAR survey

Fabien Albino* Juliet Biggs (University of Bristol)

*fa17101@bristol.ac.uk

The East African Rift System (EARS) is composed of around 78 Holocene volcanoes, but relatively little is known about their past and present activity. This lack of information makes it difficult to understand their eruptive cycles, their roles in continental rifting and the threat they pose to the population. Although previous InSAR surveys (1990-2010) showed sign of unrest, the information about the dynamics of the magmatic systems remained limited by low temporal resolution and gaps in the dataset. The Sentinel-1 SAR mission provides open-access acquisitions every 12 days in Africa and has the potential to produce long-duration time series for monitoring volcanic ground deformation at regional scale. Here, we use Sentinel-1 data to provide InSAR time series along the EARS for the period 2015-2020. We detect 18 ground deformation signals on 14 volcanoes, of which six are located in Afar, six in the Main Ethiopian Rift and two in the Kenya-Tanzanian Rift. We detected new episodes of uplift at Tullu Moje (2016) and Suswa (mid-2018), and enigmatic long-lived subsidence signals at Gada Ale and Kone. Subsidence signals are related to a variety of mechanisms including the post-eruptive evolution of magma reservoirs (e.g. Alu-Dallafila), the compaction of lava flows (e.g. Nabro) or pore pressure changes related to geothermal or hydrothermal activity (e.g. Olkaria). Our results show that ~20\% of the Holocene volcanoes in the EARS deformed during this 5-year snapshot and demonstrate the diversity of processes occurring.

Pressure evolution during recharge of a bubbly magma reservoir

Fakhri M Bintang* Ed Llewellin (Durham University), Jason Coumans (Ressources naturelles Canada; Durham University), Fabian Wadsworth (Durham University)

*f.bintang.1@research.gla.ac.uk

Pressurization of magma reservoirs through recharge has been proposed as an eruption trigger. Long-lived shallow magma reservoirs may contain an exsolved volatile gas phase in the form of bubbles suspended in incompressible melt making the magma compressible. Bubbles could mitigate pressurization through their compressibility, and by resorbing volatiles. In this study, we use a numerical model to investigate the pressure response of a bubbly magma reservoir in response to recharge. We model injection of new magma, at constant flux, into a pre-existing bubbly magma reservoir. The model assumes the end-member scenario of rigid reservoir walls and no magma mixing, so that the change in volume must be accommodated by a reduction in the volume of the pre-existing bubbles. The time taken for the gas volume to be fully compressed is described by an injection timescale λ_R. The model also incorporates a dynamic diffusivity term of H_2O in the melt where the volatile resorption rate is dependent on diffusion through the melt, described by a diffusive timescale λ_D. We find that the pressure evolution of a magma chamber can be described by a dimensionless Péclet number ($Pe=\lambda_R/\lambda_D$), which captures the ratio of the recharge timescale λ_R and the diffusive timescale λ_D. We first consider two end-members: 1) a no diffusive flux regime ($Pe \ll 1$) in which all the gas molecules remain in the bubble and the volume change is entirely accommodated by compression of the gas according to its equation-of-state; and 2) an equilibrium regime ($Pe \gg 1$) in which diffusion and resorption occur at perfect equilibrium with evolving pressure. Regime (1) constitutes the maximum rate of pressure increase, and regime (2) the minimum rate of pressure increase. We use the numerical model to explore mixed behaviour, between these limits. We find that, for natural estimates for bubble-bearing reservoirs under geological constraints of volume and injection rate, Pe is consistently well within the equilibrium regime ($Pe \gg 1$). Furthermore, we find that the viscous resistance from the melt plays a negligible role in determining pressure evolution. The system exhibits disequilibrium behaviour ($Pe \le 1$) only under extreme conditions, which are highly unlikely in nature. We conclude that models of pressure evolution in a recharging magma reservoir are justified in using the simpler equilibrium model, for which an implicit analytical solution is provided.

Investigating rhyolite petrogenesis at migrating volcanic arcs using the Atitlán volcanic centre, Guatemala

Finley Gilchrist* Chiara Maria Petrone (Natural History Museum, London), Hilary Downes (Birkbeck, University of London), Katrina Kerr (Open University), Katharina Kreissig (Imperial College London), Julie Prytulak (Durham University)

*f.gilchrist@nhm.ac.uk

Arc migration is a common occurrence at many volcanic arcs and often occurs as the result of slab rollback. The effects of arc migration on the style and composition of volcanic activity at individual volcanic centres in the short term are poorly understood. This project is therefore using the Atitlán volcanic centre (AVC) in Guatemala as a natural laboratory to investigate the potential impacts of arc migration. There is a temporal and spatial correlation at this centre between the migration of the line of the volcanic arc approximately 10km to the south, and the formation of an approximately 300 km3 (dense rock equivalent) volume body of rhyolite magma situated between the two lines of volcanoes. This rhyolite was erupted in multiple events to form the Atitlán caldera. Processes related to slab rollback and the subsequent arc migration (such as priming of the continental crust, elevated crustal assimilation and/or increased magma flux due to enhanced decompression melting of the mantle) could explain the formation of the rhyolitic magma.

A combined petrological and geochemical investigation of the AVC is being used to quantify the different inputs that resulted in the formation of the Atitlán rhyolites, and to separate out the processes that relate to 'normal' volcanic arc activity and those that are the result of the arc migration process. New modelling using EME-AFC (Equilibrated Major Element Assimilation with Fractional Crystallisation (Burton-Johnson et al., 2019)) shows that while fractionation can account for much of the evolution of the magmas at the AVC, there are significant gaps to be accounted for. Preliminary Sr isotope data suggest a strong temporal variation, with the lavas becoming less radiogenic with time. Importantly, the rhyolites are less radiogenic (87Sr/86Sr: 0.0704004 – 0.704126) than the preceding potentially parental stratovolcano lavas (87Sr/86Sr: 0.704090 – 0.704453). The rhyolites therefore require an assimilant with a lower Sr isotope ratio. Previously published suggestions for the composition of the crust under the volcanic arc are accreted oceanic crust (87Sr/86Sr: 0.702793 – 0.703077) or pyroxenite veins and associated daughter granodiorites (87Sr/86Sr: 0.703699 – 0.704004), either of which has a suitable isotopic signature to potentially be assimilants. An isotopic study of Sr, Nb, Pb and Hf is being undertaken to determine which is more appropriate. Finally, once the scale of assimilation and the required volume of primary magmas are estimated, modelling of the energy needed to form the rhyolites will determine if a higher magma flux resulting from the slab rollback process, or current 'steady state' flux into the crust can explain the formation of the rhyolites.

Tectonic Controls on Scoria Cone Locations in Volcanic Arcs - An Example From Eastern Guatemala.

Fiona Jean Gardner* Marie Edmonds (University of Cambridge)

Alex Copley (University of Cambridge)

*fjg35@cam.ac.uk

It is likely that volcano location and form is influenced strongly by the presence of extensional grabens in the crust, in a range of tectonic settings, both on Earth and on other rocky planets. Here we investigate the role of tectonics in the overriding plate in arcs in controlling the locations of volcanic edifices, including central volcanoes, calderas and scoria cone fields. With a focus on the Central American Volcanic Arc, this project looks at the relationship between local/regional tectonic features and the scoria cone locations. In particular we investigate the links between the locations of volcanic features and transtensional normal faulting and graben structures such as the Ipala graben, on the El Salvador-Guatemala border. We use 30 m resolution SRTM images to map and quantify scoria cone characteristics across the region as well as faulting and other features that are likely to be tectonically controlled, such as the elongation of calderas. Scoria cones typically occur in the centre of graben structures in the Ipala region, with cone alignment running northeast – southwest, parallel to regional graben faulting structures.

Using the collected data, we will model the relationship between the scoria cones and tensional tectonic faulting, comparing features such as the orientation of the faulting, elongation of scoria cone features and orientation of scoria cone chains, as well as comparing the location of the faults to the location of the scoria cones. Additionally, elongation in calderas in the direction of tension – in the axis perpendicular to the fault trends – is likely to also indicate tensional elongation of magma chambers in the crust, a few km in depth and at crustal depths through which dykes would propagate, following the perpendicular to the minimum stress towards the surface.

We can then be compare our results to other scoria cone emplacement models and datasets collected from other areas along the Central American Volcanic Arc, such as the Managua graben, Nicaragua, to test if the tectonic control seen in the Ipala region form a viable and reasonable model for scoria cone emplacement across a range of transtensional settings. These models may then aid the understanding of scoria cone formation in other areas where tensional regimes and faulting are likely to promote magma flow to the surface and hence scoria cone formation. This includes areas such as other trans-tensional regimes or on other rocky bodies where scoria cones and faults can be identified through surface imaging.

Homogenisation of heterogeneous mantle melts in transcrustal plumbing system

Florian Brouillet* Lydéric France (Université de Lorraine, CNRS, CRPG, F-54000 Nancy, France),

Adrien J. Mourey (Department of Earth Sciences, University of Hawai'i at Manoa, Honolulu, HI, United States),

Valentin Casola (Université de Lorraine, CNRS, CRPG, F-54000 Nancy, France),

Janne M. Koornneef (Vrije Universiteit, Faculty of Science, Amsterdam, The Netherlands)

*fcgb1@st-andrews.ac.uk

Radiogenic isotope signatures of lavas have been used for decades to characterise their mantle sources, and the heterogeneity of the mantle domain. It has been shown recently that the homogeneous signatures of lavas do not record the small-scale mantle heterogeneity that is documented by primitive melt inclusions (MI). The homogenization process of isotopes values through the magma plumbing system remains unconstrained however. Here, we present isotopic data (Sr, Nd and Pb) of single MI documenting both primitive and evolved compositions from alkaline Oldoinyo Lengai stratovolcano. We show for the first time that the isotopic variability of the mantle that is recorded in primitive MI (variability in Sr =0.50) is skewed through the magma plumbing system as evolved MI populations are rather isotopically homogeneous (variability in Sr =0.096). We propose that this homogenization proceeds progressively by melt hybridisation upon mixing through the transcrustal plumbing system and is eventually recorded by evolved samples. Our data eventually imply that serious care needs to be taken when bulk lavas are used to infer the composition and variability of the mantle source.

The Glencoe caldera fault(s) as a detailed record of a magmatic plumbing system and its collapse mechanics

Francesca L. Haywood (Earth Sciences, Durham University, Durham, DH1 3LE)* Fabian B. Wadsworth (Earth Sciences, Durham University, Durham, DH1 3LE)

Richard J. Brown (Earth Sciences, Durham University, Durham, DH1 3LE)

Dave McGarvie (The Lancaster Environment Centre, Lancaster University, Lancaster)

Annabelle Foster (Earth Sciences, Durham University, Durham, DH1 3LE)

*francesca.l.haywood@durham.ac.uk

Typically research into volcanic systems focusses on storage region processes (e.g. melt extraction from a crystal mush) or eruption processes (e.g. the mass flux, plumes, and the emplacement of eruptive products). The missing link between storage and the Earth's surface is under-investigated, in part because there is a paucity of good field examples of a preserved link. The Glencoe caldera ring fault is just such an example of an eroded feeder system with detailed exposure. Here, we present field observations of the fault geometry and the fault fill of this system. The general facies architecture of the fault fill includes (1) an aphanitic, black, so-called 'flinty crush rock' (FCR), (2) a porphyritic so-called 'red felsite' with evidence for phenocryst fractures that is variably inter-mingled with the FCR, and (3) porphyritic so-called 'fault intrusion' rocks. The ongoing debate about the origin of the FCR has resulted in two broad camps of opinion: (1) those supporting a frictional melt origin caused by the movement along caldera superfaults (Clough et al., 1909; Bailey, 1960; Kokelaar, 2007), and (2) those supporting a magmatic origin similar to the adjacent intrusions (Reynolds, 1956; Roberts 1966; Taubeneck, 1967). The defining question in this argument is the extent to which friction plays a role in this system. As part of this project, we will use field evidence, spatially-resolved geochemical data and textural studies to pick apart both hypotheses. Determining the correct origin of these lithologies is a crucial piece of information in our understanding of Glencoe's caldera dynamics. This knowledge would in turn have implications for the sub-surface dynamics of caldera-forming eruptions found in the wider world.

Insights into timescales of magmatic processes during the 2013-17 eruption at Volcán de Colima, Mexico

Gerallt Hughes* Chiara Maria Petrone (Department of Earth Sciences, Natural History Museum, London); Hilary Downes (Department of Earth and Planetary Science, Birkbeck, University of London); Nick Varley (CIIV, Facultad de Ciencias, Universidad de Colima, Mexico); Sam Hammond (The Open University, Milton Keynes); Katrina Kerr (The Open University, Milton Keynes)

*g.hughes@nhm.ac.uk

Volcán de Colima is an active stratovolcano in western Mexico. Its 2013-17 eruptive phase was characterised by transitions between effusive and explosive events. This persistent activity, comprising vulcanian explosions, pyroclastic flows, lava flows and ashfall present significant hazards to ~750,000 people near the volcano.

Tracing patterns of magma storage, recharge and mixing through volcanic systems is key to accurately interpreting monitoring data and understanding potential future hazards. However, at many volcanoes, including Colima, these patterns are poorly constrained and the link between monitoring data and magmatic processes is unclear. To better understand the magmatic plumbing system at Colima, mineral chemistry and textural studies were undertaken on representative 2013-17 samples. These samples contain plagioclase, orthopyroxene, clinopyroxene, Fe-Ti oxides, and rare resorbed olivine and amphibole, typical of Colima andesites.

We have identified pyroxene phenocryst populations reflecting complex processes in the plumbing system. Pyroxene phenocrysts have varied core compositions (Mg#~69-88) reflecting crystallisation from melts within a heterogeneous magma mush. Whilst we interpret the bulk of the system to be relatively evolved, crystallising pyroxene in the Mg# 69-75 range, the presence of disequilibrium textures and high-Cr mafic bands and rims reflect periodic recharge of mafic melts and remobilisation of both evolved and mafic mush material prior to eruption.

The mineral chemistry and petrography indicate the presence of two broad magmatic environments crystallising these pyroxenes. An evolved end-member, crystallising Mg#69-75 pyroxene at between 980-1000°C, comprises the bulk of the system. By contrast, the mafic end-member crystallises high-Mg# pyroxene ar a temperature typically between 1020-1080°C. Pressure estimates typically vary between 4-6 kbar or *c.* 12-20 km depth, in agreement with geophysical evidence suggesting a melt-rich mushy body at this depth.

Zoning patterns range from diffuse zoning in normal zoned pyroxenes to sharper core-rim boundaries in reverse zoned phenocrysts. We applied elemental diffusion modelling to constrain the timescales of pre-eruptive magmatic processes. The modelling indicates relative differences in residence times with long residence timescales for diffuse, normally zoned phenocrysts; versus shorter residence times of weeks to months in reverse-zoned phenocrysts.

Most notably, an increased frequency of reverse zoned pyroxenes was recorded in lavas erupted after an intense VEI 3 eruption in July 2015, the largest since the 1913 Plinian event. Timescale estimates suggest a recharge and mixing event occurred at approximately this time and estimates from 2016 lavas may indicate multiple injections leading up to the eruption. This suggests that the July 2015 eruption may have been directly linked to this mafic injection.

Despite both eruptions being associated with mafic recharge, the difference in the style of activity between the explosive 2015 and effusive 2016 eruptions suggest other controls on activity. These may include the volume of magmatic recharge, the frequency of injections, ascent rate, or the supply of volatiles from the mafic magmas. Further refinement of the storage timescales and recharge events, and comparison of timescales to monitoring data, also will help clarify the effect of these processes on the eruption timing and style.

Different geochemical fingerprints of Stratoid and Gulf Basalts Formations (Afar, Ethiopia)

Gianmaria Tortelli* Gianmaria Tortelli (Dipartimento di Scienze della Terra, Via La Pira, 4, 50121 Florence, Italy; Dipartimento di Scienze della Terra, Via Santa Maria, 53, 56126 Pisa, Italy),

Anna Gioncada (Dipartimento di Scienze della Terra, Via Santa Maria, 53, 56126 Pisa, Italy),

Carolina Pagli (Dipartimento di Scienze della Terra, Via Santa Maria, 53, 56126 Pisa, Italy),

Derek Keir (Dipartimento di Scienze della Terra, Via La Pira, 4, 50121 Florence, Italy; School of Ocean and Earth Science, University of Southampton, European Way, SO14 3ZH, Southampton, U.K.),

Eleonora Braschi (CNR, IGG, sezione di Firenze, via La Pira, 4, 50121 Firenze, Italy),

Ermias Filfilu Gebru (School of Earth Sciences, Addis Ababa University, P. O. Box, 1176, Addis Ababa, Ethiopia).

*gianmaria.tortelli@unifi.it

The study of volcanism during rifting is essential to understand evolution of the magma source and magma plumbing during continental break-up. Situated at the intersection between the Main Ethiopian Rift and the on-land portions of the Red Sea and Gulf of Aden Rifts, the Afar depression is a unique place to study on-land evolution and propagation of a rift system at the continent-ocean transition. Although the magmatic segments of Afar (<0.6 Ma) have been the focus of several studies, no systematic work has been carried out on the Stratoids and the Gulf Basalts volcanism of the depression from ~4 to 0.6 Ma. Covering an area of ~55.000 km2 and reaching at least 1000 m in thickness, the Stratoid Formation (from ~4 to ~1.1 Ma) occupies about 2/3 of the Afar depression and is mainly dominated by flood basalt volcanism with minor intercalated felsic activity. The Gulf Basalts Formation (from ~1.1 to 0.6 Ma), mostly associated with the recent magmatic segments, represent the transitional phase between the Stratoids and rift axial volcanism. The study of the inner variability of the Stratoids and their comparison to the Gulf Basalts Formation represents an excellent opportunity to investigate the evolution of volcanism in Afar. Here we analysed major and trace elements to investigate the evolutionary link between the Stratoid and Gulf Basalts Formations. Trace elements ratio (i.e. TbN/YbN) shows that the temporal distinction between lower and upper Stratoids suggested by Kidane et al. (2003) is correlated with a variation in the depth of the melting column. Variation of incompatible trace elements (i.e. Th/Ta, Nb/U) between the Stratoid and the Gulf Basalts Formations also indicate that, contrary to current knowledge, it is possible to distinguish the two Formations not only by their age or lava morphology but also by the fingerprint of their trace elements geochemistry.

A multi-parameter machine learning approach to understanding eruptive transitions in volcanic systems

Grace Manley* Tamsin A. Mather (Department of Earth Sciences, University of Oxford), David M. Pyle (Department of Earth Sciences, University of Oxford), David A. Clifton (Department of Engineering Sciences, University of Oxford), Mel Rodgers (School of Geosciences, University of South Florida), Glenn Thompson (School of Geosciences, University of South Florida)

*grace.manley@earth.ox.ac.uk

Volcanic eruptions are characterised by large-scale transitions in behaviour. The timing and driving processes of these transitions are not yet fully understood. The physical processes driving large-scale change in volcanic systems operate across a range of depths. Multi-parameter datasets represent a key opportunity to investigate transitions in volcanic activity, as the range of depths sampled using multiple types of observation is much greater than for one type of data alone.

Machine learning can be applied to determine the timing of transitions in large and noisy datasets. Machine learning approaches have previously been used, in fields such as healthcare, finance and meteorology, to recognise non-linear patterns that traditional analyses fail to detect. Machine learning represents a tool for detecting when the pattern of volcanic activity significantly changes, potentially signalling transitions during the onset or end of volcanic activity. Our previous work has demonstrated that machine learning approaches can successfully classify time series derived from single-station seismic data for two volcanoes displaying contrasting eruptive styles[1], and determine the timing of seismic transitions at the end of volcanic eruption.

Here, we expand on our previous approach to classification of single-station seismic data, to also consider SO2 emission rate and GPS time series data from the 2006 explosive eruption of Augustine Volcano, Alaska. We apply novelty detection models, which are only trained on non-eruptive data, and multi-class classification models, which are trained on both non-eruptive and eruptive data to these time series. We contextualise the results of these classification models using constraints from other precursory observations from the Augustine eruption including petrology, satellite and visual observations.

[1] Manley, G.F., Pyle, D.M., Mather, T.A., Rodgers, M., Clifton, D.A., Stokell, B.G., Thompson, G., Londoño, J.M. and Roman, D.C., 2020. Understanding the timing of eruption end using a machine learning approach to classification of seismic time series. Journal of Volcanology and Geothermal Research, p.106917.

The Fold Illusion: Re-Interpreting Silicic Lava Flow Emplacement

Graham D.M. Andrews* Sarah R. Brown (West Virginia University), Shelby L. Isom (West Virginia University), Stuart Kenderes (University of Missouri), Alan G. Whittington (University of Texas at San Antonio)

*graham.andrews@mail.wvu.edu

Silicic lavas like those in the western United States, the Aeolian Islands, Las Canadas caldera, and erupted in 2011 at Cordon Caulle, Chile, are typically interpreted to exhibit folds on their upper surfaces. The primary evidence for this is the ubiquitous presence of arrays of ridges and troughs called 'ogives' on the upper surface that are easily visible in aerial imagery. The ridges are commonly inferred to be buckle-style antiforms and the troughs synforms, akin to pahoehoe. Folding of the upper surface necessitates sustained ductile, compressional deformation, and that either deformation was rapid (i.e. high strain rates), cooling through the ductile-brittle transition was slow (i.e. slow cooling and retention of dissolved volatiles), or both. Neither of these conditions are likely to occur for typical rhyolitic magmas extruded on to the Earth's surface. If ogives are not folds, then estimates of lava rheology and composition using remotely-sensed data and fold theory are invalid.

We present field observations, the results of thermo-rheological experiments, and models of cooling and stress to better understand the processes that occur at the upper surface and to constrain the conditions during emplacement and deformation. We fail to identify any conclusive evidence that ogives are folds, and to the contrary, interpret ogives to be ridges separated by large-scale tensile fractures akin to horsts separated by crevasses. We demonstrate that ogives are equally well-formed where a lava is unconfined as when it is impounded against a topographic barrier. Tensile fractures exist at all scales up to 10s of meters of dilation and hundreds of meters length and are responsible for the formation of the ubiquitous autobreccia carapace. Many oxidized tensile fracture surfaces are associated with tuffisite indicating that failure occurred when the lava was hot and out-gassing. Some tuffisite veins are welded suggesting that after instantaneous brittle failure, obsidian relaxed ductilely allowing some fractures to heal. Folds are present within the lava and are exhumed and exposed in cross-section on fracture surfaces: these are small, recumbent, similar-style folds of the flow-banding and do not have a geomorphological expression.

We show that exsolution of water at atmospheric pressure is sufficient to produce a pervasive, rapidly cooled, pumiceous carapace with very low tensile strength. This carapace deforms brittlely within less than 2 hours of extrusion. This is insufficient time to allow for large-scale folding (as implied by the sizes of ogives) without exceeding the strain rate limit of the glass transition. Modeling of stress indicates that compressional forces are negligible. Rather, the low tensile strength of the pumiceous carapace and continued volume expansion due to volatile exsolution keep the carapace under weak tensile stress at or close to Byerlee’s Law conditions: a shear stress cannot be maintained making ductile deformation impossible.

We conclude that silicic lavas deform by gravity spreading (i.e. extension) and their upper surfaces are invariably in the brittle regime. Sustained brittle-tensile deformation produces a weak ‘lid’ and aids out-gassing of the flow interior, both of which suggest that emplacement must be relatively fast as observed at Cordon Caulle.

Examining the sensitivity of total grain size distributions to the inclusion of proximal data

Hannah Buckland* Katharine Cashman (University of Bristol), Alison Rust (University of Bristol), Samantha Engwell (British Geological Survey)

*hannah.buckland@bristol.ac.uk

The total grain size distribution (TGSD) of a tephra deposit provides insight into the fragmentation processes associated with explosive eruptions, and the TGSD is a key eruption source parameter for models of tephra dispersal and sedimentation. TGSDs are produced by combining multiple grain size distributions from individual sites according to the mass accumulation of tephra at that location hence they are sensitive to the spatial distribution of sampling sites as well as the method use to combine the data. In this study we derive a TGSD for the ~7.7 ka climactic eruption of Mt Mazama (Crater Lake, Oregon, USA) by combining grain size data amassed from the literature with a new distal dataset (Buckland et al. 2020). We show that the TGSD is extremely sensitive to the data used and the maximum deposit extent, and this was particularly evident when we excluded proximal data from within ~100 km from source. We also show that other published TGSDs, that include minimal or no proximal deposits (Mount Saint Helens 1980, Sarna-Wojcicki et al. 1981; Campanian 39 ka, Marti et al. 2016), are similarly sensitive to the inclusion of proximal data. The efficiency of fragmentation is typically assessed from the particle number distribution (PND) that has been calculated from the TGSD. However, in addition to the sensitivity of TGSDs to the distribution of the data, we find that changes in particle density and componentry throughout the deposit can impact the calculation and interpretation of PNDs. In conclusion, our results show that interpretations of fragmentation mechanisms and eruptive dynamics from TGSDs are contingent on the sampling distribution and assumption of particle properties. Furthermore, TGSDs without sufficient proximal data are not representative of the whole deposit, however, if sufficient distal data is available, they can still provide useful inputs for ash dispersion models.

