Virtual Annual Meeting, 10-12th January 2022

Abstract Volume

David Neave, Margaret Hartley, Brendan McCormick Kilbride
Local Organising Committee

Abstract Volume

Contents

Sincere thanks to our sponsors and supporters.

This virtual meeting has been made possible by the generous financial support of Deltech Furnaces and Zeiss.

We are also sincerely grateful to the conferencing staff of the Geological Society of London for their support in hosting the online virtual meeting.

Local Organizing Committee, Convenors & Panellists

Local Organizing Committee (University of Manchester)

David Neave	david.neave AT manchester.ac.uk
Margaret Hartley	margaret.hartley AT manchester.ac.uk
Brendan McCormick Kilbride	brendan.mccormickkilbride AT manchester.ac.uk

Contact us with any questions about the programme or participating in the meeting. For technical questions about Zoom links, registration or payments contact conference AT geolsoc.org.uk.

Session Convenors & Social Organizers (University of Manchester)

Emily Bamber

Samantha Bell

Mike Burton

Juliette Delbrel

Benjamin Esse

Catherine Hayer

Melina Hohn

Marissa Lo

Margherita Polacci

Divyareshmi Thottungal Ravy

Jorge Romero Moyano

Alexander Stewart

Emma Waters

Workshop Leaders & Panellists

Early Career meeting & Student AGM

Claire Harnett	claire.harnett AT ucd.ie
Emma Watts	E.J.Watts AT soton.ac.uk
Eilish Brennan	eeebr AT leeds.ac.uk

Panellists, Volcanic Crises

Richard Robertson	Richard.Robertson AT sta.uwi.edu
Boris Behncke	boris.behncke AT ingv.it
Severine Moune	moune AT ipgp.fr
Kristín Jónsdóttir	kristin.jonsdottir AT vedur.is
Matthew Pankhurst	mpankhurst AT iter.es

Panellists, VMSG Beyond Academia

Peter Marshall	p.marshall AT fugro.com
Natalie Starkey	natalie.starkey AT open.ac.uk
John Stevenson	jostev AT bgs.ac.uk
Richard Taylor	richard.taylor AT zeiss.com

VESIcal

Simon Matthews	simonm AT hi.is
Penny Wieser	wieserp AT oregonstate.edu

Virtual Fieldtrip to the Moon

Sam Bell	samantha.bell AT manchester.ac.uk
Marissa Lo	marissa.lo AT manchester.ac.uk
John Pernet-Fisher	john.pernet-fisher AT manchester.ac.uk
Divya Ravy	divyareshmi.thottungalravy AT postgrad.manchester.ac.uk

Conference Schedule

(purple)	Eruptions and the environment	(yellow)	Planetary volcanism
(red)	Geochemistry and petrology	(green)	Volatiles and gases
(orange)	Magma transport and ascent	(blue-grey)	Volcanoes and society

	Monday 10th January		Tuesday 11th January		Wednesday 12th January	
Morning			Virtual fieldtrip to the Moon (10:00-12:00)		VESIcal workshop (10:00-12:00)	
	Session A	**Session B**	**Session A**	**Session B**	**Session A**	**Session B**
13:00	Welcome		McGarvie	**Magee (highlight)**	**Donovan (highlight)**	**TBA**
13:10	**VMSG Award - Morgan**		Gilchrist	Alshembari	Carver	Bell
13:20			*Buckland, Dioguardi, Zhang, T Johnston, Walding*	*Clunes, Havard, Allgood, Greiner, Chalk*	Scarlett	*Cao, Bintang, Ravy*
13:30			Van Wyk de Vries	Kavanagh	Mani	Hiramatsu
13:40	**Buckland (highlight)**	Mangler	Paine	Clunes	Ligot	Liggins
13:50	Cole	A Hughes	BREAK		BREAK	
14:00	Hetherington	E Rhodes	Dylewska	*Paulatto, Mestel, Jeffery, Amstutz, Baxter*	Kavanagh	Waters
14:10	*Loisel, Winstanley, Tuffen, Calleja, Siegburg*	*Curtis, Lecoeuche, Morris, Soderman, Tien*	Liu	Oliveira	Pugsley	Balci
14:20	BREAK		Eves	Askkour	Farquharson	Matthews
14:30	Panel: Volcanic crises in 2021		*Dunn, Harnett, Johnson, Rucco*	Beckwith	*Lark, Vergara-Pinto, Dalziel, Perez, Osman*	*Brennan, Hogg, Lawford, Humphreys, Matthews-Torres*
14:40				*Gordon, Quintela, Keller, Seelig, Galbraith, Kjenes*	G Hughes	Li
14:50			BREAK		Hodgetts	Barber
15:00			Panel: VMSG beyond academia		Mani	*Dunn, Yip, Brookfield*
15:10					Gathertown (posters and discussion)	
15:20						
15:30	BREAK					
15:40	Delmelle	Stewart				
15:50	Beresford-Browne	Torres-Sanchez				
16:00	*Brouillet, J Johnston, I Rhodes, Wainman, Hutchison*	*Carter, Marsh, Toth, A Jones, Geifman*	BREAK			
16:10	Reeves	Voigt	**Fendley (highlight)**	*Crocker, Whittaker, Mattioli Rolim, Maclennan, Elms*		
16:20	Heap	Mutch	Delbrel	Shi		
16:30	Newland	Boulliung	Taylor	Colby		
16:40	BREAK		Smekens	*Azevedo, Platten, Rybak, Williams, Chrapkiewicz, Gill*		
16:50	*Moore, Meredew, Blennerhassett, Paine*	Wong	BREAK			
17:00	Pankhurst	Gleeson	Esse	Witcher	**Zeiss Post-doctoral Keynote Award - Wieser**	
17:10	Romero	Walker	Dioguardi	*Gillies, Drignon, D Jones, Pansino, Polacci*		
17:20	Burton	*Knight, Bamber, Schofield, Petrone, Hrintchuk*	*Jackson, Nash, Howe, Hayer, Mitchell*	Djouda		
17:30	Scarrow		Ulusoy	Unwin	AGM	
17:40	*James, Foster, Vale, Vineberg*		Lamb	**Lo (highlight)**		
17:50	ECR meeting (Harnett)		Student AGM (Watts)			
Evening	Movie Night		Quiz			

Panel discussions, workshops, social activities

Panel discussions

Volcanic crises of 2021

Panel: Richie Robertson (University of the West Indies), Boris Behncke (Osservatorio Etneo, INGV Catania), Severine Moune (Volcanological and Seismological Observatory of Guadeloupe, University of Clermont-Auvergne), Kristin Jonsdottir (Icelandic Meteorological Office), Matthew Pankhurst (Instituto Volcanológico de Las Canarias).

The last 12 months have seen several volcanic crises, posing major threats to life, infrastructure and the environment. In this panel discussion, we are joined by leading scientists who have worked in the forefront of these crises, to consider the question: what are the scientific opportunities arising from volcanic crises?

This panel discussion will run in Zoom session A, 1430-1530 on Monday 10th January.

VMSG beyond academia

Panel: Natalie Starkey (author and science communicator), John Stevenson (software developer, British Geological Survey), Peter Marshall (tendering engineer, Fugro), Richard Taylor (applications manager for geoscience, Zeiss).

The numerous alumni of the VMSG community are now working in a wide range of sectors across both public and private sectors. In this panel, we are joined by four representatives of a range of these sectors to hear about their onward journey beyond their time attending VMSG meetings, discussing their subsequent careers and the skills they have taken from their academic background into their new roles.

This panel discussion will run in Zoom session A, 1500-1600 on Tuesday 11th January.

Workshops

VESIcal

Hosts: Simon Matthews (University of Iceland), Penny Wieser (Oregon State University)

VESIcal is a new tool for calculating solubilities of CO_2-H_2O fluids/vapours in magmatic systems. It provides a powerful interface for many of the most frequently used solubility models, enabling the calculation of saturation pressures, degassing paths, and fluid/melt compositions. The tool leverages the power and flexibility of the python programming language, but most calculations require very little coding experience. In this short workshop we will introduce VESIcal, some of the solubility models that are built into it, and we will demonstrate how fast and easy it is to obtain results, even when using large datasets.

This workshop will be run in Zoom (link provided in the meeting information email sent to all participants), 1000-1200 on Wednesday 12th January. In preparation for this workshop, if you wish to attend, please follow the instructions here (https://swmatthews.com/2022/01/05/vesical-workshop-at-vvmsg2022/).

Virtual Fieldtrip to the Moon

Hosts: Marisso Lo, John Pernet-Fisher, Sam Bell, Divya Ravy (University of Manchester)

For this year's conference field trip, you will be taking on the role of a scientist at the NASA Johnson Space Center and going back in time to 1971, when samples from the Apollo 15 mission first became available for research. Using a combination of field images, thin sections, and 3D models, it'll be your job to make some interpretations of the geology at the Apollo 15 landing site, Hadley Rille. No prior knowledge of lunar geology is required and there will be plenty of time for discussion and questions!

ECR Meeting

Host: Claire Harnett (University College Dublin)

A chance for all ECRs to gather and discuss issues affecting them. Zoom details are in the welcome email.

Student AGM

Hosts: Emma Watts (University of Southampton), Eilish Brennan (University of Leeds)

A chance for all students to gather and discuss issues affecting them. Zoom details are in the welcome email.

Social Activities

Movie Night

Hosts: Ben Esse, Cat Hayer (University of Manchester)

Following on from the success of movie night last year, it’s back with Manchester’s attempt to find the *worst* volcano-based disaster movie. This year’s version stars Superman himself, Dean Cain, in "Airplane vs. Volcano” and yes, it really is as bad as it sounds ...

If you want to judge whether this movie can live up to the awfulness of Apocalypse Pompeii, we’ll be showing it on Monday evening, starting around 1930. Details of streaming will be announced in the meeting, but feel free to watch yourself on Youtube and join the discussion in Gather Town social areas, the Discord channel, or Twitter.

VMSG Quiz

Hosts: Juliette Delbrel, Marissa Lo, Emma Waters (University of Manchester)

The second social of the conference will be a quiz. There will be 4 rounds, and the only clue we'll give about the rounds is that you'll need to use your brain, eyes, and ears to work out the answers!

The quiz will be hosted in Gather Town, starting around 1930 on Tuesday evening. Enter the quiz rooms and find a team to join. Teams are made up of 6 people, seated around tables.

Participating in the virtual meeting

While we are disappointed not to be hosting you in person in Manchester for this meeting, we are confident that you will be able to enjoy this meeting fully and find it useful and stimulating, and to this end we are providing a range of ways to engage in the meeting's content.

Zoom

The majority of this year's meeting will take place in Zoom. We will have two parallel webinar sessions, A and B. You will receive links to each from the Geological Society of London in an initial email once you have registered (if you have received nothing by the morning of Monday 10th January, please contact the local organising committee on vmsg2022 AT gmail.com).

The presentations will comprise 8-minute talks and 2-minute flash talks. Please submit questions through the Zoom Q&A or chat functions. The session convenors will read out questions and the lead presenting author will respond verbally. There will be opportunity to continue the discussion in the Zoom chat as the meeting continues. All the talks are available in a vVMSG2022 Google Drive directory. You can watch talks from the parallel sessions outside of the conference's programmed schedule. Many of the talks will also be made available on the VMSG YouTube channel after the conference.

Gather Town

Many of the 2-minute flash talks are accompanied by a poster. These are available in the Google Drive directory for the entire duration of the conference. There will also be a live (/synchronous) poster session in Gather Town on Wednesday 12th January, 1510-1700.

Gather Town is an intuitive interactive environment where you can construct an avatar (pictoral representation of yourself) and move around a virtual conference hall, interacting with other conference delegates (via video chat or instant messenging). Our Gather Town environment (see map on next page) includes poster halls, communal social spaces, and private meeting areas. We encourage you to register in advance and explore the Gather Town interface ahead of the poster session. Gather Town will available for the duration of the conference if you wish to have a breakout area for discussions, away from the main Zoom rooms.

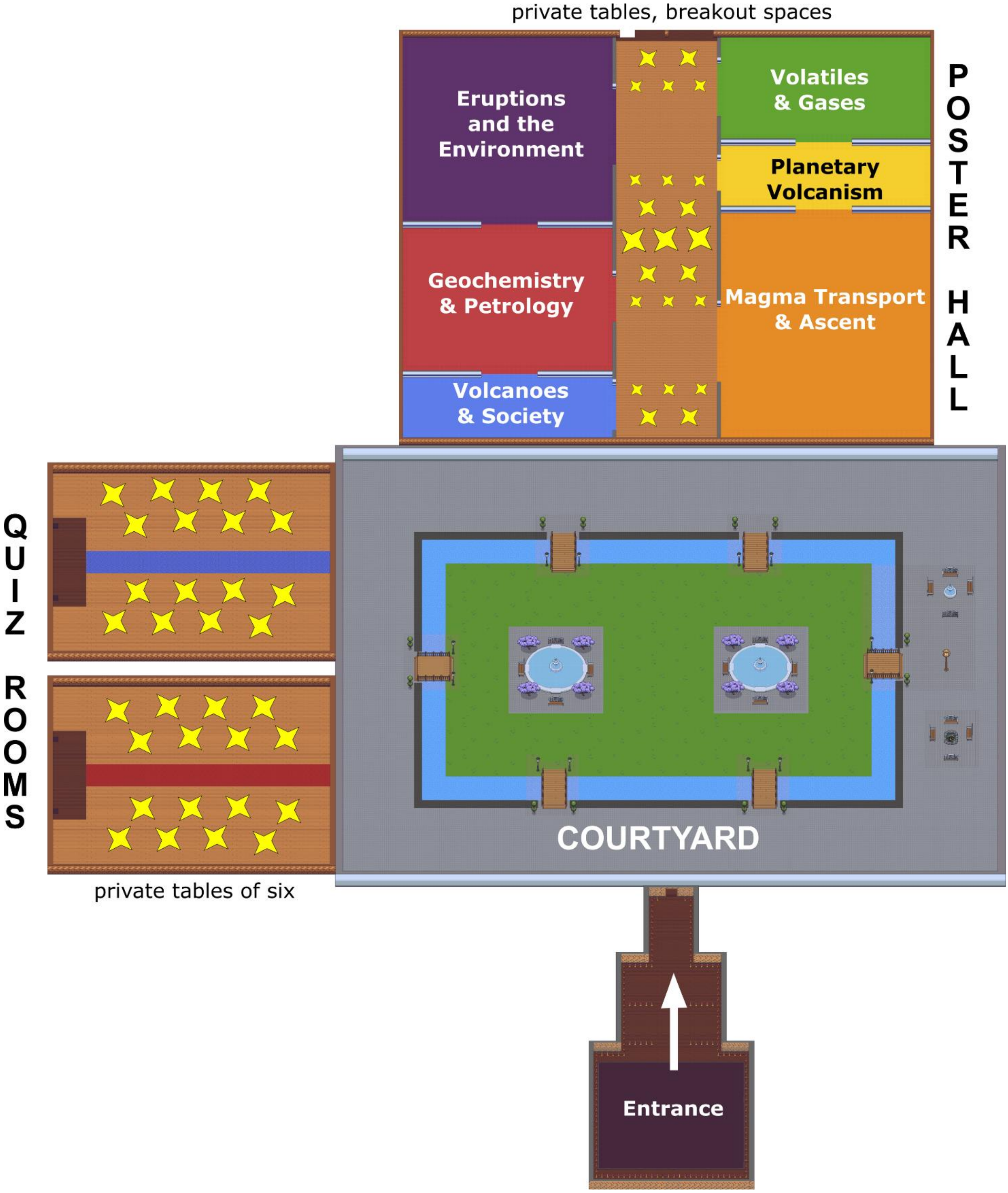
Discord

The VMSG community maintains a Discord server where you can chat to colleagues during online conferences or at any other time. Registration is quick and easy. Once logged in, you will find channels for each session of vVMSG2022 as well as others to discuss general interest topics, ECR issues, graduate student issues, etc.

Twitter

Finally, feel free to discuss the meeting using the Twitter hashtag #vVMSG2022.

Gather Town Map



On your first arrival, after designing your avatar, you will land in the Entrance. Move straight ahead to the end of the hallway, and enter the courtyard. From here you can make your way to the Quiz Rooms (doubling as social spaces throughout the meeting) or the Poster Hall.

Each session has its own poster room. In addition, there is extensive seating through the main corridor of the Poster Hall for private meetings for small groups. You may also use spaces around the fountains in the Courtyard.

List of presentations by session

(*student talks)

VMSG Award

Dan Morgan, University of Leeds
Diffusion methods in volcanic petrology: where have we come from and where are we going?

Zeiss PDRA Award

Penny Wieser, Oregon State University
Thermobar: an open-source Python3 tool for thermobarometry

Highlights Talks (selected by the Local Organizing Committee)

Hannah Buckland, University of Swansea
Modelling the transport and deposition of ash following a Magnitude 7 eruption: the Mazama tephra

Craig Magee, University of Leeds
Elements of sheet intrusions: building blocks of volcano plumbing systems

Isabel Fendley, University of Oxford
Global compilation of volcanic sulfur isotopes across tectonic settings

Marissa Lo, University of Manchester
Bubble chain phenomena in a shear-thinning magma analogue

Amy Donovan, University of Cambridge
Geographic imaginaries: understanding risk in context

Session 1: Eruptions and the Environment

Hannah Buckland, University of Swansea [**highlights talk**]
Modelling the transport and deposition of ash following a Magnitude 7 eruption: the Mazama tephra

Paul Cole, University of Plymouth
Explosive sequence of La Soufrière St Vincent April 2021: insights into drivers and consequences via eruptive products

***Morgan Hetherington**, University of Dundee
Inter-comparison of plume model mass eruption rate predictions based on the 2010 Eyjafjallajokull eruption

***Ariane Loisel**, Durham University
Determining the vertical scale in videos of lava fountains from gravitational acceleration of single clasts at their zenith

***Rebecca Winstanley**, Durham University
Contrasting eruption styles at the intermediate composition, Devil's Ink Pot fissure, Ascension Island

Hugh Tuffen, Lancaster University
Reconstructing rhyolitic conduit dynamics at Húsafell, Iceland: sintering, alteration, and permeability evolution within a plugged pyroclastic pathway

***Hannah Calleja**, University of Edinburgh
Quantifying the influence of conduit inclination and crystal fraction on basaltic eruption dynamics

Melanie Siegburg, University of Southampton
A historic multi-segment volcanic episode in the Main Ethiopian Rift

Pierre Delmelle, UC Louvain
Volcanic explosive eruptions sequestrate more carbon in soils than what they emit into the atmosphere

***Adam Beresford-Browne**, University of Birmingham
Evidence of a 60 million year old fen carr; the oldest in northwest Europe? A palynological investigation of the Ballycastle Quarry sedimentary interbed within the Antrim Lava Group, Northern Ireland

***Florian Brouillet**, University of St Andrews
New insights into the 1783 Laki eruption and plume evolution from high time resolution ice core isotope and cryptotephra analysis

***Jordan Johnston**, University of Birmingham
The effects of the rhyolitic eruption of 2008 at Chaitén and subsequent forest disturbance

***Isobel Rhodes,** University of Birmingham
Deep Onset Sill Emissions and Their Impact on The Thermogenic Methane Flux Through the North Atlantic Igneous Province Formation: A Case for Constraining the Nature of Fracturing in Deep Sills

***Laura Wainman**, University of Cambridge
The climatic impact of the 1257 Samalas Eruption

Will Hutchison, University of St Andrews
Timing and climate impact of Iceland's largest basaltic eruptions: new insights from ice core archives

***Katie Reeves**, Lancaster University
Volcanic particle-ice interaction: an experimental study

Michael Heap, University of Strasbourg
Hydrothermal alteration can result in pore pressurization and volcano instability

***Eric Newland**, University of Cambridge
Dynamics of deep-submarine volcanic eruptions

***Lily Moore**, Birkbeck College London
Ritter Island; recreating a volcano remotely

***Kerys Meredew,** University of Birmingham
Magma reservoir evolution following volcanic sector collapse

***Lucy Blennerhassett,** Trinity College Dublin
Mercury concentrations in an Irish woodland peat may be linked to the Laki AD 1783-84 fissure eruption

Alice Paine,* University of Oxford
Why lacustrine mercury reconstructions might not be good records of large volcanic eruptions

Matt Pankhurst, Instituto Volcanológico de Las Canarias
Responsive Petrology update from the Cumbre Vieja 2021 eruption, La Palma, Canary Islands, Spain: An ongoing tale of urban volcanology.