Investigating the eruptive parameters of the largest sulfur emitting volcanic event in the past 100ka using high resolution quadruple sulfur isotopes

Helen Innes* A. Burke (University of St Andrews), J. Lewis (University of Bristol), R.C.J. Steele (University of St Andrews), C.D. Coath (University of Bristol), T. Elliott (University of Bristol), S. Mahony (University of Bristol), L. Crick (University of St Andrews), E.W. Wolff (University of Cambridge), R.S.J. Sparks (University of Bristol), M. Sigl (University of Bern), W. Hutchison (University of St Andrews), J.W.B. Rae (University of St Andrews).

*hi7@st-andrews.ac.uk

Large volcanic events can cause decadal-long climate perturbations through injection of sulfate aerosols to the stratosphere, which reflect incoming solar radiation and cool Earth's surface. The climatic impact of the eruption depends on the location of the volcano, the eruptive plume height, and the mass of SO2 released into the stratosphere. One way to constrain some of the characteristics of a past eruption is to analyse sulfur isotopes of volcanic aerosols deposited in polar ice cores. We can use the mass independent fractionation (MIF) signature in sulfur isotopes to infer if the eruption plume reached the stratosphere, as well as understand more about eruption parameters and better constrain the climate forcing of the eruption. The ~80 ka event recorded in Antarctic and Greenland ice cores is one of the largest unknown eruptions of the last 100,000 years. Here we investigate the sulfur isotope fingerprint for this eruption from the NGRIP and EDC ice cores. We show the measured Δ33S peak of +3.45 ‰ is much larger than any eruption from the Common Era, suggesting a high altitude SO2 plume. The isotope signature suggests that the eruption was from a low latitude volcanic source, which we will further constrain with tephra analysis. We also report the first ever high resolution Δ36S values across a single volcanic peak in ice cores measured by collision cell multi-collector mass spectrometry. These data provide important insights into the mechanism of MIF formation and sulfur oxidation in the stratosphere.

VMSG

Effect of magma evolution on dyke emplacement and morphology: linking the geochemical and rheological signatures of segmented lamprophyre dykes at Birsay (Orkney)

Henry Eves* David Healy (University of Aberdeen) , Malcolm Hole (University of Aberdeen)

*h.eves.18@abdn.ac.uk

Dykes are key conduits for the transport of magma within the crust. Their dynamics of propagation have a significant influence on volcanic evolution and potential volcanic hazards. Significant local variation in emplacement direction is often preserved within dykes [1][2][3]. The seismicity around the 2014 Bárðarbunga-Holuhraun dyke intrusion suggests > 40 km lateral propagation at 5-7 km depth [4], and therefore understanding the controls on lateral versus vertical propagation is important. Analogue models have shown that lateral to vertical dyke propagation can be influenced by buoyancy and layering with rigidity contrasts and topographic gradients being dominant factors [5]. traditional approaches to dyke modelling are largely dependent on host rock deformation, often overlooking the role of magma rheology. However, we know that magmatic processes such as cooling, crystallization [6], and volatile exsolution [7][8] can all affect the rheological characteristics of the magma, which can therefore influence dyke propagation.

From a geochemical and petrological perspective, we have investigated the effects of magma evolution on emplacement using the dykes at Birsay as a case study. Our methods include textural analysis, chemical analysis, and system modelling to interpret the evolution of temperature, pressure and volatile conditions of crystallization relative to emplacement, and modelling the rheological evolution. The Birsay dykes are part of the Permo-Carboniferous camptonite-monchiquite suite, emplaced into intensely pre-jointed but uniformly dipping host rocks. They are segmented and show structural evidence for depth-restricted lateral emplacement such as shallow-dipping segment floor and roof geometries, along with elongate vesicles consistent with horizontal flow [3].

Our results provide key insights into the properties of the magma during the emplacement of the segmented lamprophyre dykes. Emplacement occurred post-initiation of kaersutite crystallization between 1100 °C and 1000 °C with 25-40% crystal cargo and abundance of mixed volatile vesicles. System density modelling suggests the magma was near neutrally buoyant during emplacement with small variations in exsolved volatile abundance having a relatively significant effect. Plagioclase crystallized shortly after emplacement on the time scale of minutes, taking the system over the critical threshold for solidification of 60%. The observations constrain the effect of magma evolution on dyke emplacement, suggesting that magmatic evolution and the interplay between host rock structure and magma properties can have a significant on dyke propagation.

[1] Pollard et al 2008, Bull Volcanol, 70:861–875

[2] Townsend et al 2017, Tectonophysics, 703-704, 98-118

[3] Healy et al 2018, Volcanica, 1(2): 85 – 105

[4] Ágústsdóttir et al 2016, Geophys.Res.Lett., 43, 4, 1495-1503

[5] Urbani et al 2018, J.Geophys.Res.Solid Earth, 123, 5, 3680-3697

[6] Taisne & Tait, 2011 ,Bull.Volcanol., 73, 2, 191-204

[7] Menand & Tait, 2001 ,Nature, 411, 6838, 678-680

[8] Taisne & Jaupart 2011, Bull.Volcanol., 2011, 73, 2, 191-204

Strongly unsteady conduit dynamics recorded in a large silicic tuffisite at Húsafell volcano, Iceland

Holly E. Unwin* Hugh Tuffen (Lancaster University), Fabian B. Wadsworth (Durham University), Emrys Phillips (BGS), Michael R. James (Lancaster University)

*h.unwin@lancaster.ac.uk

The dynamics of silicic magma ascent in the shallow crust control the explosive potential of an eruption. Tuffisites are formed by hydraulic fracturing of the country rock around a silicic conduit by high pressure gas and ash mixtures, and their formation is sensitive to the waxing and waning of fluid pressure within the volcanic conduit. These fractures can act as transient gas-escape valves, potentially releasing overpressure from silicic conduits. Fracture opening produces a local drop in fluid pressure, transporting gas and particles into the fracture system. Spatial and temporal variations in the fluid velocity inside the fracture can lead to particle settling, erosion and the production of sedimentary structures. Particles deposited inside the fracture can prop the fracture open, forming a permeable pathway for gas flow, but the compaction and sintering of hot particles may lower the efficiency of the degassing pathway as the tuffisite evolves. Sintered and sealed tuffisites can be refractured, potentially producing a rechargeable trigger mechanism for hybrid earthquakes.

We present the first detailed characterisation of a tuffisite. This tuffisite, at Húsafell volcano, Iceland, is one of the largest known at 0.9 m wide and 40 m long, and formed at a depth of 500 m, where a propagating rhyolitic sheet intrusion was stalled beneath a layer of strong welded ignimbrite. The tuffisite is formed of a variety of sedimentary units whose characteristics and structures record the processes, timescales and pressures of tuffisite evolution. The presence of massive and structured units within the tuffisite suggest variations in the particle concentration of the transporting fluid through time. Erosion and sedimentary structures such as cross-bedding indicate that the tuffisite was formed by multiple pulses of waxing and waning fluid pressure during unsteady flow. Taking tuffisite units 0.1 m wide and 40 m long we estimate that an excess fluid overpressure of ~6 MPa was required to elastically open the space for each unit, similar to the gas overpressure estimated just above the level of fragmentation at 500 m depth. The fluid overpressure is therefore thought to have oscillated around 6 MPa during tuffisite evolution, with up to 20 fluid pulses involved. These repeated injections thickened the tuffisite until its centre became sufficiently insulated to viscously deform. Compaction and sintering lowered tuffisite permeability, causing the tuffisite to self-pressurise and emplace new dome-shaped injections. These dome-shaped injections opened space by inelastic deformation, viscously deforming the surrounding tuffisitic material, requiring a lower excess fluid pressure than the injections emplaced previously (<6 MPa). The deformation of material surrounding these injections would drastically reduce tuffisite permeability, suggesting that tuffisites are self-limiting in their lifetimes as degassing pathways.

Tuffisites act as a fossil record for the opening of magmatic pathways, constraining the cycles of pressurisation and outgassing during volcanic unrest. The Húsafell tuffisite contains complex structures including cross-bedding and self-injections that indicate formation by multiple fluid pulses, at an excess fluid pressure that oscillated around 6 MPa before waning towards the end of tuffisite evolution.

IASI observation of SO_2 emissions from the 2019 Raikoke eruption

Isabelle Taylor* Roy G. Grainger (COMET, Sub-Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford)

Tamsin A. Mather (COMET, Department of Earth Sciences, University of Oxford)

Elisa Carboni (UK Research and Innovation, Science and Technology Facilities Council, Rutherford Appleton Laboratory)

*isabelle.taylor@physics.ox.ac.uk

The eruption of Raikoke, in the Kuril Islands, took place on the 21st June 2019 and emitted significant quantities of SO2 and ash into the atmosphere. The evolution of these plumes has been studied with tools developed by the Earth Observation Data Group (EODG) at the University of Oxford for the Infrared Atmospheric Sounding Interferometer (IASI): a hyperspectral instrument on-board three meteorological satellites. These tools can quantify the mass and altitude of both SO2 and ash. Initially the plume's development was studied with a SO2 linear retrieval. This is a fast technique for detecting elevated amounts of SO2. With this tool it was possible to observe the Raikoke plumes circulating the northern hemisphere above 30°, with parts of the plume still visible 2 months after the eruption. Following this the plumes were studied with a full SO2 iterative retrieval which is able to quantify the amount and altitude of SO2. Initially very high column amounts, in some cases greater than 600 DU, were observed. A preliminary estimate of the total mass computed from these results is around 1.6 Tg (measured on the 23rd June 2019). The height information from this retrieval showed that there were emissions into both the troposphere and stratosphere. It also shows some interesting structures to the plume in the first few days. Combining these observations with information from other satellite instruments, it appears that SO2 was injected at multiple heights over the course of the eruption.

Examining the relationship between seismic swarms and ground deformation for forecasting volcanic unrest

James Dalziel* Juliet Biggs (University of Bristol), Heidy Mader (University of Bristol)

*bz20584@bristol.ac.uk

Although volcano monitoring has improved in the past few decades, there is still difficulty differentiating between certain volcanic processes. Analysing the relationship between different sources of monitoring data during precursory unrest allows us to distinguish between magmatic, tectonic or hydrothermal activity. In the case of cyclic or repeated activity, identifying patterns in precursory signals may aid forecasting over month to year timescales, and specifically help to anticipate the location of surface volcanism. Here we examine how the relationship between seismicity and ground deformation varies during an unrest episode at an active volcanic setting (Eyjafjallajökull, Iceland). Previous studies using laboratory experiments have shown an exponential increase in fracturing events with increasing stress, whereas empirical examples using volcano and wastewater well injection data both show a linear relationship between seismic moment and volume change. Using monitoring data prior to the well-studied 2010 Eyjafjallajökull eruption, we have been able to identify a step-change in the ratio between cumulative seismic moment and ground movement, which likely relates to a change in magmatic source. This change in ratio can be thought of as an increase in seismic efficiency, suggesting a decrease in aseismic slip between the sources. This case study demonstrates how combining data for seismicity and deformation can provide new insights into subsurface processes prior to eruptive activity.

Long-term surface deformation and current magma system pressurisation at Soufrière Hills Volcano, Montserrat

James Hickey* J. Hickey (Camborne School of Mines, University of Exeter, United Kingdom)

K. Pascal (Montserrat Volcano Observatory, University of the West Indies, Montserrat)

M. Head (Camborne School of Mines, University of Exeter, United Kingdom)

J. Gottsmann (School of Earth Science, University of Bristol, United Kingdom)

N. Fournier (GNS Science, Wairakei Research Centre, New Zealand)

S. Hreinsdottir (GNS Science, Wairakei Research Centre, New Zealand)

R. Syers (Montserrat Volcano Observatory, University of the West Indies, Montserrat)

*j.hickey@exeter.ac.uk

Soufrière Hills Volcano (SHV) is an andesitic dome-building volcano on the island of Montserrat (British West Indies). SHV began its current, and anomalously long, eruption in 1995, but eruptive activity has been intermittent with phases of lava extrusion separated by periods of relative quiescence. The current pause in eruption started in February 2010 and is the longest yet recorded, 10 years and 9 months at the time of writing (November 2020). Continuous GPS measurements show island-wide inflation from 2010 onwards, with the rate of inflation slowly decreasing with time. However, the length of the eruptive pause raises questions as to whether there have been significant changes to the magmatic system and/or the eruption at SHV might have ended. To assess the behaviour and evolution of the SHV magmatic system since 2010 and the relation to ongoing hazard assessment, we analyse the continuous GPS temporal deformation trends using a suite of geodetic numerical models. Our models incorporate a temperature-dependent viscoelastic rheology, topography derived from a Digital Elevation Model and three-dimensional variations in mechanical properties derived from seismic tomography. The models are driven using one of four possible time-dependent source functions, to simulate differences in the temporal evolution of the magmatic system. The results show that the observed deformation data requires a temporal source function whereby the magmatic system pressure is increasing with time. A viscoelastic crustal response cannot explain the long-term deformation trends alone. The nature of the source pressurisation is unclear, and could be due, for example, to one or a combination of, magma supply, degassing/gas influx, or overturning within a transcrustal magmatic system. Continued pressurisation within the magmatic system highlights the need for sustained vigilance in the monitoring and management of the volcano and its surroundings.

Distribution of partial melt beneath Changbaishan/Paektu volcano, China/Democratic People's Republic of Korea

James O. S. Hammond* Jianping Wu (Institute of Geophysics, China Eathquake Administration)

Kyong-Song Ri (Earthquake Administration, DPRK)

Wei Wei (Institute of Geology, China Earthquake Administration)

Jong-Nam Yu (Earthquake Administration, DPRK)

Clive Oppenheimer (University of Cambridge)

*j.hammond@ucl.ac.uk

Changbaishan/Paektu volcano straddles the border between the Democratic People's Republic of Korea (DPRK) and China. It was responsible for one of the largest eruptions in history, the 'Millennium Eruption' of 946 CE. An episode of unrest between 2002 and 2005, characterized by inflation and seismicity, refocused attention on this volcano. While satellite remote sensing has provided synoptic observations, ground based surveillance has hitherto supported only disparate analyses and geophysical interpretations on either side of the border. Here, we derive receiver functions using seismic records from both DPRK and China. H–κ stacking indicates thick crust (up to 40 km) and high average crustal VP/VS (up to 1.93) beneath the volcano. Grid search inversions constrain a significant velocity reduction at ~7 km depth and harmonic analysis suggests this dips away from the volcano, with shallowest depths centred beneath the volcano. Common conversion point migrations show that this anomaly extends ~30 km from the volcano summit and possibly as far as neighbouring volcanoes. The co-location of the velocity reduction with a zone of high conductivity, low velocity, low density material at the depth of the inflation source implicated in the 2002–2005 unrest, indicates that partial melt is present directly beneath Changbaishan/Paektu, likely recharged during the episode of unrest. Our study highlights the importance of continued surveillance of the volcano and the need for further geophysical studies to constrain more fully the triggers for unrest and controls on its evolution. We are planning new cross-border deployments in summer 2021 with a focus on understanding the origins and extent of volcanism within Northern DPRK and northeast China.

Volcanology in the Twittersphere: tracking a year of volcano information dissemination

Jamie Farquharson* -

*jifarq89@googlemail.com

Twitter is a microblogging and social networking platform where registered users can post and interact with short messages and micromedia called “tweets”. Although Twitter—which has over 300 million monthly active users worldwide—is oft-lauded as an effective outreach and science communication tool in the geosciences, there exists limited quantitative evidence to support this. Systematic, quantitative use of Twitter-derived datasets has thus far been hindered due to limitations imposed by Twitter’s search application programming interface (API), which restricts both the number of tweets that can be crawled and the timespan over which this can be performed.

This study analyses a continuous dataset of tweets containing volcano-relevant search terms in 20 languages collected over more than a year (25 August 2019—present). This unique dataset was compiled by programmatically searching for pre-defined strings and downloading the crawled tweet objects, while circumventing the various API limitations. Search strings (translations of “volcano”, “volcanic”, “volcanic eruption”, and “volcanic activity”) were compiled from English, Japanese, Spanish, Malay, Portuguese, Arabic, French, Turkish, Thai, Korean, Chinese, German, Dutch, Icelandic, Russian, Italian, Afrikaans, Amharic, and Tok Pisin.

The entire dataset comprises over 15 million tweet objects, each of which contains a series of mixed root-level attributes and child objects. Exploring these data with both time-series and network analysis reveals several interesting phenomena:

1. By comparing long- and short-term counts of volcano-related strings, e.g. 〈volcanic〉, 〈vulcão〉, 〈火山〉, peaks above background “chatter” correspond well with discrete volcanic events;

2. English dominates the volcano-centric Twittersphere, even in discourse regarding volcanic eruptions in countries where English is not an official language. This has the effect of amplifying volcanic disasters in the global north at the expense of other regions;

3. Not all eruptions result in equal Twitter traffic, even if the characteristics of two eruptions may be similar. This is likely due to information being propagated (or not) by key “nodes”: well-connected accounts with high perceived prestige, characterised by high eigenvector centrality;

4. Some eruptions, in particular those of Whakaari (Aotearoa) and Taal (Indonesia), appear to be responsible for step-changes the amount of background “chatter”. This suggests that headline-grabbing disastrous eruptions may foster increased public interest in volcanoes more generally;

5. Events clustered in time (e.g. the eruptions of Kuchinoerabujima, Taal, and Fernandina in January 2020) also yield larger peaks, perhaps due to perceived linkages between eruptions.

Due to the strongly connected nature of “volcano Twitter,” it is possible for users to propagate information to a vast number of other users, even if they themselves have few followers. The more connected a Twitter user is (i.e. users with many followers, in particular when those followers are themselves followed by many users), the further (and faster) information they disseminate can propagate. Critically, this comes with mounting responsibility: it becomes ever more critical that information they share—in particular during volcanic crises—is accurate and non-harmful.

This growing dataset provides a unique opportunity for comparative multilingual longitudinal and network studies regarding the dissemination of volcano-focused information on Twitter.

Deciphering the magmatic plumbing system of a complex composite ocean island volcano, Ascension Island, S Atlantic - zircon insights into the plutonic-volcanic connection.

Jane H. Scarrow* Katy J. Chamberlain (University of Derby), Pilar Montero (University of Granada), Jenni Barclay (University of East Anglia), Matthew S.A. Horstwood (British Geological Survey), Bridie V. Davies (University of East Anglia)

*jscarrow@ugr.es

The relationship between plutonic and volcanic components of magmatic plumbing systems continues to be a question of intense debate. However, it is challenging to view these relationships in active volcanism where eroded roots of volcanic systems are not exposed. Here, we study a Pleistocene mingled pumice-scoria fall on Ascension Island, with abundant plutonic lithic enclaves in juvenile volcano deposits. Field relations, petrography, geochemistry, and zircon age and compositional data are used to consider the source, timing and context of magma generation and evolution.

Ascension Island is a small composite ocean island volcano, subaerial dimensions 8 km by 12 km, located in the south Atlantic (7° 56' S; 14° 22' W) on 5-7 Ma ocean crust. It lies ~100 km west of the Mid-Atlantic Ridge and 50 km south of the Ascension Fracture Zone. Only a fraction of the 5-6 Ma volcano is represented by the 1 Myr of subaerial volcanism. The island is composed of compositionally diverse rocks: picrites to rhyolites and trachytes, as effusive-explosive volcanic deposits with associated plutonic enclaves that range from gabbros to granites and syenites. A recent model for the island magmatic plumbing system has proposed small-scale, short-lived magma storage regions feeding felsic eruptions, rather than large long-lived magma chamber(s) (1).

New precise SHRIMP U-Th-Pb zircon ages from four syenite enclaves and two samples of pumice and scoria from the mingled fall record numerous magmatic events. Zircon from volcanic rocks, that traversed the crust, have ages of ~2.2 Ma, ~1.3 Ma and ~0.6 Ma; the youngest of these is comparable to an Ar/Ar age for the deposit (2) and is interpreted as the eruption age. Enclave zircons have ages of either ~1.3 Ma or ~0.6 Ma.

Zircon δ18O isotope data range from well below typical mantle values, 4.7–5.9, in the volcanic rocks, to higher values in the enclaves. We suggest the enclaves high δ18O values are the result of a component of low temperature hydrothermally altered crust in mantle-derived magmas. Pumice and scoria low δ18O values, on the other hand, are indicative of interaction with high temperature, > 300 °C, isotopically-light meteoric water from either hydrothermal alteration of the crust or fluid circulation. Preliminary zircon trace element data shows enclave chondrite-normalised rare earth element values are parallel to, but more enriched than, pumice values. Both datasets are consistent, therefore, with a common source for the plutonic and volcanic samples.

Future work will include: i. detailed petrographic characterisation of a broader range of enclaves to assess crustal heterogeneity and consider how this controlled the magmatism (3); and, ii. further analysis of zircon trace elements as well as Hf isotopes and apatite trace elements and Sr-Nd-Pb isotopes to identify source character of the different components in the mingled fall and micro-scale evidence for eruption triggering interaction of a mafic melt with lower-crustal evolved melts (4).

1. Chamberlain et al., 2016 http://dx.doi.org/10.1016/j.jvolgeores.2016.08.014

2. Preece et al., 2016, CoV9

3. Chamberlain et al, 2019 https://doi.org/10.1093/petrology/egz037

4. Chamberlain et al., 2020 https://doi.org/10.30909/vol.03.01.139153

Identifying Pyroclastic Density Currents from Partial Outcrop Exposure on Mt Ruapehu, New Zealand

Janina Gillies* Ben Kennedy (University of Canterbury, NZ), Darren Gravley (University of Canterbury, NZ), Graham Leonard (GNS Science, NZ), James Cowlyn (University of Canterbury, NZ)

*lrnr96@durham.ac.uk

Pyroclastic density current (PDC) deposits, especially small to medium volume events, have low preservation potential at many volcanoes, particularly when unconsolidated or deposited on steep, glaciated slopes. This may lead to an underrepresentation of these events in the eruptive record, and consequently, in hazard management planning; leaving populations on and around the volcanoes unprepared for the threat of these smaller eruptions. Therefore, it is important to investigate and recognize these smaller events in the volcanic record to create more comprehensive plans for future eruptions. Mt. Ruapehu is one of New Zealand's most active volcanoes, last erupting in 2007. Few studies have investigated the PDC occurrence on this volcano, despite PDCs being one of the most hazardous volcanic processes. Poor preservation of PDC deposits, due to small volume, past glaciations, erosion, burial, and poor consolidation has left a significant gap in Mt. Ruapehu's eruptive record. By identifying and characterizing PDCs on Mt. Ruapehu we provide an updated account of PDC occurrence on this volcano, especially for smaller scale PDCs. Comprehensive field-mapping forms the basis for this study by identifying PDC deposits from partial outcrop exposures. We use field observations of these deposits to describe the lithofacies and infer PDC behaviour. Relative stratigraphy and whole-rock geochemistry are used to correlate deposits with dated units from literature and provide approximate age ranges. We describe 12 PDC deposits representing at least 10 previously unidentified flows. Combined with PDCs identified in previous studies there are a total of 23 PDC deposits found on Mt. Ruapehu, including the PDC observed during the 1945 eruption. These PDCs have been emplaced throughout Mt. Ruapehu's 250 ka eruptive history. The PDCs were concentrated and dominated by granular flow or granular fluid-based flow transport regimes. The lithofacies show PDCs forming from column collapse and dome collapse or explosion events. This demonstrates that Mt. Ruapehu is capable of producing a spectrum of PDC styles and sizes, something that must be considered during future hazard planning on the volcano.

Brittle and Ductile Fragmentation in Explosive Basaltic Eruptions

Janina Gillies* Ed Lewellin (Durham University), Fabian Wadsworth (Durham University), Richard Brown (Durham University)

*lrnr96@durham.ac.uk

Explosive basaltic eruptions span a range of styles, including spattering, strombolian bursts, lava fountaining, and sub-Plinian to Plinian eruptions. The eruption style strongly influences the associated hazard. The characteristics of the clast produced by these eruptions styles differ greatly, depending on the dynamics of the fragmentation processes that produce them. Examining the clasts can therefore inform both the style of the eruption, and on the physical process of fragmentation. The morphology of the products of lower-energy explosive activity – spatter, spindle bombs, Pele's hair and tears – indicates ductile processes are involved in fragmentation, whereas the morphology of the products of higher-energy activity – ash, scoria, and pumice – indicates brittle processes. This activity forms a spectrum, and brittle and ductile processes are not exclusive to any single eruption style. Processes both in and out of the conduit control the style of fragmentation and the type of eruptive product, but the processes that influence this balance of brittle and ductile fragmentation are still poorly understood. This study will provide a quantitative framework linking ductile and brittle textures in eruptive products to the eruption processes that produced them, across the spectrum of basaltic activity. As there can be a diversity of different fragmentation processes within the same eruption style, we will investigate the relative abundance of different morphologies within natural tephra samples from a range of eruption styles to determine the relative influence of each fragmentation process. We also aim to use natural and synthetic glass melts to recreate these fragmentation styles and eruptive products in order to constrain the brittle and ductile fragmentation regimes. The growth and bursting of bubbles will also be investigated in collaboration with the National Glass Centre (University of Sunderland), using synthetic glass compositions and glass blowing and manipulation techniques. Overall, this work will allow better reconstruction of basaltic eruptions in the geological record, and better forward modelling of the products and impacts of future eruptions.