***Jorge Romero,** University of Manchester
Volume and stratigraphy of the Cumbre Vieja 2021 eruption tephra fallout, La Palma island

Mike Burton, University of Manchester
Insights into the 2021/2022 Cumbre Vieja eruption (La Palma, Spain) from ground- and satellite-based remote sensing of magmatic degassing

Jane Scarrow, University of Granada
Rapid response petrology for the opening eruptive phase of the 2021 Cumbre Vieja eruption, La Palma, Canary Islands

***Honor James,** Durham University
Volcanic Debris Avalanche and accompanying shear zone slip surface formed by a perched scoria cone collapse on Ascension Island, South Atlantic

***Annabelle Foster**, Durham University
Explosive textures found in rhyolitic lava, Hrafntinnuhryggur, Iceland

***Amelia Vale,** University of Bristol
Pyroclastic Density Currents Over Ice: An Experimental Investigation of Microphysical Heat Transfer Processes

***Sophie Vineberg**, University of Oxford
Refining tephra dispersal in Japan and understanding the impact of past volcanic eruptions

Dave McGarvie, Lancaster University
Glaciovolcanism and geochronology of Late Pleistocene eruptions at Quetrupillán, Chile

***Finley Gilchrist,** Natural History Museum
Geochemical trends at Atitlán volcanic centre, Guatemala

Hannah Buckland, Swansea University
Using R and version control in volcanological and tephra studies

Fabio Dioguardi, British Geological Survey
A facility to investigate (volcaniclastic) debris flows in Mexico

***Jingwei Zhang**, China Earthquake Adminstration Institute of Geology
Insights from a bizarre silicic “flow”, Mt. Changbaishan, China/DPRK

Thomas Johnston,* University of Hull
How does grain size distribution impact the mobility of aerated granular flows?

Nemi Walding,* University of Hull
The PDC flow units problem: Deposit heterogeneity from varying cohesive behavior and sediment flux

***Maximilian Van Wyk de Vries**, University of Minnesota
Frequent late Holocene volcanic activity in glaciated Southern Patagonia

***Alice Paine**, University of Oxford
The case for volcanism as a major driver of the Last Glacial millennial-scale climate change

***Zuzanna Dylewska**, University of East Anglia
Why don't earthquakes follow the Gutenberg-Richter law during the 2018 eruption and caldera collapse of Kilauea Volcano, Hawaii?

***Fei Liu,** University of Leeds
Intraslab Earthquake (Mw 6.8) heralds first detected unrest at Socompa Volcano, Northern Chile

***Henry Eves,** University of Aberdeen
Effect of dyke emplacement on host rock deformation within natural systems: microfracture analysis of Dalradian orthoquartzites and marbles

Matthew Head, University of Illinois **[withdrawn]**
How does a thermos-viscoelastic crust affect magma reservoir failure?

***Eleanor Dunn**, Dublin Institute for Advanced Studies
Introducing the SPIN-ITN and its sub-project: Ground motion and unrest triggering on volcanoes

Claire Harnett, University College Dublin
Lava dome collapse: destabilisation of existing domes by renewed dome growth

Jessica Johnson, University of East Anglia
What can evolving seismic anisotropy tell us about the 2018 Kilauea eruption?

***Ilaria Rucco**, Heriot-Watt University
Flowability measurements and rheological investigations of volcaniclastic debris flows

Session 2: Geochemistry and Petrology

Martin Mangler, Durham University
Variation of plagioclase shape with size in intermediate magmas: a window onto incipient plagioclase crystallisation

***Amanda Hughes,** Edge Hill University
The occurrence and petrogenesis of Icelandic high silica rhyolites

***Emma Rhodes,** Uppsala University
Rapid formation and eruption of a silicic magma chamber

***Ella Curtis**, University of Leeds
Chemical and isotopic tracers of the transition between oceanic and continental lithosphere

***Camille Lecoeuche**, Cardiff University
Heterogeneity of the Hawaiian mantle plume

***Matthew Morris**, University of Cambridge
Evaluation of pyroxenite as a source of post-subduction alkali basalts in the Antarctic Peninsula

***Carrie Soderman,** University of Cambridge
The Evolution of the Galapagos Mantle Plume: an Fe Isotope Perspective

***Chia-Yu Tien**, University of Cambridge
Constraining Neogene Mantle Dynamics of Western Mediterranean Region Encompassing Iberia by Quantitative Modeling of Basalt Geochemistry

***Alexander Stewart,** University of Manchester
The petrology, geochemistry, and geochronology of St. Barthelemy – implications for the geodynamics of the Lesser Antilles island arc

Dario Torres Sanchez, Universidad Autónoma de México
Petrogenesis and geochronology of volcanic rocks from the Sierra de San Miguelito Volcanic Complex, San Luis Potosí, Mexico

Elliot Carter, Trinity College Dublin
Re-evaluating the geochemistry and chemostratigraphy of the Antrim Lava Group (N Atlantic Igneous Province)

***Jenn Marsh,** University of Cambrige
The origin of tachylite clasts in the 1959 Kilauea Iki (Hawai'i) eruption products

***Norbert Toth**, University of Cambridge
Automated petrography using Machine Learning

***Alexander Jones**, University of Cambridge
A machine learning approach to magmatic barometry based on multiple saturation of phases

***Eshbal Geifman**, Durham University
Real-time observations of plagioclase crystallization from basalt

***Annika Voigt,** University of Oxford
Experimental investigation of trachydacite magma storage prior to the 1257 eruption of Mt Samalas

Euan Mutch, Columbia University
Magnesium Partitioning in Plagioclase with Notable Implications for Diffusion Chronometry

Julien Boulliung, University of Oxford
Experimental study on sulfate solubility in silicate melts at atmospheric pressure: implications for sulfur degassing processes

***Kevin Wong**, University of Leeds
Petrological evidence for focussed mid-crustal magma intrusion in the Main Ethiopian Rift

Matt Gleeson, Cardiff University
Non-Hawaiian style evolution of ocean island volcanoes

***Steven Walker,** Edge Hill University
Temporal magmatic evolution of the Mull lava succession, Palaeogene Igneous Province, western Scotland

***Hazel Knight,** University of Birmingham
Project PORO-CLIM initial results: A new oceanic crustal record of magma productivity throughout initiation of the North Atlantic Igneous Province

Emily Bamber, University of Manchester
Cool storage of crystal-rich magmas drives basaltic Plinian eruptions at Las Sierras-Masaya volcano, Nicaragua

***Katherine Schofield**, University of Southampton
Re-evaluating magma storage beneah Tenerife using cumulate mush

Chiara Maria Petrone, Natural History Museum
Critical assessment of pressure estimates in volcanic plumbing systems: the case study of Popocatépetl volcano, Mexico

***Jade Hrintchuk**, University of Liverpool
A new kimberlite database and analysis of southern African examples

Session 3: Magma Transport and Ascent

Craig Magee, University of Leeds [**highlights talk**]
Elements of sheet intrusions: building blocks of volcano plumbing systems

***Rami Alshembari,** University of Exeter
Numerical analysis of volcano surface deformation generated by a poroelastic magma reservoir

Matias Clunes, Universidad Catolica de Chile
Local stress field perturbations during magma emplacement in folded crustal segments: observations and numerical modelling from magma sheet-fold interactions in the Chilean Central Andes

Caitlin Chalk, University of Liverpool
Numerical models of dykes: a phase field approach

***Sonja Greiner,** Uppsala University
The role of pre-existing fractures in the propagation of basaltic dykes through hyaloclastite

***Ceri Allgood,** Durham University
Banding in dyke margins suggests pulsatory propagation

***Tegan Havard,** University of Liverpool
Magma interaction in dyke geometries

Janine Kavanagh, University of Liverpool
Fundamental flow regimes during dyke propagation

Matias Clunes, Universidad Catolica de Chile
Dike-induced ground deformation influenced by the orientation of geological strata: insights from numerical modelling

Michele Paulatto, Imperial College London [**withdrawn**]
Is the mush model a giant with clay feet? A volcano tomography meta-analysis

***El Mestel,** Victoria University of Wellington
Using seismology to probe the modern magma reservoir at Taupō volcano, New Zealand

Adam Jeffery, Keele University
A trachyte among basalts: assessing the 'shadow zone' hypothesis of Sao Miguel, Azores

***Fay Amstutz,** Trinity College Dublin
The impact of mush assimilation on magma evolution at the Campi Flegrei caldera, Italy

***Rachael Baxter**, University of Cambridge
Final depth of magma storage under Iceland regulated by magma flux

***Arthur Oliveira,** University of Sao Paolo
Magmatic interaction between mafic-ultramafic rocks and intruding syenites (São Sebastião Island, Brazil)

***Fatiha Askkour,** Ihn Zohr University
Zircon U–Pb ages and geochemistry of the Oued Tamoussift tonalite from the Bas Draa inlier (Western Anti-Atlas, Morocco)

***Jack Beckwith,** Royal Holloway University London
What processes drive voluminous granite generation? Insights from Scottish cumulates

***Charlie Gordon,** University of Cambridge
Crystal aggregation mechanisms in granites

***Orlando Quintela,** Uppsala University
Linking magma batch intrusion to the formation of geothermal systems and mineral deposits – Slaufrudalur pluton, Eastern Iceland

Tobias Keller, ETH Zurich
Numerical modelling of crustal magma chamber dynamics: fractionation, assimilation, recharge

***Laura Seelig,** Victoria University of Wellington
Plutonic insights into shallow magma systems beneath the central Taupō Volcanic Zone (New Zealand) and their relationship to the magma-hydrothermal interface

***Rebecca Galbraith,** University of Oxford
How did Vesuvius's magma chemistry change over time from 1631 to 1944, and why?

***Martin Kjenes,** University of Bergen
Lithological controls on sill development in sedimentary basins: field observations from the San Rafael Volcanic Field, Utah

***Jasmine Crocker,** Imperial College London
2021 Paroxysmal Events of Mount Etna: Pre-eruptive Magmatic Conditions and Timescales

***Lydia Whittaker,** Trinity College Dublin
Determining the depths and timescales of pre-eruptive processes at Campi Flegrei caldera, Italy

***Julia Mattioli Rolim,** Universidade Federal de Minas Gerais
New U-Pb age constraints from plutonic enclaves preserved in alkaline volcanic rocks of oceanic islands - Fernando de Noronha Archipelago, Southwest Atlantic Ocean, northeast Brazil

John Maclennan, University of Cambridge
Years of Deep Magmatic Unrest Prior to the 2021 Fagradalsfjall Eruption

***Hannah Elms,** Victoria University of Wellington
Timescales of Magmatic Processes at Ōkataina Volcano from Fe-Mg Diffusion in Orthopyroxene

***Sarah Shi**, University of Cambridge
Magma stalling weakens eruption

***David Colby,** University of Oxford
Stratigraphy and Eruptive History of Corbetti Caldera in the Main Ethiopian Rift

***Vitor Azevedo,** Trinity College Dublin
The Pre-Campanian Ignimbrite period: geochemistry of tephra layers preserved between 40-100 ka at Lago Grande di Monticchio, Italy

Ian Platten, Independent
Field evidence for the passage of a dyke tip cavity

***Dawid Rybak**, University of Liverpool
Reconciliing physical and chemical fluid-fracture interface dynamics

***Kate Williams,** University of Liverpool
From microstructures to regional scale flow indicators - evidence of magma flow in a mafic sill

***Kajetan Chrapkiewicz,** Imperial College London
Discovery of a small magma chamber beneath Kolumbo volcano, Greece, by full-waveform inversion

Simon Gill, University of Leicester
Dike scaling revisited

***Taylor Witcher,** Uppsala University
Immobile elements trapped as precipitants in magmatic fractures

***Janina Gillies,** Durham University
New approaches for creating reproducible analogue material for bubbly magma

Melissa Drignon, Durham University
Rheology of multi-phase lava: case study of the 2018 Kilauea eruption

***Dan Jones,** Durham University
Simulations of foamy magma

Steve Pansino, Durham University
Analogue analogues of fissure eruption localization

Margherita Polacci, University of Manchester
Magma ascent and eruption dynamics at basaltic volcanoes by integrating 4D experimental petrology, numerical modelling and field observations: examples from Mt Etna, Italy

***Igor Collins Djouda,** University of Yaounde 1
Magma ascent dynamics and volcanic eruption styles modelling: a new approach combining fluids mechanics laws and thermodynamics principles

***Holly Unwin,** Lancaster University
Tracking volcanic conduit wall stability during evolution of the Mule Creek Vent, USA

***Marissa Lo,** University of Manchester [**highlights talk**]
Bubble chain phenomena in a shear-thinning magma analogue

Session 4: Planetary Volcanism

Sam Bell, University of Manchester
Fe-Mg diffusion modelling of olivine in Apollo 15 mare basalts

***Ri Cao,** University of Edinburgh
Formation of steep-sided volcanic domes on Venus

***Fakhri Bintang,** University of Glasgow
Numerical modelling of melting and magmatic differentiation in planetesimals

***Divyareshmi Ravy,** University of Manchester
Mineral records of magma storage and crystallization in the basaltic systems on the Moon

***Reina Hiramatsu,** University of Glasgow
Origin of the pallasites from the Sericho Meteorite

***Pip Liggins,** University of Cambridge
The fingerprints of volcanism: secondary atmospheres on rocky planets

Session 5: Volatiles and Gases

Isabel Fendley, University of Oxford [**highlights talk**]
Global compilation of volcanic sulfur isotopes across tectonic settings

***Juliette Delbrel,** University of Manchester
SO2 flux discrepancies between satellite- and ground-based measurements of low-lying plumes: Kilauea 2020-21 case study

Jean-Francois Smekens, University of Oxford
A unified approach to measuring plume composition with emission OP-FTIR

Isabelle Taylor, University of Oxford
Over a decade of SO2 measurements made with the IASI satellite instrument

Ben Esse, Univeristy of Manchester
SO2 emissions during the 2021 eruption of La Soufrière St. Vincent

Fabio Dioguardi, British Geological Survey
VIGIL: a tool for (probabilistic) gas dispersion modelling

***Lucy Jackson,** Durham University
Bubble rise in silicate melts and magmas: An experimentally validated model for non-isothermal conditions

***Jacob Nash**, University of Bristol
Experiments on Gas-Escape Pipe Formation in Pyroclastic Flow Deposits

***TiVonne Howe,** Lancaster University
CO2 systematics in the Lesser Antilles arc and the 2020-21 eruption of La Soufriere St Vincent

Catherine Hayer, University of Manchester
How low can we go? Long-term averaging of a low concentration volcanic plume

Sam Mitchell, University of Bristol
Vapor-phase cristobalite: Insights into cooling rates and outgassing in a submarine lava dome

Inan Ulusoy, Hacettepe University
Multisource remote thermal monitoring of Hasandağ volcano (Central Anatolia, Turkey)

Oliver Lamb, University of North Carolina at Chapel Hill
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Emma Waters, University of Manchester
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***Uğur Balci**, University of Glasgow
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Simon Matthews, University of Iceland
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***Eilish Brennan,** University of Leeds
Boron isotopes as a tracer for the volatile sources under Kozelsky and Khangar volcanoes, Kamchatka

***Olivia Hogg**, University of Cambridge
Water-rich versus water-poor: maximising the outgassing metal flux from arc volcanoes

***Sarah Lawford**, University of Cambridge
Outgassing of CO2 reflected in trace element chemistry of mineral phases at Oldoinya Lengai, N.Tanzania

Madeleine Humphreys, Durham University
Steaming, not stewing? Lithium enrichment in response to diffusive dehydration in volcanic dome rocks

***Clara Matthews Torres**, Birkbeck College London
Variability of Slab Fluxes of Mobile Chalcophile Elements from Slab to Wedge: A Case Study of Popocatépetl Volcano, Mexico.

Weiran (Alex) Li, University of Cambridge
Eruption explosivity revealed by volatile chemistry in apatite

***Nick Barber**, University of Cambridge
Global slab dehydration recorded in arc magmas

***Eleanor Dunn,** Dublin Institute of Advanced Studies
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***Stanley Yip,** University of Bristol
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Anna Brookfield, University of Oxford
Magmatic volatile content and the overpressure 'sweet spot': implications for volcanic eruption style.

Session 6: Volcanoes and Society

Amy Donovan, University of Cambridge [**highlights talk**]
Geographic imaginaries: understanding risk in context

Rachael Carver, The Coal Authority
How should risk be communicated in volcano tourism?

Jazmin Scarlett, Independent
First-hand experience and lessons learned from social media communication during a volcanic crisis

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***Noa Ligot,** Université Catholique de Louvain
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***Tom Lark,** Durham University
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Examining the relationship between seismic swarms and ground deformation during volcanic unrest

***Velveth Perez,** University of Glasgow
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***Sara Osman,** University of Leeds
Tephra sliding on roofs - insights from laboratory tests

Gerallt Hughes, Natural History Museum
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***Alastair Hodgetts,** University of Birmingham
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Lara Mani, University of Cambridge
Global catastrophic risk from lower magnitude volcanic eruptions

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Banding in dyke margins suggests pulsatory propagation

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Dykes are the primary magma transport pathway feeding basaltic eruptions, the most common form of volcanism on Earth. Understanding the timescales and processes involved in transporting magma to the surface is key for judging the location, behaviour and duration of basaltic fissure eruptions, which can produce long-lasting lava flows threatening property and infrastructure. However, as magmatic flow within dykes cannot be observed directly, flow processes must be inferred from the textures of phenocrysts and vesicles in exposed, solidified dykes. Many dykes show banding at their margins, defined by variations in the concentration of phenocrysts and/or vesicles. These bands are typically millimetres to a few centimetres in width, becoming wider and less distinct towards the dyke centre. Marginal bands have been observed in various volcanic settings, including Tenerife, the Columbia River Basalts, and Paleogene dykes in Scotland.

Dyke margins are the earliest material to solidify, originating in the tip of the dyke as it propagated. Marginal bands are therefore likely to result from processes operating within the dyke tip, and can provide insight into propagation dynamics. We analysed thin-sections from the Teno Massif, Tenerife, an eroded 5.0-6.3 Ma shield volcano, and found that the bands comprise cyclic variations in phenocryst and vesicle concentration. Cyclic variations in phenocryst concentration suggest episodes of flow differentiation within discrete magma pulses. These are each associated with peaks in vesicularity, likely caused by pressure drops driving bubble growth. We propose that magma pulses and associated pressure fluctuations were produced by rapid solidification, stalling and re-fracturing in the dyke tip, on the timescale of seconds to minutes, leading to pulsatory propagation. Marginal bands therefore provide insight into dyke propagation mechanisms, with the potential to inform models of magma transport and support interpretations of seismicity.

Numerical analysis of volcano surface deformation generated by a poroelastic magma reservoir

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Understanding the mechanical behaviour of melt reservoirs is vital for advancing geophysical models that aim to constrain the evolution of subvolcanic systems and inform hazard monitoring and mitigation. From geophysical and petrological studies, large melt-dominated (magma) reservoirs are difficult to sustain over long periods of time. Melt is more likely to reside within reservoirs which consist of variably packed frameworks of crystals, so-called crystal mush, as well as in pockets of magma, in changing proportions over time. The behaviour of crystal mush, in particular, is emerging as a vital consideration in understanding how magmatic systems evolve. In addition, current models for volcano deformation often consider static magma sources and thus provide little insight into the internal dynamics of melt reservoirs; and these models ignore the presence of crystals and therefore the likely poroelastic mechanical response to melt intrusion or withdrawal. Our study considers the melt reservoir to be partly crystalline (> 50% crystal fraction), with melt residing between crystals. We examine the influence of poroelastic mechanical behaviour on the evolution of reservoir pressure and the resultant surface deformation. From our results, the modelling of a crystal mush rather than a 100% melt magma reservoir can significantly modify the resulting spatial and temporal mechanical evolution of the system. Specifically, the poroelastic behaviour of a mush reservoir will continue to develop following the end of a melt injection period, generating further time-dependent surface displacements. Post-injection and post-eruption inflation can occur, which are linked to a poroelastic response associated with continuous melt diffusion. Following an injection/eruption, a steady-state point is eventually achieved when the fluid pressure reaches a uniform value throughout the reservoir. This process is controlled by the poroelastic diffusivity. Increasing the reservoir crystal fraction from 50 % to 90 % reduces the mobility of melts, decreases permeability, and leads to a slow rate of melt diffusion. Our study confirms that volcanic surface deformation can occur without continued intrusion or withdrawal of melt.