Dyke propagation processes in the Southern Andes: insights from an outstanding field case of a Pleistocene-Holocene dyke swarm associated with a fissure complex

Javiera Ruz* Javiera Ruz (1,2), John Browning (1,2,3), José Cembrano (1,2), Pablo Iturrieta (4), Muriel Gerbault (5), Gerd Sielfeld (6)

(1) Departamento de Ingeniería Estructural y Geotécnica, Escuela de Ingeniería, Pontificia Universidad Católica de Chile, Santiago, Chile

(2) Centro de Excelencia en Geotermia de los Andes (CEGA, FONDAP-CONICYT), Departamento de Geología, Universidad de Chile, Santiago, Chile

(3) Departamento de Ingeniería Minería, Escuela de Ingeniería, Pontificia Universidad Católica de Chile, Santiago, Chile

(4) Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Potsdam, Germany

(5) GET/UMR5563 (UPS, CNRS, IRD, CNES); Obs. Midi-Pyrénées, Université P. Sabatier, Toulouse, France

(6) Prisma Austral Foundation, Punta Arenas, Chile

*jnruz@uc.cl

During periods of unrest, dykes may feed eruptions at surface fissures. A dyke's propagation path is governed by the crustal stress field, which in turn is affected by preexisting heterogeneities, loading from a volcanic edifice, magma overpressure, and by previous dyke injections, resulting in dyke segmentation, arrest or propagation. Here we study an outstanding exposure of a shallow feeder dyke swarm and the eruptive center it fed, to understand the role of dyke injections in modifying the stress field and potential propagation paths of later dyke injections. The fissure complex is associated with the Tatara-San Pedro volcanic complex, in the southern Andes.

Detailed mapping of 35 dyke segments over a ~1km long exposure of the dyke swarm reveals two preferential strike orientations N80ºE and N60ºE that appear to cross cut each other. Some of these dyke segments likely fed a fissure eruption, as an intrusion into a minor eruptive center. Analytical estimations from dyke geometry (strike, dip, length and thickness) indicate a variable range of magma origin depths (~3 to 23 km) that could be associated with shallow intrusions or mid crustal magma reservoirs, both of which have been interpreted from previous 2D magnetotelluric inversions and that are associated with a high enthalpy geothermal reservoir.

We complemented our field observations with 2D FEM elastic models to evaluate the temporal and spatial evolution of the dyke swarm and the role of regional compression in the propagation paths of the observed dykes. To do so, we modelled a volcanic complex and dyke swarm embedded in an elastic domain that represents a crustal segment at equivalent depth. The volcanic complex was modelled as a zone of excess pressure, while two dyke populations were modelled as either zones of excess pressure or as rigid inclusions. In some models we also applied a regional compression to mimic what could be a bulk regional transpression that governs in the Andean continental margin.

Our modelling results indicate that (1) individual dyke injections can locally rotate the principal stresses, thus influencing the range of orientations over which later dykes may form, and (2) that the effect of a bulk regional compression locally increases the magnitude of favorably oriented tensile stresses in the bedrock and at the same time reduces the range of possible propagation orientations by ~20º. This

implies that under a far-field compressive to transpressive stress regime, regional dyke swarms will tend to maintain their strike orientation parallel to the regional stress. These effects combine to influence the trajectories over which new dyke injections will propagate and hence the arrangement of shallow magmatic plumbing systems, as well as the distribution of heat sources for hydrothermal systems. Finally, these results should also be taken into account during periods of volcanic unrest and monitoring.

Quantifying gas, ash and aerosols in volcanic plumes using emission OP-FTIR measurements

Jean-François Smekens* Tamsin Mather (University of Oxford)

Mike Burton (University of Manchester)

*Jean-Francois.Smekens@earth.ox.ac.uk

Monitoring of volcanic emissions (gas, ash and aerosols) are crucial to our understanding of eruption mechanisms, as well as to developing mitigation strategies during volcanic eruptions. Ultraviolet (UV) spectrometers and cameras are now ubiquitous monitoring tools at most volcano observatories for quantifying sulphur dioxide (SO2) emissions. However, because they rely on scattered UV light as a source of radiation, they are limited to daytime use only, and measurement windows are often restricted by unfavourable weather conditions. On the other end of the spectrum, Open Path Fourier Transform Infrared (OP-FTIR) instruments can be used to measure the concentrations of a series of volcanic gases, and allow for night-time operation. However, the retrieval methods rely on the presence of a strong source of IR radiation in the background - either natural (lava flow, crater rim, the sun) or artificial – restricting their use to very specific observation geometries. Here we present a new approach to derive quantities of SO2, ash and aerosols from measurements of a drifting volcanic plume. Using the atmosphere as a background, we measured self-emitted IR radiation from plumes at Stromboli volcano (Italy) capturing both passive degassing and ash-rich explosive plumes. We use an iterative approach with a forward radiative transfer model (the Reference Forward Model – RFM) to quantify concentrations of sulphur dioxide (SO2), aerosols and ash in the line of sight of the spectrometer. This new method could significantly enhance the scientific return from OP-FTIR instruments at volcano observatories, ultimately expanding their deployment as part of permanent scanning networks (an alternative to DOAS instruments) to provide continuous data on the emissions of gas, ash and aerosols.

An element mapping approach to petrology

Johan Lissenberg* Matthew Loocke (Louisiana State University)

*LissenbergCJ@cardiff.ac.uk

In order to fully understand the magmatic and petrogenetic history of an igneous rock, it is critical to obtain a thorough characterisation of the chemical and textural relationships of its mineral constituents. Traditional microanalytical methods of geological materials (e.g. spot or line profiles by electron microprobe) determine compositions of constituent minerals from target locations previously identified by the user during petrographic analysis, under the assumption that the chosen spots are representative of the sample. However, it is statistically unlikely that a relatively limited number of spot analyses represent the true distribution of mineral compositions, given that most natural rocks consist of a heterogeneously distributed, diverse assemblage of minerals. Furthermore, choosing representative spots is complicated by the fact that chemical zoning is often petrographically cryptic (e.g., olivine, pyroxene, amphibole) and/or heterogeneously distributed both at the grain- and sample scale.

Here, we present a method for the production of sample-scale quantitative element maps using EDS-SEM. Capitalising on advances in EDS detector capability (>1,000,000 cps), we routinely map full thin sections at a resolution of tens of microns in a relatively limited amount of time, while still generating enough counts to enable each pixel to be quantified. Quantification of element ratios (e.g., An content of plagioclase, Mg# of pyroxene, Fo content of olivine) can be done precisely (<2% two sigma uncertainty) without the need for standardisation.

The resulting element maps provide a powerful visual representation of the full history of igneous rocks, enabling an effective reconstruction of underlying processes. Furthermore, the maps enable full modal proportions to be determined, including an immediate inventory of trace phases and their relationships with main constituents. Finally, and most importantly, the maps reveal the true distribution of compositions within samples, allowing population statistics to be employed to derive the relative compositions and volumes of melts which contributed to the crystallisation history of the rock.

New stratigraphic and petrologic observations of the catastrophic ~4 ky sector collapse of Antuco, a basaltic stratovolcano (Southern Andes, Chile)

Jorge E. Romero* Margherita Polacci (Department of Earth and Environmental Sciences, University of Manchester, Manchester, United Kingdom), Fabio Arzilli (Department of Earth and Environmental Sciences, University of Manchester, Manchester, United Kingdom), Giuseppe La Spina (Department of Earth and Environmental Sciences, University of Manchester, Manchester, United Kingdom), Sebastian Watt (School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, United Kingdom), Miguel A. Parada (Departamento de Geología, Universidad de Chile, Santiago, Chile), Mike Burton (Department of Earth and Environmental Sciences, University of Manchester, Manchester, United Kingdom)

*jorge.romero@postgrad.manchester.ac.uk

Sector collapses in arc basaltic edifices seem to be frequent but underreported in the literature; despite, they produce widespread environmental and societal consequences, and dramatic transformations in volcanic activity during short and long-term. Antuco (37.4°S, 71.4°W) is an active basaltic composite stratovolcano which experienced a 5 km3 sector collapse at ca. 4 ka BP with the edifice loosing c. 1000 m of height. The debris avalanche deposit (DAD) was distributed to the W and does not contain juvenile material. It is immediately overlaid by a sequence of diluted pyroclastic density currents (PDCs) and two thick, far-reaching (>8 km W from the vent) and less mafic lava flows than the pre-collapse basalts at Antuco. Collapse-driven tephra fall deposits are not recognised W of the volcano, but a Plinian deposit with an age of 3.5-4.0 ka BP and textural similarities to that of post-collapse PDC deposits has been recently recognised 8 km SE from the crater.

We carried out new field observations by January 2020 in the W pre- and post-collapse stratigraphic succession. The DAD has hummocky surface and is constituted of massive and scarcely disturbed, kilometric toreva blocks in proximal locations (< 4km W from the volcano). Some of them lie perpendicular to the original stratigraphy, and overlying fine-grained fluvial/alluvial basal facies. These blocks are intruded by abundant dikes and affected by moderate hydrothermal alteration. Blocks are progressively fragmented with distance (6 to 11 km W from the volcano), transforming into hectometric pieces of the edifice, which are then incorporated within a mixture of smaller blocks and matrix (mixed facies). Finally, all these blocks are intensely fragmented at a distance of 11 to 15 km W from the summit, producing a poorly sorted, polymodal (pebble to very fine sand) matrix still preserves some insight of the original stratigraphy, supporting some metric-sized megablocks and jigsaw fragments.

At “El Peñón” (c. 10 km from the summit) the DAD is overlaid by a well-bedded, c. 4 m-thick dilute PDC containing abundant lenses of highly vesicular porphyritic basalt scoria lapilli. The subsequent columnar jointed lava flows have been deeply eroded and their relicts are scarce. The erosive landforms have been filled with a succession of terraced alluvial deposits which generally overly in erosive contact the DAD deposits, covering a great extent of it in medial to distal locations were only small hummocks (< 10 m height) emerge. These alluvial deposits consist of three different units interpreted as debris flows (base) and hyperconcentrated flows (top).

Preliminary geothermometry and geobarometry obtained from mineral core/rim compositions (plagioclase, clinopyroxene and olivine) and glassy groundmasses in pyroclasts from the post-collapse stage points to a storage zone at depths of less than 5 km, while a shallower, likely post-collapse reservoir is imaged at 1-2 km below the crater.

Studying the case of Antuco, including the collapse’s unloading effect of its shallow magma system, may contribute to better understand sector collapses in active basaltic stratovolcanoes in arc settings, and ultimately to assess their volcanic hazards.

Thermo-Mechanical Behavior of the Liquiñe Granodiorite in the Southern Volcanic Zone

Josefa Sepúlveda* J. Sepúlveda (a,b), G. Arancibia (a,b), E. Molina (a,b), P. Gilbert (d), M. Duda (d), J. Browning (a,e), T. Roquer (a,b), D. Morata (b,c), R. Bracke (d).

[(a) Departamento de Ingeniería Estructural y Geotécnica, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile.

(b) Centro de Excelencia en Geotermia de los Andes (CEGA, FONDAP-CONICYT), Universidad de Chile, Plaza Ercilla 803, Santiago, Chile.

(c) Departamento de Geología, Universidad de Chile, Plaza Ercilla 803, Santiago, Chile.

(d) GZB - International Geothermal Centre, Bochum, Germany.

(e) Departamento de Ingenieria Mineria, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile.]

*jbsepulveda@uc.cl

The North Patagonic Batholith is located in the Southern Volcanic zone (33°- 46° S), in Chile, and it is composed by low permeability tonalitic to granodiorite rocks of Jurassic, Cretaceous and Miocene age. These intrusives are cut by the Liquiñe Ofqui Faults System (LOFS) and Andean Transverse Faults (ATF). The LOFS is a 1200 km long active intra-arc fault system and it is composed by both NS-NNE to NE-ENE faults. The ATF are a group of active NW-striking faults and morphotectonic lineaments. These faults increase the secondary permeability of the zone, which is produced by networks of faults and fractures. Additionally, actives volcanoes in the zone increase the geothermal gradient allowing the circulation of hot fluids through the fractures and faults producing a fractured geothermal system in Liquiñe zone (39° S). In this area several hot springs are observed spatially above the granitoids and likely related to the LOFS and ATF. The aim of this study is to estimate how low temperature thermal stressing and the rate and amount of mechanical loading, simulating the geothermal system and tectonic forcing, alter the geomechanical and hydromechanical properties of the Miocene granodiorite. To achieve this goal, a sample of the Miocene granodiorite was selected and tested at different conditions of temperature, stress and strain rate. Also, X-ray microtomography images were analyzed and modelled to provide estimates of the permeability of fractures in the tested samples. The results indicate that strength and Young's modulus decreased with an increase in temperature and a decrease in strain rate. Also, the permeability indicates that the temperature at lower values (< 300 °C) did not significantly affect the permeability. However, larger strain rates do increase the secondary permeability. From these results, we conclude that in the Liquiñe Geothermal fractured System the hot fluids circulate through a permeable network of open fractures within the fault zones which increase in amount and size when a critical limit stress is applied to the granodiorite during periods of tectonic forcing.

Evaluating the current state of activity at Ol Doinyo Lengai volcano, Tanzania.

Kate Laxton* Dr. Emma Liu (UCL), Prof. Adrian Jones (UCL), Dr. Chiara Petrone (NHM), Dr. Charles Kasanzu (UDSM), Mr. Maruvuko Msechu (GST)

*kate.laxton.17@ucl.ac.uk

In the remote Maasai lands of northern Tanzania, local communities rely on wildlife and geo-tourism to sustain their pastoral livelihoods. As the world's only active natrocarbonatite volcano, Ol Doinyo Lengai—otherwise known as the 'Mountain of God'— plays a critical role in this respect. However, as evidenced by the devastating Whakaari (White Island) eruption in 2019, active volcanic systems necessitate rigorous scientific investigations and clear public communication on the risks and hazards posed, no matter how remote.

Ol Doinyo Lengai is famed for its low-temperature, effusive and 'approachable' natrocarbonatite eruptions. However, in the past century alone, local communities have experienced at least four (VEI 3) and seven (VEI 1-2) explosive eruptions, the most recent of which occurred in 2007 (GVP,2020). The absence of affordable, long-term monitoring facilities ensures that no precursory eruption signals can be detected nor any early warning systems implemented.

Despite substantial advances in our understanding of natrocarbonatite magmatism since the 1960s (Dawson, 1962; Keller et al., 2010), knowledge of Ol Doinyo Lengai's parental magma composition, conduit geometry and outgassing behaviour remain largely unresolved. In essence, the processes controlling its cyclical eruption dynamics are unclear (de Moor et al., 2013). Our mission is to assess the current state of activity at Ol Doinyo Lengai, both in terms of its outgassing regime and effusive natrocarbonatite activity.

Considering the impact of the 2007 eruption on the morphology of the summit area, novel sampling techniques were required to access the crater floor, approximately 100 m below the crater rim (Laxton, 2020). An array of custom-built 100%-CO_2 sensors were deployed in tandem with a state-of-the-art Multi-Component Gas Analyser System, suspended from ropes across the 300 m wide crater. Stainless steel sampling units were similarly lowered into a lava pond on the crater floor. By these means in July-August 2019, our team retrieved the first crater gas data and lava samples since August 2007.

Geochemical analyses suggest the composition of natrocarbonatite erupted in 2019 is similar to that of pre-2007 'type' composition (Keller and Zaitsev, 2012): SiO_2 0.31 wt %, Na_2O+K_2O 38.05 wt % and CO_2 32.5 wt %. We also find that molar proportions of CO_2-H_2O gas emissions are highly variable and dependent on coincident extrusive activity and ambient atmospheric conditions.

The overarching goal of this project is to contribute towards international efforts to set up a locally run monitoring partnership. However, we now know that the geochemistry of natrocarbonatite is not known to change prior to, or after explosive eruptions (Bosshard-Stadlin et al., 2014). As such, monitoring and understanding long-term compositional trends in gas emissions at Ol Doinyo Lengai, will be of the utmost importance for decision-makers in the event of future unrest.

Focused flow during the formation and propagation of sills: Insights from analogue experiments

Kate Williams* Dr. Janine Kavanagh (University of Liverpool), Dr. David Dennis (University of Liverpool)

*k.williams14@liverpool.ac.uk

Understanding magma transport within sills is important for explaining diverse processes including volcanic plumbing systems, petroleum systems and kimberlites. Recent geophysical observations of sills suggest magma can be transported 100's of kilometers within these horizontal sheet-like magma bodies. However, existing magma flow models cannot explain how sills propagate so extensively without solidifying. Scaled analogue experiments were conducted to explore the geometry of sills and the dynamics of magma flow. Two gelatine layers with a contrasting stiffness and a weakly-bonded interface were prepared as the elastic crustal analogue. Two different fluids were injected through the base of the tank as the magma analogues: water (a Newtonian fluid) or Xanthan gum (a non-Newtonian, shear-thinning fluid). During the experiments, the evolving stress field was imaged using polarizing light, and flow within the intrusions that formed was visualized using passive tracer particles that fluoresce when interacting with a correctly orientated and positioned laser sheet. From this, Particle Image Velocimetry (PIV) was used to create a velocity flow map. The injections of fluid created a penny-shaped feeder dyke in the lower layer, that transitioned into a sill at the interface. Fluid flow within the dykes differed, with re-circulation occurring in the Newtonian dyke and a continuous, upwards jet present in the non-Newtonian dyke. At the interface, flow within the dyke transitioned to a single upwards jet for both fluids. The sills that formed at the interface had different geometries depending on the fluid. The Newtonian fluid sill had a variable thickness across its length, and a more domed appearance. By comparison, the non-Newtonian fluid sill had a more constant thickness across its length, resulting in a "slab-like" appearance. This geometry difference influenced the results obtained from the PIV experiments, as limited focused flow was evidenced within the Newtonian fluid sill. In contrast, a distinct region of focused flow (channelised flow adjacent to near stagnant regions of the intrusion) developed immediately and was maintained for the duration of the experiment. These experiments suggest that focused flow may be common within shear-thinning fluids, although there is still the potential for similar flow dynamics to be observed within Newtonian fluids. If such focused flow occurred in nature, this could explain how larger sills develop as magma would be predominantly transported 100's of kilometers through a small, localized region within a greater volume of potentially eruptible magma which is near stagnant. Within only a smaller, focused region of flow within the intrusion heat would become concentrated within this channelised region, decreasing the viscosity of the flowing magma and aiding in the continued flow over long distances.

Using artificial neural networks with joint muon-gravity datasets for shallow subsurface density prediction at volcanoes

Katherine Cosburn* Brady Spears (University of New Mexico)

Mousumi Roy (University of New Mexico)

*kcosburn@unm.edu

Estimating subsurface density is important for imaging and monitoring many geologic structures, such as volcanic edifices. Muon tomography has been used in recent years to complement traditional gravity measurements in Bayesian joint inversion techniques as an effective method for probing shallow subsurface density variations beneath volcanoes. Also in recent years, the use of deep learning to address complex inverse problems in the geosciences has gained increasing attention, particularly in the field of seismology. Using an artificial neural network (ANN) on a joint gravity and muon dataset, however, has yet to be explored and we present a first study here.

In this study, we examine the results of a deep learning model on sets of noisy synthetic gravity and muon data, which are generated based on theoretical knowledge of the forward kernels that relate these datasets to density. The deep learning model is trained with a suite of possible density values and variation patterns and its accuracy is determined by comparing against the known forward calculation. After testing our ANN on a toy model structure (a gaussian hill), we use an optimization algorithm for placement of muon detectors and gravimeters on real volcano topography to test the feasibility of our model for use by geologists in the field. We consider two ways to address the anomaly prediction problem: (1) as an inversion, where the ANN learns to predict an anomaly with a continuous density value and localized coordinate within the model domain, and (2) as a pattern recognition tool, where the ANN learns to predict discrete anomalous patterns that can vary both spatially and in density value. We explore the benefits and limitations of each approach and show that our methodology is very promising for actual volcano monitoring and hazard assessment.

Understanding volcano-tectonic links research symposium: 26th April 2020

Katy J Chamberlain* Dan J Morgan (University of Leeds, UK), Eleonora Rivalta (GFZ-Potsdam, Germany), Luis Lara (SERNAGEOMIN, Chile)

*k.chamberlain@derby.ac.uk

We invite you to attend a half-day virtual research symposium (26th April, 1pm – 5pm GMT) focusing on the developing research currently examining the interactions between volcano tectonics and magmatism. Tectonics on both local and regional scales are known to exert significant controls on magmatism and volcanism. Buoyancy forces and stress states of the upper crust are known to together influence the propagation pathway, the storage volume, crustal residence time and the rates of differentiation and vertical transport of magma prior to eruption. On a larger scale, the location of active volcanoes in space and the topographic and magmatic evolution of arcs can be linked to evolving tectonic regimes.

We aim to bring together a variety of experts in geophysics, tectonics, remote sensing, petrology, rheology, engineering geology and geodynamics to offer perspectives on these problems, share and discuss current research.

The symposium will operate in a ‘live’ environment with oral presentations (10-minute maximum length), and time for discussions following presentations. If you would like to participate in this event, initial expressions of interest should be registered by 1st February 2021. Participants wishing to present their work will then be required to submit a short (<250 word) abstracts by the 26th March- full schedule & abstracts will be available in advance of the event.

This event is open to any with an interest in the interactions between magmatic and volcanic processes and the tectonic environment they are operating in. Early career researchers and PhD students applications to give a presentation are particularly welcomed. For more information on this free event, and to register to attend or give a presentation, please visit https://magmastress.wordpress.com

VMSG

Spatio-temporal Evolution of the Magma Plumbing System at Masaya Caldera

Kirsten Stephens* Christelle Wauthier (Pennsylvania State University; Institute for Computational and Data Sciences, Pennsylvania State University)

Peter LaFemina (Pennsylvania State University)

*kjs51@psu.edu

Calderas are volcanic structures that form after the subsurface magma plumbing system depressurizes due to a violent expulsion of large volumes of magmatic and crustal material. While there are over 130 calderas in the world that exhibit changes in seismicity, ground deformation, thermal, and gas emissions, not all unrest results in explosive volcanic activity. Alternative activity may include a period of quiescence or effusive activity in the form of lava flows or appearance of lava lakes. The conditions that control the transitions between effusive and explosive activity are poorly-defined, and this is a major concern in caldera systems that are nearby to large population centers. Remote sensing techniques provide improved spatial and temporal coverage of these systems, which allows for a more comprehensive understanding of how caldera magma plumbing systems evolve. The primary objective of this research is to understand how changes within the magma plumbing system influence ground surface deformation and volcanic activity in order to improve forecasting and mitigation of volcanic hazards in caldera systems. This will be addressed by examining the ground deformation patterns associated with effusive and explosive activity at Masaya caldera in Nicaragua to further understand the link between changes in the magma plumbing system and how they may or may not manifest in volcanic activity. This objective will be accomplished by processing multiple Synthetic Aperture Radar (SAR) datasets with different orbit geometries, wavelengths, spatial and temporal resolutions over a period of 10 years over Masaya caldera using the Interferometric SAR techniques (InSAR). The processed datasets will then be incorporated into a multidimensional time-series approach (MSBAS) to assess the spatio-temporal changes in ground surface deformation within the caldera and link these changes with observed volcanic activity. Modeling of the detected ground surface deformation will provide insight into changes in volume within the magma plumbing system and potentially provide insight into the transitions between explosive versus effusive activity at the summit. Additional observational datasets, such as GPS, gas geochemistry, MIROVA thermal data, seismicity, webcam and visual observations will be used to validate results. Combining and validating these results with other multidisciplinary observation and monitoring datasets will also allow for the proposed research to be incorporated as forecasting parameters in probabilistic risk and hazard assessments.