The impact of mush assimilation on magma evolution at the Campi Flegrei caldera, Italy

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The recent conceptual shift from understanding of sub-volcanic magma systems as liquid-dominated magma chambers to transcrustal mush zones[1] raises important questions about the interaction between ascending magmas and magma residues in the crust. While mushes and ascending magmas may originate from a common source and be compositionally related, mush zones can exist within the crust for millennia, attaining a high degree of compositional heterogeneity. Furthermore, mushes are poorly consolidated and could be more easily assimilated into ascending magmas than ridged country rock. While assimilated, mush-derived crystals and melts are difficult to identify in erupted products, they could exert an important control on the compositional and rheological evolution of ascending magmas and thus the timing and style of eruptions.
Campi Flegrei (central Italy) provides an ideal location to assess how mush dynamics impact volcanism at the Earth's surface because it has produced ~60 eruptions in the past 15 kyr that span a wide range of styles and compositions[2], but the magmatic system has been active for >60 kyr[3] and hosts a transcrustal mush zone[4]. There have been three caldera forming eruptions at Campi Flegrei in the last 40 ka (CI, ~40 kyr; MdMT, ~29 kyr[5]; NYT, ~15 kyr), which define distinct cycles within the magmatic system. As major eruptions are associated with periods of mush zone reorganisation[6], following caldera eruptions there are systematic changes in composition[7] and magma-mush interactions.

This project will determine the amount of pre-eruptive mush assimilation in sequential Campi Flegrei eruptions, correlating this with eruption frequency, style and composition. Our initial investigation of published whole rock and glass data show[2,8] that successive eruptions follow a single liquid line of descent, but some whole-rock analyses plot with anomalous major element compositions, consistent with crystal accumulation, particularly potassium feldspar. Additionally, glass data record the eruption of compositionally distinct liquids that cannot be related by fractional crystallisation and may indicate mixing between ascending magmas and melts in the pore space of a mush. These data are being investigated using Rhyolite-MELTS models to identify temporal trends in the assimilation of mush components.

Zircon U–Pb ages and geochemistry of the Oued Tamoussift tonalite from the Bas Draa inlier (Western Anti-Atlas, Morocco)

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The Paleoproterozoic basement of the Bas Draa inlier consists of: (i) low grade supracrustal metamorphic rocks, mainly greenschist facies and, (ii) widespread batholiths including diorite, leucogranite, granodiorite, tonalite, and granite. The late Neoproterozoic granite of Taourgha that intrudes the Paleoproterozoic series is related to the post-collisional event of the Ouarzazate Group. Geochronological analyses (LA-ICPMS, U-Pb on zircon) yielded Paleoproterozoic age for the crystallization of the Oued Tamousift tonalite, (around 2,1 Ga). The mineral assemblage of the tonalites includes plagioclase, biotite, quartz, muscovite, microcline and garnet. They have SiO2 content range from 59 to 66 wt. %, Al2O3 content range from 17.22 to 14.4 wt% and their Na2O + K2O is higher than 6 wt. %. They display medium-K calc-alkaline affinities and a peraluminous character (A/CNK>1). Trace elements argue for an arc environment for the genesis of the magma. However, compared to the Ocean Ridge Granites (ORG), the tonalities show Low field strength (LFS) element depletion, negative Ba and Nb anomalies and high Ce and Sm contents. These characteristics are discussed with respect to the Paleoproterpozoic magmatic setting of the North-Western edge of the West African Craton.

The Pre-Campanian Ignimbrite period: Geochemistry of tephra layers preserved between 40-100 ka at Lago Grande di Monticchio, Italy.

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The 39.8 ka[1] Campanian Ignimbrite (CI), at Campi Flegrei (CF), was the most explosive eruption in Europe over the last 200 ka. As such, it is one of the most studied caldera-forming eruptions. Proximal volcanic deposits extend back to 60ka, however, medial and distal tephra archives provide the only information on earlier volcanic activity at Campi Flegrei. Here we present new major and trace element data from previously uncharacterised tephra layers[2] preserved in the varved sequence from Lago Grande di Monticchio, Italy, for the period 40-100 ka. This new tephra data preserve a high-resolution record of the frequency and chemical evolution of the Campi Flegrei magmatic system. We hope that with these data we can better understand the eruptive frequency and composition changes across the caldera cycle as well as the transition from predominantly mafic to more evolved magma at ca. 80ka. Additionally, we will test if there is geochemical evidence for more caldera-forming eruptions prior to the cataclysmic Campanian event.

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Low He content of the high $^3He/^4He$ Afar mantle plume: Origin and implications

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Basalts from high flux intra-plate volcanism (Iceland, Hawaii, Samoa) are characterised by $^3He/^4He$ that are significantly higher than those from the upper mantle sampled at mid-ocean ridges. The prevailing paradigm requires that a largely undegassed deep Earth is enriched in primordial noble gases (^3He, ^{20}Ne) relative to degassed convecting upper mantle. However, the He concentration of high $^3He/^4He$ oceanic basalts are generally lower than mid-ocean ridge basalts (MORB). This so called 'He paradox' has gained infamy and is used to argue against the conventional model of Earth structure and the existence of mantle plumes. While the paradox can be resolved by disequilibrium degassing of magmas it highlights the difficulty in reconstructing the primordial volatile inventory of the deep Earth from partially degassed oceanic basalts.

Basalts from 26 to 11°N on the Red Sea spreading axis reveal a systematic southward increase in $^3He/^4He$ that tops out at 16 Ra in the Gulf of Tadjoura (GoT), Djibouti, bear the Afar triple junction. The GoT $^3He/^4He$ overlaps the highest values measured in sub-aerial basalts from Afar and Main Ethiopian Rift and is arguably located over modern Afar plume. The along-rift $^3He/^4He$ variation is mirrored by a systematic change in incompatible trace element ratios that appear to define two-component mixing between E-MORB and HIMU. Despite some complexity, hyperbolic mixing relationships are apparent in $^3He/^4He$-K/Th-Rb/La space. Using established trace element concentrations in these mantle components we can calculate the concentration of He in the Afar plume mantle. Surprisingly it appears that the upwelling plume mantle has 3-8 times less He than the convecting asthenospheric mantle despite the high $^3He/^4He$ (and primordial Ne isotope composition). This contradicts the prevailing orthodoxy but can simply be explained if the Afar mantle plume is itself a mixture of primordial He-rich deep mantle with a proportionally dominant mass of He-poor low $^3He/^4He$ HIMU mantle. This is consistent with the narrow range of radiogenic isotope and trace element ratios of the Afar plume basalts, and is in marked contrast to high $^3He/^4He$ plumes that do not have unique geochemical composition. It, however, implies that large domains of essentially He-free mantle exist within the deep Earth. We will demonstrate how these form and explore the implications.

Cool storage of crystal-rich magmas drives basaltic Plinian eruptions at Las Sierras-Masaya volcano, Nicaragua

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Plinian eruptions are rare at basaltic volcanoes but are highly explosive and hazardous events when they occur. The Fontana Lapilli (60 ka) and Masaya Triple Layer (2.1 ka) eruptions of Las Sierras-Masaya volcano, Nicaragua, both produced several km^3 of tephra. Given the proximity of the current Masaya system to the capital of Nicaragua, Managua, understanding the conditions which promote Plinian activity at this volcano is crucial for hazard assessments.

We use an approach which combines numerical modelling with analytical results from natural samples to identify the conditions which may have promoted Plinian activity at Las Sierras-Masaya volcano. We provide new constraints on major, trace and volatile element chemistry for the Fontana Lapilli and Masaya Triple Layer eruptions. We explore these conditions using a 1D numerical conduit model and sensitivity analysis and find that the conditions which promote Plinian activity at Las Sierras-Masaya volcano are pre-eruptive temperatures <1100 °C and a total crystal content >30 vol.%.

Samples of the Fontana Lapilli eruption show evidence of a crystal mush, which crystallised at temperatures <1100 °C. Cooling, crystal-rich, large-volume basaltic magma bodies within the shallow crust may therefore have the potential to erupt with Plinian magnitude.

Global Slab Dehydration Recorded in Arc Magmas

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The transfer of material from subducting slabs to the overlying mantle is one of the most important chemical and tectonic processes regulating many of Earth's geochemical cycles. One of the major processes involved in this material cycling is the de-volatilization of the slab, and the release of sediment- and slab-derived fluids to the mantle wedge, where they can trigger subduction zone melting. Previous geodynamic, geophysical, and geochemical studies have revealed some of the important controls on slab fluxing to the mantle, and its manifestations in arc magmas. However, these studies have often been limited either (1) spatially – choosing to focus on a singular arc segment, or to the global arc front or (2) compositionally – prioritizing primitive arc basalt compositions with the assumption that these should best reflect the source parameters of melting regions. While such data reduction strategies have great benefits – namely, a much greater control over model variability and sources of error – reductive models inherently lose a large amount of data, particularly where volcanoes manifest beyond the arc front. Here we present several key findings arising from a comprehensive global compilation called *ArcMetals*. We focus on global arc magma trace element systematics (e.g., Ba/Nb, Th/Nb, Pb/Ce) that allow identification of the progressive dehydration of slabs and sediment processing occurring at several distinct depths-to-slab (DTS) globally. We observe, for example, three clear peaks in Ba/Nb in arc magma whole rocks corresponding to DTSs of 50-150 km and 260-280 km, which we infer to represent progressive dehydration of hydrous minerals (e.g., antigorite, lawsonite, chlorite). We relate these trace element trends to slab thermal and physical conditions by constructing a model of slab devolatilization that is based on observed geochemical and tectonic characteristics of the global subduction system.

Final depth of magma storage under Iceland regulated by magma flux

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An essential component of continuing to advance volcano-monitoring efforts, is to further improve understanding of volcanic system processes, architecture, and timescales for magma storage, extraction, and ascent. One important variable is constraining magma storage depths prior to imminent eruption. While some individual volcanoes have been scrutinised in detail, there is no well-consolidated understanding of magma storage-depth distribution across volcanic systems. There is some speculation of a relationship between plumbing architecture and magma-flux, but no focused effort to investigate the extent of this relationship. We investigate final magma storage depths across Iceland, for which suspected controls on magma-flux (spreading rates, mantle potential temperature) and resulting magma productivity are well constrained.

We created PyOPAM, an open-source software that runs in Python, to estimate final storage depths of basaltic melt. This streamlined, reinvigorated Olivine-Plagioclase-Augite-Melt barometer estimates the position of the eutectic of the melt, the depth where basaltic melt was three-phase-saturated. Using 366 experimental glass compositions compiled from literature, we calibrate this barometer and constrain 1 σ to 1.26 kbar. We apply PyOPAM to a dataset of ~13,400 compositional analyses compiled from Iceland. Of these, 3809 analyses generate robust pressure estimates, elucidating final storage depths for 23 of the 30 volcanic systems across Iceland.

Modal magma storage pressures increase with decreasing crustal thickness and spreading rates. Inversely, modal storage pressures decrease with increasing crust thickness and spreading rates, indicators of increasing magma flux. The thermal structure of the crust adds a secondary control on the depth of storage for basaltic magmas. High magma flux in cold crust results in deep storage of basaltic magma, while high magma-flux in warm crust results in shallow magma storage. This demonstrates that magma flux is the primary control of the final storage depths for basaltic magma, with some modulation by crust thermal structure.

What processes drive voluminous granite generation? Insights from Scottish cumulates

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Cumulates from the Appinite Suite of western Scotland preserve information about crustal processes responsible for voluminous granite generation. The spatial, temporal, and geochemical similarities between these Scottish cumulates and adjacent Ballachulish granites imply a genetic association between the rocks. Geochemical similarities between Ballachulish granites and Archean TTG rocks suggest that these cumulates could provide an insight into the evolution of crustal magmas, potentially analogous to Archean continent formation.

Appinite suites have been recognised globally and recent work suggested their genesis from voluminous melts generated through deep melting of a metasomatised mantle[1]. However, little work has focussed on the processes responsible for the differentiation between the massive felsic intrusives and coeval mafic enclaves.

Here, for the first time, combined qualitative and quantitative textural and *in* situ mineral geochemical analyses are applied to two Appinite suite cumulates to elucidate their crustal evolution. The results reveal a dichotomy between their similar whole-rock geochemistry and unique textures and mineral geochemistry, indicating a genetic association but unique evolutionary history. If the crustal processes that generated the Scottish appinites were also responsible for the formation of Archean TTGs, then plate tectonics may have evolved much earlier in Earth's history than some models suggest.

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Fe-Mg diffusion modelling of olivine in Apollo 15 mare basalts

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Based on whole-rock major element chemistry, mare basalts collected at the Apollo 15 landing site can be classified into two groups: the quartz-normative basalt suite and the olivine-normative basalt suite[1,2]. Two main theories have been proposed for the origin of the chemical difference between these suites: (1) they are from different sources or degrees and depth of partial melting in the lunar mantle[2,3], or (2) they are from the same mantle source but experienced considerably different magmatic evolution and eruption histories[4]. In this study we use modelling of Fe-Mg diffusion in zoned olivine crystals to gain insight into the eruptive processes experienced by the two suites of mare basalts, helping to understand their petrogenetic relationship. Diffusion of Fe-Mg was modelled in 29 olivine crystals in total, from six olivine-normative basalt thin sections (15016, 15105, 15536, 15545, 15555 and 15556) and from 3 quartz-normative basalt thin sections (15125, 15485 and 15595). We used a dynamic diffusion model that includes terms for both crystal growth and intracrystalline diffusion during magma cooling[5]. Calculated diffusion timescales range from 5 to 24 days for quartz-normative samples, and 6 to 91 days for olivine-normative samples. A maximum diffusion timescale uncertainty of 0.41 log units (1σ) was determined for the samples in this study. Similarities in diffusion timescales point to both suites experiencing comparable eruptive processes. The diffusion timescales are short, and the zonation profiles are dominated by growth, which indicates that the diffusion is most likely taking place during cooling and solidification within lava flows at the lunar surface. As such, our study does not support the differences in bulk chemistry between the two suites being due to different magmatic histories[4]. We also used a simple conductive cooling model to link our calculated diffusion timescales with possible lava flow thicknesses, and from this we estimate that Apollo 15 lava flows are a minimum of 1.5 to 6 m thick, consistent with flow thickness estimates from photographs taken near the Apollo 15 landing site. Our study demonstrates that diffusion modelling is a valuable method of obtaining information about lunar magmatic environments recorded by individual crystals within mare basalt samples.

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Evidence of a 60 million year old fen carr; the oldest in northwest Europe? A palynological investigation of the Ballycastle Quarry sedimentary interbed within the Antrim Lava Group, Northern Ireland

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The Antrim Lava Group (ALG) is a sequence of basalts in Northern Ireland that achieve a thickness of 900 m in places. These lavas were erupted over a period of c.3 million years from 61.5 Ma to c.58.5 Ma, within the larger North Atlantic Igneous Province (NAIP) of which remnants can be found in Canada, Greenland, Faeroes, Ireland and Scotland. Our research has taken a holistic approach to understanding the timing and emplacement of the Antrim Lava Group, incorporating the use of geochemistry, palaeomagnetism, palynology and volcanostratigraphy.

In October 2020, fieldwork investigations identified a rare sedimentary interbed within flows of the Causeway Tholeiite Member at Ballycastle Quarry, Antrim, reaching a thickness of 2.5 m at outcrop. The interbed can be subdivided into geologically distinct units of cross-bedded sands, bedded sands and sandy silts, all rich in visible organic remains such as rootlets and fragments of bark. A total of 18 samples were extracted from the sequence and subsequently analysed for palynological content. The palynomorph data point toward an estuarine/fluvial depositional environment, with inputs from chalky soils, and fen carr, fen and ombotrophic bog ecological communities.

Contradictory to current understanding, the palynological data revealed the presence of flora that favour a temperate climate rather than the subtropical climate that is generally believed necessary to have supported the formation of laterites and lateritic soils within the Antrim Lava Group.

Deepening our knowledge of the climate at this time will further our understanding of how the basalts were weathered, and in turn aid with the research into climatic changes in the Palaeocene and Eocene. It will also give insights into how much time was taken to form the various interbeds and palaeosol horizons upon and within the basalt flows, and thereby allow us to estimate rates of basalt emplacement, and the pace of volcanic activity by identifying periods of inter-volcanic quiescence.

Numerical modelling of melting and magmatic differentiation in planetesimals

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Shortly after the formation of the solar system, nebular material accreted into planetesimals (up to 100s km diameter), the earliest terrestrial bodies in our solar system. The collision of these planetesimals formed the planets of the inner solar system. It is thought that the internal structure and composition of the colliding planetesimals affect the development of our planets. Therefore, the internal evolution of planetesimals is an important period in our solar system's development. Internal heating due to the decay of short-lived radionuclides, most significantly ^{26}Al, can cause the interior of planetesimals to melt. The mobility of magma then allows planetesimals to mechanically differentiate into layered structures such as a core, mantle, and crust. The mechanism for magma transport varies depending on the melt fraction, from melt percolation at low melt fraction, to mush flow and then eventually crystal suspension flow as melt fraction increases.

Our understanding of planetesimal interiors derives predominantly from analyses of meteorites. However, since meteorites are only tiny fragments of a parent body, it is impossible to fully constrain global-scale processes. Therefore, physics-based models are essential to infer global-scale processes from small-scale meteorite analysis. Here we present the development of a 2-D, multi-phase fluid dynamics, multi-component thermochemistry reactive transport model to simulate the melting and differentiation of planetesimals. Previous 1D-modelling[1] has shown that the formation time and radius of a planetesimal are important factors on its degree of melting; early accreted and larger planetesimals have more ^{26}Al to heat the interior, with the possibility of rapidly creating a global magma ocean interior. Grain size is an important factor in the fluid dynamics of the system; larger initial grain sizes increase the permeability, allowing for rapid early melt segregation, which aids in the rapid cooling and differentiation of the interior. Extending the model to 2-D will allow us to investigate crucial dynamic aspects including flow channelling, convection and gravitational stability of compositional layers. We aim to use our model to quantify the timescales and mechanisms of rapid core formation in early planetesimals.

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Mercury concentrations in an Irish woodland peat may be linked to the Laki AD 1783-84 fissure eruption

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The Laki fissure eruption of AD 1783-1784 in Iceland is an historically significant episode of volcanism, due to its notable environmental and societal impacts on a local, regional and even global scale. This episode of volcanism released a significant amount of SO_2 to the atmosphere, as well as high levels of chlorine and fluorine. Well documented, tephra linked sulphate residuals and acidity peaks in arctic ice cores coincide with changes in northern hemisphere climate from AD 1783-1785. Enrichments in heavy metals such as lead, cadmium, copper, and zinc have also been resolved from Greenland ice cores and are linked to the heavy degassing of volatiles during the Laki fissure eruption.

Mercury is a volatile heavy metal highly associated with volcanic activity, where enrichments of this element in paleoenvironmental records can often be correlated with significant volcanic eruptions. Ombrotrophic peat has previously been used as a reliable record of atmospheric mercury deposition. However, records of mercury aerosol deposition in peat are virtually non-existent for the Laki AD 1783-1784 eruption.

We present here, the first, preliminary evidence of mercury enrichment linked to the Laki eruption recorded in an Irish woodland peat. The study site at Brackloon, Wood, Co. Mayo, Ireland, is known to host the Laki AD 1783-1784 tephra at a depth of 12-16 cm from the peat surface. Enrichments detected here correlate with tephra position, where increases in mercury relative to organic matter and background levels may suggest volcanic aerosol deposition onto the peat surface during this infamous fissure eruption. Therefore, potentially expanding the known heavy metal aerosol distribution away from the poles. Future work aims to resolve additional sulphur and heavy metal signatures via novel methodology and a robust age-depth relationship through tephrochronology and radiocarbon dating.

Experimental study on sulfate solubility in silicate melts at atmospheric pressure: implications for sulfur degassing processes

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Knowledge of the solubility of sulfur (S) in silicate melts is fundamental to an understanding of a number of different igneous processes (e.g., volcanic degassing, the formation of magmatic ore deposits and planetary differentiation). Several oxidation states of sulfur are present in natural environments and these exert control over the distribution of sulfur between Earth's different geochemical reservoirs (mantle, core, crust, atmosphere, oceans). Although the solubility of sulfide (S^{2-}) in silicate melts is well constrained under the reducing conditions (below the fayalite-magnetite-quartz FMQ oxygen buffer) where it is stable, only a few data are available for sulfate (S^{6+} or SO_4^{2-}) solubility under the more oxidizing conditions relevant to many volcanic systems.

In this study, we investigated the influence of temperature and melt composition on sulfate solubility in silicate melts using equilibration experiments at atmospheric pressure under fixed oxidizing fO_2 (i.e., log fO_2 = -1.1) and relatively high sulfur fugacity. The temperature was varied from 1200 to 1500°C and 14 different silicate melt compositions were studied (e.g., andesite, basalt, phonolite). The S contents of the quenched run products (i.e., silicate glasses) were determined by electron microprobe with *in-situ* SIMS being used for the lowest S concentrations (i.e., > 70 ppm).

The data obtained here highlight a fundamental control of both the temperature and melt composition on the sulfate solubility. At constant fO_2, as the temperature increases, the sulfate solubility decreases significantly. For example, with a fixed Air/SO_2 ratio of 0.6, the sulfate solubility decreased by a factor ~4 as temperature was increased from 1300 to 1400°C (e.g., for a basalt composition, the S content decreased from 448±20 ppm to 118±17 ppm). Concerning the melt composition effect, a strong positive correlation is observed between S solubility and CaO content (e.g., from 229±16 ppm to 1935±25 ppm at 1300°C for a basalt with 9.7% CaO and a CMAS like composition with 21.2% of CaO respectively). The new sulfate solubility results are used to provide new equations to determine the sulfate capacity of silicate melts at atmospheric pressure for the temperature range 1200-1500°C. This new equation can be used to simulate different scenarios for sulfur degassing processes in oxidized magmatic systems. The simulations shows for SO_2-degassing from ascending silicate melts of basaltic and andesitic compositions that SO_2 partitions strongly into an H_2O-rich fluid phase and that most sulfur is lost at relatively high pressures in the crust.

Boron isotopes as a tracer for the volatile sources under Kozelsky and Khangar volcanoes, Kamchatka

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Boron is a highly fluid mobile trace element and can be employed as a tracer of slab-derived fluids in the mantle wedge, where it is nearly absent. The heavy isotope of boron (^{11}B) preferentially partitions into the fluid phase during dehydration of slab assemblages (sediments and altered MORBs). This is making it useful for pinpointing slab versus crust-sourced origin of the volatiles that contribute to arc magma generation. Boron isotopes in melt inclusions (MI) allow for an insight into the conditions of the little evolved (deep) arc melts prior to their transit through the arc crust.

My research will focus on using boron and B isotopes as a geochemical tracer of the volatile sources of the Kamchatka arc volcanoes, improving our understanding of the processes driving subduction zone volcanism. Recent geophysical and geochemical results [3,4,5]how that the Kamchatka volcanoes sample fluids derived from slab depths from as little as 50k m to as deep as 350 km. Hence, the wide volcanic front of Kamchatka presents an ideal environment in which we can utilise boron isotopes to elucidate the across arc magmatic processes. In particular I shall focus on studies of one shallow (Kozelsky) and one very deep (Khangar) volcanoes that have never been studied. I have a selection of basaltic to dacitic samples from these volcanoes and plan to do fieldwork in Kamchatka in the summer of 2022. I plan to examine the mineralogy, petrology and geochemistry (incl. B-Sr-Nd isotopes) of the entire sample suite and to select olivines from the most primitive rocks for MI study of B and volatiles (H_2O, CO_2, halogens).

Magmatic volatile content and the overpressure 'sweet spot': Implications for volcanic eruption style

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Volatile-exsolution within a magma reservoir is a well-established mechanism for increasing magmatic overpressure and triggering volcanic eruptions. However, the heterogeneity of volcanic systems in terms of composition, volatile content and storage conditions, means that each one has a different overpressure-generating capacity. We use Rhyolite-MELTS thermodynamic modelling to track the evolution of exsolution-driven overpressure during cooling[1] for Kelud (Indonesia), Nisyros-Yali (Greece), and Calbuco (Chile), focusing on the effect of initial magmatic water content and XH_2O (molar H_2O/ (CO_2+H_2O).

We find that the highest overpressures are generated by magmas which are initially at their H_2O solubility limit, and that higher or lower initial H_2O contents result in a decrease in peak overpressures. This overpressure sweet spot results from the balance between high volumetric expansion and low system compressibility – both of which favour higher overpressures. Whilst fluid-oversaturated magmas have the highest volumetric expansion, they also have high compressibilities. Conversely, fluid-undersaturated magmas have the lowest compressibilities, but also very low volumetric expansion. We also find that peak overpressure decreases as XH_2O decreases.

Our modelling for the magma reservoir at Kelud shows differences in peak overpressure of 10s of MPa when comparing the $XH_2O = 1$ and $XH_2O = 0.5$ simulations. This finding may provide an explanation for recent, varying eruption style at Kelud – where high XH_2O values are associated with the 2014 explosive eruption, and low values are linked to the 2007 effusive eruption[2]. The higher overpressures generated at the volatile sweet spot have the potential to drive faster magma ascent rates, leading to more explosive eruptions. The link between overpressure, water content and explosivity is also explored using data compiled from Nisyros and other systems[3]. This shows that explosive eruptions often occur close to water solubility - where we model the highest overpressures - highlighting the potential link between overpressure and explosivity.

New insights into the 1783 Laki eruption and plume evolution from high time resolution ice core isotope and cryptotephra analysis

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The ice core record preserves the finest time-resolved records of past volcanic events on Earth. Volcanologists have various tools for interrogating these records and two of the most powerful techniques are sulfur isotopes and analysis of cryptotephra. These analyses can provide detailed information about the source location, injection height and plume evolution. However, the vast majority of volcanic ice core horizons have only been sub-sampled and analysed at low time resolution, and this means isotopic signals are often averaged over many months, and that tephra records are rarely related to primary eruption and/or plume processes.

The 1783 Laki eruption is one of the largest eruptions of the last common era and is estimated to have injected 100-200 MT of sulfate into the atmosphere as well as 15 km^3 of tephra. During this eruption Europe experienced an exceptionally hot summer and this was followed by a cold winter and a "dry fog" that persisted for several months over Western Europe and even as far as North Africa. However, large uncertainties remain about the plume evolution in time and space, and whether Laki was directly responsible for these climate events in north hemisphere climate.

To better understand the plume evolution of Laki we collected an exceptionally high time resolution record of the NGRIP ice core (which gives us ~10 samples/year). We identified possible cryptotephra throughout this record which suggest several pulses in volcanic activity or plume deposition. We use SEM imaging and EDS analyses to evaluate particle composition and abundances throughout the sequence. The S analyses carried out as well as the preliminary results of the tephras allow us to show a residence time or at least a fairly low sulphur deposition time.

Thus, our high-resolution recording of sulphur and tephra from the Greenland ice core will allow us to look at the evolution of the volcanic plume, as well as the interaction of this volcanic sulphur with the atmosphere. We will then be able to better map and understand the true impact of the 1783 Laki eruption.

Modelling the transport and deposition of ash following a Magnitude 7 eruption: the Mazama tephra

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Volcanic Ash Transport and Deposition Models (VATDMs) are necessary for forecasting the tephra dispersal during volcanic eruptions and are a useful tool for interpreting prehistoric tephra deposits. Here we use Ash3D, a Eulerian VATDM to simulate the tephra deposit from the ~7.7 ka climactic eruption of Mount Mazama in an effort to test and improve the accuracy of VATDMs using the Eruption Source Parameters (ESPs) characteristic of a large magnitude eruption (M≥7). We simplify the simulation to focus on the distal deposit as if it was formed by a single phase of Plinian activity using a total magmatic volume of 40 km^3. Our results firstly emphasise the importance of determining appropriate reanalysis meteorological data to recreate prehistoric deposits. Secondly, the off-axis spreading of the Mazama deposit is only reproduced when umbrella cloud spreading regimes are used in addition to advection-diffusion. Thirdly, we show the importance of using grain size distributions based on field deposits. Overall, the Ash3D simulations were able to reproduce the thickness and grain size of the Mazama tephra deposit to a reasonable degree given the uncertainties inherent in using modern wind profiles for a prehistoric eruption. However, this exercise highlighted the simplifications and assumptions required to simulate the deposition of fine-grained (<125 µm) volcanic ash that constitutes the distal Mazama tephra. To accurately predict where fine-ash will be concentrated in the air and on the ground during and following future eruptions of any scale, further research in needed into the atmospheric and particle processes that drive the deposition of fine-ash.

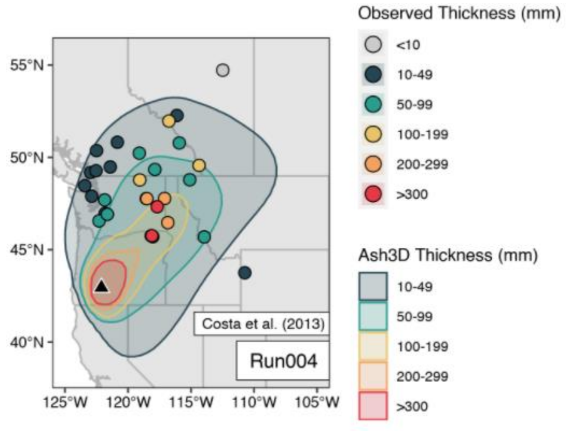

Fig. 1 – The deposit simulated using Ash3D versus the observed thickness of the distal Mazama tephra.

Using R and version control in volcanological and tephra studies

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Here I present the utility of the free R programming language in volcanological and tephra studies. Often the R language is thought of as being primarily for statistical computing. However, a diverse range of user written packages mean that it is perfectly suited for use in the Earth Sciences. Examples of volcanological applications of R include: the computation of grain size distribution statistics, isopach construction, erupted volume estimates and the production of high-quality data visualisations. Here I will present an example of a reproducible workflow from the stage of data collection in the laboratory right through to the data analysis, visualisation and manuscript preparation stage. I use RStudio with the internet hosted version control platform GitHub. It should be noted that the workflow presented can easily be integrated with Jupyter Notebooks, Excel and other widely platforms and languages in the Earth Sciences. I will demonstrate how the use of programming and version control can reduce sources of user error as well as enhance collaboration and facilitate open science. I will share resources for those interested in learning how to code and want to bust the myth that programming is intimidating and not for everyone. We can all learn to write code and it is such a valuable and desirable skill for geoscientists in and outside of academia.

Insights into the 2021/2022 Cumbre Vieja eruption (La Palma, Spain) from ground- and satellite-based remote sensing of magmatic degassing

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The eruption of Cumbre Vieja, La Palma Spain, is the first sub-aerial eruption of the Canary Islands for 50 years. The eruption produced a strong magmatic gas plume which was readily measured from space by the TROPOMI instrument on board Sentinel-5P every day. We applied the PlumeTraj algorithm to calculate flux and plume height time series for the complete eruption. Ground-based flux measurements were conducted by Involcan staff every day, and this allows a detailed comparison of the two techniques, revealing a strong impact of ash and high SO2 concentrations on SO2 flux measurements. We also conducted daily OP-FTIR measurements of the gas composition, revealing strong evolution of the gas emissions during the eruption. In this paper we present the key insights offered by gas monitoring from this remarkable eruption.

Quantifying the influence of conduit inclination and crystal fraction on basaltic eruption dynamics.

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Basaltic activity is the most common form of volcanism on Earth. Eruptions can happen suddenly and unexpectedly, resulting in widespread disruption, infrastructural damage and adverse public health impacts. Recent events like the ongoing La Palma eruption highlight the need for insight into eruptive styles and transitions. This can be achieved by increasing our understanding of the flow processes at depth that operate within volcanic plumbing systems and generate observable surface activity.

Whilst recent decades have seen progress in identifying and understanding simple flow process problems in single vertical conduits and their relationship with outgassing dynamics, much more work can be done. This particularly applies when we think about adding realistic complexities to magma and conduit properties and how these affect resultant surface eruptive activity.

Emerging experimental technologies and analogue approaches, specifically, play a major role in developing a more complete understanding of the natural complexity of open vent volcanic systems. The lack of study into subsurface system complexity is addressed here using a novel experimental setup (Figure 1) to examine slug ascent through particle-rich suspensions over a range of tube inclinations.

The scaling of resulting observations to real volcanic scenarios reveals important implications for volcano-scale flow dynamics and eruption vigour. Results indicate that slug parameters follow a trend of increase to a maximum, usually within the region of ~40° - 60° inclination, immediately followed by a decrease, as a function of inclination, fluid viscosity, and particle fraction. The variation between these results and the current model parameters for slug-driven eruption dynamics can be used to suggest parameter adjustments for existing values at applicable volcanoes, thus expanding on existing theoretical framework to accommodate for inclination and crystal fraction.

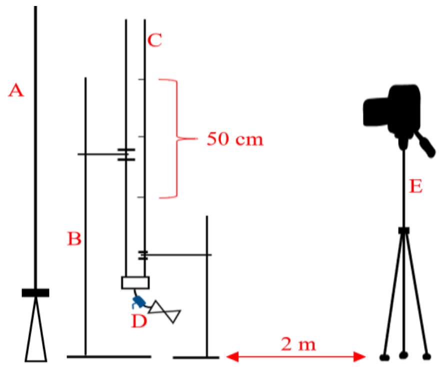

Figure 1: Adapted experimental setup showing *A* white background, *B* frame, *C* tube, *D* gas-injection point and *E* DSLR camera.

Formation of steep-sided volcanic domes on Venus

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Steep-sided domes are one of the most noticeable volcanic landforms on Venus. In the absence of plate tectonics, heat loss on Venus is controlled by plume-driven volcanism and catastrophic planet-wide resurfacing. By studying these volcanic landforms on Venus we can understand why the volcanic histories of Earth and Venus are so different. Steep-sided volcanic domes on Venus suggest eruption of more viscous lava. This might represent eruption of more evolved lava or the mobilisation of hot crystal mush.

To investigate the magmatic processes that control the formation of steep-sided domes on Venus, we ran fractional crystallization (FC) and batch melting (BM) models using Rhyolite-MELTS (version 1.0.2). Venera 13 was chosen as a bulk composition (silica-undersaturated basalt from Venus landing site[3]) for modelling crystallisation and melting processes at different pressures (0.01-1GPa), temperatures (960°C-1400°C), water content (0-0.2wt.%), CO_2 (0-0.2wt.%) and oxygen fugacities (ΔFMQ=-1, 0, 1).

Fractional crystallisation results in a maximum 57 wt.% SiO_2 after 67% fractional crystallisation at 1011°C, 0.01 GPa. SiO_2 content slightly reduces to 54% at 1 GPa, after 63% fractional crystallisation at 1113 °C. Importantly, approximately 60% solid fraction is required for the fractional crystallisation process to yield approximately phonolitic compositions at lower pressures.

Modelling on Venera 13 was also used to test whether silica-rich magmas can form by re-melting of Venusian crust. 20% batch melts with 54% SiO_2 are produced at 920°C/0.01 GPa, raising to 1000°C at 1GPa. For the first 10–20% crystallisation, olivine and clinopyroxene are the primary phases at 1 GPa and 0.1 GPa, whilst olivine and feldspar are the dominant phases at 0.01 GPa, implying that remobilised crystal mush would be broadly troctolite in composition.

Addition of CO_2 to BM models results in initial formation of a small volume of carbonatite melt, with silicate melts forming at higher temperatures. Carbonatite melts deplete residues in Na and K, slightly inhibiting the extent (and thus the viability) of melting at higher temperatures. In contrast, H_2O depresses the solidus (960°C to 914°C at 0.01 GPa for 0.2wt% H_2O) and enhances melt fractions. The presence of water might, therefore, control the viability of formation of silica-rich partial melts on Venus.

Re-evaluating the geochemistry and chemostratigraphy of the Antrim Lava Group (N Atlantic Igneous Province)

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The Antrim Lava Group in Northern Ireland is among the largest and earliest-formed expanses of the British and Irish Paleogene Igneous Province (BIPIP), part of the larger North Atlantic Igneous Province[1]. Despite this, it remains comparatively little-researched, with very few geochemical or petrological investigations undertaken in the past 30 years. Addressing this shortcoming represents an excellent opportunity to develop our understanding of the mantle sources, melting conditions (temperature, depth) and crustal interactions associated with initiation of large igneous province (LIP) volcanism in the North Atlantic.

During a field campaign in autumn–winter 2020, 208 new samples were collected from active quarries and cliff sections in Co. Antrim and from cores held by the Geological Survey of Northern Ireland (GSNI). These comprise (olivine-) basalts from massive, stacked flows (5–20 m thick) and smaller lobate flows, as well as rare, evolved units. At each locality, all logged flows were sampled, unless physically inaccessible. A further field campaign in summer 2021 yielded an additional 14 samples from the Tardree Rhyolite Complex. These evolved rocks formed just prior to a hiatus in basaltic volcanism that lead to the development of a regional marker horizon known as the Interbasaltic Formation.

Major and trace element geochemical analyses by XRF are ongoing and will be presented. These data will be combined with petrological and stratigraphic constraints from borehole and field logs to construct, for the first time, a thorough chemostratigraphical framework for the Antrim Lava Group.

The new data produced in this study will be used to: (i) target further analyses and sampling of primitive lavas suitable for thermodynamic models of mantle melting (e.g. PRIMELT3); (ii) assess the evolution (or lack thereof) of mantle and crustal temperatures, along with melt-crust interactions during LIP emplacement; and (iii) interrogate the petrogenesis of the Tardree Rhyolite Complex (and other evolved magmas) and its relationship to hiatuses in basaltic volcanism. These insights will be integrated with data from the wider North Atlantic Igneous Province to assess current models of its magmatic and thermal development.

1. Ganerød, et al. (2011). Chem. Geol. 286, 222–228.

How should risk be communicated to volcano tourists?

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Volcano tourism involves the study and exploration of volcanic and geothermal environments (Erfurt-Cooper, 2014) and is becoming increasingly popular following eruptions including Eyjafjallajökull (Donovan and Oppenheimer, 2016). Volcano tourism supports local economies however, following the eruption of White Island, 2019 questions have been raised over the safety of volcano tourism (Dempsey, 2020). Despite this, research on volcano tourism is limited.

This research addresses research gaps by assessing 1. Tourists' perceptions of volcanic hazards; 2. The role social media has in volcano tourism; 3. How risk should be communicated to volcano tourists; through questionnaires, semi-structure interviews and social media posts from tourists, tourism operators and hazard monitoring agencies.

Tourists' perceptions of volcanic hazards are representative of risk from volcanic hazards when compared to their spatial extent and fatalities.

Social media is mainly used to market volcano tourism and share experience in volcanic environments. Over recent years, volcano tourism is increasingly being used to educate tourists and as a form of risk communication. However, this presents challenges with "fake news".

Risk should be communicated to volcano tourists using a mixed-method approach incorporating hazard signs, hazard maps, safety briefings, designated footpaths, official social media profiles and government websites. Furthermore, risk from volcanic hazards should be compared to everyday hazards like driving to help tourists visualise risk. Hazard maps and hazard signs should be carefully crafted incorporating colour theory, use carefully chosen words and symbols and be use a clear font to enable tourists from different countries and with different disabilities to still be able to understand hazard signs and hazard maps.

Future research should assess to what extent are tourists, tourism operators and hazard monitoring agencies responsible for tourists' safety in volcanic environments. Furthermore, research needs to find methods of encouraging tourists, tourism operators and hazard monitoring agencies to collaborate to co Finally, research needs to explore how risk communication can be adapted to suit different cultures.

1. Dempsey et al., *Nat. Comm.,* 11(1), (2020).

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Numerical models of dykes: a phase field approach

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Dykes are magma-filled fractures that are responsible for transporting magma from deep within the Earth's interior toward the surface. When the driving pressure of the magma inside the dyke exceeds the resistive strength of the host rock, fluid magma is able to pierce through solid rock like a sharp object and propagate toward its destination. The governing physical processes are a complex combination of fracture mechanics, fluid dynamics, and solid-fluid interactions. Naturally these processes are hidden from view, and numerical models of dyke propagation are vital for understanding how magma is transported in dykes, and ultimately predicting whether or not a volcanic eruption will occur. However, capturing such multiphysics processes with a numerical model is very challenging. Existing models typically consider the dynamics of a single, vertically orientated dyke, and either neglect or simplify the fluid dynamics of the problem. Yet in nature dykes interact with both each other and their surroundings, resulting in complicated, non-conventional pathways. Furthermore, analogue experiments show that fluid flow in dykes is not always as simple as is often assumed.

In the *phase field approach* to modelling, fractures are defined by a continuous variable – a phase field – that denotes the presence or absence of a fracture. Derived from first principles, the phase field evolution is governed by a single equation. A major benefit of this is the ease of simulating complex fracture pathways, such as those that comprise magma plumbing systems. Despite the phase field method showing strong potential in the field of hydraulic fracturing, it has not been applied to volcanic plumbing systems before. I will present a phase field model for fluid-driven fractures, and share preliminary results of dyke propagation. This model has the potential to simulate a broader range of dyke behaviour than is currently possible, which could be of great importance for volcano observatories.

Discovery of a small magma chamber beneath Kolumbo volcano, Greece, by full-waveform inversion

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Continental volcanoes are underlain by complex systems of molten-rock reservoirs ranging from melt-poor mush zones to melt-rich magma chambers. Petrological and satellite data indicate that eruptible magma chambers form in the topmost few kilometres of the crust. However, no such a chamber has ever been imaged unambiguously, suggesting that large chambers responsible for caldera-forming eruptions are too short-lived to capture. Here we use a high-resolution imaging method utilising whole seismic waveforms to detect a ~6 km3 magma chamber ~3 km beneath a submarine Kolumbo volcano near Santorini, Greece. The chamber coincides with a termination depth of the recent earthquake swarms, and may be a missing link between a deeper melt reservoir and the high-temperature hydrothermal system venting at the crater floor. Though too small to be detected by standard seismic tomography, the chamber is large enough to threaten the nearby islands with tsunamigenic eruptions. Our results suggest that similar melt reservoirs are yet to be discovered at other active volcanoes.