Vent unloading evoked intense explosive eruption behaviour following the 2018 lateral collapse of Anak Krakatau, Indonesia

Kyra S. Cutler* Sebastian F.L. Watt (University of Birmingham), Mike Cassidy (University of Oxford), Amber L. Madden-Nadeau (University of Oxford), Samantha L. Engwell (British Geological Survey)

*kyra.cutler@stx.ox.ac.uk

Understanding the factors that initiate sector collapse is important to determine the monitoring signals associated with incipient collapse. This remains challenging, particularly when collapse occurs during an ongoing eruption, as was the case with the lateral collapse of Anak Krakatau in December 2018. The Anak Krakatau collapse resulted in a devastating tsunami impacting the surrounding coastlines of Java and Sumatra, Indonesia. The collapse occurred six months into a relatively elevated eruption phase characterised by Strombolian/Vulcanian and effusive activity, comparable to previous decades of activity. The question remains as to whether: (1) this collapse was primarily a consequence of long-term edifice growth and gravitational instability; (2) the prior six months of volcanism progressively destabilised the edifice; or, (3) a shift in magmatic behaviour before the collapse acted as a short-term trigger for failure. An intense phreatomagmatic explosion accompanied the collapse, and phreatomagmatic activity in the post-collapse period resulted in rapid edifice regrowth. However, whether this sharp change in eruptive activity acted as a trigger for the collapse, or whether it was simply a response to unloading, remains unclear.

Here we integrate physical, microtextural and geochemical characterisation of 2018/19 tephra deposits spanning the collapse period, to define magma ascent and fragmentation processes, constraining the link between eruptive activity and flank failure at Anak Krakatau. Crystallisation textures within the initial post-collapse deposit comprise a low microlite number density with relatively large-sized microlites. Such textures reflect pre-collapse conditions dominated by crystal growth, driven by slow decompression and magmatic ascent. The absence of unloading perturbation textures (i.e., textural disequilibrium) thus suggests this magma batch, already in the shallow conduit, rapidly evacuated, erupting as one of the largest explosions recorded in the volcano’s history [1]. Nevertheless, unloading is captured physically in the initial deposit as highly angular ash grain morphology, recording extensive brittle fragmentation from downward-propagating decompression. Post-collapse deposits higher up the tephra-stratigraphy highlight how the underlying shallow magmatic system was subsequently destabilised and rapidly decompressed, as observed by high densities of smaller microlites with abundant disequilibrium morphologies, indicating nucleation-dominated textures driven by fast magmatic ascent.

Our data suggest that no anomalous magma ascent patterns immediately preceded the collapse. This implies that the geophysical signals [2] prior to collapse were driven by structural and gravitational instabilities developed from long- and short-term edifice growth controls [3], rather than being a magmatic signal.

[1] Engwell S.L. et al. (2020). In AGU Fall Meeting 2020, AGU.

[2] Walter T.R. et al. (2019) Nature Communications, 10:1-11.

[3] Grilli S.T. et al. (2019). Scientific reports, 9:1-13.

Crustal Contamination: Petrogenesis and Magma Mixing of the Cabezo Maria Lamproites, SE Spain

Lara Tritton* Marie Edmonds (University of Cambridge)

*lut20@cantab.ac.uk

Cabezo Maria is an eroded volcano in the Vera basin in South-Eastern Spain, which erupted between 8.3 and 6.7 Ma. The Vera basin is known for its lamproitic magmas, and were amongst the first lamproites identified [2]. Cabezo Maria was assumed to be a lamproite volcano. Lamproites are believed to have a similarly short ascent history, limited pre-eruption storage and eruption timescale to kimberlites, and this study aimed to better understand the mechanisms and timings of ascent. Eruption of these highly potassic magmas is thought to be facilitated by the development of large-scale crustal faults associated with extension and slab rollback in this area in the Miocene. Lamproites are typically Mg- and K-rich, with extreme concentrations of incompatible elements and volatiles. The lamproite eruption here began with magmas intersecting water-saturated basin sediments, forming peperites and hyaloclastic material. This was followed by a cone-building eruption that deposited spatter and scoria. The eruptive sequence has been reconstructed in detail by [1], and detailed petrogenetic studies had been done on other volcanoes in the area such as [3]. Understanding the petrogenesis of lamproites provides important insights to an understanding of the sub-continental lithospheric mantle.

Here we present a detailed petrological description, applying geochemical procedures to a range of samples: the hyaloclastic peperites, massive lavas from the dyke sequence, and scoria from the cinder cone. We used bulk rock analysis from [1], and analysed both glass and mineral separates, using a Scanning Electron Microscope (SEM) and Electron Microprobe (EMPA). Petrographic analysis was done with thin section and QEMSCAN mapping. The rocks were highly altered, but phases identified are: olivine, phlogopite, sanidine, clinopyroxene, apatite, (Cr-)spinel, and secondary carbonates and Fe-rich ores. Analysis of the Cabezo Maria rocks classifies them as crustally-contaminated hyalo-olivine phlogopite diopside lamproites. The rocks contain distinct populations of olivine: mantle-derived highly forsteritic olivines with extreme Ni contents and strong zonation, as well as reverse zonation in low-Fo (80-86) olivines. Mineral separates are clearly out of equilibrium with the matrix, indicative of magma-mixing. These rocks are notable for their elevated Al and Si which classify them as largely peraluminous, in contrast to typically peralkaline lamproites.

The Cabezo Maria rocks are deduced to have originated as small-fraction melts from a phlogopite-bearing, enriched mantle source, in a metasomatised fossil Benioff zone, and ascended through the lithosphere via major lithospheric faulting. However, the chemical signatures and extent of zonation implies that there was significant crustal contamination of the lamproitic magma during ascent, of around 30%. Thus, they are closer to magmas retaining lamproitic character than true lamproites.

[1] T. M. Gernon et al., “Emplacement of the Cabezo María lamproite volcano (Miocene, SE Spain),” Bull. Volcanol., vol. 77, no. 6, 2015.

[2] R. H. Mitchell and S. C. Bergman, Petrology of Lamproites. New York, 1991.

[3] S. Duggen, K. Hoernle, P. van den Bogaard, and D. Garbe-Schönberg, “Post-collisional transition from subduction-to intraplate-type magmatism in the westernmost Mediterranean: Evidence for continental-edge delamination of subcontinental lithosphere,” J. Petrol., vol. 46, no. 6, pp. 1155–1201, 2005.

New insights on the ~74 ka Toba eruption from sulfur isotopes of polar ice cores

Laura Crick* A. Burke (School Of Earth And Environmental Sciences, University Of St Andrews), W. Hutchison (School Of Earth And Environmental Sciences, University Of St Andrews), S. Sparks (School Of Earth Sciences, University Of Bristol), S. Mahony (School Of Earth Sciences, University Of Bristol), E. W. Wolff (Department Of Earth Sciences, University Of Cambridge), E. A. Doyle (Department Of Earth Sciences, University Of Cambridge), J. W. B. Rae (School Of Earth And Environmental Sciences, University Of St Andrews), J. Savarino (Institut Des Géosciences De L'environnement, Grenoble, France), M. Kohno (Department of Geochemistry, Georg-august-universität Göttingen, Germany), S. Kipfstuhl (Alfred-Wegener-Institute, Bremerhaven, Germany), G. Wörner (Department of Geochemistry, Georg-august-universität Göttingen, Germany)

*lc258@st-andrews.ac.uk

The ~74ka Toba eruption in Indonesia was one of the largest volcanic events of the Quaternary and loaded an estimated 100 million tonnes of H2SO4 into the atmosphere. Understanding the precise timing of this colossal eruption is vital to unravelling the climatic and environmental impacts of the largest volcanic events on Earth. Sulfur aerosols injected into the stratosphere following large volcanic events reflect incoming radiation and lead to global cooling, and in the case of Toba it has been suggested that it led to cooling of 1 – 5°C and extinctions of some local hominin populations. One of the most enigmatic features of the Toba eruption is that the S peak has yet to be identified in the ice core records, although numerous candidate sulfate peaks have been identified in both Arctic and Antarctic ice cores. To address this, we analysed the sulfur isotope fingerprint (δ34S and Δ33S) of 11 Toba candidates from two Antarctic ice cores by multi-collector inductively coupled plasma mass spectrometry. This approach allows us to evaluate injection altitudes and to distinguish large tropical eruptions from proximal eruptions because stratospheric sulfur aerosols undergo UV photochemical reactions that impart a sulfur mass-independent isotopic fractionation (S-MIF). In contrast, tropospheric sulfur aerosols do not exhibit S-MIF because they are shielded from the relevant UV radiation by the ozone layer.

We identify three stratospheric, tropical eruption candidates with two recording the largest Δ33S signals measured to date in the ice core archives. The largest of these Δ33S signals is >2 ‰ more negative than previous measurements of the 1257 Samalas eruption (the largest eruption of the last 2000 years), despite having a similar integrated sulfate flux for this event to the ice core. These three candidates are within uncertainly of the Ar40/Ar39 age estimates for the Toba eruption and when considered with other paleoclimate proxies place the event during the transition into Greenland Stadial 20. Finally, we further analyse the relationship between the Toba eruption candidates and these proxies to determine the precise timing and potential climatic impacts of one of the largest eruptions of the Quaternary period.

Measurement and modelling of halogen-ozone chemistry in the plume of Mount Etna

Luke Surl* Tjarda Roberts (LPC2E, CNRS Orléans)

Slimane Bekki (LATMOS)

Global Mercury Observation System project

*luke.surl@latmos.ipsl.fr

Ozone destructive halogen chemical cycles occur in volcanic plumes, however, measuring these processes and these effects within plumes is inherently difficult. Only a small dataset of in-plume ozone measurements exist. We expand this dataset with observations of the plume of Etna from an aircraft-based campaign in the summer of 2012 when the volcano was passively degassing. Ozone mixing ratios in the plume are found to be reduced up to around 10 ppbv. We find a strong negative correlation between ozone levels and plume intensity, allowing for a quantitative estimate of the rate of ozone destruction.

To further our understanding of the processes occurring within the plume, we modified the 3D chemistry and transport model WRF-Chem to model volcanic emissions and halogen chemistry, creating "WRF-Chem Volcano (WCV)", which we intend for community use.

Our focus in this study is on plume aged less than one hour, which we model at 1 km spatial resolution. With volcanic emissions of species within typical ranges for Etna in a degassing state, the model reproduces the ozone trends seen in the aircraft observations and matches reasonably with spectroscopic measurements of the in-plume BrO/SO2 ratio from other studies.

Given the model's apparent skill, inspection of the model yields insight into the chemical processes occurring within passive degassing plumes. In the case modelled, the 'bromine explosion' occurs rapidly during daytime, converting bromine from HBr (the dominant form at emission) to other forms within minutes. The model finds that BrO and HOBr are the dominant forms of bromine in the evolved plume, with proportions remaining approximately stable after the initial evolution. Wind speed and time of day can have impacts upon bromine chemistry due to their impacts on plume density and photo-chemistry respectively. These factors may be significant where BrO measurements are used as proxies for volcanic bromine fluxes.

We quantify the modelled ozone destruction rate and find this continual process to be mostly linear with time and also impacted by wind speed. The ozone destruction can be "attributed" to different bromine-recycling reactions. We find reactions between halogen oxide species to have the largest contribution to in-plume ozone loss.

The model returns significant production of reactive chlorine due to the involvement of HCl in bromine cycling. This yields ClO and OClO, species which have been observed in some volcanic plumes.

As well as halogen–ozone chemistry, we also find that the model shows in-plume phenomena for other families of species. HOx is depleted in the plume, with near-total loss of OH. This results in only a very small fraction of SO2 being oxidised, though this fraction is significant in terms of aerosol levels within the plume. Although the model volcano is a source of NOx, the plume is NOx-depleted, as halogen chemistry promotes its conversion to HNO3. WCV also predicts the displacement of nitrate from background aerosol to the gas-phase.

A very simple mercury-halogen mechanism is implemented. Our results suggest that in the downwind plume, the net oxidation of mercury by halogens is slow, being limited by photo-reduction.

The importance of petrographic textures to model Fe isotope fractionation in intrusive settings

Madeleine Stow* Julie Prytulak (Durham University)

Madeleine Humphreys (Durham University)

Geoffrey Nowell (Durham University)

*madeleine.a.stow@durham.ac.uk

The continental crust is largely built from chemically diverse plutons, but the precise differentiation mechanism(s) in the crystal mush bodies that form these plutons are still debated. Transition metal stable isotopes (e.g. Fe, Zn, V, Cu) are useful tools used to provide information on T-X-fO2 during magmatic differentiation, so application to plutonic suites is a tempting prospect. Stable isotopic variations in genetically related, extrusive lavas have been successfully modelled with a variety of approaches. The critical assumption is that whole rock isotopic composition is analogous to the evolving liquid composition. While this is true for crystal-poor lavas, samples from intrusive settings are texturally complex. They are composed of primocrysts and interstitial phases crystallised from trapped interstitial melt, which means that phases in solidified samples are not necessarily in equilibrium with one another. Therefore, it is inappropriate to model equilibrium isotope fractionation in intrusive settings without a detailed consideration of petrographic textures.

We measured the Fe isotopic composition of whole rock powders, silicate and oxide mineral separates from the well characterised I-type Boggy Plain pluton, SE Australia. The pluton is concentrically zoned following closed system fractional crystallisation of a calc-alkaline magma [1].

Two broad textural groups are identified: cumulate assemblages, and assemblages representative of a crystallising magma. We developed a texturally informed Rayleigh model to explain the whole rock Fe isotopic variation. Textural observations are used to determine the changing modal abundance of primocryst phases throughout the differentiation sequence, and to estimate an appropriate parental melt composition. From the mineral separate data, we calculate temperature dependent mineral-melt Fe isotope fractionation factors, which can vary by up to 0.1‰ over the 300°C crystallisation temperature range. This is very significant relative to the overall isotopic shifts observed.

Rayleigh models show that the whole rock Fe isotopic variation in Boggy Plain can be completely explained by closed system fractional crystallisation of an I-type magma, but only when the appropriate balance between crystallisation of isotopically heavy magnetite and isotopically light silicates (biotite and hornblende) is applied, combined with an increase in mineral-melt fractionation factors at lower temperatures. The success of this combined petrographic and stable isotopic approach in a simple system like Boggy Plain opens up the potential for a detailed understanding of the controls on stable isotope fractionation in more complex mushes.

[1] Wyborn (1983)

Global Survey Reveals Intermediate Elastic Thickness at Steep-Sided Dome Volcanoes on Venus

Madison Borrelli* Joseph O'Rourke [Arizona State University]

Suzanne Smrekar [Jet Propulsion Laboratory]

Colby Ostberg [University of California, Riverside]

*meborrel@asu.edu

Volcano shape as seen on the surface can reveal information about the interior of a planet. Signs of lithospheric flexure around volcanoes can help us interpret the lithospheric thickness and heat flow at certain locations. Though Venus' lithosphere is poorly understood, previous work has predicted that elastic thickness may influence magma ascent and volcano morphology. McGovern et al. (2013) [1] hypothesized that volcanic-tectonic features called coronae are expected to form in regions with elastic thicknesses of less than ~10 km, while steep-sided dome volcanoes may be found at regions with elastic thicknesses of ~10–40 km. Others have used flexural studies to determine that many coronae are indeed associated with thin lithosphere and high heat flow [2,3]. However, the hypothesis remained untested for steep-sided or "pancake" domes.

We conducted the first global survey of flexural signatures around pancake domes on Venus. We took 8 topographic profiles at regular increments around 75 steep-sided domes and found convincing evidence of flexure in 29 profiles from 14 different domes. We then used a curve-fitting algorithm to determine the elastic thickness at the location of domes for which we found flexural signatures. A yield stress envelope converts elastic to mechanical thickness, allowing us to determine the surface heat flow at each location.

Elastic thickness at domes not near coronae averaged ~30 km, which supports the original hypothesis. Domes located near coronae were generally associated with thin lithosphere in the range expected for coronae. Heat flow was also higher at most domes near coronae than those not near coronae, with an average of ~197 mW/m2 compared to ~57 mW/m2. We quantitatively verify that volcano morphology is a clue to internal heat flow. We assert that a new mission to Venus to collect higher-resolution data is essential.

[1] McGovern et al. 2013, JGR Planets, 118(11), 2423–2437. [2] O'Rourke & Smrekar (2018), JGR Planets, 123. [3] Smrekar et al. (2019), VEXAG17 #8035.

Boron isotopic signatures reveal recycled material in the Icelandic mantle

Margaret Hartley* Cees-Jan de Hoog (University of Edinburgh)

Oliver Shorttle (University of Cambridge)

*margaret.hartley@manchester.ac.uk

Trace element and volatile heterogeneity in the Earth's mantle is influenced by the recycling of oceanic lithosphere through subduction. Ocean island basalts commonly have high concentrations of volatiles compared to mid-ocean ridge basalts, but the extent to which this enrichment is linked to recycled mantle domains remains unclear. Boron is an ideal tracer of recycled subducted material, since only a small percentage of a recycled component is required to modify the bulk δ11B of the source mantle. Boron isotopic compositions of primary melts thus have potential to trace the fate of recycled subducted material in the deep mantle.

We present new measurements of volatiles, light elements and boron isotopic ratios in basaltic glasses and melt inclusions that sample the mantle at two endmember spatial scales: (1) Submarine glasses from the Reykjanes Ridge sample long-wavelength mantle heterogeneity on the broad scale of the Iceland plume; (2) Crystal-hosted melt inclusions from the Askja and Bárðarbunga volcanic systems in North Iceland sample short-wavelength mantle heterogeneity close to the plume centre. The Reykjanes Ridge glasses record only very weak along-ridge enrichment in [B] approaching Iceland, and there is no systematic variability in δ11B along the entire ridge segment. These observations constrain ambient Reykjanes Ridge mantle to have a δ11B of -6.1 ‰ (2SD=1.5 ‰, 2SE=0.3 ‰). The North Iceland melt inclusions have widely variable δ11B between -20.7 and +0.6 ‰. We screened the melt inclusions against influence from crustal contamination, identifying high [B] and low δ18O as fingerprints of assimilation processes. Only the most primitive melt inclusions with MgO>8 wt.% reliably record mantle-derived δ11B. In North Iceland, incompatible trace element (ITE)-depleted primitive melt inclusions from Holuhraun record a δ11B of -10.6 ‰, a signal that has also been seen in melt inclusions from southwest Iceland. In contrast, primitive ITE-enriched melt inclusions from nearby Askja volcano record a δ11B of -5.7 ‰, overlapping with our new constraint on the δ11B of Reykjanes Ridge mantle. Coupled [B], δ11B and δ18O signatures of more evolved melt inclusions from North Iceland are consistent with primary melts assimilating <5-20% of hydrothermally altered basaltic hyaloclastite as they ascend through the crust.

Our data reveal the presence of a depleted, low-δ11B and an enriched, higher-δ11B mantle component, both intrinsic to the Icelandic mantle and distinct from Reykjanes Ridge mantle. Non-modal melting calculations suggest that the enriched and depleted mantle components both contain ~0.085 µg/g B, slightly lower than the 0.10-0.11 µg/g calculated for Reykjanes Ridge mantle. These data are consistent with the Icelandic mantle containing [B]-depleted dehydrated recycled oceanic lithosphere, in keeping with the low B/Pr of Icelandic melt inclusions in comparison to Reykjanes Ridge glasses or MORB. Our new data provide strong support for the role of recycled subducted lithosphere in melt generation at ocean islands, and highlight the need for careful screening of melt inclusion compositions in order to study global volatile recycling in ocean island basalts.

Constraints on the Holocene volcanic history of Flores Island (Azores): insights from lacustrine and on land records

Mariana Andrade* Mariana Andrade (Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal; Departamento de Geologia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Lisboa, Portugal);

Ricardo Ramalho (Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal; Departamento de Geologia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Lisboa, Portugal; School of Earth Sciences, University of Bristol, Bristol, UK; Lamont-Doherty Earth Observatory of Columbia University, New York, USA);

Adriano Pimentel (Centro de Informação e Vigilância Sismovulcânica dos Açores (CIVISA), 9501-801 Ponta Delgada, Azores, Portugal; Instituto de Investigação em Vulcanologia e Avaliação de Riscos (IVAR), Universidade dos Açores, 9501-801 Ponta Delgada, Azores, Portugal; Centro de Investigação em Biodiversidade e Recursos Genéticos (CIBIO), InBIO Laboratório Associado, Pólo dos Açores, 9501-801 Ponta Delgada, Azores, Portugal);

Armand Hernández (Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal);

Steffen Kutterolf (GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany);

Mario Benavente-Marín (Geosciences Barcelona (GEO3BCN-CSIC), 08028 Barcelona, Spain);

Alberto Saez (Department of Earth and Ocean Dynamics, Universitat de Barcelona, Barcelona, Spain);

Santiago Giralt (Geosciences Barcelona (GEO3BCN-CSIC), 08028 Barcelona, Spain);

*mdandrade@fc.ul.pt

The interaction of ascending magmas with groundwater at near-surface levels may result in sudden changes in eruptive behaviour, e.g. between strombolian and phreatomagmatic styles. This change is particularly acute at hydraulically-charged ocean island volcanoes where tiny variations in the water/magma ratios may turn relatively mild basaltic volcanism into violent phreatomagmatic activity. Flores is one of the two islands of the Azores that lie west of the Mid-Atlantic Ridge. Since its settlement in the 15th century the island did not experienced any eruption and therefore its volcanic hazard is considered to be low. However, Flores has a rich Holocene record of phreatomagmatic and magmatic volcanism that created several large maars and tuff rings. Very little is known about these recent eruptions, and therefore the volcanic hazard potential of Flores Island should not be underestimated and the possibility of future highly-explosive eruptions should be properly considered.

Our study aims to assess the volcanic hazard potential of Flores, through a detailed reconstruction of its Holocene eruptive history, using tephrostratigraphy of terrestrial and lacustrine records combined with glass geochemistry and radiocarbon dating. Two main recent volcanic centres have been

recognized, both characterized by a basaltic to phonotephritic initial magmatic phase that rapidly shifted to a highly explosive phreatomagmatic phase:

i) Funda Volcanic System (FVS) which is located on the southern central part of the island and comprises three main craters (including Funda and Rasa lakes) aligned along a SE-NW direction. FVS has a complex history and a large variety of volcanic products such as fall deposits of magmatic and phreatomagmatic origin, and dense and dilute pyroclastic current deposits.

ii) Comprida Volcanic System (CVS) is located in the northern central part of the island and includes at least four craters, Comprida, Negra, Seca and Branca.

Our field observations suggest a cyclicity in the style of Holocene volcanic eruptions, invariably resulting in abrupt transitions from strombolian to phreatomagmatic events, demonstrating that small monogenetic eruptions may rapidly turn into a highly hazardous events at hydraulically-charged ocean island volcanoes such as not only the case of Flores Island but also the case of many Islands of the British overseas territories. Future work of this project will involve a paleoclimate analysis of the Atlantic North during the time of these Holocene eruptions, in order to investigate how the hazard potential of small-volume monogenetic eruptions may be amplified by environmental controls such as rainfall variability, which ultimately controls the available groundwater.

Modelling magma ascent on the Moon to understand the effect of volatile content on magma ascent dynamics.

Marissa Lo* Giuseppe La Spina, Katherine Joy, Margherita Polacci, Mike Burton (all University of Manchester).

*marissa.lo@manchester.ac.uk

Quantifying the volatile content of the lunar interior is valuable for understanding the formation, thermal evolution, and volcanic history of the Moon. Improvements to analytical instruments have facilitated more precise measurements of the volatile content of lunar samples and meteorites, leading to a paradigm shift from an anhydrous lunar interior, to a wet lunar interior. While major advances have been made in measuring volatile abundance within lunar pyroclastic glass beads, the role of different volatiles in driving lunar magma ascent is still unclear.

We have adapted a terrestrial model for magma ascent for the ascent of picritic magma in the Moon's crust. This model has previously been used to calculate various eruption conditions for the 2007 Stromboli eruption and for scenarios such as equilibrium and disequilibrium crystallisation. Numerous parameters were adjusted for lunar conditions, including: gravity, pressure, magma composition, and volatile solubility. Using the numerical magma ascent model, we have calculated values for magma ascent processes, such as mixture velocity, gas exsolution depth, and mass flow rate. We can use these results to comment on the relative importance of different volatile species during magma ascent on the Moon, and for comparison with previous geophysical or experimental models for lunar magma ascent. Later work will involve modelling eruptions, using results from the magma ascent model, and verifying the results of both models using images and digital elevation models of the lunar surface.

The 2017 Agung eruption as case study for precursory volcano deformation detection and analysis using InSAR

Mark Bemelmans* Prof. Juliet Biggs (University of Bristol)

Dr. Micheal Poland (Cascades Volcano Observatory, USGS)

*mark.bemelmans@bristol.ac.uk

Unlike many other natural hazards, volcanic eruptions are sometimes preceded by warning signs indicating increased activity, hours to years before an eruption. Understanding these precursors and their relations to the eruptions is crucial to mitigate the impacts of volcanic hazards. One of these precursors is volcano deformation, which we can measure at volcanoes globally using satellite InSAR.

Over the last two decades, InSAR has become better at detecting deformation with smaller and smaller spatial extents. This sheds light on sources which we expect to find closer to the surface and which may become active shortly before eruption onset.