Local stress field perturbations during magma emplacement in folded crustal segments: observations and numerical modelling from magma sheet – fold interactions in the Chilean Central Andes.

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For magma chambers to form or volcanic eruptions to occur magma must propagate through the crust as dikes, inclined sheets and sills. The vast majority of models that investigate magma paths assume the crust to be either homogeneous or horizontally layered, often composed of rocks of contrasting mechanical properties. In subduction regions that have experienced orogenesis, like the Andes, the crust has been deformed over several million years, resulting in rock layers that are commonly folded and steeply dipping. The assumption of homogeneous properties or horizontal layering then does not capture all the potential magma path crustal interactions. Here we tackle this problem by determining the effect of a crust made of steeply inclined layers in which sills and inclined sheets are emplaced. We combine field observations from a sill emplaced in the core of an anticlinal fold at El Juncal in the Chilean Central Andes, such as lithologies, sill and fold limbs attitude, sill length and layers and sill thickness, with a suite of finite element method models to explore the mechanical interactions between inclined layers and magma paths. Our results demonstrate that the properties of the host rock layers as well as the contacts between the layers and the crustal geometry all play an important role on magma propagation and emplacement at shallow levels. Sill propagation and emplacement through heterogeneous and anisotropic crustal segments changes the crustal stress field promoting sill arrest, deflection or propagation. Specifically, sills are more likely to be deflected when encountering shallow dipping layers rather than steeply dipping layers of a fold. Mechanically weak contacts encourage sill deflection due to the related rotation of the maximum principal compressive stress and this effect is attenuated when the fold layers are more steeply dipping. These processes may change the amount and style of surface deformation recorded, with significant implications for monitoring of active volcanoes.

Dike-induced ground deformation influenced by the orientation of geological strata: insights from numerical modelling

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The crust through which the magma propagates as sheet intrusions is normally assumed as an isotropic media or a horizontally layered media. In areas that have been intensely deformed during millions of years, such as regions where subduction or collisional tectonics has built mountain chains, the assumption of an isotropic and homogeneous crust or heterogeneous but horizontally layered does not hold true. In these geological settings the crust is formed by deformational structures such as folds, making the layers inclined at different angles rather than horizontal. Volcanoes often are formed by inclined layers too, for example, in stratovolcanoes, where lava flows and pyroclastic deposits forms steep-sided landforms or in calderas, where rock layers dips away or towards the collapse crater. For this reason, sills, dikes, and inclined sheets will propagate often through crustal segments formed by layers dipping at different angles.

Although progress made in volcano monitoring, we cannot yet know with certainty where a magma sheet will propagate to, making volcanic forecasts difficult. In part, as we mention before, this may be because there are some crustal properties that are not considered in the different models used to make interpretations about volcano deformation. Therefore, in this work we analyse results from numerical models on surface deformation generated during dike injection in a crust formed by rock layers with contrasting mechanical properties and dipping at different angles. We try to explain and discuss the implications of the surface deformation signals recorded at surface for the interpretation of volcano deformation during magma injection. Our results shows that both the angle of inclination and the mechanical properties of crustal layers are important parameters to understand the deformation signals observed at surface during dike injection. These observations are important for the interpretations of deformation source and can contribute to volcanic eruption forecasting.

Stratigraphy and Eruptive History of Corbetti Caldera in the Main Ethiopian Rift

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The East African Rift (EAR) hosts the highest density of peralkaline volcanoes of any region globally, making it an ideal location to study the subaerial and magmatic processes of peralkaline volcanism. Corbetti caldera is one such peralkaline centre found within the southern part of the Main Ethiopian Rift (MER), a segment of the EAR. Corbetti is actively deforming and is known to have previously undergone large-scale Plinian eruptions. However, our broader understanding of Corbetti's evolution is limited. Here we present a detailed study of the pre-, syn-and post-caldera eruptive deposits and compile them into a composite stratigraphy of the volcanic sequence. We find evidence for multiple previously undocumented large-scale eruptions, which include the deposition of two pre-caldera large lithic lag breccias and identify three additional post-caldera obsidian lavas. We have constrained the age of a young Tuff Cone, Biftu, which sits outside the caldera walls, to < 7375 ± 54 cal BP through ^{14}C dating of shells within an associated PDC deposit. The Wendo Koshe Cone, the most recent cone within the complex, is interpreted as the remains of two cones that opened in close proximity to each other and formed the vents for two pyroclastic eruptions: Bedded Pumice and Wendo Koshe Younger Pumice (WKYP). There is abundant evidence for the occurrence of pyroclastic density currents (PDC) within the caldera, usually associated with pumice cone-forming eruptions. These flow deposits rarely extend beyond the caldera walls. From our compiled stratigraphy, we estimate a recurrence rate of one eruption per 300-400 years over the last 2.3 ky.

These findings are especially significant as Corbetti is earmarked for potential geothermal exploration, and an understanding of eruptive frequency and style provides vital context to assess the potential hazards associated with this future infrastructure.

Explosive sequence of La Soufrière St Vincent April 2021: insights into drivers and consequences via eruptive products

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We document the products of the 2021 explosive activity 2021 of La Soufrière, St Vincent. Between 8 and 22nd April some 23 discrete explosions were recorded, declining in intensity and increasing in eruptive interval from the 11th of April. A detailed stratigraphy of the tephra fallout products was constructed during fieldwork immediately following the cessation of explosive activity. The tephra deposits are composed of a sequence of layers that can be correlated around the volcano. These are divided into at least six 'units'- U1, U2 etc based on their overall characteristics; typically coarser lapilli-rich units are interbedded with more ash-rich layers. Each unit is the product of several individual explosions. Isopach maps show that the initial phase (U1) was strongly dispersed to the northeast whereas U2 through U5 were more radially distributed. The total estimated volume through the explosive sequence is ~10^8 m^3 DRE, with ash fallout on Barbados (230 km to east) from 10th-12th April.

Vesicular scoria are present throughout the tephra sequence, however initial component analysis reveals that the lowermost layers of the sequence (U1) contain around 10 wt% vesicular scoria whereas this increases to 40-50% in later phases. Other lapilli largely consists of lithics inferred to be pulverised fragments of the 1979 and 2021 domes and conduit. U2, found across the island, has a distinctive bimodal grain-size distribution. Field, textural and eyewitness observations with the satellite and instrumental records suggest that the initial explosive activity was modulated by the surface overburden (until am 10th April), then influenced by extensive pulverised material around the vent (late 10th April). True Vulcanian activity commenced with unit U3 and continued until 22nd April with dispersal increasingly influenced by the trade wind inversion as plume height and intensity waned.

Pyroclastic density currents (PDCs) were formed during the latter part of the explosion sequence, from 11th April onwards, and moved down the several valleys to the south and west. Multiple units in the Larikai possibly reflect repeated occurrence associated with a number of explosions. Accretionary lapilli rich fallout units (U6), dominate the upper part of the fallout sequence on the Leeward side, and likely formed from moisture-rich ash plumes associated with PDCs that entered the sea.

2021 Paroxysmal Events of Mount Etna: Pre-eruptive Magmatic Conditions and Timescales

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In the last months of 2020, the South-East Crater of Mount Etna volcano in Sicily entered into a new, stronger phase of explosive activity producing ash emission as well as increased seismicity levels and inflation on the flanks. This activity was interspersed with a few paroxysms in December 2020 and January 2021 which culminated in a sequence that, starting from 16 February 2021 to 23 October 2021, has produced 53 paroxysmal episodes, whose frequency has decreased since August 2021. We studied scoria and lava samples from the 1st, 3rd 5th, 7th, 8th and 11th paroxysms at Etna between 16 February and 10 March 2021. This study aims to use a combination of petrological analysis and numerical modelling to investigate the crystal cargo and constrain the magmatic conditions and timescales of pre-eruptive magmatic processes. All samples have a porphyritic seriate texture with a hypocrystalline groundmass. The studied samples have phenocrysts, microphenocrysts and microlites of plagioclase, clinopyroxene and olivine with the following composition: pyroxene Mg# [100*(Mg/(Mg+Fe_{total})) a.p.f.u.] 69-78, olivine Fo% (Fosterite) 70-83, plagioclase An% (Anortite) 55-88. All crystal types exhibit complex zoning patterns with concentric, oscillatory, patchy, and sector zoning. A limited number of crystals, mostly olivines, are unzoned. These textures were investigated further in clinopyroxene.

Two populations of clinopyroxene were recognised: one characterised by mafic mantles (Mg# 74-79) with more evolved cores and rims (Mg# 71-76); and a second characterised by evolved mantles (Mg# <74) with either a mafic core or an evolved core (Mg#>74 and Mg# <74 respectively) and rims similar to the mantle (Mg# 72-75).

Textural characteristics and chemical composition of clinopyroxene rims indicate that injection of mafic magma is not the immediate trigger of this phase of paroxysmal strombolian activity. Instead, paroxysms may have been driven by shallow crystallisation, differentiation and gas vesiculation. However, mafic recharge event(s) prior to eruption are clearly recorded by the mafic mantles of clinopyroxene of the first population. After the injection, it is likely there were no further additions of magma as recorded by the more evolved rims. Therefore, a complete homogenisation of the mafic magmas upon injection is indicated. The presence of clinopyroxenes with more mafic cores is suggestive of mush remobilisation.

Chemical and isotopic tracers of the transition between oceanic and continental lithosphere

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The Canary Islands are an archipelago of ocean island volcanoes, overlying a mantle hotspot from which their volcanic activity originates. By analysing the isotopic and chemical compositions of detrital volcanic sands from the Canary Islands, as well as tephra and lava samples from the ongoing eruption on La Palma, the compositions and origins of the mantle components that contribute toward Canarian volcanism can be constrained.

Furthermore, the Canary Islands transect the West African passive continental margin. Over the course of my PhD project I will investigate whether the enriched signature observed in samples from previous studies is derived from interaction of the plume with continental material, or from a deeper mantle source. If this signature can be attributed to a continental source, as has been postulated in previous studies (e.g. Hoernle et al., 1991; Sagan et al., 2020; Day and Hilton, 2021), then the influence of the enriched component would be expected to decrease with increasing distance from the continental margin.

My project will analyse the isotopic (Sr-Nd-Pb-O) compositions of olivine-hosted melt inclusions, in addition to the major and trace element compositions of the melt inclusions and their host olivine. Utilising new 10^{13} Ω resistors with the University of Leeds Thermal Ionisation Mass Spectrometer will allow the collection of precise isotope ratio measurement of nanogram quantities of Sr, Nd and Pb. By doing so I aim to constrain heterogeneity in the mantle source of the Canary Islands, on various scales, which is key to understanding the evolution of the Earth's mantle and Canarian magmatism.

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Examining the relationship between seismic swarms and ground deformation during volcanic unrest

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Analysing the relationship between different streams of monitoring data during precursory volcanic unrest can distinguish between magmatic, tectonic or hydrothermal activity. Identifying patterns in these precursory signals may aid forecasting over month to year timescales, and help anticipate the location of surface volcanism. Here we examine the relationship between seismicity and ground deformation during an unrest episode at an active volcanic setting (Eyjafjallajökull, Iceland). Using monitoring data prior to the well-studied 2010 Eyjafjallajökull eruption, we are able to identify a step-change separating two relatively constant linear ratios between cumulative seismic moment and radial GPS ground movement. This step-change is interpreted as a change in magmatic source between two sills, given the sudden increase in seismic energy release relative to deformation and changes in direction of radial displacement. The change in ratio can be thought of as an increase in seismic efficiency, suggesting a decrease in aseismic inflation without frictional slip between sills. Locations of seismic foci and further changes in speed and direction of radial GPS movement allows us to identify a third source; a tilted dyke connecting both sills to ground surface and feeding the effusive eruption. By examining changes in seismic efficiency within each source and relating these to focal locations, we can see differences in how the inferred inflation generates seismicity. The decrease in aseismic inflation present in the shallower of the two sills relates to a number of 'lobes' separated by seismogenic fault zones[1]. Combining these observations with relationships between seismic moment and modelled volume (by combining radial and vertical GPS data) for the different sources, we compared evolution of the magmatic complex of Eyjafjallajökull to previous studies of different volcanic terrains and found a linear trend similar to other empirical examples[2]. This case study aims to provide new insights into subsurface processes prior to eruptive activity and help with forecasting at other volcanic settings, by relating patterns in the relationship between precursory seismicity and deformation to the volcano's characteristics.

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SO_2 flux discrepancies between satellite- and ground-based measurements of low-lying plumes: Kilauea 2020-21 case study

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Satellite- and ground-based measurements of sulfur dioxide emissions can obtain different flux results. When comparing satellite results with ground measurements for the 2020-21 Kilauea grounded plumes, the same SO_2 emission trend was visible; high emissions during the first week, followed by a sharp decrease and a plateau until the end of the eruption. But the satellite flux was up to 26 times lower than that of the ground. This research aims at finding the source of this discrepancy. The satellite measurements, conducted by the TROPOMI spectrometer onboard Sentinel-5P, were able to give daily SO_2 measurements from Kilauea using the analysis toolkit PlumeTraj. The ground-based measurements were conducted by the USGS at the Hawaii Volcano Observatory, using a UV spectrometer mounted on a car. It was found that the flux was calculated differently; the two methods used different wind speeds, the remote sensing one was measured by the Global Forecast System and the other with an anemometer. New calculations were done in order that the two measurements used the same wind speeds. It was concluded that when both use the same wind speeds, the fluxes are similar when taking into consideration the standard deviation. This means that wind speed influences flux calculations. On this basis, wind speed accuracy is primordial to create a reliable flux time series. Meteorological clouds were often present above the low-lying plume, masking the SO_2 signal, and hence underestimating satellite-based fluxes.

Volcanic explosive eruptions sequestrate more carbon in soils than what they emit into the atmosphere

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Volcanoes emit magmatic CO_2 into the atmosphere during explosive eruptions, contributing directly to the global carbon cycle on long (>1 Myr) time scales. Explosive eruptions also produce widespread tephra which blankets the landscape and provide a substrate on which volcanic soils form. These soils have an outstanding capacity to accumulate organic carbon, and their recurrent burial by tephra from eruptions of nearby volcanoes enhances soil organic carbon storage. The question we ask here is whether explosive eruptions ultimately sequestrate more carbon in soils than what they emit in the atmosphere. Based on a field study around Atacazo-Ninahuilca volcano, Ecuador, we find that the total amount of organic carbon in the tephra-buried and modern soils combined exceeds that released into the atmosphere by the volcano's last explosive event. Thus, a volcanic explosive eruption may be carbon-negative. We then develop a model to test this result on the Ecuadorian segment of the Andean volcanic belt, and demonstrate that, throughout the Holocene, explosive eruptions with a Volcanic Explosive Index (VEI) ≥ 4 have sequestrated more carbon in soils than the total magmatic carbon they have emitted over the same period.

VIGIL: a tool for (probabilistic) gas dispersion modelling

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Volcanic gas emission is a hazard to humans and livestock. In fact, many gas species can affect human health and even threaten life at concentrations and doses above species-specific thresholds. Furthermore, volcanic gas emissions are frequent and widespread, since they can occur both during volcanic unrest, eruptions and in quiescent stages of the volcanic activity. Two types of gas emissions are generally considered: dilute passive degassing and dense gas flow. The former occurs when the gas concentration is low and/or temperature is high, hence the density of the gas plume is lower than the atmospheric density (e.g. fumaroles). The latter takes place when the gas density is higher than the atmosphere and the gas accumulates on the ground and may flow due to the density contrast with the atmosphere to form a gravity current (e.g. limnic explosions).

In order to quantify the hazard related to gas dispersion and/or accumulation, monitoring and numerical modelling are generally employed, often together. Numerical simulations of gas dispersion involve a workflow that can be time consuming, since it starts with the modelling of the wind field, proceeds with the gas dispersion simulation and ends with the post-processing stage. This process should be replicated several times (hundreds to thousands) for probabilistic volcanic hazard applications, in which the uncertainty of the relevant input parameters (e.g. wind field, emission rates, source locations) is explored to obtain probabilistic outputs. In order to simplify the whole workflow and to produce probabilistic outputs, we created VIGIL[1] (automatic probabilistic VolcanIc Gas dIspersion modeLling), a simulation tool made of a collection of Python scripts. VIGIL is interfaced with two dispersion models: a dilute (DISGAS[2]) and a dense gas (TWODEE[3]) dispersion model. The post-processing script offers the option to create Empirical Cumulative Distribution Functions (ECDF) of the gas concentrations combining the outputs of multiple simulations. Here we present VIGIL and some application examples showing the wide range of options that the tool offers.

[1]https://github.com/BritishGeologicalSurvey/VIGIL
[2]http://datasim.ov.ingv.it/models/disgas.html
[3]http://datasim.ov.ingv.it/models/twodee.html

A facility to investigate (volcaniclastic) debris flows in Mexico

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We present the outcomes of the first two years of the ongoing Royal Society Newton Advanced Fellowship "Quantitative characterization of the rheology and transport-sedimentation mechanisms of debris flows by integrating deposits analyses, large- scale experiments and numerical modeling" (NAF\R2\180833). The project is also supported by the Official Development Assistance (ODA) Programme of the British Geological Survey, specifically the Research Platform 3 'Global geological risk'. The aim of the combined RS/ODA project is to investigate the rheology and depositional processes of volcaniclastic hyperconcentrated and debris flows and at the same time develop capacity and capabilities in field and experimental studies in Mexico.

Volcaniclastic hyperconcentrated and debris flows are also known as lahars when they involve unconsolidated volcanic material from historical eruptions. Lahars represent a hazard in areas surrounding active or dormant volcanoes and in valleys draining from them. In order to quantify lahar hazard, we must first understand the processes involved, including triggering mechanisms, flow properties and depositional features all of which are complex. This understanding requires fundamental research in geophysics by coupling experiments with monitoring of lahars, fieldwork studies on lahar deposits, and modelling. Mexico is one of the countries most-affected by lahars, a fact that has led to the development of many research groups in Mexico focusing on this hazardous process over the years. Improving the experimental and field work capacity for investigating lahars in Mexico will benefit many research groups in Mexico and Latin America and is the purpose of this project. In fact, the experimental facilities will be made available to researchers in Mexico and Latin America and, in order to advertise it, dissemination activities are being planned, including an international workshop hosted at UASLP in which the facilities will be showcased.

Magma ascent dynamics and volcanic eruption styles modelling: a new approach combining fluids mechanics laws and thermodynamics principles.

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Magma forms in the depths of the Earth. The process is known but cannot be described accurately. Various scientific studies reveal its presence beneath the earth, but volcanism would have taught us the most. Volcanism is therefore the manifestation of hot spots beneath the earth. Despite the depth at which the magma is found, it ends up on the surface of the earth, and this leads to scientific curiosity. Indeed, for a volcanic eruption caused by plate motions, the magma reservoir is estimated to be tens of kilometers deep. It is also known that the earth interior is discontinuous, so the route taken by the magma during its ascent is complex due to this discontinuity. However, a distinction is made between explosive and effusive eruptions; it is therefore necessary to define the impact of the conduit on the Volcanic Explosivity Index (VEI). In this work, we investigate the effect of conduit properties on the variability of eruption styles. The laws of fluid mechanics are used to describe the magma flow. Due to the high temperature and high viscosity of the magma, frictional forces are taken into account while weight forces are modified by thermal expansion. The first principle of thermodynamics is also used to model the heat transfer in the magma. By adding the stress tensor, we obtain the parameters that describe the intrinsic and extrinsic properties of the conduit. These include permeability, conduit radius, perturbation, viscosity, density and others. The first-order perturbation of the system allows us to recover the solutions of the pressure gradient, temperature and velocity which are numerically simulated and subjected to observation. We found that this model fully describes the flow of the magma in the conduit. The temperature of the magma in the duct and its velocity increase as the permeability increases, this is also the case for the increase of the perturbations and rather the opposite for the dimensionless numbers such as the Reynolds number and the Grashoff number. These results show that this model can be used to predict the variability of volcanic eruption styles observed at the Earth's surface. This model can also be used as a reference for modelling the dynamics of lava flows. If time is taken into account, it can also be used to track the evolution of an eruption and explain the changes in style that are generally observed.

Geographical imaginaries: Understanding risk in context

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This short talk will discuss preliminary findings from the ERC IMAGINE research project, which is working on volcanoes in Latin America to understand the diversity of perspectives and cultures around volcanism and changing environments. IMAGINE is an interdisciplinary project that aims to examine the spaces around hazard and vulnerability in understandings of risk, recognising that many communities do not primarily view volcanoes as “risks” at all. This creates a cross-cultural challenge for scientists in communicating with them, and requires interdisciplinary collaboration to understand multiple ways of viewing the earth.