We start by tabulating observed volcano deformation with an estimated major axis of 3 km or less. We find that of 39 recorded deformation events meeting that criteria, 13 occurred less than 4 years before an eruption and were most often attributed to magmatic (23/39) or hydrothermal processes (7/39). The magmatic processes were the only group for which deformation occurred less than 1 year prior to eruption. The deformation events that include an estimate of source depth almost exclusively take place within 1 km of the surface (21/25). However, we expect that deformation events of this nature frequently go unnoticed because many volcanoes are under-monitored, and detecting deformation at a small spatial scale requires high-resolution images or a very dense ground-based network.

Between September and October 2017 a seismic swarm occurred between the volcanoes Agung and Batur on Bali, Indonesia, which led to an eruption at Agung in November 2017. Sentinel-1 was able to detect deformation associated with the intrusion of a dyke in September 2017. High-resolution TerraSAR-X (TSX) and Cosmo-SKYMED (CSK) images captured a second, smaller deformation event within the summit crater of Agung with a spatial footprint of 300 metres and that occurred only months prior to the eruption. Here we present analysis of the 2017 CSK and TSX data catalogue to fully characterise this smaller signal.

Bridge under troubled magma: emplacement of segmented alkaline sills in San Rafael Volcanic Field, Utah

Martin Kjenes* Christian Haug Eide (University of Bergen)

Atle Rotevatn (University of Bergen)

Nick Schofield (University of Aberdeen)

Lauren Chedburn (University of Aberdeen)

*martin.kjenes@uib.no

Igneous intrusions, such as dikes, sills and laccoliths, are important components of volcanic plumbing systems in extensional tectonic settings, e.g. rifted margins and sedimentary. In contrasts to dikes (i.e. vertical conduits), sills appear as layer parallel, tabular bodies of magma with structural signatures. There is a vast range of different models that explain the emplacement mechanisms of sills, but these are only valid in certain circumstances. Subsequently, it is not entirely clear in which scenario these models apply. The majority these mechanic models illustrate that sills emplace as continuous igneous sheets with low thickness-to-length aspect ratios, and propagate as hydraulic fractures. These models, however, account for purely elastic host rocks and function as theoretical and numerical models of sill propagation. In addition, they hold the assumption that sill tips propagate as wedge-shaped (tapered) tips, but this is not representative for all intrusions. A numbers of studies have reported sills with non-tapered geometries, which results in multiple propagation models to fit each case study.

An issue that often omits from intrusion propagation models is that the existing models are limited and may not be able to explain complex sill architecture, which directly influences sill propagation. This lack of understanding is potentially problematic for subsurface reservoirs in terms of groundwater- and petroleum exploration, or related to geohazard in active volcanic areas, such as Iceland. One other issue is that magma and host rock properties may change during an intrusive event. Modifications in, e.g., viscosity during cooling exert strong influence of intrusion geometry and associated style of host rock deformation.

To address these issues, we present the results from a study of combined UAV- and outcrop datasets from a 1.3 km long meandering river channel, Mussentuchit Wash, in San Rafael Swell, Utah. The section is c. 30 meter thick of heavily intruded Jurassic sedimentary rocks by an alkaline trachybasalt. This section was at an approximate depth of 0.8-1 km depth at the time of magma emplacement, related to intraplate volcanism along the transition zone of the Colorado Plateau and the Basin and Range province. Our data shows in detail the high complexity of sill propagation and evolution, which is evident by multiple magmatic textures (e.g. fluidization, brecciated magma), segmenting splays, structural signatures (e.g. magmatic bridges) and host rock interplay. This suggests that sill propagation depends heavily on local factors, such as viscosity, remote stress and host rock lithology, combined with magma driving pressure.

Quantifying Platinum Group Element (PGE) Enrichment, Through Unsupervised Learning of Optical and EDS Data

Matt Divers* Dr Joshua Franz Einsle (University of Glasgow), Dr Brian O'Driscoll (University of Manchester), Dr John Faithfull (University of Glasgow/Hunterian Museum), Dr Daniel Lonsdale (LIG-Nanowise Ltd.), Dr Sébastien Vilain (LIG-Nanowise Ltd.)

*2251460d@student.gla.ac.uk

Platinum Group Elements (PGE) are of increasing global importance due to their role in the automotive and electronics industries. This demand drives a need to not only understand existing resources, but investigate methods for enhanced recovery of PGE from previously extracted ore – a prospect whose economic viability depends on metal price(s).

The Eastern Layered Intrusion – Rum, NW Scotland – provides an excellent opportunity for studying the processes by which PGE's are mobilised and enriched during precious metal ore formation. Although the Rum intrusion is not enriched to a grade suitable for ore extraction, its relatively young age (~60Myr) and lack of significant deformation should result in the preservation of valuable primary magmatic signatures. These characteristics are not always preserved in the older (>2Gyr), economically significant counterpart of the Rum intrusion: the Bushveld Complex, South Africa (the world's most productive PGE resource). This makes Rum a valuable locality to examine PGE distribution and develop new approaches to quantitatively characterise the phases that control the distribution of these metals.

Previous efforts to map PGE mineralisation – using quantitative automated mineralogy tools on the scanning electron microscope (SEM) – have been limited by the trade-off between automation throughput versus spatial resolution. By leveraging the lithological and structural similarities between the Rum Layered Suite and the Bushveld Complex, this projects wider aims are to statistically quantify PGE mineralisation in the Rum intrusion, whilst also developing a holistic model for PGE enrichment in layered mafic/ultramafic intrusions more generally.

In order to improve upon the efficiency of pre-existing quantitative methodology, we present the great potential of using high resolution, oil immersive optical microscopy – allowing a pixel resolution of up to 16nm (leveraging advanced nano-optics developed by LIG Nanowise). Conducting unsupervised machine learning techniques on optical data, allows for an algorithm to pin-point areas of mineralogical interest (i.e. those likely to contain PGE) to be analysed in greater detail by SEM. Then, analysing the EDS maps with probabilistic machine learning tools will produce quantitative phase maps which can be explored for both PGE bearing phases, as well as textural relationships. These mineral phase relationships will be used to derive statistically robust datasets based on the full range of grain sizes, down to the nanoscale – connected across multiple thin sections.

We envisage that the workflows and analytical methods developed here will be redeployable across a broad range of geological applications in petrology, mineralogy and beyond.

The influence of mantle melt flux on the physiochemical characteristics of magma storage

Matthew Gleeson* Sally A. Gibson (Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, UK, CB2 3EQ)

Michael J. Stock (Department of Geology, Trinity College Dublin, College Green, Dublin 2, Ireland)

*gleesonm1@cardiff.ac.uk

The physicochemical characteristics of sub-volcanic magma storage regions have important implications for magma system dynamics and pre-eruptive behaviour. The architecture of lithospheric magma storage located above high buoyancy flux mantle plumes (such as Kīlauea, Hawai'i and Fernandina, Galápagos) are relatively well understood. However, far fewer constraints exist on the nature of magma storage beneath ocean island volcanoes that are distal to the main zone of mantle upwelling or above low buoyancy flux plumes, despite these systems representing a substantial proportion of global ocean island volcanism. To address this, we present a detailed petrological study of erupted material from Isla Floreana in the Galápagos Archipelago, which is characterised by an extremely low flux of magma into the lithosphere from the underlying mantle plume.

In-situ major and trace element analyses of crystal phases from exhumed cumulate xenoliths, lavas and scoria deposits, indicate that magma storage beneath Floreana is dominated by crystal-rich domains (i.e. mush). Trace element disequilibria between cumulus phases and erupted melts, as well as trace element zoning within the xenolithic clinopyroxenes, reveals that reactive porous flow (previously identified beneath mid-ocean ridges) is an important process of melt transport within these crystal-rich storage regions. In addition, after filtering the dataset to avoid crystal compositions modified by reactive melts, multiple petrological barometers demonstrate that the Floreana mush zones are located in the upper mantle, at ~24 ±5 km depth.

Comparison of our results with recent barometric estimates from other ocean island volcanoes worldwide reveals a clear relationship between the volumetric flux of magma into the lithosphere and the depth of magma storage. As a result, we suggest that the volumetric magma flux represents a first-order control on the depth magma storage beneath ocean island volcanoes owing to its influence on the thermal structure of the lithosphere.

Sensitivity of Magma Reservoir Failure to Variations in Thermal Parameters

Matthew Head* James Hickey (University of Exeter), Joachim Gottsmann (University of Bristol), Nico Fournier (GNS Science, NZ)

*m.head2@exeter.ac.uk

As volcanic systems undergo unrest, understanding the conditions required for reservoir failure, the associated timescales, and the links to observed ground deformation are critical when evaluating the potential for eruption. The characteristics and dynamics of a pressurised magmatic system can be inferred from episodes of surface deformation, but this process is heavily reliant on the assumed crustal rheology. In volcanic regions, shallow or long-lived magmatic systems can significantly perturb the regional geothermal gradient, altering the rheology of the surrounding crustal rock. Viscoelasticity incorporates a time-dependent viscous deformation response, so can be used to account for induced thermomechanical heterogeneity.

In this study, we investigate the influence of an imposed thermal regime on the critical reservoir overpressure (OPc) required to facilitate failure in elastic and viscoelastic models, alongside the predicted critical surface uplift (Uc). We use the Standard Linear Solid viscoelastic rheology, together with a temperature-dependent viscosity structure calculated from the thermal constraints. We consider combinations of background geothermal gradients and reservoir temperatures, representing felsic, intermediate, and mafic magma compositions. Our models feature mechanical heterogeneity in the form of a depth-dependent Young's modulus, which is then adjusted to account for thermal weakening. The mechanical stability of the magma reservoir is determined by evaluating the tensile and Mohr-Coulomb failure criteria in the surrounding crustal rocks.

We identify that reservoir failure is systematically inhibited by incorporating viscoelasticity, with OPc for Mohr-Coulomb failure increasing by up to 65% with respect to the corresponding elastic model. The greatest increases in OPc, and Uc, are observed when pairing cool reservoir temperatures (i.e., felsic composition) with low background geothermal gradients. In contrast, failure at the ground surface is promoted by the viscoelastic rheology, decreasing the required OPc for tensile failure by up to 32%. The greatest reductions in OPc are produced in models that couple a hot reservoir temperature (i.e., mafic composition) with low background geothermal gradients. By resisting mechanical failure on the reservoir wall, temperature-dependent viscoelasticity impacts the conditions required for dyke nucleation and propagation. Further to this, a viscoelastic rheology dramatically reduces the timescales for throughgoing failure, occurring much earlier than suggested by elastic models, which has major implications for interpreting the conditions, and onset, of a potential eruption.

The muesli effect in pyroclastic density currents - what does reverse grading in an ignimbrite mean?

Matthew Johnson* Dr Natasha Dowey (University of Hull), Dr Pete Rowley (University of West England), Dr Rebecca Williams (University of Hull)

*m.johnson-2017@hull.ac.uk

Pyroclastic density currents (PDCs) are hot, density-driven flows of gas, rock and ash generated during explosive volcanic eruptions, or from the collapse of lava domes (e.g. Sparks, 1976; Fisher, 1979; Branney and Kokelaar, 2002; Cas et al. 2011). They pose a catastrophic geological hazard and have caused >90 000 deaths since 1600AD (Auker et al. 2013). Improved understanding of PDCs will enable us to better understand the explosive eruptions that generate them, improving our preparedness for future volcanic events. However, these deadly hazards are rarely observed up close and are difficult to analyse in real-time. To understand the flow dynamics of density currents we must use models and interpretations of their deposits (e.g. Smith N and Kokelaar, 2013; Rowley et al. 2014, Williams et al. 2014, Sulpizio et al. 2014; Lube et al. 2019, Smith G 2018, 2020).

The deposits of pyroclastic density currents, known as 'ignimbrites' can reveal important clues about how these deadly volcanic hazards behave in time and space Reverse grading in an ignimbrite can be interpreted in different ways (Branney & Kokelaar, 2002). It could record a growing eruption intensity through time - where increasingly larger clasts are introduced into the pyroclastic density current. Alternatively, it could record Kinematic sorting (the 'muesli effect') and transport processes within the current where larger particles became increasingly likely to be deposited as the current wanes (Palladino & Valentine,1995). The link between current dynamics and reverse grading is currently untested in aerated granular currents.

This project seeks to investigate the relationship between current dynamics and deposit architecture, specifically by considering granular sorting mechanisms in unidirectional flow. We will use an analogue flume (following methods in Rowley et. al., 2014, and Smith G et al., 2018, 2020) to explore how reverse grading and lateral grading may be related to changes in grain sizes at source versus kinematic sorting processes. A mix of grain sizes will be incorporated into the current via a hopper which allows for the starting composition of the current to be varied e.g. homogenous mix versus layered. Photographs of the deposit will be taken through the transparent sidewall of the flume and analysed using image analysis software. These experiments will be complimented by static tests of kinematic sorting, where a Perspex column will be sliced to reveal internal 3d architecture.

This project will contribute to our understanding of lithofacies architecture in the field, and help to quantity how we interpret the sedimentation of ignimbrites.

References

Auker et al. (2013) Journal of Applied Volcanology22 https://doi.org/10.1186/2191-5040-2-2
Branney and Kokelaar (2002) Geological Society Memoir 27 https://doi.org/10.1144/GSL.MEM.2003.027
Cas et al. (2011) Bulletin of Volcanology 731583 https://doi.org/10.1007/s00445-011-0564-y
Fisher (1979) Journal of Volcanology and Geothermal Research 6:3-4 (305-318) https://doi.org/10.1016/0377-0273(79)90008-8
Lube et al. (2019) Nature Geoscience 12(381–386) https://doi.org/10.1038/s41561-019-0338-2
Palladino & Valentine (1995). Journal of Volcanology & Geothermal Research 69 3-4 (343-364). doi.org/10.1016/0377-0273(95)00036-4
Rowley et al. (2014) Bulletin of Volcanology 76855 https://doi.org/10.1007/s00445-014-0855-1
Smith N. and Kokelaar (2013) Bulletin of Volcanology 75768 https://doi.org/10.1007/s00445-013-0768-4
Smith G. et al. (2018) Bulletin of Volcanology 8067 https://doi.org/10.1007/s00445-018-1241-1
Smith, G. et al. (2020) Nat Commun 11, 2873 . https://doi.org/10.1038/s41467-020-16657-z
Sparks (1976) Sedimentology 23:2 (147-188) doi.org/10.1111/j.1

Quantifying and correcting light dilution in UV measurements of SO_2 from Masaya, Nicaragua

Matthew Varnam* Mike Burton (University of Manchester), Ben Esse (University of Manchester), Giuseppe Salerno (INGV-Catania), Ryunosuke Kazahaya (Geological Survey of Japan, AIST)

1. The Department of Earth and Environmental Sciences, The University of Manchester, Manchester, UK

2. Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Catania, Italy

3. Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

*matthew.varnam@manchester.ac.uk

SO_2 emission rate is the most commonly measured gas signal from volcanoes. This is because SO_2 has a high plume and low background concentration, as well as a strong UV absorption, making it more suited for passive measurements than the more abundant CO_2 and H_2O. Gas emissions reflect magma chamber dynamics. Ultraviolet measurements of volcanic SO_2 flux underpin the quantification of all volcanic gas emissions, as well as volatile metals, through their combination with in-plume gas ratios measured using equipment such as LIDAR and Multi-Gas. Challenging volcanic terrain means that, in many situations, volcanologists must capture SO_2 flux measurements several kilometres away from the plume. This leaves them vulnerable to scattering effects between the plume and instrument, commonly called light dilution. Previous work has corrected radiative transfer effects using Markov chain Monte-Carlo methods, but such corrections are not widespread in the volcanological community due to the need for prior knowledge or iteration to obtain plume, atmospheric and measurement conditions. Other studies use higher wavelength windows where scattering is marginally reduced, though not eliminated.

We combine intensity fitting (iFit) with modelling of simulated spectra using two wavelength windows, specifically 306-316 nm and 312-322 nm, to examine and correct the effect of photon scattering between the plume and instrument using only information available in the spectra. Our modelling demonstrates low SO_2 column density measurements can be heavily diluted, yet show fitting residuals of a similar magnitude to normal fitting errors. It also shows a hard upper limit on retrieved column density imposed by the dilution that decreases with increasing dilution. We apply our model to correct empirical observations from Masaya volcano, Nicaragua, conducted in January 2018. The observations show excluding the correction leads to underestimates of SO_2 column density reaching a factor of 5. We further use the retrieved column densities to correct traverses and calibrate an SO_2 camera, showing the emission rates of both measurements only match if the correction is included. If light dilution is not corrected, emission rates of all volcanic volatiles may significantly underestimated, especially at volcanoes that have a large distance between their instrumentation and SO_2 plume.

The influence of hydrothermal alteration on volcano stability: a case study of La Soufrière de Guadeloupe (France)

Michael Heap* Tobias Baumann (Johannes Gutenberg University Mainz)

Marina Rosas-Carbajal (IPG Paris)

Jean-Christophe Komorowski (IPG Paris)

H. Albert Gilg (TU Munich)

Marlène Villeneuve (University of Leoben)

Roberto Moretti (IPG Paris)

Patrick Baud (University of Strasbourg)

Lucille Carbillet (University of Strasbourg)

Claire Harnett (University College Dublin)

Thierry Reuschlé (University of Strasbourg)

*heap@unistra.fr

Volcanoes are inherently unstable structures built haphazardly, in both space and time, from the products of successive effusive and explosive eruptions. As a result, mass wasting events (such as slope failure, rockfalls, and debris flows) are commonplace at many volcanoes worldwide. Hydrothermal alteration, common to many volcanoes, is often invoked as a mechanism that contributes significantly to volcano instability. We present here a study that combines laboratory deformation experiments and large-scale numerical modelling to better understand the influence of hydrothermal alteration on volcano instability. La Soufrière de Guadeloupe, located on the island of Guadeloupe (France) in the Lesser Antilles Volcanic Arc, is a hazardous andesitic volcano that hosts a large hydrothermal system and therefore represents an ideal natural laboratory for our study. Uniaxial and triaxial deformation experiments were performed on samples prepared from variably-altered blocks collected from La Soufrière de Guadeloupe. The alteration minerals include quartz, cristobalite, tridymite, hematite, pyrite, alunite, natro-alunite, gypsum, kaolinite, and talc. Our uniaxial compressive strength experiments show that strength and Young's modulus decrease as a function of increasing porosity and increasing alteration. Our triaxial deformation experiments show that cohesion decreases as a function of increasing alteration, but that the angle of internal friction does not change systematically. We assigned upscaled mechanical properties (e.g., Young's modulus, cohesion, and angle of internal friction) to zones identified by a recent electrical survey of the dome of La Soufrière de Guadeloupe. Two-dimensional numerical modelling (using the software LaMEM) was then performed on a "present-day" model, informed by the recent electrical data, and on a model in which we artificially increased the size of the hydrothermally altered zone. Our modelling shows that increasing the size of the hydrothermally altered zone significantly increases the deformation rate of the slope. We therefore conclude, using models informed by experimental data, that hydrothermal alteration decreases volcano stability and thus increases the likelihood of mass wasting events. Hydrothermal alteration, and the evolution of alteration, should therefore be monitored at active volcanoes worldwide.

Can halogen degassing tell us underlying magmatic processes?

Mike Cassidy* N/A

*N/A

Well, potentially…

Some of the commonly monitored gases in plumes are SO2 & CO2, which are useful for volcano monitoring and prediction of eruptive phenomena. Their abundance and relative gas ratios dominantly change in response to pressure changes within the magma system (e.g. magma ascent), but are less sensitive to magmatic processes occurring within a stationary magma reservoir at depth.

We show with high temperature and pressure experiments how Cl, F and Br partition between the gas phase (fluid) and melt under different conditions. The larger ionic size of the halogen ion (F -> Cl ->Br), corresponds to a greater likelihood that it enters the gas phase. Our data, supported by a compilation of previous experiments, show that halogen concentration in the system, melt composition, pressure, degree of water saturation and temperature (in order of importance), control the how halogens partition into the gas phase, and thus have the potential to be used to trace such processes in the magmatic system (though with caveats!).

New understanding of hybrid pyroclastic processes revealed from proximal deposits.

Natasha Dowey* Rebecca Williams (University of Hull)

*N.J.Dowey@hull.ac.uk

The deposits of Plinian and sub-Plinian eruptions provide critical insights into the behaviour and magnitude of past volcanic events, and inform numerical models that aim to mitigate against future volcanic hazards. However, the rock record is rarely complete, particularly in the zone closest to (<5 km) the vent, and investigations of proximal stratigraphy are rare (e.g. Druitt and Sparks, 1982; Nairn et al., 2001; Houghton et al., 2004; Smith and Kokelaar, 2013). In the proximal zone, multiple processes related to the eruption column, low fountaining and pyroclastic density current (PDC) activity are likely to impact the same geographic position at the same time. Deposits that capture these hybrid processes are common at tuff cones and maars (e.g. Cole et al., 2001; Zanon et al., 2009 and references therein), but there have been relatively few studies of hybrid deposits formed during Plinian eruptions (Valentine and Giannetti, 1995; Wilson and Hildreth, 1998; Di Muro et al., 2008). Pyroclastic deposits are often considered from either a fallout or flow perspective, with relatively little attention given to the complex spectrum of hybrid processes that occur between the two end members.

This study presents analysis of hybrid deposits that display evidence of deposition by a mixture of both Plinian fallout and PDC processes. We briefly review previously reported hybrid lithofacies, and define a new type of proximal hybrid lithofacies based on evidence from the 273 ka Poris Formation of Tenerife and the 46 Ka Green Tuff of Pantelleria. This lithofacies differs from previously described hybrid lithofacies; it has a different componentry to associated fallout deposits, contains predominantly block-sized pumice clasts and large lithics, and displays higher-angle cross-stratification. The lithofacies is interpreted to record hybrid interaction between coarse proximal fallout from low-fountaining parts of a sub-Plinian to Plinian eruption column and PDCs that added a vigorous, lateral component.

Hybrid pyroclastic processes are likely ubiquitous in dynamic Plinian/sub-Plinian eruptions; different hybrid processes are likely to occur both at different locations around the volcano, and at different stages of an eruption. We attempt to synthesise a snapshot of this complexity, and discuss how our findings inform understanding and uncertainty in hazard dynamics. Improved consideration of these complex processes both in the field and in modelling will improve our understanding of the uncertainties inherent in the analysis of pyroclastic successions.

References

Cole et al. (2001) https://doi.org/10.1007%2Fs004450100136
Di Muro et al. (2008) https://doi.org/10.1029/2004GL019709
Druitt and Sparks (1982) https://doi.org/10.1016/0377-0273(82)90025-7
Houghton et al. (2004) https://doi.org/10.1007/s00445-003-0297-7
Nairn et al. (2001) https://doi.org/10.1080/00288306.2001.9514950
Smith and Kokelaar (2013) https://doi.org/10.1007/s00445-013-0768-4
Valentine and Giannetti (1995) https://doi.org/10.1016/0377-0273(94)00049-M
Wilson and Hildreth (1998) https://doi.org/10.1130/0091-7613(1998)026%3C0007:HFDITB%3E2.3.CO;2
Zanon et al. (2009) https://doi.org/10.1016/j.jvolgeores.2008.09.018

Intraplate vs. Subduction Signals in the Sunda Back-Arc: Petrology and Geochemistry of Pulau Bawean, Java, Indonesia

Nicholas Barber* Marie Edmonds [University of Cambridge], Esti Handini [Universitas Gadjah Mada], Helen Williams [University of Cambridge], Frances Jenner [The Open University], Agung Harijoko [Universitas Gadjah Mada], Haryo Edi Wibowo [Universitas Hadjah Mada]

*ndb38@cam.ac.uk

The island of Java, Indonesia, has experienced multiple phases of volcanic activity throughout the Cenozoic. Today, Java is one of the most volcanically active terrestrial environments on Earth, with some of the world's most active and historically deadly volcanoes (Merapi, Kelud, Semeru) nestled next to major population centers (Yogyakarta, Surabaya). However, like many subduction zones, Java has had a complex tectonic past, which is preserved most strikingly in the back-arc volcano of Pulau Bawean, located 600 km above the subducting Indian Ocean slab [3]. Found 150 km. N of Surabaya (capitol of East Java) in the Java Sea, Bawean is sparsely settled, and it is marked by heavily eroded lava flows, domes, and a possible crater, with no feature exceeding 900 m in height [1,2]. Bawean erupts highly potassic and silica-undersaturated lavas, all formed in the past 800 ka [2,4]. Bawean is also historically significant as the first volcano outside of Europe where leucite was identified [5]. Given these observations and Bawean's spatial proximity to the back-arc potassic volcano Muria on the Javanese mainland, there has been intense debate as to whether these highly alkaline back-arc volcanic centers are the product of subduction or intraplate processes. Some studies suggest that Bawean aligns with E-W trending normal faults in the Javanese basin, and shows geochemical trends supporting a strong intraplate signal [6], while other posit that something like a slab tear leading to enhanced heat flux in the back-arc [7], or a N-ward shift in Java's active volcanic arc ~ 1 Ma due to a compressional regime [7,8] can explain the unusual chemistry and volcanism as a product of primarily subduction zone processes. In this contribution we aim to highlight our initial study of Iddings original 1914 samples, using modern microanalytical methods such as melt inclusion analysis (Raman, SIMS), electron microprobe, and QEMSCAN. We aim to constrain the storage conditions, differentiation, and chemical contributions of the slab vs. the mantle to the volcanism in Bawean, to build a better picture of how back-arc potassic volcanism fits in to the story of Java's volcanic history.

REFERENCES

1) Iddings, J. P., and E. W. Morley. PNAS 3.2 (1916): 105.

2) Elmaleh, A., et al. Geophysical Journal International 157.1 (2004): 441-454.

3) Leterrier, J., et al. J SE Asia ES 4.3 (1990): 171-187.

4) Bellon, H. Proceedings of the Regional Conference in Geology, Mineral and Hydrology Resources SE Asia, 1989. 1989.

5) Keijzer, F. Proceedings of the Koninklijke Nederlandse Akademe Van Wetenschappen 43.1/5 (1940): 620-629.

6) Edwards, Caroline, Martin Menzies, and Matthew Thirwall. JPet 32.3 (1991): 555-592.

7) Hall, Robert, and Wim Spakman. Tectonophysics 658 (2015): 14-45.

8) Setijadji, Lucas Donny, et al. Resource Geology 56.3 (2006): 267-292.

Investigating icequakes at ice-covered volcanoes in Chile with implications for volcanology and glaciology

Oliver Lamb (University of North Carolina at Chapel Hill)* Jonathan Lees (University of North Carolina at Chapel Hill)

Luis Franco Marin (OVDAS-Sernageomin)

Jonathan Lazo (OVDAS-Sernageomin, Universidad de la Frontera)

Andres Rivera (Universidad de Chile)

Michael Shore (University of North Carolina at Chapel Hill)

Stephen Lee (US Army Research Laboratory/Army Research Office)

*olamb@email.unc.edu

The evaluation of seismic activity at ice-covered volcanoes is problematic as volcanic and glacial earthquakes (i.e. icequakes) can have overlapping characteristics (i.e. frequencies, waveform shape and magnitude). This presents a challenge for organizations monitoring active volcanoes which host at least one glacier on the edifice. Icequakes have been extensively studied across all major glacial regions as they shed light on sub-glacial hydraulic and geological properties. However, they have only been described at a handful of the 245 volcanoes around the world that currently host one or more glaciers. Here we present results from the first study to target icequakes at active ice-covered volcanoes in the Southern Chile. The primary focus so far has been on Llaima volcano, one of the largest and most active volcanoes in the region which also features extensive glacial ice on the flanks. Seismic data from 2015 and 2019 was analysed using a combination of automatic multi-station event detection and waveform cross-correlation to find candidate repeating icequakes. We identified dozens of low magnitude families of repeating seismic events across both time periods; the largest of which included over 200 events over a period of 2 months. The persistent, repetitive nature of these events combined with their waveform characteristics and source locations suggest they originated from multiple sub-glacial stick-slip sources around the upper flanks of the volcano. We also targeted Villarrica volcano in early 2020 with a network of seismo-acoustic sensors to record icequake activity in concurrence with the ongoing eruptive activity at the summit. Altogether, results so far suggest icequakes may be more common than previously thought and has implications for how seismic data at ice-covered volcanoes may be used for assessing future eruptive potential. Furthermore, this study highlights how present volcano seismic networks can be used to evaluate sub-glacial properties with implications for assessing glacial hazards as well as projecting future glacier mass balance variations.

The role of magmatic chlorine in transporting chalcophile metals in the Vanuatu Arc.

Olivia Hogg* Marie Edmonds (University of Cambridge), Jon Blundy (University of Oxford), Lena Melekhova (University of Bristol)

*orh23@cam.ac.uk

Volcanoes emit significant fluxes (comparable to industrial smelters) of metals as gases and aerosols, that may adversely affect the environment and proximal populations (Pyle and Mather, 2009); or may act as nutrients for life. The aerosols are derived from an exsolved magmatic volatile phase that is representative of those involved in the formation of ore deposits. Copper and molybdenum are some of the many metals outgassed by volcanoes. Ore deposits containing these metals are fundamental but finite resources. Demand for them is growing as we transition towards an electrically-driven future. The majority of global demand for these metals (e.g. 75% of Cu) is met by hydrothermal ores associated with arc volcanoes at convergent margins. To understand metal systematics and the processes involved in their transport and deposition we must understand the ligands responsible for binding with them in the magmas gas phase. Chlorine (as chloride) is a major complexing agent for metals and tracer of magmatic processes, and it is of interest to reconstruct the behaviour of chlorine in magmatic systems. The Cl content of primitive melts is variable and controlled by slab fluid contribution to arc magmas. Primitive melt inclusions in arc settings preserve mean values of 100 ppm Cu – far less than concentrations observed in hydrothermal ores deposits (Blundy et al., 2015); clearly significant processing (differentiation, sulfide-saturation, crustal contamination, enrichment degassing) must occur in the crust before ore-forming conditions are met. Volcanic gas, aerosol, and melt inclusion geochemistry, allow reconstruction of these processes.

The Vanuatu arc, encompasses volcanoes that erupt mainly basalts, and has complex tectonic configuration. Erupted basalts preserve some of the highest recorded dissolved Cl contents in olivine-hosted melt inclusions globally (~7000 ppm, Moussallam et al., 2019). Several of the volcanoes are listed among the most prodigiously outgassing globally. For example, Ambrym emits 1060 tonnes HCl gas and 1.3 tonnes copper per day (Allard et al., 2016). A critical question is: how does the chlorine contents of the magmas affect metal outgassing at these volcanoes? This project will study the geochemical behaviour of Cl through arc magma genesis, vapour saturation and degassing along the Vanuatu arc, in an attempt to resolve the main controls mediating Cl and subsequent metal transport and outgassing. Our primary melt inclusion data already distinguishes significant Cl enrichment variability (1600-6100 ppm) along the arc. Whole rock and melt inclusion trace element compositions will allow the contributions of slab fluids, mantle wedge and crust to be defined. Chlorine and metal degassing with pressure will be reconstructed based on both melt inclusion and volcanic gas data. The effect of Cl content of the exsolved vapour phase on metal speciation and transport will be quantified by observation and modelling. The impact of magma volatile content, oxygen fugacity, pressure, temperature, and the timing of sulfide-saturation will be evaluated for metal degassing from magmas. We expect this research to further our understanding of magma petrogenesis beneath Vanuatu, but also of the controls on volcanic metal outgassing and on the sporadic location of hydrothermal ores in the region.

VolKenya: Rates and Styles of Volcanism Along the Central Kenya Rift

Paul A. Wallace* Karen Fontijn (Université Libre de Bruxelles, Brussels, Belgium)

Victor Otieno (Kenya Electricity Generating Company, Olkaria, Naivasha, Kenya)

Lorenzo Cappelli (Université Libre de Bruxelles, Brussels, Belgium)

Nicholas Mariita (Dedan Kimathi University of Technology, Nairobi, Kenya)

*Paul.Anthony.Wallace@ulb.be

Improved forecasting and management of volcanic hazards demands a better understanding of the magmatic processes that regulate them. Over the last two decades, a plethora of observational, analytical and experimental datasets have greatly improved our knowledge of volcanic processes. However, such data has primarily been derived from well monitored subduction-related volcanoes where magma is chemically distinct and experiences opposing tectonic stresses compared to relatively poorly monitored continental rift settings. The East African Rift (EAR) represents a classic example of continental rifting, hosting >100 active volcanoes in densely populated areas, bringing significant risk together with socio-economic advantages to those living in close proximity. Finding an optimal balance and reducing the vulnerability to volcanic activity thus requires a comprehensive understanding of the physical and chemical processes involved. The VolKenya project's aims build upon previous and ongoing efforts towards understanding East African volcanism and will place new constraints on the architecture of magma storage reservoirs, dynamics of magma ascent and fragmentation mechanisms during the eruption of alkali-rich rift magmas. In particular, the project will investigate the spatial and temporal controls on explosive silicic eruptions along the south–central Kenya Rift, a mature, magma-assisted segment of the EAR. In southern Kenya, several volcanoes are currently targeted or actively being exploited for geothermal energy production. The new data collected will provide a more rigorous understanding of magmatic storage conditions and controls on eruptive behaviour that will assist in improving estimates of heat flux in geothermal reservoirs, and at the same time inform future volcano monitoring strategies. As such, the project will be carried out in close collaboration with Kenyan partners.

Modelling and Simulation of Volcanic Ash Particles Falling on Building Roofs to Determine the Stress and Deformation Levels.

Philip Kwame Quainoo* Professor Nick Petford (Faculty of Arts, Science & Technology, The University of Northampton, Northampton, NN1 5PH, UK)

Professor Stefan Kaczmarczyk (Faculty of Arts, Science & Technology, The University of Northampton, Northampton, NN1 5PH, UK)

*(philip.quainoo@northampton.ac.uk

Modelling and Simulation of Volcanic Ash Particles Falling on Building Roofs to Determine the Stress and Deformation Levels.

Philip Quainoo1, Nick Petford1, Stefan Kaczmarczyk1

1Faculty of Arts, Science & Technology, University of Northampton, Northampton, NN1 5PH, UK

This paper presents a numerical procedure for testing the effects of both static and dynamic loading of volcanic ash deposition on concrete roofs. The study aims to propose, a revision to the building regulations to make existing and future European buildings more resilient. The investigation uses a multi-physics simulation approach. Mathematical modelling is developed to investigate the volcanic ash effects in the context of the EN1991 code. A numerical modelling tool (EDEM software) for the Discrete Element Method (DEM) and structural analysis tool (ANSYS) for the Finite Element Method (FEM) are used to investigate 1 m x 1 m x 0.0154 m concrete slab plate subjected to pressure load considering the wind and no-wind effects. The modelled wind velocity was held constant at 0. 2 m/s. The density of the volcanic ash is low compared to natural systems but can be changed to reflect a range of relevant (measured) eruptive products. The key parameters and the results are illustrated in Table 1 and Figure 1 below. While initial results only, it is clear that our modelling technique has potential to explore the loading effects of ash over a range of geological and environmental conditions during deposition.

The number of simulated volcanic ash particle loads is 80000, Volcanic ash particle density of 1000 (kg/m3). The simulated particle variable results for wind effects in the horizontal direction of (0.2 m/s) are as follows: the maximum pressures 20042 (Pa), maximum deformation 0.177 (mm) and maximum stress10.3 (MPa). The no wind effect (controlled condition) simulations particle variable results are as follows: the maximum pressures of 6411.3(Pa), maximum deformation 0.061 (mm) and the maximum stress of 3.44 (MPa).

As expected, the wind effect resulted in an uneven distribution of the ash on the roof surface, which in turn produced areas of high-pressure load and stress levels. These results will have a possible impact on the designs of buildings on flat roof considerations. We aim to continue with further investigations to determine the stress impact and collapse failure due to loading over a wide range of relevant volcanic ash particle size compositions

(Please Note, I couldn’t include table and figures as the system is word text only.)

Modelling of volcano ground deformation from numerical benchmarking of fluid-structure interaction using the finite element method

Rami Alshembari* James Hickey (University of Exeter) and Ben Williamson (University of Exeter)

*ra500@exeter.ac.uk

Investigating the temporal development of magma reservoir pressure and associated surface displacement can reveal fundamental aspects of subsurface magmatic processes and aid in eruption forecasting. Magma fluid dynamics, rather than the widely used kinematic techniques, should be incorporated into magmatic modelling to track the temporal development of a system. Existing volcano deformation models typically ignore magma injection dynamics and focus on the response of surrounding rocks to source boundary pressure. Here, we derive the analytical solution for Newtonian magma injection from a deep source through a vertical cylindrical conduit into a shallow reservoir. We use two schemes of injection boundary condition, inlet pressure and inlet mass flow, to simulate different conceptual magmatic system models. When applying an inlet pressure, for injections of highly viscous magma, or a narrow feeder conduit, the resultant pressure and surface deformation develop at a very slow rate. In the case of magma injection mass flow boundary conditions, the number of parameters is reduced compared with when there is a defined inlet pressure. We show that a mass flow inlet is also more consistent with a transcrustal magmatic system (TCMS) than the traditional conduit-chamber model since it focuses on the final product of either magma injection or migration. The results obtained from the analytical solution are compared to those calculated using the Finite Element Method (FEM). We then consider more complex reservoir geometries using FEM and test model parameter sensitivity.

Devil's Ink Pot Fissure: an insight into intermediate magma genesis on Ascension Island

Rebecca Winstanley* Richard J. Brown (Durham University)

Charlotte Vye-Brown (British Geological Survey)

Katy J. Chamberlain (University of Derby)

Katie Preece (Swansea University)

Fabian Wadsworth (Durham University)

*ngkc74@durham.ac.uk

Ascension Island, an active volcano in the South Atlantic, is a British Overseas Territory with strategically important UK and USA military infrastructure. The volcanic material on Ascension Island exhibits a compositional range of basalt-hawaiite-mugearite-benmoreite-trachyte-rhyolite (Weaver et al., 1996). By combining detailed field study with petrographic and geochemical data on the juvenile components, the nature of the volcanic eruption(s) and the feeding magma will be established. Furthermore, this project will constrain the potential volcanic hazards from intermediate-composition eruptions of this style and size and the impact on the island during future eruptions. Here we present preliminary findings from a two-month field season. The 1.3 km long Devil's Ink Pot fissure (DIPF) which was fed by benmoreite magma, is located in the south east corner of the island and is composed of 18 volcanic edifices, 7 lava flows and tephra fall deposits up to 2 m thick. Some edifices are characterised by abundant moderately to densely welded spatter and appear to have fed lava flows. Other edifices are characterised by weakly agglutinated spatter to loose lapilli and bomb clasts and an abundance of lithic and ballistics clasts, up to 20 m in diameter, within the craters and on the crater rims. Ballistic clasts, > 50 cm in diameter, reach 450 m from the fissure. Initial results suggest these craters represent different eruptive styles, including weak lava fountaining events with a moderate to high accumulation rates and more explosive, Vulcanian eruptions. Future petrological analysis, whole rock and trace element geochemistry and crystal chemistry will probe the genesis of the magma that fed the DIPF.

Volcanic and geochemical evolution of the Northern Main Ethiopian Rift (NMER) in East Africa: volcanism in the NMER–Afar transition zone

Rhiannon Rees* Tom Gernon (School of Ocean and Earth Sciences, University of Southampton)

Derek Keir (School of Ocean and Earth Sciences, University of Southampton)

Carolina Pagli (Department of Earth Sciences, University of Pisa)

*r.rees@soton.ac.uk

The EARS is the world's longest and best exposed example of a continental rift, and thus presents an ideal location to study active rift systems. Varying stages of rift development are manifested along the EARS, from early-stage continental rifting in the southern Malawi Rift, to near continental breakup in the Danakil, Afar (e.g. Ebinger, 2005; Corti, 2009). The EARS therefore showcases both magma poor rifting (in the south – where extension is accommodated primarily through faulting), and magma-assisted rifting (in the north – where extension is accommodated not only through faulting, but also by dyke intrusions) (Ebinger, 2005).

The overarching aim of this project is to investigate factors resulting in spatial and temporal variations in petrology and geochemistry and surface volcanism in active continental rift zones. Specifically, this project's focus is on three volcanoes in the NMER–Afar transition zone (Abida–Ayelu [10.1°N, 40.8°E] and Yangudi [10.6°N, 41.0°E]), and is investigating the timescale and nature of their magmatic systems. In addition, we will be testing hypotheses regarding the roles of mantle plumes, depleted mantle and crustal assimilation on the style and composition of rift volcanism in the region where the NMER opens up into Afar.

For this study, 60 rock samples from Abida, Ayelu and Yangudi volcanoes are being studied through the Afar Repository collection at the University of Pisa. An initial 16 rock samples have been selected for major element, trace element and Pb-isotope analysis [ongoing]. Results from these geochemical analyses are supported through qualitative and quantitative petrological analyses of thin sections of all the samples. Rock units and their relative ages established from remote sensing (using satellite imagery and topographic data) and published geological maps of the area provide both a spatial and temporal context for these results, allowing the evolution of volcanism in the NMER–Afar transition zone to be better evaluated through space and time.

References:

Corti, G. (2009) 'Continental rift evolution: From rift initiation to incipient break-up in the Main Ethiopian Rift, East Africa', Earth-Science Reviews. Elsevier, pp. 1–53. doi: 10.1016/j.earscirev.2009.06.005.

Ebinger, C. J. (2005) 'Continental break-up: The East African perspective', Astronomy and Geophysics. Oxford University Press, 46(2), pp. 2.16-2.21. doi: 10.1111/j.1468-4004.2005.46216.x.

Constraining the Shallow Pressure Source Parameters of the Sakurajima Volcano and Aira Caldera Magmatic System

Robert Backhurst* James Hickey (University of Exeter), Ben Williamson (University of Exeter).

*rb735@exeter.ac.uk

Sakurajima, located on the southern rim of Aira caldera, is one of the most active volcanoes in Japan. From long term deformation trends, the volcano is showing an increased risk of a large scale eruption, emphasizing the need to better understand the entire magmatic system.

Deformation modelling, primarily using the Mogi method, has dominated the geodetic assessment history of Sakurajima. However these methods contain limitations, such as having assumed a homogeneous crust, and have not accurately depicted the magmatic system. Numerical modelling techniques have reduced this limitation by accounting for subsurface heterogeneity.

Analytical modelling studies have suggested multiple magmatic sources beneath Aira caldera and Sakurajima volcano, whilst the only numerical study produced a single source. This current study is testing the multiple deformation source hypothesis while also incorporating subsurface heterogeneity, using Finite Element (FE) numerical modelling, and geodetic data from Sakurajima.

Using a full 3D model geometry for Sakurajima and Aira caldera, preliminary forward modelling suggests a second deformation source produces the best fit to the measured geodetic data. Optimum results indicate a shallow prolate source 7-9 km below sea level (bsl), in addition to a deeper oblate source at ~13 km bsl. These preliminary findings agree with petrological estimates of magma storage depths, which are greater than in the previous analytical models, and ties in with the trans-crustal magmatic system hypothesis.

Increasing the understanding of the Sakurajima magmatic system enables improved interpretations of geodetic data prior to eruptions, with volcanoes across the globe being able to benefit from similar modelling approaches.

Introducing Project 'IMAGINE', Goals, Gaps and Groundwork

Rory A. Walshe* Julie Morin (University of Cambridge)

Amy Donovan (University of Cambridge)

Elisabeth Gallant (University of Cambridge)

*rw647@cam.ac.uk

This presentation will introduce the new interdisciplinary ERC project 'IMAGINE: Geographical imaginations and the (geo)politics of volcanic risk: cultures, knowledges, actions'. The goal of this five-year research project is to investigate the diverse local, scientific and governmental understandings of volcanoes, volcanic areas and volcanic risk, examining how these understandings are created and interact in the management of volcanic risk and volcanic environments. Bringing together both physical and social volcanology and working with local collaborators and stakeholders, ultimately the project hopes to better understand the role of scientific advice in disasters, develop new theory and practice for disaster risk reduction in volcanic contexts and help break down the divide between studies of hazard and of vulnerability. It aims for a holistic and transdisciplinary approach to volcanic and volcanic-related risk.

The research will initially be conducted in Argentina, Chile and Peru. As a result of the pandemic, planned fieldwork has been postponed so this presentation will detail the theoretical and methodological background of the project. The presentation will also deliver some initial findings and gaps in knowledge from an online survey of over 600 participants working or studying volcanoes in South America. This survey includes implications regarding perceptions of trust in various groups, sources of vulnerability and responses to eruptions.

Complex crystal cargoes from monogenetic magmas: Tracking magmatic maturation through mineral-melt δ18O.

Sally Law* Geoff Bromiley (University of Edinburgh)

Geoff Kilgour (GNS Science, NZ)

Godfrey Fitton (University of Edinburgh)

Adrian Boyce (SUERC, University of Glasgow)

*s.law-8@sms.ed.ac.uk

A key question in volcanology is understanding how and why some magmatic systems evolve to produce large volumes of eruptible silicic magma, and others do not. One of the main controls is the flux rate of magma over time. The Taupo Volcanic Zone (TVZ) New Zealand, is dominated by high-silica magmatism, often resulting in large-volume explosive eruptions, and is one of the most volcanically productive silicic systems worldwide. The TVZ is one of the clearest examples of maturation of a magmatic system, where the shift from andesitic continental arc-type volcanism to rhyolitic volcanism is both spatial and temporal. Recent studies have identified changes in the composition of primary mantle melt in the TVZ between caldera-forming and non-caldera forming systems. Large melt fractions sourced from shallow mantle are associated with caldera-forming volcanism, whereas melt fractions become smaller and melting occurs deeper as the mantle becomes progressively depleted, eventually causing caldera-forming volcanism to cease.

However, the implications of this model on magma storage and processing in the crust have not yet been explored. Where new models imply that flux of magma into the TVZ varies through the lifespan of a caldera-forming system, it is important to consider the effect this has on open vs. closed system processes and magmatic evolution. As the magmatic system matures, the relative importance of fractional crystallisation and crustal melting should vary, as the basement crust is modified by repeated intrusion of magma. This maturation of the system can be evaluated through measuring compositional changes that arise from addition of crust, such as the oxygen isotopic composition (δ18O).

We examine crustal contamination by measuring δ18O of crystals and groundmass in mafic rocks from pre-, syn- and post caldera settings in the TVZ. We use mineral-melt equilibria to assess the extent of crustal assimilation, magma mixing and crystal remobilisation, and draw comparisons between the different magmatic segments of the arc. Our results show that the interpretation of δ18O in mafic rocks in of TVZ is far from straight forward, and individual samples can show a significant range in δ18O. We interpret this as strong evidence for open-system processes occurring in mafic magma in the TVZ, highlighting the importance of crustal assimilation at an early stage in magma evolution. The relative contribution of continental crust appears to lessen through the maturation of the system, in broad agreement with previous work. We propose that the variation in crustal contribution to mafic TVZ magmas is primarily controlled by two factors. Firstly, how heavily intruded the crust is, controlling how much continental crust new pulses of magma come into contact with and can therefore assimilate; and secondly, the heat flow of the region, controlled by flux of hot mantle melt into the crust. Variation of these two factors in rocks erupted in pre-, syn-, and post-caldera settings accounts for the textural and oxygen isotopic variability.

Laboratory volcano geodesy: Inversion of analogue magma-induced surface displacements

Sam Poppe* Christelle Wauthier (The Pennsylvania State University)

*sam.poppe@ulb.be

Most volcano geodetic models consider a half-space homogeneous medium and assume that the host rock behaves linearly elastically during shallow magma emplacement. However, geological and geophysical observations, such as in the Oslo rift in Norway (Poppe et al., 2020), show that that non-elastic deformation behaviour can dominate in heavily fractured volcanic edifices. Deformation processes, in particular at the magma intrusion propagation front, can only be observed indirectly by using geophysical monitoring techniques. We aim to assess by how much modelled magma intrusion characteristics – volume, geometry, orientation, depth – deviate from reality in circumstances where non-elastic deformation processes are important by using laboratory experiments.

A recently developed application of medical X-ray Computed Tomography (CT) and Digital Volume Correlation allows to image and quantify deformation induced by analogue magma intrusion in granular, non-elastic host media in scaled laboratory experiments (Poppe et al., 2019). We use a tensile Okada dislocation in a homogeneous, linearly elastic half-space (Okada, 1985) to invert the three components of near-surface displacements extracted from laboratory experiments of analogue dyke injection in cohesive mixtures of quartz sand and gypsum powder. The Okada models favored by the inversions are then compared to the three-dimensional characteristics of the analogue magma intrusions observed in the X-ray CT imagery. This test study helps gain insight on the limitations of commonly-used volcano geodesy modeling and inversion methods and provides a novel basis for interpreting geological, geodetic and geophysical data related to volcanic deformation.

References:

Okada (1985). Bulletin of the Seismological Society of America, 75(4), 1135–1154.

Poppe et al. (2019). Frontiers in Earth Science, 7, 62.