The talk will briefly outline some of the theoretical basis for the project, in the gaps between hazard and vulnerability, particularly focussing on intersections between the assessment of risk, the politics of expertise (particularly the role of scientists in advisory contexts), culture, landscapes, values and geopolitics[1]. It will then discuss some of the early findings, focussing on the intersection between social and physical sciences in approaching risk holistically and in producing change through research methods themselves.

Initial fieldwork at Chaitén (South Patagonia) and Melipeuco and Malalcahuello (in the Kütralkura Geopark) using traditional and walking interviews and incorporating storyspheres will be discussed to illustrate the views of local people in both regions. This will highlight some of the opportunities in interdisciplinary approaches in understanding how people understand, relate to, and imagine the future trajectory of, the volcanic places that they inhabit.

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Rheology of multi-phase lava: case study of the 2018 Kilauea eruption

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Accurate predictions of lava flow emplacement are crucial for effective hazard mitigation. This need is evidenced by the 2018 Lower East Rift Zone (LERZ) eruption of Kilauea (Hawaii, USA), which produced extensive lava flows that caused substantial damage to property and infrastructure. Lava flow emplacement is controlled by rheology, which is complex because lava is a multi-phase system, comprising bubbles and crystals suspended in a melt. Lava rheology evolves over the course of an eruption as the lava cools and propagates away from its source. Despite extensive research over the last few decades, our understanding of the rheology of multiphase suspensions is still incomplete – in particular, three-phase suspensions at intermediate to high total suspended volume fraction are under-investigated. In this study, we will characterize the rheology of analogue suspensions with custom bubble and particle contents, designed to reproduce the textures found in lavas erupted throughout the 2018 LERZ eruption. Rheology of analogue materials will be validated against high temperature rheometry on natural samples, and inversion from videographic data. These case-study experiments will constitute a baseline from which more general rheological models will be derived for multi-phase lava across the range of textures found in natural flows. The multi-phase analogue experiment approach allows us to replicate natural textures whilst avoiding the complexity of continuous crystallization that magmatic conditions (high P-T) would generate in natural samples. Even though analogue materials constitute a simplified system, they can accurately describe natural phenomena and are widely used by geologists. We anticipate that our results will yield more general and more accurate models of lava rheology that will support forecasting of lava flow emplacement during future volcanic emergencies.

Accounting for Thermal Resorption of Bubbles in Magma in Experiments and Volcanic Eruptions

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The growth of bubbles drives volcanic eruptions and plays a major role in determining eruption style. Therefore, 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, which 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 study quantifies the extent to which bubble resorption during cooling/quenching modifies the gas volume fraction (ϕ) of the products of decompression experiments. We apply a numerical model that captures bubble growth and resorption processes over arbitrary pressure-temperature-time (P-T-t) pathways to a published experimental dataset[1]. Our analysis proceeds in two stages: 1) Reconstruct the experimental P-T-t pathways and determine how ϕ evolves with time, in order to reconstruct pre-quench values. 2) Vary values of experimental parameters, such as bubble number density (BND) and cooling rate and show when quench modification is most important. This analysis reveals the conditions under which bubble resorption is most significant and should be considered during experimental analysis. Resorption is predicted to have occurred in all experimental samples. In sample ABG14 , the final ϕ is between 12% and 18% lower than the peak values, consistent with values determined by a previous study[2]. The analysis indicates that thermal resorption must be accounted for in the interpretation of experimental results and that greater resorption occurs when BND is high and when cooling rate is low. In some instances, this leads to bubbles resorbing completely from a peak ϕ value as high as 0.10. The numerical model can be used as a tool to design experiments that minimise the effect of resorption, and we anticipate that this will support more meaningful interpretation of vesicle textures and size distribution.

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Introducing the SPIN-ITN and its sub-project: Ground motion and unrest triggering on volcanoes

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Seismological Parameters and INstrumentation (SPIN) is an Innovative Training Network (ITN) funded by the European Commission. The overarching goal of the SPIN network is to advance seismic observation, theory, and hazard assessment. The ITN is divided into 4 work packages (WP) with each WP consisting of 3-4 PhD projects, hosted at different beneficiary institutions.

The SPIN-ITN includes a series of short courses, workshops, and a joint field deployment to encourage collaboration between projects as well as SPIN partners. The first short course and workshop took place in late November 2021 and was hosted online, but future meetings are optimistically being scheduled to take place at several locations across Europe in future years. WP1 looks at new ground-motion sensing technology, WP2 will be developing new models of wave propagation, WP3 will involve designing experiments using the new sensing technologies and WP4 will be applying these new technologies and methodologies to different geohazard settings.

I will be focussing on WP4.1. This project will be utilising methodologies from the adjacent WP's to further understand volcanic responses to seismic triggering. Dynamic excitation from both local and regional earthquakes trigger volcanic seismicity so can yield additional information from both the pre-eruptive state of volcanic systems and about material behaviour. Evidence for this dynamic triggering has recently been recorded at Sierra Negra[1]. The current understanding of volcanic triggering raises many questions which will be addressed during WP4.1. These include, but are not limited to: 1) What new evidence of triggering is there at Sierra Negra post-2018 eruption? 2) Is there a critical stress which is reached when Sierra Negra is being reinflated, post-eruption, which leads to subsequent triggering? 3) Are there non-linear wave effects at work? 4) Is there a possibility to compare Sierra Negra to a volcano which may also be demonstrating signs of dynamic triggering e.g., Hekla, Iceland. The collection of seismic data from a variety of locations such as Hekla will be supported by numerical simulations of dynamic excitation. WP4.1 aims to better understand the role that the interplay between ground motion and the detailed properties of a volcanic edifice play in a volcano's pathway to eruption.

[1]Bell, A.F. et al. Dynamic earthquake triggering response tracks evolving unrest at Sierra Negra volcano, Galápagos Islands. *Sci. Adv.* **7** (2021).

Why don't earthquakes follow the Gutenberg-Richter law during the 2018 eruption and caldera collapse of Kilauea Volcano, Hawaii?

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During the May-August 2018 eruption of Kilauea, magma drained from the summit to the eruption site, leading to >50 collapse events in the summit caldera. Between collapses, low magnitude earthquake swarms ramped up before M≥5 implosive earthquakes associated with the collapses. When the magnitude-frequency distribution of the summit catalogue is analysed, it is shown to not follow the Gutenberg-Richter (G-R) scaling relation.

Each collapse cycle presents a set of earthquake data which follows the G-R law except for one M≥5 earthquake. In each separate cycle, this event may be treated as a statistical anomaly. However, observing this process repeated over 50 cycles with the M≥5 consistently present suggests a significant shift in properties or processes that affects the scaling relation.

Earthquakes with magnitudes M<5 are used to study the temporal b-value variations and show consistently high (b>1) values with decreasing trends within each collapse cycle. The evolution of b-values within collapse cycles in studied in more detail and compared to other models. We also observe a decrease in b-value over multiple cycles, with a change in the trend in the middle of the sequence.

The M≥5 events, when analysed as a separate dataset, display an extremely low b-value of 0.5. However, even though there are enough of these earthquakes to complete statistical analyses, the range of magnitudes is too small to be confident in this value. Instead, we focus on the comparison of local magnitudes and moment magnitudes of the different earthquakes observed during the collapses.

The higher-than-expected magnitudes are indicative of these types of events not following the G-R law because they represent the system moving on from sub-critical to critical to super-critical within each collapse cycle. These anomalous events may be a relatively common phenomenon at volcanoes, however not observed on such a large scale as during the 2018 Kilauea collapse.

Timescales of Magmatic Processes at Ōkataina Volcano from Fe-Mg Diffusion in Orthopyroxene

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One of the main challenges in assessing the risk posed by an active volcano is determining the likely timescales over which its magmatic processes operate. Constraining pre-eruptive timescales is important for understanding the likely range of signals and warning times a volcano may give prior to an eruption. Here we present the results of a study into the timescales of pre-eruptive magmatic processes operating at Ōkataina volcano, in the northern part of the central Taupō Volcanic Zone. We use Fe-Mg diffusion across initially sharp compositional boundaries in orthopyroxene from three rhyolitic eruptive episodes covering the three main vent regions of the young Ōkataina system (the 15.6 ka Rotorua episode from the Ōkareka Embayment, the 14 ka Waiohau episode from Mt Tarawera, and the 5.5 ka Whakatāne episode from the Haroharo Massif). Coupled with melt chemistry data and evidence from physical volcanology, this study shows how rapidly the magmatic systems involved can recharge from dormancy into an eruption-ready state. A Monte Carlo model was used to ensure full consideration of the (often large) uncertainties associated with diffusion timescales such as these.

Our findings suggest that recharging (or priming) of the magmatic system at Ōkataina occupied times on the order of decades up to a few centuries prior to eruption, with residence times for individual, eruptible melt-dominant magma bodies, and the processes that prime these bodies into an eruptible state, being on the order of months to decades. Processes which directly trigger the primed system into eruption (or significant unrest), for example injection of mafic magma, appear to be too rapid at Ōkataina to be preserved in the orthopyroxene crystal record. These results highlight the importance of present-day geophysical monitoring in detecting changes in the volcano over yearly to decadal timescales, which are relevant to the possible assembly of eruptible magma bodies.

SO_2 emissions during the 2021 eruption of La Soufrière St. Vincent

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After approximately four months of effusive activity, La Soufrière volcano on the island of St. Vincent in the Lesser Antilles Arc underwent an explosive eruption during 9 – 22 April 2021, producing the largest emission of SO_2 from an explosive volcanic eruption from the Caribbean in the satellite era. This SO_2 was injected at altitudes up to 16 km a.s.l. and transported around the globe. Determining the emission time series during an eruption is key to understanding changes in the magmatic system and eruptive processes, however it is difficult to accurately determine. Ground-based measurements are not able to accurately quantify emissions due to the high altitude of emissions and the presence of volcanic ash in the plume, while satellite measurements alone can lack the spatial or temporal resolution necessary to reconstruct the emission history.

Here, we tackle this problem by combining observations of SO_2 measured by the TROPOspheric Monitoring Instrument (TROPOMI) onboard the European Space Agency's Sentinel-5P satellite with PlumeTraj, a back-trajectory analysis toolkit, to reconstruct the emission time-series during the onset of the explosive activity at La Soufrière. Our analysis shows that the initial explosion was relatively sulphur poor, followed by a sulphur rich phase of explosions. This suggests that the initial explosion cleared previously degassed magma, followed by the eruption of the main undegassed magma source.

The methods shown here make use of publicly available data that are generated in near-real-time, demonstrating the potential of 24-hour SO_2 emission rate monitoring during future eruptive crises. This could provide crisis managers with a key monitoring tool in understanding the eruptive processes and mitigating risks from future volcanic eruptions.

Effect of dyke emplacement on host rock deformation within natural systems: microfracture analysis of Dalradian orthoquartzites and marbles.

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Nearly all volcanic eruptions are fed by dykes and sills which propagate through the crust. Magma supply, ascent rate and rheology are known to control the dynamics of propagating magma Intrusions and consequently may directly influence the duration, style, and potentially climatic impact of volcanic eruptions. A wide variety of geophysical, geochemical, and geodetic techniques are used in active volcanic systems to monitor magma intrusion during the build-up and eruptive phases. However, the ability to correctly interpret these data is dependent on and limited by the validity of the underling models derived from field observations and analogue experiments. In this study, we examine the emplacement of dykes from a micro-structural perspective.

We present microfracture and deformation analysis of Dalradian limestone and quartzites, at Lismore and Islay respectively, caused by the emplacement of tholeiite dykes of the British Paleogene igneous province. Our data analysis focuses on constraining the evolution of deformation associated with dyke emplacement and the differing response of the two host rocks. Orientated samples were collected in transects away from the dyke contacts and prepared as polished section orientated on the XY, XZ and ZY planes relative to the dyke wall. Microfracture trace-maps of the differing fracture sets were generated from Scanning Electron Microscopy (SEM) cathode luminescence (CL) and backscatter electron (BSE) images. The FracPaQ toolbox for Matlab™ was then used to quantify the characteristics of the fracture sets such as fracture orientation, length, intensity distributions.

Multiple phases of deformation were observed within the host rock, with deformation and healing primarily controlled by i) propagation of the dyke tip; ii) dyke normal compression from magma pushing outwards on the dyke wall; iii) thermal anisotropic expansion/contractions; and iv) the release of volatiles. These observations provide evidence for the evolution of strain during dyke emplacement within natural systems and demonstrate the significance influence of anisotropy within the host rock on deformation.

Outliers and archetypes: network analysis of analogue volcanoes

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While the number of potentially dangerous volcanoes on Earth is large, the resources available for detailed monitoring and study is finite: we have a data scarcity and resource allocation problem. In addition, a common issue encountered in stochastic modelling of volcanic hazard is the (flawed) assumption that information about relatively small eruptions at a given volcano provides information regarding the likelihood of larger eruptions of the same system. This is compounded by the occurrence of ``black swan'' events, whereby future large-magnitude eruptive scenarios may not be reflected in the prior eruption chronology of a given volcano (consider Chaitén Volcano, Chile, which erupted unexpectedly after over 9000 years of repose). To alleviate these problems, the concept of “analogue” volcanoes—a set of volcanic systems that are deemed to share sufficient characteristics to a given volcano to be a reasonable proxy—is of increasing interest and utility in terms of hazard assessment, general volcano classification, and comparison of numerical or experimental data.

Building on the work of Tierz et al.[1,2], this work analyses the degree of similarity (analogy) between volcanic systems using *graph theory*: allowing volcano analogues to be visualised and analysed as complex networks based on relational data. Relations in this case are defined by each volcanic system being connected to another by an analogy score greater than a defined threshold. In this way, we can detect and identify archetypal and outlying volcanoes, and we can distinguish clusters or communities of similar volcanoes (i.e. volcanoes which can serve as suitable analogues for others within that community). The calculated distributions show that these networks are manifestly non-random. A modularity-optimising community detection method captures the majority of community structure within the graphs. Indeed, systems that we might expect *a priori* to be similar (e.g. Kīlauea, Piton de la Fournaise, Bárðarbunga, Wolf, and La Palma) are partitioned into the same communities, and thus can be considered reasonable analogues of each other.

Complex networks appear to be an effective way of analysing volcano similarity, and could prove invaluable for transferring site-specific knowledge between systems, identifying spatial patterns, identifying target volcanoes for additional study, and detecting anomalous volcanic systems.

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Global compilation of volcanic sulfur isotopes across tectonic settings

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Volcanoes are an integral part of the global volatiles cycle, transferring volatiles from the mantle, subducting slab, and/or crust into the atmosphere. Much work has been put into quantifying and understanding the carbon cycle surrounding volcanoes, but there has been growing attention given to sulfur as the third most abundant volcanic volatile element. We have compiled a global database of sulfur isotope values ($\delta^{34}S$, relative to the Vienna Canyon Diablo Troilite) from volcanic gases and rocks, including species specific (H_2S and SO_2) and total S values. Our compilation includes 1259 $\delta^{34}S$ measurements from >80 global volcanic regions across all tectonic settings. We review the processes that can alter sulfur isotope compositions from their original value, such as degassing, assimilation, and precipitation and find that most gas species are not in isotopic equilibrium with their collected temperature.

We find that single volcanoes show a large range of sulfur isotope values, often as large as inter-volcano differences. However, despite this variability, median values by species for each volcano show coherent trends. As expected, H_2S is usually isotopically lighter (lower $\delta^{34}S$) than SO_2, and total S $\delta^{34}S$ (gas and rock) can span the range between the two. There are also trends by tectonic environment: arc volcanoes tend to have heavier sulfur isotope values than MORB, hotspots, and rifts. Arc volcanoes also tend to have more variable $\delta^{34}S$ compositions and span a wider range of $\delta^{34}S$. We also examine carbon isotope compositions ($\delta^{13}C$) and Ba/La ratios for the same volcanoes as our $\delta^{34}S$ compilation whenever possible. Comparing carbon and sulfur isotope values demonstrates that sulfur and carbon sources are often decoupled. Comparison with Ba/La ratios, our data separates into three groups: (1) MORB and hotspots have low Ba/La but variable sulfur isotopes, indicating deep recycling of sulfur; (2) some arcs have high Ba/La and heavy sulfur isotope values, indicating sulfur released from the subducting slab, and (3) other arcs have medium Ba/La but heavy sulfur isotope values, indicating sulfur assimilation in the overlying crust. This compilation illustrates the strength of $\delta^{34}S$ for aiding in understanding of volcanic systems, and the utility of inter-volcano comparison.

Explosive textures found in rhyolitic lava, Hrafntinnuhryggur, Iceland

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Silicic volcanoes can produce the most devastating explosive eruptions on Earth or gently emit lava. Recent rhyolitic eruptions at Volcán Chaitén and Cordon Caulle (2008-09 and 2011-12 respectively), both in Chile, demonstrate that both effusive and explosive eruption styles can occur coincidently from the same vent. Magmas that feed effusive and explosive eruptions appear to start out with similar dissolved volatile abundances at their storage regions, however, effusively erupted products always have lower H_2O concentrations than their explosive counterparts, which implies eruption style is not dictated by volatile exsolution but is a consequence of outgassing in the shallow conduit. Therefore, we aim to use detailed fieldwork to explore the shallow outgassing processes in the conduit, and to reconcile observed rhyolitic eruption styles with models of magma transport processes from storage to surface.

Here we present a detailed characterisation of silicic lava at Hrafntinnuhryggur, Krafla, Iceland, emplaced during a rhyolitic fissure eruption. The lava represents shallow, late-stage conduit-plugging material, with multiple lithofacies containing heterogeneous textures such as healed fractures, healed brecciated and flow-banded obsidian, and poorly sintered particles of obsidian in open-fracture systems. Additionally, in the feeder dyke, exposed at the southern edge of the ridge, round primary pumice pyroclasts and pumice breccia grades into dense obsidian. These textures are all interpreted to be closely associated with fragmentation and sintering, short-range clast transport, and repeated cycles of erosion and deposition in the conduit. Therefore, we suggest that the lava at Hrafntinnuhryggur has a purely explosive origin, followed by sintering and late-stage lava emplacement. With reference to examples elsewhere, such as Big Obsidian Flow, Oregon and Mule Creek, New Mexico, we suggest that other apparently effusive silicic lavas and plugs are the remnants of explosively erupted ash and pumice that sinter in an increasingly restricted conduit as an eruption progresses.

How did Vesuvius's magma chemistry change over time from 1631 to 1944, and why?

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From 1631 to 1944 Vesuvius was persistently active. This time span was characterised by variously effusive, explosive, and effusive-explosive eruptions producing alkaline, silica-undersaturated lavas and pyroclasts of tephritic to phonolitic composition. Ejecta commonly contain leucite, plagioclase and (Ca,Al)-rich clinopyroxene, with intermittent contributions from amphibole, olivine, nepheline, and sanidine (e.g., Belkin et al., 1993; Redi et al., 2017). An analysis of time-series data from samples of known eruption ages from GEOROC suggests there are correlations between eruption style and magma composition that have not previously been recognised, indicating that major and trace element whole rock and glass compositions vary systematically over time. For example, lavas may have become increasingly alkaline since 1631. However, there are also significant sampling biases towards the larger, more explosive eruptions (such as 1631, 1906 and 1944).

To build on this work I will analyse textures and compositions of clinopyroxene crystals in lavas from selected eruptions available from the Oxford University Museum of Natural History. Clinopyroxene data will be used for thermobarometry to infer the magmatic conditions fuelling the eruptions for these samples. My combined geochemical approach seeks to provide an integrated study of how Vesuvius' geochemical evolution from 1631 to 1944 scales with eruption size, eruption parameters, and variations in conditions within the volcano's plumbing system.

Real-Time Observations of Plagioclase Crystallisation from Basalt

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In order to understand igneous rock textures and the history of erupted products it is necessary to understand how crystals grow and what effects different cooling histories have on their growth. Previous studies on crystal growth have often assumed constant crystal growth rates[1,2], and focused on crystallisation over long timescales more appropriate to igneous intrusions[1], however crystal growth rates and timings may not be constant or as accurate as they could be, especially for short timescales relevant to extrusive igneous rocks. This work aims to quantify and describe crystal growth rates, morphological variations and textural development of crystals growing from experimental samples made using a natural starting material, primarily focussing on plagioclase feldspar. High Temperature Heating Stage experiments are carried out at temperatures (1225 - 1140°C) and cooling rates (0.1 - 1.7°C/min) appropriate to zones a few centimetres deep within basaltic lava flows. The experiments involved melting and recrystallisation of wafers of the glassy rind from Hawaiian Blue Glassy Pahoehoe basalt. In these experiments, crystal growth was directly observed and recorded over time at controlled cooling rates. The experiments in this study grow crystals at low undercoolings, maintaining an interface controlled growth regime and facetted crystal morphologies. Mean plagioclase growth rates for the total samples over the full cooling time are 2.5×10^{-6} – 3.2×10^{-5} mm/s, whilst measured time evolution of crystal growth indicates that growth rates are not constant over time, decaying as they grow. Additionally, the relationship between aspect ratio and crystallisation time proposed in Holness (2014) was experimentally tested and validated for crystals growing within short timeframes. The results of this study will contribute to better future interpretations of magmatic histories and crystallisation conditions in natural basaltic lava flows, as well as refinement of Crystal Size Distribution studies.

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Geochemical trends at Atitlán volcanic centre, Guatemala

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The 75 ka Los Chocoyos eruption (LCY) was a VEI 8 supereruption[1] from the Atitlán volcanic centre (AVC) in Guatemala. This eruption (as well as several other smaller rhyolite pumice eruptions) was coincident with a period of trenchwards arc migration, and the caldera lies between the old and new lines of stratovolcanoes. This project investigates the impact which arc migration had on the style and chemistry of the volcanism of the AVC through a combination of petrology, major and trace element geochemistry, and the use of the Sr and Nd isotope systems on whole rock material.

Two geochemical trends are present in the stratovolcano lavas of the AVC and are defined by K_2O content (high- and low-K andesites). Modelling the formation of these trends using EME-AFC[2] shows the low-K trend can be formed by fractional crystallisation of primitive basaltic andesites, while the high-K trend is best explained by fractional crystallisation combined with assimilation of a very high K_2O (>6 wt.%) rhyolite melt. This assimilant is present as voluminous interstitial glass in cumulate xenoliths from pre-LCY stratovolcano Volcán Tecolote. It is assumed that this source is also present underneath the other pre-LCY stratovolcanoes, due to the presence of high-K lavas there that are associated with cumulate xenoliths[3].

The high- and low-K trends are also present in the rhyolites of the AVC, most significantly within the LCY pumices[4]. An additional subdivision of the LCY pumices can be argued based on mineralogy and K2O content – a mid-K pumice containing both biotite and cummingtonite, in contrast to the other two pumice groups that only contain either biotite (high-K) or two amphiboles (low-K). Further modelling shows that the high- and low-K LCY pumices can be formed by fractional crystallisation of respective high- and low-K andesite magmas. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios plot the AVC rhyolites in the intermediate region between the old and new stratovolcano fields, suggesting a mixing of inputs from both, reflecting the spatial and temporal relationships between the rhyolites and the pre- and post-LCY stratovolcanoes.

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Dike scaling revisited

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In linear elastic fracture mechanics (LEFM), veins, dikes, and sills grow in length when the stress intensity factor K_I at the tip reaches a critical value: the host rock fracture toughness K_{Ic}. This criterion is applied broadly in LEFM models for crack growth and assumes that the pressure inside the crack is constant. When applied to intrusion length versus thickness scaling, a significant issue arises in that derived $K_{IC} = 300\ to\ 3000\ MPa\,\sqrt{m}$, which is about 100–1000 times that of measured K_{Ic} values for rocks at upper crustal depths. The same scaling relationships applied to comparatively short mineral vein data gives $K_{Ic} < 10\ MPa\,\sqrt{m}$, approaching the expected range. Here we propose that intrusions preserve non-equilibrated pressures as cracks controlled by kinetics, and therefore cannot be treated in continuum with fracture-controlled constant pressure (equilibrium) structures such as veins, or many types of scaled analogue model. Early stages of dike growth may give rise to increasing length and thickness, but magma pressure gradients within intrusions may serve to drive late-stage lengthening at the expense of maximum thickness. For cracks in 2D, we find that intrusion scaling in non-equilibrium growth is controlled by the growth rate and initial sheet scaling, effective (2D) host rock modulus, and magma viscosity and cooling rate, which are different for all individual intrusions and sets of intrusions. A solidified intrusion can achieve its final dimensions via many routes, with relaxation acting as a potentially significant factor in this, hence there is no unique scaling law for intrusions.

New approaches for creating reproducible analogue materials for bubbly magma

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Analogue materials are designed to replicate key features of magmas, such as the relative fractions of gas, solid, and liquid phases, among other properties. Such materials help volcanologists to replicate the behaviour of volcanic processes in laboratory settings. Bubble suspensions in different materials (for example, golden syrup) have been used to study the rheology and behaviour of bubbly magma. However, currently there is no standardised method for creating bubble suspensions in a way that would allow researchers to systematically control their characteristics, such as gas volume fraction (ϕ). We present preliminary results in developing a method to create reproducible bubble suspensions in both an isothermal material with a constant viscosity liquid phase, and a non-isothermal material that undergoes a liquid-to-solid transition during cooling. The isothermal method involves combining predetermined amounts of citric acid and sodium bicarbonate in golden syrup to create a suspension of carbon dioxide bubbles through a chemical reaction between the two reagents. The proportion of citric acid and sodium bicarbonate to golden syrup is based on the calculated amount of carbon dioxide produced in the reaction, and the target value of ϕ. By changing the amounts of reagents, we can produce suspensions with ϕ in the range of 0.1—0.8. For the non-isothermal case, we introduce the use of bubbly toffee (also known as cinder toffee or honeycomb) as an analogue material for studying cooling and fragmentation processes within bubbly magma. Cinder toffee is created by mixing sodium bicarbonate into melted sugar to create carbon dioxide bubbles through thermal decomposition; the bubbles are then preserved as vesicles in the sugar as it solidifies. When the cinder toffee is hot it can be pulled and manipulated under various forces. As it cools and solidifies, replicating the glass transition in a silicate melt, it preserves different textures and morphologies. These two analogue materials have a broad range of applications in experimental volcanology, including in studying the rheology of bubbly magma, the textures of solidified bubbly magma under different forces, and in recreating different textures seen in natural volcanic samples. Having a systematic and standardised approach for creating these analogues will mean that the experiments can be more controllable, and that other researchers can use these analogues to design reproducible experiments to investigate a range of volcanic processes.

Non-Hawaiian style evolution of ocean island volcanoes

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The magmatic architecture of ocean island volcanoes, formed through melting of upwelling mantle plumes, is controlled by the flux of magma into the lithosphere. As a result, as a volcanic system moves away from the centre of plume-upwelling (i.e., transitions into a post-shield stage of activity), it is often assumed that the depth of magma storage will increase. This hypothesis is supported by barometric estimates of shield stage and post-shield stage volcanism in the Hawaiian and Galápagos Archipelagos, which show a transition from shallow to deep magma storage as the distance from the plume stem increases. However, comparison of present-day shield and post-shield stage systems does not truly evaluate the evolution of a volcanic system. To do so, we need to consider a single volcanic centre where multiple stages of magmatic activity are exposed at the surface.

In many ocean island settings it is difficult to access multiple stages of a systems volcanic history. In fact, in the Galápagos Archipelago shield stage and post-shield stage lavas from a single volcanic centre are rarely seen at the surface. However, cumulate xenoliths found in lava and scoria deposits from Isla Floreana in the southern Galápagos record ~2.5 Myrs of volcanic activity on the island and thus provide a direct insight into the volcanic evolution of a single ocean island volcano. In this study, we consider the major and trace element composition of two different xenolith groups from Floreana to determine how the magma storage conditions change as the island moved away from the centre of plume upwelling. Specifically, we present published barometric estimates for a series of 'recent' wehrlite xenoliths (<1 Ma) alongside new data from a suite of older gabbro xenoliths (~2.5 Ma).

Our trace element analysis confirms that there are significant chemical differences between the wehrlite and gabbro xenoliths, as well as the association of the gabbros to the shield stage of volcanic activity on Floreana. Analysis of clinopyroxene-orthopyroxene pairs in the gabbroic nodules, as well as thermodynamic modelling of phase stability, demonstrates that there is little to no difference in the magma storage pressures of the different xenolith groups: both groups indicate storage at elevated pressures (~500 – 600 MPa), below the base of the crust. As such, our results indicate that there has been no significant increase in the pressure of magma storage beneath Floreana over the last ~2.5 Myr, despite the island's migration away from the Galápagos plume stem. Our results therefore indicate that the traditional model of ocean island volcano evolution does not apply to Galápagos, and that its general applicability needs to be re-evaluated.

Crystal aggregation mechanisms in granites

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Crystal clusters offer a unique insight into the dynamic processes that operate in magmatic systems. Clusters are often interpreted to have formed by synneusis, whereby crystals drift together and attach in a melt-rich environment. Synneusis-derived clusters are therefore considered evidence for processes involving the relative motion of suspended particles, such as gravitational settling and turbulent flow, typically in conditions of low viscosity and a low crystal fraction.

Recent research has suggested that such processes may be inhibited in granite intrusions due to the high viscosities, low Reynolds numbers, and low crystal-melt density contrasts of silicic magmas. Synneusis should therefore be rare in granites. Yet crystal clusters are common in granites, and some features, such as systematically aligned plagioclase inclusions in K-feldspar phenocrysts, are considered classic examples of synneusis. We investigate whether synneusis is the best explanation for these structures, or whether they could have formed by another mechanism such as heterogeneous nucleation.

We collected samples from porphyritic units within the granodioritic Tuolumne Intrusive Complex in California. Euhedral K-feldspar phenocrysts from this pluton reach over 15 cm in length and contain abundant inclusions of plagioclase, quartz, amphibole, biotite, and titanite, many of which are aligned parallel to the host crystal's growth faces.

We used EBSD to quantify the crystallographic orientations of hundreds of inclusions and compared them to the orientations of their host K-feldspars. We also modelled the crystal faces of inclusions and compared their orientations to those of the host crystal. Here we present these data, evaluate whether they are consistent with synneusis being the primary crystal-attachment mechanism, and explore the implications for the magma dynamics of granitic reservoirs.

The role of pre-existing fractures in the propagation of basaltic dykes through hyaloclastite

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Magmatic dikes are fundamental feeders of active volcanism. A large number of parameters influence a dyke's path through the Earth's crust, such as the host rock properties, crustal heterogeneity, discontinuities, and the surrounding stress field.

This study aims at constraining to which extent dykes use pre-existing fractures or instead create their own pathway at shallow crustal depths. To achieve this goal, we mapped exposed basaltic dykes emplaced in a caldera-filling hyaloclastite within the extinct Dyrfjöll volcano in Northeast Iceland. The orientations and spatial distribution of the dykes and fractures in the host rock were measured in virtual 3D-models computed from drone-based photogrammetry data collected at three mountain faces/cliffs with varying orientations located inside the caldera.

Dykes and fractures dip mostly within 20° of the vertical and show three dominant strikes, which are present at all three sites. The most prominent set strikes 010-040 and is perpendicular to the recorded extensional tectonic stress field related to the divergent plate boundary at the time of formation. Two less pronounced sets of dykes and fractures strike 060-080 and 110-130. Some dykes clearly occupy pre-existing fractures, while others seem to have propagated into previously intact rock. In the latter case, their orientations are nonetheless aligned with one of the three fracture sets, indicating a large influence of the external stress field.

When occupying discontinuous fractures, dykes seem to be able to move between fractures of the main (tectonic) set by propagating along a fracture with a less favourable orientation, resulting in repeated sharp changes in the dyke direction. This switching between fracture sets appears to be preferred over the formation of new cracks. Dykes cutting through initially intact host rock are found to form thin offshoots aligned with the orientations of the other observed fracture sets.

In conclusion, our study shows that dykes propagating through hyaloclastite prefer to use pre-existing weaknesses, such as fractures. This insight can help to improve our understanding of how pre-existing fractures and the stress-field influence pre-eruptive dyke paths in active volcanic systems where hyaloclastite is one of the major rock types.

Lava dome collapse: destabilisation of existing domes by renewed dome growth

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Lava dome collapse hazards are intimately linked with their morphology, their internal structure, and the existing volcanic topography. We present new lava dome emplacement models that use calibrated rock strengths and allow material behaviour to be simulated for three distinct units: (1) a ductile, fluid core; (2) a solid upper carapace; and (3) disaggregated talus slopes. We simulate sequential dome emplacement, demonstrating that renewed growth can destabilise otherwise stable pre-existing domes. This destabilisation is exacerbated if the pre-existing dome has been weakened following emplacement, e.g., through processes of hydrothermal alteration. We also show that higher rock strengths do not necessarily lend themselves to lower displacements, as a higher proportion of disaggregated talus slopes can act as unstable substrate, and provide a detachment plane which still culminates in displacement of the dome. A better understanding of dome growth and collapse is an important component of hazard mitigation at dome-forming volcanoes worldwide.

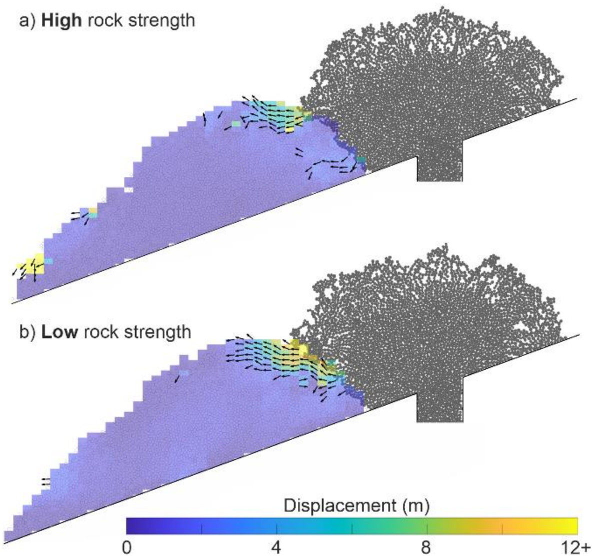

Figure 1: displacement of a previously stable dome due to emplacement of new adjacent dome. Displacements shown as a function of rock strength. In both cases, the older dome is destabilised.

Magma interaction in dyke geometries

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Basaltic fissure systems display a wide range of eruptive behaviour, posing danger to nearby people and infrastructure. The physical and chemical interaction between magmas stored in the subsurface plumbing systems that feed basaltic fissure eruptions can determine the nature of eruptive products produced and the eruption longevity. To date, most analogue experimental studies investigating the fluid dynamics of magma in plumbing systems have used pipe-like or chamber-like geometries (i.e. cylindrical or cuboid respectively). It is difficult to extrapolate these previous results to high aspect ratio, dyke geometries that characterise fissure systems. Therefore, we have designed a new analogue experimental setup to explore magma mixing in a rectangular duct geometry.

We present preliminary results from scaled analogue experiments whereby miscible fluid pairs, representing two magmas of differing composition, interact in a dyke geometry. The higher density fluid is layered below the lower density fluid in a stable initial configuration before the apparatus is inverted to initiate interaction between the fluids. Images were captured over the course of an experiment (Fig. 1) and processed to quantify mixing and change in Reynolds number over time. Fluid samples were also taken to track the evolving fluid physical properties (density, viscosity) during mixing. Lastly, we relate our experimental results to evolving magma chemistry and viscosity during subsurface magma replenishment and eruption.

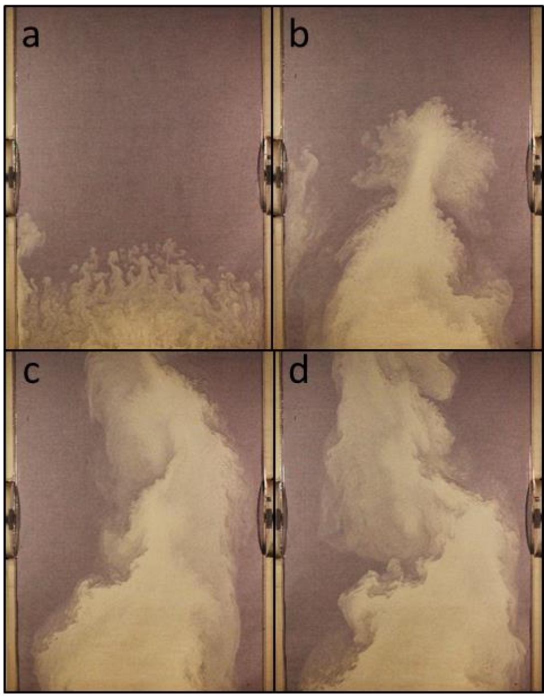

Figure 1: Sequence of images showing the evolution of two miscible fluids interacting in a dyke geometry.

How low can we go? Long-term averaging of a low concentration volcanic plume

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Satellite measurement of volcanic gas emissions has been a key method in volcano monitoring for decades. Until recently however, it has been largely limited to explosive events and a few very high flux passive emitters. The 2017 launch of TROPOMI (the Tropospheric Monitoring Instrument), on board ESA's Sentinel-5P satellite platform, was a step-change in the spatial resolution of satellite remote sensing and has brought about the possibility of measuring passive degassing emissions from both lower altitude and lower flux volcanic sources.

The individual orbit operational products from TROPOMI have had a poorer S/N ratio than had been expected. A newer algorithm (COBRA) based on optimal estimation has significantly improved the noise level, resolving passive degassing from larger sources such as Mt. Etna, Italy. However, there are still numerous volcanoes that are known from ground measurements and direct observations to be passively degassing, that are still below the detection limit.

Long-term averaging of satellite remote sensing measurements is an established technique for low-altitude, low concentration emission sources, both anthropogenic and volcanic in origin.

There are now over 3 years of scientific-quality SO_2 measurements from TROPOMI, allowing us to study the temporal evolution of even very small volcanic plumes.

Soufrière Hills volcano, Montserrat, has been passively degassing since the end of the recent period of high activity in Feb. 2010. Gas emissions have been monitored using the installed scanning DOAS network, giving a comparative SO_2 flux, but the plume is not visible in daily imagery from either the operational or COBRA data sets. Given the volcano's geographical location, the wind direction is to the West 85-90% of the year, making the averaging technique more effective, as emitted gas will be blown in the same direction.

Averaging is performed for Soufrière Hills for 3 monthly periods from June 2018 to Aug 2021. A clear plume is visible from almost all periods, with an average daily SO_2 mass emission of 174 tonnes. The flux timeseries is compared to those from other geophysical datasets.

This averaging technique, applied globally, would allow for an improved global volcanic SO_2 flux inventory, as well as enhancing the monitoring of many volcanoes that were previously undetectable via satellites.

How does a thermo-viscoelastic crust affect magma reservoir failure?

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As volcanoes undergo unrest, understanding the conditions and timescales required for reservoir failure, and the links to geophysical observations, are critical when evaluating eruption potential. Inferring the dynamics of a pressurised magmatic system from episodes of surface deformation is heavily reliant on the assumed crustal rheology; shallow or long-lived magmatic systems can significantly perturb the regional geothermal gradient, altering the behaviour of the surrounding crustal rock. Here, we investigate the overpressures required to initiate reservoir failure within a thermo-viscoelastic crust and the predicted displacements at the ground surface. We use Standard Linear Solid viscoelasticity with a temperature-dependent viscosity, exploring a range of reservoir temperatures and geothermal gradients, and evaluate tensile and Mohr-Coulomb failure criteria on the reservoir wall.

Our results demonstrate that reservoir failure is systematically inhibited by a thermo-viscoelastic crust, with respect to the corresponding elastic model. The non-uniform crustal viscosity facilitates compression of the ductile wall-rock, in response to continued reservoir inflation, and impacts the evolution of the induced tensile stress. These processes are underpinned by viscous timescales related to the imposed thermal constraints, and therefore affect reservoir failure requirements. Critical overpressures and ground displacements are minimised for high-temperature (i.e., mafic) reservoirs and are maximised for low-temperature (i.e., felsic) reservoirs. The elastic strain-rate is ~6.7×10^{-13} s^{-1}, whilst critical strain-rates for failure in a thermo-viscoelastic crust exceed 1×10^{-12} s^{-1}. We show that thermo-viscoelasticity plays a significant role across a wide range of overpressure loading rates, and therefore its effects should not be neglected. By resisting mechanical failure on the reservoir wall, thermo-viscoelasticity impacts the conditions required to nucleate dykes and form shear fractures, which may place greater focus on other processes that act to promote reservoir failure, such as regional stresses (e.g., topographic and tectonic), geometric stress concentration, external triggers (e.g., earthquake stress drops), or pre-existing weaknesses along the reservoir wall.