Poppe et al. (2020). Geochemistry, Geophysics, Geosystems, e2019GC008685

Using H and O isotopes to identify the sources, temperatures, and timescales of secondary hydration in subaqueous volcanic deposits

Samuel J. Mitchell* Michael Hudak (University of Oregon)

Ilya Bindeman (University of Oregon)

*mitchels@edgehill.ac.uk

Many fundamental questions in volcanology rely on the accurate measurement of water concentrations in volcanic glass. However, the addition of external, secondary water to volcanic glass post-eruption and -quenching can misinform physical interpretations of eruption and fragmentation dynamics. Volcanic rocks in the deep-sea environment can experience secondary hydration across a range of temperatures and physical states, and from many H2O sources – not just cold, liquid seawater. This study used H and O isotopes (δD-VSMOW and δ18O-VSMOW) to identify sources and temperatures of secondary hydration in pumice and lava from a deep-sea rhyolitic eruption in 2012, and from older Holocene silicic submarine deposits. Old seafloor pumices were rehydrated with up to 6 wt.% H2O by the diffusion of cold seawater over 100's to 1000's of years, and thus, enriched in δD, bulk-δ18O, and water-in-glass (wig) δ18O up to -30‰, +9‰ and -5‰ respectively. The 2012 deposits showed a much wider range of isotopic enrichment and depletion with δD = -50 to -120‰, δ18Obulk = +5.7 to +6.2‰, and δ18Owig = -10 to +4‰ dependent on eruptive units, but from unknown sources. We used magmatic degassing and vapor δD-H2O modelling, a volatile-melt fractionation δ18O-geothermometer, and previous textural studies to identify multiple high-temperature rehydration sources in the recent deposits. Pumice clasts were found to be rehydrated by coexisting magmatic fluid in pore space during clast cooling, in the minutes following eruption from the submarine vent, at temperatures of 320 – 670°C. Lava fragments appear to have been rehydrated by heated seawater in the hours following the eruption at glass temperatures of 100 – 150°C. These results provide a natural confirmation of recent experimental findings that tackle the fundamentals of H and O diffusion and isotope exchange in silicate materials at temperatures of 100 – 400°C.

Vulnerability of roof collapse to tephra loading: Ascension Island case study

Sara Osman* Mark Thomas (University of Leeds),

Julia Crummy (British Geological Survey),

Steve Carver (University of Leeds).

*eesjo@leeds.ac.uk

During an explosive volcanic eruption, the tephra fallout from the eruptive plume can lead to significant additional loading on roofs, particularly for buildings close to an eruptive vent. Data on roof damage are scarce because surveys often take place after roofs have collapsed, clean-up has started, or deposits have been disturbed by wind and rain. We use laboratory tests and numerical model simulations to fill the gaps, taking Ascension Island (a volcanically active UK Overseas Territory) as a case study. Tephra sliding tests can identify roof vulnerability and probabilistic hazard analyses can identify areas on Ascension at risk of loads likely to lead to roof collapse. Fieldwork on Ascension will be used to ground truth results.

Building design standards routinely take account of snow loading, and the Structural Eurocodes, as an example, take characteristic values for snow loading on the ground and then use roof shape coefficients to estimate equivalent loads depending on characteristics of the roof. We are investigating whether this approach can be adapted for tephra loading and if successful it could be applied on a wider scale, to more populated areas and those at risk from multiple volcanic centres.

We will discuss the required modification of the snow loading approach and what data are needed to make this viable. Results so far include initial probabilistic hazard analyses for a range of eruption scenarios on Ascension and laboratory results comparing synthetic tephra to be used in sliding tests with samples from Ascension and published data.

Volcanoes in video games: the portrayal of volcanoes in Commercial-Off-The-Shelf (COTS) video games and their learning potential

Scarlett, J.P.* McGowan, E. (University of Leicester)

*j.scarlett-2014@hull.ac.uk

Volcanoes are a very common staple in mainstream video games. Particularly within the action/adventure genres, entire missions (e.g. Monster Hunter: Generation Ultimate) or even full storylines (e.g. Spyro: The Reignited Trilogy) can require players to traverse an active volcano. With modern advancements in video game capabilities and graphics, many of these volcanic regions contain a lot of detail. Most video games nowadays have gameplay times in excess of 50 hours. The Legend of Zelda: Breath of the Wild for example brags a minimum of 60 hours to complete. Therefore, players can spend a substantial amount of time immersed within the detailed graphics, and unknowingly learn about volcanic traits while playing. If these details are factually accurate to what is observed in real world volcanic systems, then video games can prove to be a powerful learning tool. However, inaccurate representations could instill a false understanding in thousands of players worldwide. Therefore, it is important to assess the accuracies of volcanology portrayed in mainstream video games and consider whether they can have an educational impact on the general public playing such games. Or, whether these volcanic details are overlooked by players as they focus solely on the entertainment factor provided. We have therefore reviewed several popular commercial video games that contain volcanic aspects and evaluated how realistic said aspects are when compared to real-world examples. It was found that all the games reviewed had a combination of accurate and inaccurate volcanic features and each would vary from game to game. The visual aesthetics of these features are usually very realistic, including lava, ash-fall and lahars. However, the inaccuracies or lack of representation of hazards that come with such features, such as ash-related breathing problems or severe burns from contact with molten lava, could have great negative impacts on a player's understanding of these deadly events. With further investigations assessing the direct impact on the general public, there is the opportunity to correctly assess how to incorporate the use of mainstream video games in educational systems and outreach.

We need to go deeper! - Numerical modelling of geothermal systems and the effect of permeability, topography and the lower system boundary

Shelly Mardhia Faizy* Alex Hobé (Uppsala University)

Tobias Schmiedel (Uppsala University)

Abigail K Barker (Uppsala Universiy)

*shellymardhia.faizy.2783@student.uu.se

The world energy consumption is projected to keep rising in the future. Thus, there is a growing need to expand our sources of sustainable energy, in particularly geothermal energy. To keep exploration costs low, numerical models are generally used to predict the potential of new geothermal systems. However, most current numerical models have not really change in the last 30 years. It concentrates only on the shallow part around the geothermal heat source, ignoring the role of a deeper-rooted parts on the evolution of a geothermal system. We present here a case study to showcase the effects of permeability and topography on the evolution of a geothermal system, while taking into account the effect of the deeper parts of the system below the heat source.

Our study is based on the Cerro Bayo laccolith a fossil geothermal system in the Chachahuén volcanic complex (Neuquén Basin), Argentina. We use HYDROTHERM (USGS) an open-source numerical modelling software to simulate the physical geothermal system which represent in the domain. Our simulations compare the evolution of the geothermal system when systematically changing the following three aspects of the models: 1) having a layer below the intrusion, or having the bottom boundary directly below it, 2) different topographies with volcanic significance, and 3) varying permeabilities of the host rock.

The comparison between the models with an added layer and without one show that there is a problem with putting the boundary just below the intrusion when assuming a constant host-rock permeability. The bottom of the convective geothermal systems is bound by the bottom boundary in these models and thus the entire system evolution changes in its specifics. This is the case, even when using a low impermeable layer just below the intrusion. Nevertheless, the models confirm that both permeability and topography are strong influences on the dynamic (live-span) and lateral distribution of geothermal systems. Therefore, the overall conclusions from e.g. Hayba & Ingebritsen (1997) are still compelling.

The models show the importance of two temperature anomalies to geothermal extraction and mapping of fossil geothermal systems: 1) A caldera volcano's geometry "traps" heat below the caldera, whereas shield and stratovolcano topography "push" heat away from below the topography, and 2) a low temperature anomaly develops below the intrusion in all models with an added layer. Both anomalies could possibly produce mineral alteration observable in e.g. fossil geothermal system, and geophysical results.

Overall, the findings of this study can be implemented as future investigations, particularly in assessing the geological applicability of numerical models in geothermal system. Moreover, the knowledge in the evolution of heat transfer based on permeability, topography and lower system boundary can be applied to optimize the potential location for heat extraction on geothermal fields. Equally important, along with the information on thermal anomalies, such knowledge can also be used to explore further the mineral extraction potential from geothermal fluids, ore formation processes, and geophysical exploration.

Plaster and Magnets: Tracking magma intrusion dynamics in the laboratory

Simon Martin* Prokop Závada (Institute of Geophysics, Czech Academy of Sciences, Prague, Czechia)

Janine Kavanagh (University of Liverpool, UK)

*smartin@liverpool.ac.uk

Understanding magma behaviour during emplacement within the crust is vital for determining the dynamic processes occurring in volcanic systems. Here results from analogue laboratory experiments that study fluid flow during magma intrusion are described. Multi-coloured plaster of Paris (a pseudoplastic fluid and the magma analogue) seeded with magnetite particles (magnetic crystal analogue) was loaded sequentially or annularly into a piston, and injected through a central port in the base of a 1.2 x 1.2 x 0.5 m3 box filled with compacted fine-grained wheat flour (a cohesive granular material and the crust analogue). This created experimental magmatic plumbing systems which once solidified were excavated and photographed so the external morphology could be characterised in 3D. Cup structures, radial intrusions and arrested dykes were identified, which all had surface planar lineations and ridges. Sequential colouring allowed the temporal development of the intrusions to be documented, and annular colouring enabled characterisation of the internal structures by slicing the intrusions into thin sheets. Asymmetrical ridges and concentric internal colouring suggested intrusion propagation occurred in cycles of stress build up and break out from the stagnated tip.

Closely-spaced sampling of the solidified plaster across the length, breadth and thickness of the intrusion slices facilitated the construction of detailed three-dimensional maps of their magnetic fabrics using anisotropy of magnetic susceptibility (AMS). The observed fabrics, preserved by the orientation of the magnetite particles, indicate that the intrusion progressed by localised shear at the flow margins. Comparison of magnetic fabrics from intrusion margins of analogue (plaster) and natural (basaltic to rhyolitic) dykes shows they both have imbricated K1 axis directions within 30° of the intrusion plane, with these imbrication fabrics being direct evidence of fluid flow. These results suggest it is possible to successfully model the development of magnetic fabrics in analogue magma intrusions in the laboratory, providing a new method for direct comparison with field-based indicators of magma flow in solidified intrusions. This has important implications for the identification and interpretation of the origin and evolution of magma flow fabrics in fossil and active intrusions in nature.

Spatial variations of primordial and recycled noble gases across Iceland

Simone Cogliati* Margaret Hartley, Greg Holland, Ray Burgess (University of Manchester, Manchester M13 9PL, U.K.)

Sæmundur A. Haldórsson (Institute of Earth Sciences, University of Iceland, 101 Reykjavik, Iceland)

Oliver Shorttle (Department of Earth Sciences, University of Cambridge, Cambridge, CB2 3EQ, U.K.)

Antonio Álvarez Valero (Department of Geology, University of Salamanca, 37008 Salamanca, Spain)

*simone.cogliati@manchester.ac.uk

Noble gas (He, Ne, Ar, Kr, Xe) compositions of mid-ocean ridge basalts (MORB) and ocean island basalts (OIB) have been widely used to investigate the geochemical structure and evolution of Earth's mantle. Many studies provide evidence for the existence of different mantle domains having distinctive chemical and noble gas signatures. Primordial mantle domains have isotopic signatures that have remained largely unmodified since the Earth's formation, while recycled mantle domains have undergone extensive modification following chemical fractionation during melt extraction and magma degassing, mantle convection, and subduction recycling. Iceland represents a perfect natural laboratory to study the inventory of primordial and recycled noble gases within the mantle thanks to its particular location above a mid-ocean ridge and a mantle plume. In this hybrid setting, melts with a deep OIB-like mantle origin and with near-primordial mantle gas signatures interact and coexist with melts formed at shallower levels that exhibit MORB-like recycled mantle chemical characteristics. On Iceland, chemical and lithological mantle heterogeneities exist on both long and short length scales, and primordial and recycled noble gases signatures can both be present even in a single sample set. We investigated the spatial relationships between Iceland's primordial and recycled mantle components by combining new high-precision noble gas (He, Ne, Ar, Kr, Xe) analyses of basaltic glass with a large existing dataset of noble gas data from subglacially erupted basalts collected across the Iceland. Here, we present noble gas data for the Western Volcanic Zone (WVZ), one of the most geologically interesting areas of Iceland. The data indicate a significant and consistent lateral variability in the noble gas signatures in relation to the distance from the plume centre. We discuss possible explanations for these variations, ways to improve our systematic understanding of mantle volatile distribution beneath Iceland, and outline future directions of this research.

The Cameroon Volcanic Line – an alternative intraplate melt model constrained by Mount Etinde

Sophie Baldwin* Linda Kirstein (Grant Institute, School of GeoSciences, University of Edinburgh, Scotland, UK), Godfrey Fitton (Grant Institute, School of GeoSciences, University of Edinburgh, Scotland, UK)

*S.L.Baldwin@sms.ed.ac.uk

Hot, upwelling currents originating deep in the mantle (mantle plumes) are commonly invoked as the driving force for magmatic activity at intraplate settings. In some of these settings, such as the Hawaiian-Emperor chain and the Galápagos Islands, there is abundant evidence supporting a mantle plume origin for magmatism. However, there is a distinct lack of a suitable mechanism that can account for intraplate magmatic activity at many other locations worldwide, where there is a lack of evidence for mantle plume involvement. The Cameroon volcanic line (CVL) is one such location with magmatism spanning both oceanic and continental lithosphere.

Mount Cameroon, and the smaller, neighbouring Etinde are situated at the boundary zone between oceanic and continental lithosphere in the CVL. As such, insights from these volcanic centres are hugely valuable. Samples are silica-undersaturated (nepheline-normative), varying from less-evolved melilitites to apatite-bearing melanephelinites and rarely, olivine-nephelinites. Whole rock analyses show that the rocks are highly enriched in sulphur and incompatible trace elements. Sulphur isotopic compositions of this sample suite, in combination with whole-rock analyses and textural insights from petrography, will help elucidate the nature of the melt source for Etinde. In turn, this will aid the current understanding of the origin of magmatism at the CVL, which remains contentious.

Specifically, it is anticipated that the data may help test a new hypothesis for a mechanism for magmatism at the CVL proposed by Guimaraes et al., 2020. This mechanism invokes (1) the volatile-enrichment of thickened lithospheric mantle beneath supercontinents; (2) its thermal relaxation and conversion to asthenosphere; and (3) its spreading into neighbouring regions following break-up of supercontinents. Topography on the base of the lithosphere may facilitate channelised flow of melt and could concentrate asthenospheric mantle upwelling, providing an alternative mechanism for the generation of some intraplate magmatism.

Investigating the 2016 seismic crisis at Cayambe Volcano, Ecuador

Sophie Butcher* Sophie Butcher (1), Andrew Bell (1), Stephen Hernandez (2), Mario Ruiz (2)

(1) School of Geosciences, University of Edinburgh, UK

(2) Instituto Geofísico Escuela Politécnica Nacional, Ecuador

*sophie.butcher@ed.ac.uk

Cayambe is a 5790m high andesitic-dacitic stratovolcano, located on the equator in the eastern cordillera of the Andes in Ecuador. It is capped by extensive glaciers, and a future eruption at Cayambe would pose significant hazards to the city of Cayambe and surrounding areas. The last recorded eruption of Cayambe was in 1785, but it has been persistently restless in the last 20 years. Approximately 10-20 earthquakes are recorded daily and mountaineers regularly report sulphur smells high up on the flanks. Instituto Geofísico maintain a permanent geophysical monitoring network and in 2016 were alerted to a seismic crisis. Significant swarms of volcano tectonic (VT) type events were recorded, reaching as many as 300 daily events. In this study we aim to characterise a ‘baseline’ seismicity for Cayambe prior to the 2016 crisis and identify the source of the new swarms. As having a better quantified understanding of typical and historical seismicity at Cayambe, will be informative for future seismic hazard assessment.

We use a template matching method to expand a catalogue of 9,500 picked events, to over 13,000 events. For every earthquake signal we run a quantitative analysis to characterise the event. This includes the peak spectral frequency, the quality (Q) factor magnitude estimate and temporal patterns including the periodicity. We also use a cross correlation method to identify similar types of events and group them into families.

Here we show the two swarms in June and November 2016 are unrelated. There are clear distinctions highlighted in Q, the frequency content and signal envelope. The June swarm is associated with slip on a regional fault line that bounds Cayambe, whilst the November swarm is likely to have been associated with movement within Cayambe itself. We identify highly similar, repeating long-period (LP) events throughout 2016, that are unaffected by swarms of VT type activity. We investigate the source of these LPs and the implications of basal slip at the glaciers for volcanic hazard assessment.

Reconciling observations of volcanic deformation and degassing from basaltic volcanoes

Stanley Yip* Juliet Biggs (University of Bristol)

Marie Edmonds (University of Cambridge)

Oliver Shorttle (University of Cambridge)

Philippa Liggins (University of Cambridge)

*stanley.th.yip@bristol.ac.uk

The wide array of datasets available for global volcano monitoring have provided us the means to understand the different phases of volcanic eruptions. Syntheses of multi-parameter observations are becoming common, yet there remains a lack of quantitative models to integrate these observations. Here we use thermodynamic models to explore how magma volatile contents affect magma properties such as density and compressibility; and assess the consequent impact on co-eruptive observations of volcanic deformation and degassing. We define $\overline{V}$ as the observed reservoir volume change, and $\overline{S}$ as the observed SO2 output, both normalised by the volume of magma erupted. Using One-at-a-Time sensitivity analysis for the parameter space explored, we show that basalts with high initial gas content have high $\overline{S}$ and high compressibility, hence during eruptions, $\overline{V}$ is small. As an illustration, increasing the initial gas content from 0.01 to 4.0 wt% increases $\overline{S}$ up to 450% and decreases $\overline{V}$ up to 61%. While increasing initial magmatic H2O content from 1.0 to 3.0 wt% increases $\overline{S}$ up to 41% and decreases $\overline{V}$ up to 62%, $\overline{S}$ starts decreasing when the initial magmatic H2O content is greater than 3.4 wt%, which could be contributed by how sulfur partitions into the gas phase. Varying magmatic oxygen fugacity, which also affects sulfur partitioning, from NNO –1 to NNO+1 increases $\overline{S}$ up to 112% but decreases $\overline{V}$ by only <10%. We find that magmatic CO2 content have little effect on both $\overline{S}$ and $\overline{V}$. Moreover, we used a constant k to define pre-eruptive gas segregation, where k > 0 and -1 < k < 0 represents pre-eruptive gas accumulation and degassing, respectively. Our model shows that gas-rich basalts with k = 1 have twice the $\overline{S}$ and lower $\overline{V}$ by <29%, while degassed basalts, such that k = 0, have $\overline{S}$ = 0 and 0.8 < $\overline{V}$ < 1. These results allow us to understand the role of each parameter, which can be used to link observations of volcanic deformation and degassing. Arc basalts have higher initial volatile contents than ocean island basalts, which leads to a higher $\overline{S}$ by <400% and a lower $\overline{V}$ by <80%. Consequently, for the same eruption volume, the vertical displacement observed during basaltic arc eruptions (normalised by volume erupted) may be 90% less than that observed for ocean island eruptions for magma stored at depths of 2 km prior to eruption. Consistent with our conceptual models, we observe that deformation has been detected at 91% of oceanic island basalts volcanoes (10/11) which have erupted during the satellite era (2003-2020), but only 31% for arc basalt volcanoes (15/48). Finally, we compare the model predictions with eruptions compiled from global deformation and degassing catalogues and the Global Volcanism Project. We find that while there is often a mismatch between our model predictions and observations, these disparities can be explained by pre- or co-eruptive gas segregation processes. This suggests that the gas phase can behaves independently of its source magma and can accumulate or degas prior to eruption, often dominating surface observations.

On the tidal influence of the 2014-2015 Fogo eruption (Cape Verde) and the characterization of the volcano response to this external forcing

Stéphanie Dumont* Maria Silveira [Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal; Instituto Superior de Engenharia de Lisboa (ISEL), Lisboa, Portugal]

Susana Custodio [Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal; Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal]

Fernando Lopes [Institut de Physique du Globe de Paris, Sorbonne Paris cité, Paris, France]

Jean-Louis Le Mouël [Institut de Physique du Globe de Paris, Sorbonne Paris cité, Paris, France]

Mathieu Gouhier [Université Clermont Auvergne, CNRS, IRD, OPGC, Laboratoire Magmas et Volcans, Clermont- Ferrand, France]

Yannick Guéhenneux [Université Clermont Auvergne, CNRS, IRD, OPGC, Laboratoire Magmas et Volcans, Clermont-Ferrand, France]

*sdumont@segal.ubi.pt

Volcanoes are complex systems that evolve in space and time as a result of their eruptive activity. Volcanic eruptions represent the ultimate expression of a complex interplay between internal and external processes that span different time scales. Deciphering how internal and external processes interact at the time scale of eruptions may provide key insights on the temporal evolution of eruptions and also help to better evaluate associated volcanic hazards. Studies of the tidal influence on volcanic activity have fallen within this context, although the cause-effect relationship between tides and eruptions is still unclear.

In this study, we used Singular Spectrum Analysis to analyze three time-series, namely the seismic tremor, SO2 emission and lava volume flow rate, which cover the first month of effusive activity at Fogo volcano, Cape Verde, in 2014-2015. We detect a total of 9 tidal periodicities and up to 5 in each time-series ranging from semi-diurnal to fortnightly periods. By reconstructing the time-series using the identified tidal periodicities, we are able to explain up to 96.2% of the SO2 time-series, 85.6 % of the seismic tremor and 53.1% of the lava VFR variations. These observations show that the movement of magma at crustal depths and at surface as well as gas emission during the effusive eruption are all modulated by lunisolar gravitational forces as suggested by a few studies. Moreover, we highlight the relevance of the volcano location on Earth, which together with the timing of the eruption, associated with a specific astronomical configuration, result in a specific combination of tides that directly influence the volcano eruptive activity. Finally, with this data set, we further investigate the response of Fogo volcano to this external forcing using the identified tidal periods. We show that during the 2014-2015 eruption, Fogo volcano acted as a bandpass filter to quasi-permanent tidal oscillations.

Syn-emplacement magma fracturing

Taylor Witcher* Steffi Burchardt (Uppsala University), Micheal J. Heap (Université de Strasbourg), Bjarne Almqvist (Uppsala University), Anne Pluymakers (Technical University Delft), Alexandra Kushnir (Université de Strasbourg), Tobias Mattsson (Stockholm University)

*taylor.witcher@geo.uu.se

The Miocene Sandfell laccolith, a 0.6 km3 rhyolitic intrusion emplaced at ~500 m depth during the Miocene in eastern Iceland, contains concentric, margin-parallel 'bands' of parallel mode I fractures <15 cm long that were proposed to have formed during emplacement (Mattsson et al., 2018). Here we use polarization microscopy, micro-CT scanning, Scanning Electron Microscopy (SEM) and Electron Dispersive X-ray spectroscopy (EDS), and permeability measurements to analyze the nature and formation of these "fracture bands," revealing some preliminary results on the conditions for magma fracturing during emplacement.

The rhyolitic rock forming Sandfell is crystal- and bubble-poor with <5% plagioclase phenocrysts in a microcrystalline groundmass. Between the fracture bands is dense, impermeable rock (k = 2 x 10-17 m2). Fractures in the same fracture band are parallel to each other with uniform length and spacing between them, and perpendicular to the fracture band orientation. Each fracture terminates along a sharp boundary, often characterized by a slight color change in the surrounding rock. Mattsson et al. (2018) interpreted these boundaries as flow bands characterized by minor differences in grain size. Apart from that, our EDS analyses did not find any compositional change in the groundmass.

Within fracture bands, individual fractures have sharp tips and a maximum thickness in the center. Micro-CT scans display the fractures in 3D and confirm their uniform lengths while also revealing "stretched" penny-shape geometries with a low thickness compared to the fracture length and width. Thin sections show irregular (rough) fracture walls, and consistent aperture, length, and spacing within each sample. Some fractures appear to have propagated around large plagioclase phenocrysts, and others broke through them. Hence, the fracture asperity and relationship with phenocrysts support that the fractures formed while the magma was still liquid.

Along with void space, the cracks are filled with oxides and carbonates. The crack fillings are irregular, with oxides and pore spaces dominating the tips, centers, and edges throughout the sample. SEM images reveal complex, multi-stage and high-energy textures within the oxides, locally resembling sedimentary breccias and tuffisites. The compositions of the oxides are dominantly MnO and FeO, and the carbonates primarily CaCO3 and MnCO3. Significant traces of the REE La occur as oxide fill within multiple samples. Major- and trace-element geochemistry is currently in preparation to determine if the La is derived from the host magma.

Further research aims at determining (1) what mechanical processes formed these fractures in such a systematic and unusual array, (2) how the filling precipitated in the fractures out of impermeable magma, and (3) if the fracture band networks provided a permeable pathway for fluids to escape the magma and migrate toward the surface, creating the possibility for an ore deposit or geothermal system.

Magma storage and transport in basaltic fissure systems

Tegan A. Havard* Tegan A. Havard 1, Janine L. Kavanagh 1, Thomas J. Jones 1, Elisabetta Mariani 1

1 (Department of Earth, Ocean and Ecological Sciences, University of Liverpool)

*t.havard@liverpool.ac.uk

Basaltic volcanism, the most abundant form of volcanism on Earth, commonly erupts through high aspect ratio (fissure) geometries. The dynamics of the subsurface plumbing systems, the interconnected network of magma-filled fractures (dykes and sills) that feed basaltic fissure eruptions, are only partially understood due to the indirect methods of study. The unprecedented 2018 eruption of Kīlauea, Hawaii highlighted these knowledge gaps and posed new questions about magma storage and transport processes in fissure systems. The intent of the PhD project is to study the subsurface dynamics of these fractures, and of the magma in them, using a combination of scaled analogue experiments, field observations, and textural analysis of field deposits.

We propose to: (a) utilise a novel 3-dimensional-3-component tomographic particle image velocimetry (3D3C TomoPIV) technique during gelatine analogue experiments in order to map the flow dynamics within experimental dykes that feed fissure eruptions; (b) perform analogue magma mixing experiments to quantify efficiency of magma mixing in dyke/sill geometries; and (c) collect petrographic, mineralogical and microstructural measurements of samples from an ancient fissure eruption. Through this multi-component study, the aim is to advance our understanding of dyke emplacement and the subsurface plumbing system dynamics, which ultimately will aid hazard assessments.

The Independent Volcanic Eruption Source Parameter Archive (IVESPA) and its application to evaluate mass eruption rate-column height scaling relationships

Thomas J. Aubry* Samantha Engwell [British Geological Survey, The Lyell Centre, Edinburgh], Costanza Bonadonna [Department of Earth Sciences, University of Geneva, Geneva, Switzerland], Guillaume Carazzo [Université de Paris, Institut de physique du globe de Paris, CNRS], Simona Scollo [Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo], Alexa R. Van Eaton [U.S. Geological Survey, Cascades Volcano Observatory], Isabelle A. Taylor [COMET, Atmospheric, Oceanic and Planetary Physics, University of Oxford], David Jessop [Université de Paris, Institut de physique du globe de Paris, CNRS,Observatoire volcanologique et sismologique de Guadeloupe, Institut de physique du globe de Paris, Université Clermont Auvergne, CNRS, IRD, OPGC Laboratoire Magmas et Volcans], Julia Eychenne [Université Clermont Auvergne, CNRS, IRD, OPGC Laboratoire Magmas et Volcans], Mathieu Gouhier [Université Clermont Auvergne, CNRS, IRD, OPGC Laboratoire Magmas et Volcans], Larry G. Mastin [U.S. Geological Survey, Cascades Volcano Observatory], Kristi L. Wallace [U.S. Geological Survey, Alaska Volcano Observatory], Sébastien Biass [Earth Observatory of Singapore, Nanyang Technological University], Marcus Bursik [University at Buffalo], Roy G. Grainger [COMET, Atmospheric, Oceanic and Planetary Physics, University of Oxford], A. Mark Jellinek [Earth Ocean and Atmospheric Sciences, University of British Columbia], Anja Schmidt [Department of Geography & Department of Chemistry, University of Cambridge]

*ta460@cam.ac.uk

Eruptive column models are powerful tools for investigating volcanic ash transport, reconstructing past explosive eruptions, and simulating future hazards. However, the evaluation of these models is challenging as it requires independent estimates of the main model inputs (e.g. mass eruption rate) and outputs (e.g. column height). In particular, there exists no database of independently estimated eruption source parameters that is extensive, standardized, maintained, and consensus-based. To address this gap, we introduce the Independent Volcanic Eruption Source Parameter Archive (IVESPA) as a result of a community effort endorsed by the International Association of Volcanology and Chemistry of the Earth's Interior Commission on Tephra Hazard Modelling. We compiled data for 134 explosive eruptive events that occurred since year 1902 with independent estimates of: i) total erupted mass of fall deposits; ii) duration; iii) eruption column height; and iv) atmospheric conditions. Crucially, we distinguish plume top versus umbrella spreading height, and the height of ash versus SO2 injection. All parameter values, which were compiled from the literature, have been vetted independently by at least two volcanologists. Uncertainties are quantified systematically, including flags to describe the degree of interpretation of the literature required for each estimate. IVESPA also includes a range of additional parameters such as total grain size distribution, eruption style, and mass contribution from pyroclastic density currents. The database website is under construction and will be advertised as soon as available, in December 2020/January 2021. We have applied IVESPA to calibrate and evaluate the most popular scaling relationships linking the eruption column height to the mass eruption rate. In particular, we quantify improvements in column height prediction when accounting for atmospheric stratification and wind effects in such scaling. We also calibrate scaling models for the three types of column height provided in IVESPA (top, spreading, SO2), enabling a richer and usage-specific application.

CENTA 4 VMSG & EDI

Tiff Barry* CENTA Committee

*tlb2@le.ac.uk

CENTA have a number of projects that may be of interest to the VMSG community this year. These projects are based at the OU, University of Leicester, or University of Birmingham (go to centa.ac.uk for full details or see titles listed below).

There are two ways to apply to be a CENTA doctoral researcher this year. One is the traditional route, applying direct to one of the advertised projects (deadline 11th January). For the first time, if you identify as having BAME characteristics or your secondary school falls within quintile 1 on the POLAR4-scale of higher education participation, we hope to be able to offer you a guaranteed interview.

Secondly, to address a historical imbalance, we plan to offer up to 3 scholarships to Home-award-eligible BAME applicants (unfortunately the closing date is 5th January this year, so will have closed by the time of VMSG). The scholarship will be awarded to candidates prior to project development, so once awarded, CENTA will then put the awardee in touch with academics in their area of research, who will design a suitable project for the awardee.

A big thanks to the VMSG community for the August discussion on 'Improving diversity in the UK now: changemakers and becoming better allies'… views shared at that meeting lent weight to putting ambition into practice.

List of relevent project titles:
University of Leicester

- Apatite: a proxy for pre-eruptive volcanic gas emissions?
- Unpicking global mantle convection influences from the local: investigating asthenospheric versus lithospheric constraints on the evolution of landscapes
- New techniques in ore analysis
- Catastrophic emplacement and depositional processes during large asteroid impacts: lithofacies analysis and applied volcanology, Manicouagan (Canada) and Chicxulub (Mexico)

University of Birmingham

- How fast is the formation of new subduction zones?
- Did the North Atlantic igneous province drive the Paleocene-Eocene Thermal Maximum?
- Magma-reservoir evolution following edifice destruction at Krakatau and Ritter volcanoes

Open University

- Rapid emplacement of the Thakurvadi Formation of the Deccan Traps and its implication for late Cretaceous climate change
- After the dust has settled: the post-impact hydrothermal system at Rochechouart impact crater and implications for Early Earth

Extreme curvature of shallow magma pathways controlled by competing stresses

Timothy Davis* Marco Bagnardi (NASA Cryospheric Sciences Laboratory)

Paul Lundgren (NASA Jet Propulsion Laboratory)

Eleonora Rivalta (GeoForschungsZentrum)

*davis@gfz-potsdam.de

To feed off-summit eruptions at volcanoes, magma moves by creating and passing through cracks that can propagate many kilometres downslope. Typically, these cracks are vertical (dykes). Here we show the propagation of a flat-lying magma-filled crack (sill) at Sierra Negra volcano, Galápagos Islands, using space-borne radar interferometric data spanning the 2018 eruption. This sill propagated along a 15-km-long curved trajectory, which is hard to explain with current understanding and models. We develop both a simple analytical analysis and a three dimensional (3D) numerical crack propagation model, which incorporates the effects of magma buoyancy, realistic topography and tectonic forces that may control the sill's propagation. We show that sill trajectories can only be understood and predicted if accounting for the interaction of all these factors, and explain the observed trajectory at Sierra Negra as the result of competing stresses being close to one another throughout the propagation of the sill. Under certain conditions, these events may be inherently unstable but remain predictable by combining high resolution observations with sophisticated theoretical understanding.

Modelling of localised melt transport patterns due to rock failure at low shear stress

Tobias Keller* n/a

*Tobias.Keller@glasgow.ac.uk

Igneous systems provide abundant geological evidence of localised magma transport linked to wall rock failure. This includes features such as magma-filled dykes, sills, tears, shear bands, and tubes. It is thought that in the course of visco-elastic rock deformation, stress can accumulate to a critical threshold where rock begins to fail plastically forming strongly localised ductile shear bands or discrete brittle fractures which can accommodate localised melt segregation.

It has long been known that the failure stress is lowered significantly by pressurised fluids present in the pore space of a permeable solid. As a consequence, the presence of partial melt in the uppermost mantle and crust can promote the onset of failure even at comparatively low shear stress, where dry rock would not fail. Modelling failure in a continuum mechanics framework can be challenging. Failure introduces strong non-linearity leading to localisation of matrix deformation and pore fluid flow which can be challenging to resolve numerically. In this presentation, I will review the effective-viscosity approach to modelling failure rheologies and highlight some of its challenges and limitations.

First results produced from a finite-difference implementation of the problem show a variety of localisation patterns emerging spontaneously depending on magnitude and orientation of applied simple or pure shear stress conditions. Under buoyancy-dominated conditions at low shear stress, failure leads to melt flow localisation into tubes or chimneys. Under pure-shear conditions en-echelon structures form, comprising melt-shear bands at high angles and tensile bands at right angles to the least compressive stress direction. Under simple-shear conditions melt-shear bands form at low angles to the shear direction. What emerges throughout is that conditions required to initiate such failure patterns may be ubiquitous along the pathway of melt from source to surface and that therefore these features may be critical to our understanding of magma extraction, ascent, and emplacement.

Emplacement and segment geometry of large, high-viscosity dykes

Tobias Schmiedel* Steffi Burchardt (Uppsala University)

Tobias Mattsson (University of St. Andrews & Stockholm University)

Frank Guldstrand (University of Oslo)

Octavio Palma (Under-secretariat of Mining Buenos Aires & National University of La Plata)

Olivier Galland (University of Oslo)

Henrik Skogby (Swedish Museum of Natural History Stockholm)

*tobias.schmiedel@geo.uu.se

The transport and propagation of magma in dykes in the subsurface is crucial to understand and predict the behaviour of volcanoes and their hazard potential. Geological studies of dyke emplacement and geometry have come a long way, with the majority of research focussing on low-viscosity, mafic dykes. Felsic (silica-rich) dykes have a viscosity up to six magnitudes higher, but does that result in a similar emplacement and dyke/dyke segment geometries?

Here we present an in-depth field study of two high-viscosity dacitic dykes in the Chachahuén volcanic complex in Argentina. To characterize the physical processes of magma emplacement and resulting geometries, we combine field work and state-of-the-art analytical techniques, i.e., UAS (Unmanned Aerial System)-based photogrammetry, Fourier Transform Infrared Spectroscopy (FTIR), and Anisotropy of Magnetic Susceptibility (AMS), with traditional geological methods, i.e., microstructural analysis and igneous petrology.

Through field observations and orthophotos we could map the Great Dyke (1900 m) consisting of 8 segments (19-34 m thick) and the Sosa Dyke (c. 1300 m) with 3 mapped segments (42-63 m thick). The observed segment tips often show a bifurcation with a thin abandoned arm and an arm which connects two segments. Furthermore, host rocks with a range of physical properties (basaltic lava flows to unwelded rhyolitic ignimbrites) had no observable impact on the overall geometry of the dyke segments. Looking at the overall dyke geometry, the centre of the dyke is thicker (>50%) compared to its edges, similar to the well-established penny-shape model for fluid-driven hydrofractures. Our geochemical/petrological analyses show the magma had a viscosity of 105-106 Pa s during dyke emplacement. In addition, our AMS data shows a lateral flow of magma in the dyke segments as opposed to vertical flow often associated with vertical magma sheets.

Our study presents a detailed data set on dyke morphology of high-viscosity felsic dykes. We showcase the similarity of felsic and mafic dykes in their overall dyke geometries, as well as quantify the differences in dyke segment shapes, i.e., felsic: oval, thicker, blunt tip, etc. It thus contributes to the general understanding on how the physical properties of the magma affect the shape of magma bodies and magma flow in the Earth's shallow crust and provides a reference for analogue and numerical models.

No evidence for nitrogen degassing during igneous differentiation at Hekla, Iceland

Toby Boocock* Sami Mikhail (University of St Andrews), Julie Prytulak (Durham University), Paul Savage (University of St Andrews), Eva Stueeken (University of St Andrews)

*tjb7@st-andrews.ac.uk

Historically considered an atmophile element, nitrogen is thought to be easily lost from igneous systems along with carbon (CO2) and hydrogen (H2O) during fractional crystallisation due to its volatility. However, the partitioning and magnitude of nitrogen isotopic fractionation by magmatic differentiation has not yet been systematically assessed. In this study we analyse the nitrogen abundance and 15N/14N ratios for a well characterised suite of cogenetic magmas from the Hekla volcanic complex, Iceland. These samples span a large compositional range from basalt to rhyolite (46% to 72% SiO2) and are thought to have derived from magmatic differentiation, with minimal evidence for degassing, metasomatism or assimilation of crustal materials (e.g. Schuessler et al. 2009; Savage et al., 2011, Prytulak et al., 2017). Our data show nitrogen behaving like a non-volatile incompatible element throughout magmatic evolution, closely correlating with Rb, Cs, K, and Tl. Magmatic differentiation has minimal impact on nitrogen isotope values, in fitting with predicted behaviour of stable isotopes at high temperatures. However, assimilation of small quantities of metabasaltic country rock does appear to have modified the primary isotopic signature for some of the intermediate composition samples in the Hekla system, in fitting with best current models of the history of this volcano. We find no evidence for volatile induced effects on nitrogen systematics in this system. These data suggest that when undersaturated in magmas, nitrogen appears to be decoupled from the other commonly grouped volatile elements (H, B, F, Cl, C, He-Xe). Therefore, our data are important for understanding the development of telluric planetary atmospheres (Mikhail & Sverjensky, 2014) and the nitrogen geochemistry of the early Earth ecosystem as life took hold (Stüeken et al., 2016).

References

1. Mikhail, S and Sverjensky, D. A., 2014. Nitrogen speciation in upper mantle fluids and the origin of Earth's nitrogen-rich atmosphere. Nature Geoscience, 7 (11), pp. 816-819.

2. Prytulak, J., Brett, A., Webb, M., Plank, T., Rehkamper, M., Savage, P. S., and Woodhead, J., 2017. Thallium elemental behavior and stable isotope fractionation during magmatic processes. Chemical Geology, 448, pp. 71-83.

3. Savage, P. S., Bastian Georg, R., Williams, H. M., Burton, K. W., and Halliday, A. N., 2011. Thallium elemental behavior and stable isotope fractionation during magmatic processes. Geochimica et Cosmochimica Acta, 75 (20), pp. 6124-6139.

4. Schuessler, J. A., Schoenberg, R., and Sigmarsson, O., 2009. Iron and lithium isotope systematics of the Hekla volcano, Iceland - evidence for Fe isotope fractionation during magma differentiation. Chemical Geology, 258 (1-2), pp. 78-91.

5. Stueeken, E. E., Kipp, M. A., Koehler, M. C., and Buick, R. 2016. The evolution of Earth's biogeochemical nitrogen cycle. Earth-Science Reviews, 160, pp. 220-239.

From slab to surface: Earthquakes provide evidence for fluid migration at Uturuncu volcano, Bolivia

Tom Hudson* JM Kendall (University of Oxford), Matt Pritchard (Cornell University), Ying Lui (University of Science and Technology of China)

*thomas.hudson@earth.ox.ac.uk

Uturuncu volcano is situated in the Bolivian Andes, directly above the world's largest body of silicic partial melt, the Altiplano-Puna Magma Body (APMB). Although Uturuncu last erupted 250,000 years ago, it has recently exhibited significant uplift and is seismically active. We present results using seismicity to elucidate what fluids and where fluids are at Uturuncu. We then link these observations to other geophysical, geochemical, and geomechanical analyses of Uturuncu in order to attempt to explain the behaviour of the Uturuncu volcanic system. Our key findings specifically relevant to Uturuncu are: (1) The seismicity delineates fault structures above and below the APMB; (2) b-values provide evidence that fluids likely migrate along these faults at both shallow and deep depths; (3) Velocity and attenuation tomography delineate regions of elevated temperature and higher fracture density. While our results are directly relevant for the understanding of the Uturuncu volcanic system, they also have significant implications for studies of volcanic seismicity globally. We compare b-values calculated using local magnitudes and moment magnitudes. The local magnitudes analysis yields b-values less than one, suggesting a lack of fluid involvement, while the more rigorous moment magnitudes analysis yields b-value greater than one, inferring the presence of fluids. We suggest that if at all possible, one should use physically motivated moment magnitudes rather than other, empirically derived magnitude scales for volcano-tectonic studies. This step change in the derivation of b-values sheds light on fluid migration through the crust, both above and below a massive body of silicic partial melt.

Volcanic processes and hazard assessment of Torfajökull volcano and surrounding areas

Velveth Perez* Tobias Keller (University of Glasgow)

David Brown (University of Glasgow)

Hugh Tuffen (Lancaster University)

Dave McGarvie (Lancaster University)

*2591740p@student.gla.ac.uk

The Torfajökull volcanic area, located in south-central Iceland, has grown to be one of the country's most popular tourist destinations. The Torfajökull volcanic system is not only Iceland's largest silicic centre but it also hosts Iceland's largest geothermal area of about 140 km2. The system has been moderately active in the Holocene, with the last eruption occurring in 1477 CE.

Given the recent unrest at Bárðarbunga and the 2014 eruption in its NE fissure (Holuhraun), there is good reason to look carefully at volcanic hazards in its SW fissure swarm, where propagating dykes have repeatedly intruded the magma chamber below the Torfajökull caldera and caused magma mixing that have resulted in hybrid rhyolite/tholeiite lavas and have also triggered eruptions of tephra and ash in explosive Plinian phases.

This project aims to understand the processes by which a stagnant rhyolite reservoir is activated by a laterally-intruding basaltic dyke, and on what timescale a renewed silicic eruption cycle might be triggered. Modelling of magma mixing and thermo-chemical evolution combined with field work and laboratory characterisation of the mingled lavas would enable us to answer key questions that would be critical to test hypotheses of volcanic processes as well as develop realistic early warning scenarios that would be useful for hazard assessments.

Origins and Actions. Three Panels to tackle the lack of progress in addressing diversity in the Volcanic and Magmatic Studies Group Membership

VMSG Committee, Michal Camejo-Harry (Seismic Research Centre, University of the West Indies, Trinidad), Chris Jackson (GEES, Manchester University, UK), Matthieu Kervyn (Vrije Universiteit Brussel, Belgium), Richie Robertson (Seismic Research Centre, University of the West Indies, Trinidad), Elisa Sevilla (Universidad de San Francisco de Quito, Ecuador), Jazmin Scarlett (University of Hull, UK), and Shanaka de Silva (CEOAS, Oregon State University, USA)

'Talent is equally distributed, opportunities are not'

Wise words from one of our panelists that focuses attention on the increasing recognition of historic entrenched inequities and bias towards underrepresented groups of our society. For VMSG, this is manifested in the lack of substantive progress towards representation of under-served minorities in the geosciences, and particularly volcanology, over the last few decades, despite the changing demographics of society as a whole. In response to this and recognizing that the opportunity to thrive in our field should be available to all, the VMSG Committee convened three panels, each with a different focus. These panels provide insights culminating in new actions the VMSG will incorporate into its equality, diversity and inclusion program. Although not as diverse a community as we should be, we collectively recognise that change will not happen without those in the majority also 'doing the work' towards that end.

The first panel shared knowledge, understanding and experience of the historical construction of inequalities in our field. The historical generation of geoscience knowledge through colonial power and infrastructures is now manifest in global inequalities in ownership and distribution of knowledge, and the physical resource generated by that knowledge. We can seek to address this by developing more equitable partnerships when working overseas and by challenging the orthodoxy of publishing and resource norms (with most emphasis on funding of western scientists and English language journals). Together we should place greater emphasis on rewarding excellent research that develops partnerships, celebrates role models from under-served minorities and that is sensitive to local cultures and traditions. These views were also reflected in the survey of the 120 VMSG participants before, during and after the panel.

The second panel featured those who had already acted against systemic bias and underrepresentation in the geosciences as it exists today and in the recent past. From their initiatives and experiences we learned that initiatives need to be appropriately motivated (designed around the needs of the recipients) and sustainable (with appropriate funding and time commitment to achieve longitudinal change). It is important that efforts to address underrepresentation recognise that we are not dealing with a homogenous entity, and effective actions are thus most likely to come via an intersectional approach (identifying actions that will benefit more than one under-served minority).

Building on this, the VMSG committee identified coincident actions from its new Equality, Diversity and Inclusion policy and further actions that could amplify benefits for under-served minorities.

Panel 3 will be convened in December to allow the broader community to input into and prioritise these actions, to ensure their sustainability. We will also report on the outcome of that meeting here.

The record of catastrophic, ignimbrite-forming, prehistoric eruptions of Taal Caldera Volcano, Philippines

Yannick Withoos* Michael Branney (School of Geography, Geology and the Environment, University of Leicester, UK)

Catherine Lit (National Institute of Geological Sciences, University of the Philippines, Diliman, Philippines)

Stephen Self (Department of Earth & Planetary Science, University of California at Berkeley, USA)

Tiffany Barry (School of Geography, Geology and the Environment, University of Leicester, UK)

Darren Mark (NERC Argon Isotope Facility, Scottish Universities Environmental Research Centre, Rankine Avenue, East Kilbride, UK)

*yw382@leicester.ac.uk

Taal Volcano is an active flooded basaltic andesite–dacite caldera volcano in the Philippines, 50 km south of Manila. It poses a substantial hazard to the ca. 25 million people who live within a 100 km radius, but recent research has focused mainly on the smaller, historical (e.g. Taalian style) eruptions (such as in Jan. 2020; ~250,000 evacuated), leaving the much more formidable prehistoric ignimbrite-forming eruptions poorly understood.

A revised 140 ky pyroclastic stratigraphy comprises at least 4 possible caldera-forming eruption-units, 3 other major eruption-units and numerous (min. 47) minor eruption-units. The Sampaga and Batangas Formations are newly identified as the oldest exposed eruption-units at Taal Volcano. Each of the major eruption-units comprises multiple ignimbrite flow-units of massive and diffusely cross-bedded lapilli-tuff variously with pumice lapilli, scoria lapilli, spatter rags, accretionary and armoured lapilli, and subordinate accidental clasts of lava and tuff. They have proximal lithic breccias and scoria agglutinates, and intercolated cross-stratified layers and thin, pellet-bearing and locally vesicular ashfall layers. A total absence of welding of the ignimbrites combined with the abundance of fine ash and ash aggregates in ignimbrites and fall deposits suggests that interaction with water was important during most of the eruptions.

The largest eruption-unit is the 5–6 ka Pasong Formation (estimated bulk DRE volume of 90 km3), and the most recent major eruption-unit is the ≤5 ka Buco Formation (28 km3 DRE). The partly obscured ignimbrite distributions indicate that the pyroclastic density currents were broadly radial, capable of overtopping 600 m high hills, and left ≥10 m thick deposits even 30 km away from the caldera. Even some of the ‘minor’ eruption-units like the Sampaga Formation are as much as 2 m thick 30 km from the caldera. The densely populated, low-lying region around Taal would be vulnerable to these eruptions, and radiometric Ar-Ar dating is in progress to help determine whether future catastrophic ignimbrite eruptions are likely.

Joint inversions of extrusion flux, ground deformation and gas emissions using physics-based models for the Mount St. Helens 2004-2008 eruption

Ying-Qi Wong* Paul Segall (Stanford University)

*ying-qi.wong@glasgow.ac.uk

Physics-based models provide a natural and meaningful way to bring together diverse geophysical and geochemical data from volcanoes. By incorporating these models into quantitative inversions, we can obtain constraints on important properties of the volcanic system that are consistent with these observations. Here we develop a framework for joint inversions of diverse time series data using a physics-based model for dome-forming eruptions. The time-dependent, one-dimensional (in depth) model simulates the ascent of magma through a conduit that connects a magma chamber to the surface. During ascent, magma exsolves volatiles and crystallizes, which causes its viscosity to increase. Exsolved gases can escape vertically through the column or laterally through the conduit walls. Time- and depth-dependent magma properties are used to calculate the time series of cumulative extruded volume, ground deformation and carbon dioxide emissions.

We apply this model to data from the 2004-2008 eruption at Mount St. Helens to estimate essential system parameters, including chamber geometry, pressure, volatile content and material properties. The model parameter space is first sampled using the neighborhood search algorithm (Sambridge 1999, GJI). The resulting ensemble of models is resampled to generate posterior probability density functions (PDFs) of the parameters. We find models that fit all three datasets well. Posterior PDFs suggest an elongate chamber with aspect ratio less than 0.5 with its centroid located at 9–17 km depth. Volume loss from the chamber is 0.20–0.66 km3. Since the model calculates the pressure change during the eruption, we can also constrain chamber volume to 64 and 256 km3. This represents a volume of material that deforms like a fluid on the time scale of the eruption, and may contain regions of relatively high solid fraction. At the top of the chamber, total (dissolved and exsolved) water contents are 5.0-6.4 wt% and total carbon dioxide contents are 1600-3900 ppm, giving a porosity of 5.3-16.6% depending on the conduit length. Observed dome porosities (<40%) constrain the magma permeability to 10-17–10-15 m2 such that the magma loses sufficient volatiles before reaching the surface. This inversion incorporating a physics-based model was therefore able to constrain a wide variety of system parameters, which would not be possible with traditional, discipline-specific modeling.