Hydrothermal alteration can result in pore pressurization and volcano instability

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The collapse of a volcanic flank can be destructive and deadly. Hydrothermal alteration is common to volcanoes worldwide and is thought to promote volcano instability by decreasing rock strength. However, some laboratory studies have shown that not all alteration reduces rock strength. Our new laboratory data for altered rhyodacites from Chaos Crags (Lassen volcanic center, California, USA) show that pore- and crack-filling mineral precipitation can reduce porosity and permeability and increase strength, Young's modulus, and cohesion. A significant reduction in permeability, by as much as four orders of magnitude, will inhibit fluid circulation and create zones of high pore fluid pressure. We explored the consequences of pore fluid pressurization on volcano stability using large-scale numerical modeling. Upscaled physical and mechanical properties for hydrothermally altered rocks were used as input parameters in our modeling. Results show that a high-pore-pressure zone within a volcano increases volcano deformation and that increasing the size of this zone increases the observed deformation. Hydrothermal alteration associated with mineral precipitation, and increases to rock strength, can therefore promote pore pressurization and volcano deformation, increasing the likelihood of volcano spreading, flank collapses, and phreatic/phreatomagmatic explosions. We conclude that porosity-decreasing alteration, explored here, and porosity-increasing alteration can both promote volcano instability and collapse, but by different mechanisms. Hydrothermal alteration should therefore be monitored at volcanoes worldwide and incorporated into hazard assessments.

Inter-comparison of plume model mass eruption rate predictions based on the 2010 Eyjafjallajökull eruption

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During an explosive volcanic eruption, real time estimates of the source mass eruption rate are required to predict tephra dispersal and sedimentation. Observational constraints and physical limitations make it difficult to directly measure mass eruption rate. As such, simple models (0D) have been developed to provide rapid estimates of mass eruption rate from plume height observations. Due to their simplicity, these relationships can be inaccurate and underestimate mass eruption rate, particularly during windy atmospheric conditions. On the other hand, one-dimensional plume models incorporate meteorological conditions and additional physical processes not considered within 0D; however, by introducing more parameters into the model, the overall uncertainty propagated into mass eruption rate prediction increases. This presents a challenge in monitoring ongoing eruptions and quantifying accurate mass eruption rates in real time. A fundamental question to address is whether incorporating additional parameters into the prediction of mass eruption rate provides more accurate estimates. To address this question, this contribution compares and evaluates the one-dimensional plume model FPLUME[1] to the empirical and theoretical relationships contained within REFIR[2] software. Mass eruption rates are predicted for the first phase of the 2010 Eyjafjallajökull eruption using observations of plume heights from C-band radar at Keflavik Airport. The results of this study demonstrate that REFIR underestimates mass eruption rates compared to FPLUME. Nonetheless, it was found that there are uncertainties in the quantification of numerous key input parameters required to initiate FPLUME, resulting in a significant increase in the number of plausible mass eruption rates predicted. These results highlight the significance of model choice and the parameters used to estimate mass eruption rate. A balance must be found between increasing model complexity and reducing uncertainty. The results of both models, their implications and potential areas for future development are presented.

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Origin of the Pallasites from the Sericho Meteorite

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The origin of pallasite meteorite is poorly understood. Because their composition is mainly olivine and Fe-Ni metal alloy, the environment of the formation was initially defined as core-mantle boundaries. However, recent studies using paleomagnetic techniques, and examining the metal concentrations across multiple pallasites, demonstrate that core-mantle boundaries are unsuitable environments in which these meteorites could have originated. Ferrovolcanism models which invoke Fe-FeS magma injection into mantle lithologies support both the paleomagnetism results, compositional trends, and the olivine crystals' growth conditions. Here we have used combined energy dispersive X-ray spectrometry (EDS) and e*lectron back-scattered diffraction* (EBSD) to further explore the ferrovolcanism hypothesis. We present results from the recently found pallasite Sericho and compare results to previously studied pallasites.

Study of thick sections of Sericho using optical and scanning electron microscopy (SEM) imaging and EDS reveal a jigsaw-like texture of olivine crystals surrounded troilite. Based on the EDS chemical analyses, those olivine crystals are forsterites. If all olivine crystals are assumed to have been initially aligned in the same directions, the olivine crystals have been rotated, as would be expected if the Fe-Ni metal matrix had intruded into an olivine-troilite mixture. Other observation includes that one of the olivine crystals has a tabular inclusion, as identified by optical microscopy, which suggests that Sericho experienced mild shock events in contrast to other previously studied pallasites including Eagle Station. This study has also identified phosphate minerals that have not been found in other Sericho specimens.

To conclude, our interpretation of the origin of the Sericho pallasite is that a planet-planet collision formed a planetesimal with an olivine rich mantle and large iron core. During segregation of the mantle and core, iron could have intruded into the mantle olivine region, with the slow cooling producing troilite. The presence of phosphate supports the slow cooling, but not the ferrovolcanism model as phosphate tends to remain towards surface of planetesimals. Ferrovolcanism cannot fully explaining the origin of pallasites, and it may be that they are a product of more chondritic planetesimals.

Assessing the type and frequency of volcanic hazards affecting Mexico City using a sediment core from Lake Chalco.

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[3]https://www.icdp-online.org/projects/world/north-and-central-america/lake-chalco-mexico/details/

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Sediment cores are crucial records of the geological past, and can aid the reconstruction of past climatic and/or archaeological events and provide evidence of past volcanic activity. In 2016, a deep (520 m) sediment core was recovered from Lake Chalco, SE of Mexico City for the MexiDrill project, which aims to address a breadth of paleoenvironmental questions, and obtain a long-term record of volcanism in the region.

Mexico City is home to >25 million people, and is surrounded by polygenetic volcanoes, such as *Popocatépetl and Nevado de Toluca, and the Sierra Chichinautizin volcanic field. As such, the city is vulnerable to a diverse range of volcanic hazards, including tephra fallout from distal calderas in Central America (e.g., Los Humeros, Mexico and* Atitlán, Guatemala). The Chalco core provides a long-term record of explosive volcanism, principally as airfall deposits, from all these sources, on timescales comparable to the lifetimes of polygenetic volcanoes. This exceptional archive provides a unique and continuous record of the physical characteristics of explosive volcanic events, and allows frequencies, magnitudes and temporal variation in volcanism to be assessed.

This continental sediment core records a diverse range of volcanic deposits from both distal and proximal sources, and requires a careful investigative approach that can account for a wide variety of volcaniclastic deposits. We devised an approach to extract volcanological information, which can be replicated in any lacustrine or marine sediment core. Limitations and constraints (e.g., core preservation) are discussed, and a confidence is ascribed to each unit that feeds into interpretations. Although the Chalco core does not provide a complete history of explosive volcanism, the detailed data from the record provides important physical information about individual eruptions and their sources. The systematic approach taken with the Chalco core bridges the gap between volcanology and sedimentary archives and allows a fairly rapid assessment of a regions' vulnerability to volcanic hazards to be deduced.

Water-rich versus water-poor: maximising the outgassing metal flux from arc volcanoes

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Volcanoes emit significant fluxes of trace volatile metals and metalloids (e.g. Cu, Mo, As, Se) in the form of gas and aerosols and play an important role in the global geochemical cycling of these elements, which are nutrients and/or pollutants in the surface environment. Volcanoes in different tectonic settings emit characteristic assemblages of volatile metals[1]. Arc volcanoes outgas high fluxes of trace metals that are linked to slab devolatilization and the high chlorine content of arc magmas. Arc volcanoes exhibit significant variability however in their outgassing X/S ratios, where X is a trace metal such as Cu, Pb, Zn and S is sulfur, suggesting that there are some intrinsic controls on outgassing trace metal fluxes that vary between volcanic systems. Volcanic gases are the low-density surface manifestations of the exsolved magmatic volatile phase (MVP) that forms throughout the crustal transport, storage and fractionation of magmas. The MVP, made up of mostly water and CO_2, plays a pivotal role in trace metal transport within arc magmatic systems by acting as the reservoir into which metals partition. Some trace metals speciate with chloride and partition strongly into a chloride-bearing MVP[2]. Here we ask: which factors are most important for maximising the metal content of the exsolved MVP and ultimately, the volcanic trace metal flux to the surface environment? Magmas with a high water content saturate in exsolved volatiles deep in the crust, which promotes early and deep partitioning of trace metals into the MVP. The bulk chlorine content of the magma likely influences the metal content of the exsolved MVP and is pressure-dependent: deep crustal fluids are expected to be more saline[2]. We expect bulk magma water and chlorine content, as well as the depth of magma storage and fractionation, to be important factors in determining the mass flux and chalcophile metal composition of the gas and aerosol emitted from arc volcanoes. Here we develop models based on four arc magmatic systems with variable water and chlorine contents to describe the development of an exsolved MVP during both isobaric fractionation and decompression. We model the behaviour of three hypothetical trace metals with different speciation behaviours that partition between the melt and MVP. Chloride-speciating trace metal concentrations in the MVP are highest for saline, deep-stored magmas. Metal fluxes carried via the MVP (expressed as kg per kg of magma) are maximised by shallow, isobaric fractionation of water-rich magmas. The exsolved volatile phase associated with decompression degassing, is analogous to that generated during volcanic eruptions. In this case both water-poor and water-rich chlorine-bearing systems can produce high trace metal fluxes via the MVP, but syn-eruptive fluxes are maximised by decompression of volatile-rich magmas from mid-crustal reservoirs.

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CO_2 systematics in the Lesser Antilles arc and the 2020-21 eruption of La Soufriere St Vincent

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Volatiles including CO^2 continuously migrate from their storage regions to the Earth surface. Studying the degassing processes of volatiles are a key part of understanding systematics and dynamics of volcanic degassing. As volatiles can be exsolved and released at volcanoes before eruption of their parent magma, they provide useful information in terms of forecasting and hazard mitigation, especially at island arc settings as these volcanoes are characterised by dome building and explosive eruptions and are therefore highly hazardous. Diffuse degassing of CO^2 is well-characterised in many volcanic settings, including island arc settings, however, this has been less studied in the Lesser Antilles Arc. This project will use three different approaches on seven volcanic systems along the Lesser Antilles Arc including diffuse soil degassing, volatiles degassed through plumes and fumaroles, and volatiles present in melt inclusions. Previous studies have quantified CO^2 degassing in most but not all of the three approaches, however, they have not been integrated in an attempt to constrain the CO^2 budget of the individual systems, nor at the arc scale. A quantitative approach is being applied, with samples being prepared for melt inclusion studies, fieldwork being carried out for measurement of diffuse degassing and raw data from plumes and fumaroles collected at observatories being collated.

The eruption of La Soufriere volcano, St Vincent lasted approximately four months, beginning with lava dome building at the end of December 2020 and culminating in a series of explosive events in April 2021. Raman spectroscopy and SIMS carried out on melt inclusions from both phases of the eruption will (i) compare the CO^2 & H^2O concentrations in an attempt to identify any relationship or lack thereof with products of both phases, as well as products of the last eruption in 1979, (ii) use the CO^2 and H^2O concentrations together with solubility-pressure models constrain entrapment pressures and therefore magma storage depths, and (iii) use matrix and melt inclusion CO^2 and H^2O to provide a first estimate of gas fluxes in the 2020-2021 eruption.

A new kimberlite database and analysis of southern African examples

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Kimberlite magmas comprise low viscosity ultramafic melts that are rich in volatiles, carry a xenolithic cargo from the deepest parts of our planet (depths greater than 150 km) and can host diamonds. The nature of kimberlite eruptions can be identified by their deposits, where diatremes and pipes (or rare lavas) are commonly fed by a network of dykes and sills at depth. To assess the reliability and completion of the published kimberlite record, a new kimberlite database 'KimberDat' has been created. The new database structure comprises 16 categories and 51 sub-categories to capture representative information of the kimberlite deposits (e.g., age, geographical location, volcanic structure and the presence and composition of xenoliths) based on published data. This data has been categorised into primary (published and peer-reviewed), secondary (published and un-reviewed e.g., conference abstracts) and tertiary (news articles and websites). The database has been initially populated with data on southern African kimberlite dykes and pipes, with 316 individual entries that capture the key characteristics of 23 kimberlite clusters and 70 individual pipes, dykes, and sills. Preliminary analysis shows these kimberlites are clustered both spatially and temporally across the Kalahari Craton, a major geological structure in southern Africa comprising the Archaean aged Kaapvaal and Zimbabwe Cratons. Most of the southern African kimberlites in the database erupted during the Cretaceous and are found in the Kaapvaal Craton (e.g., the eponymous kimberlite locality 'Kimberley' in South Africa), with others erupted during the Precambrian, Cambrian, Triassic and Jurassic. The database also highlights the current gaps in the published kimberlite record; constraints on the total deposit volume are often not reported, and this is information that is needed for the hazard assessment of future kimberlite eruptions in the area. KimberDat has great potential to be expanded to include global kimberlite occurrences.

The occurrence and petrogenesis of Icelandic High Silica Rhyolites

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High Silica Rhyolites are defined as rhyolites with over 75 wt.% SiO_2 on an anhydrous basis, and they occur within all tectonic environments (subduction, intra-plate, divergent/extensional). Until now, their wider occurrence within Iceland has not been recognised.

Here we report on four occurrences of High Silica Rhyolites (hereafter HSR) within Iceland. All are isolated and single eruptions unconnected with central volcanoes. Three occur in rift zones (characterised by tholeiitic volcanism), and one occurs in a flank zone (characterised by transitional alkalic volcanism).

HSR are sparsely porphyritic (typically 1–4%), containing ≤2 mm oligoclase phenocrysts. Fayalitic olivine and ilmenite occur as accessory phases. Sparse allanite and hedenbergite crystals occur, and the significance of these atypical crystals is discussed later.

Geochemically, HSR show important differences from typical Icelandic rhyolites, and of particular note are their low incompatible element concentrations. For example, Zr concentrations in HSR are only 200-400 ppm, significantly lower than values for normal Icelandic rhyolites (800-1600 ppm).

The low trace element concentrations, particularly of Zr, are suggestive of a primitive source rock. This rules out fractional crystallisation as the sole genetic process, as this would act to enrich incompatible elements within the melt. Furthermore, the geochemical characteristics of these HSR indicates a depth of formation that is consistent with pressures of 200-300 MPa, following the minimum within the haplogranite system[1].

HSR geochemical characteristics can be modelled using rhyolite-MELTS as a two-stage process: (1) fractional crystallisation of mantle-derived gabbroic melt to generate plagiogranite; (2) partial melting of this plagiogranite at shallow depths (~200 MPa). As rhyolite-MELTS modelling does not predict the occurrence of hedenbergite, and as allanite is a known mineral within intrusive rocks, we propose that this part of the mineralogy is xenocrystic and is derived from the plagiogranite.

The proposed petrogenetic model provides an explanation for the geochemical peculiarities of high silica rhyolites in Iceland. This model may help to explain occurrences of HSR elsewhere across the globe.

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Linking magmatic processes and the monitoring record: the view from the 2013-17 eruption at Volcán de Colima

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Volcán de Colima, a highly active stratovolcano in western Mexico, has a history of persistent interplinian activity, characterised by transitions between effusive and explosive events; along with intense, cycle-ending Plinian eruptions, the most recent in 1818 and 1913. Despite these eruptions being a hazard to >750,000 nearby residents, the processes which control eruptive style changes and timing is still poorly understood. In particular, the relationship between magma storage, recharge and mixing, and volcano monitoring data needs to be investigated further.

Petrological studies have shown that these andesites contain a diverse crystal cargo (plagioclase and pyroxene, with limited olivine and amphibole), with unzoned phenocrysts suggesting shallower crystallisation in vapour-saturated conditions in the upper crust at *c.* 6 km beneath the crater[1,2,3]; and complexly zoned crystals suggest mixing and crystallisation between evolved and mafic magmas and remobilisation of a heterogeneous crystal mush in a deeper mid-crustal storage region[4].

Diffusion modelling of pyroxene crystals show that long residence timescales of decades to centuries are recorded in the evolved magmas, in contrast to shorter residence times of weeks to months in mafic magmas, indicating that mafic injections are ephemeral events within the mostly evolved crystal mush. Placing these recharge events in time shows a strong relationship between some recharge events and volcano monitoring data, with three main mafic recharge periods identified between late 2013 and mid 2016 in the months prior to three different eruptions.

Our data indicate that Volcán de Colima is an open-system, steady-state volcano, where the magmas and crystal mush are kept in a persistently warmed and near-eruptible state, a feature recognised at an increasing number of arc volcanoes.

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Steaming, not stewing? Lithium enrichment in response to diffusive dehydration in volcanic dome rocks

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Magmatic volatiles are an important transport agent for potentially economic metals, as well as an important driver of volcanic eruptions. Minerals such as amphibole incorporate volatiles (Cl, OH and F) into their crystallographic structure, as well as taking in both light (e.g. Li) and heavy (e.g. Sr, Ba, Y, La) trace elements. Amphibole can therefore preserve geochemical evidence for magma differentiation and trace metal enrichment, as well as changes in volatile composition, which allows investigation of processes associated with the magmatic-hydrothermal transition.

Here we present in situ major (EPMA) and trace element (LA-ICP-MS) data for amphiboles (MgHbl-MgHst) from Shiveluch Volcano, Kamchatka and Soufrière Hills volcano, Montserrat. The major element compositions of melts calculated to be in equilibrium with amphibole are in agreement with previously published melt inclusion datasets. For Shiveluch, amphiboles from dome samples show variable extents of enrichment in lithium (to >100 ppm) and copper (to >60 ppm), whereas amphiboles from pyroclastic flow-forming eruptions have low lithium (~5 ppm) and copper (typically ≤10 ppm), despite having identical major element compositions. Soufrière Hills amphiboles show a similar pattern but additional SIMS data demonstrate that lithium enrichment is strongly related to OH depletion.

We speculate that lithium and copper are enriched in the amphiboles in response to partial diffusive dehydration or dehydrogenation of the amphiboles. Lithium enrichment appears to be achieved during prolonged storage of magma in the volcanic dome at very low pressures, by steaming in fluids released during higher pressure degassing. This contrasts with previous suggestions that magmas stew in lithium-rich brine during pre-eruptive magma stalling. This raises questions over the partitioning of Li and Cu between vapour and brine, and the importance of dense, high-pressure fluids in transporting trace metals in porphyry deposits.

Timing and climate impact of Iceland's largest basaltic eruptions: new insights from ice core archives

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Icelandic volcanic eruptions can have profound environmental and societal impacts on Europe. For example, the relatively minor 2010 eruption of Eyjafjallajökull caused major disruption to travel and cost the global economy an estimated £3 billion. The largest Icelandic fissure eruptions pose more severe hazards to Europe in terms of air quality, environmental pollution, and climate change. Detailed records of the source, style, and impacts of these events is vital for simulating such eruptions and improving societal resilience.

Some of the best long-term records of Icelandic volcanism are preserved in the Greenland ice cores, and there have been major recent advances in our ability to generate high time resolution geochemical records of these events.

Here, we present new records of the 939–940 CE Eldgjá lava flood eruption, and the 750–765 CE pulsed basaltic eruptions associated with Katla volcano (Hrafnkatla event). Multiple sulfur isotopes are used to infer plume injection height. We show that for both Katla and Eldgjá $\Delta^{33}S$ values are mainly ±0.2 ‰ and consistent with tropospheric SO_2 injection. However, in both cases $\Delta^{33}S$ down to –0.4 ‰ is observed and taken as evidence for a stratospheric component and hence a climate impacting phase.

At Eldgjá the anomalous $\Delta^{33}S$ values follow the main S peak and, importantly, while early tephra match Eldgjá compositions, later populations show rhyolitic arc-like signatures. For Katla, anomalous $\Delta^{33}S$ is only identified in the final phase of the eruption at 765 but in this case there is a clear tephra match with Icelandic basalt compositions.

These data provide the first ice core evidence of stratospheric S isotope signals associated with Icelandic eruptions. Both eruptions have been linked to northern hemisphere climate change and while our new evidence strongly supports this for Katla, the picture from Eldgjá is more complex and requires multiple closely timed Icelandic and arc eruptions.

Overall, the combination of high time resolution glaciochemistry, S isotopes and tephra offer exceptional new insights into the source, style and impacts of these major volcanic episodes.

Bubble rise in silicate melts and magmas: An experimentally validated model for non-isothermal conditions

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Eruptive activity at basaltic volcanoes can include lava effusion, lava fountaining, and Strombolian behaviour. This diversity of eruptive style is partly dictated by the organisation and rise rate of gas bubbles relative to the magma. Whilst bubble rise rates are well understood for isothermal conditions, the shallow volcanic plumbing system can be subject to substantial temperature changes, which may modify the rise rate.

The Hadamard-Rybczynski equation provides a theoretical description of the buoyant terminal rise velocity of a spherical bubble in a viscous fluid, showing that in a volcanological context, the most critical parameters are the viscosity of the fluid surrounding the bubble, and the bubble radius. Here, we use existing viscosity-temperature relationships and Charles' Law to develop an integral solution of this equation for non-isothermal conditions.

Experimental validation of the analytical model was completed with a suite of tests using bubble-entrapment methods to seal a known volume of air within a block of soda-lime-silicate sheet glass. When heated above the glass transition temperature this air bubble rises at terminal velocity before being 'frozen' at the final rise height when the glass undergoes rapid cooling. Observing these final bubble positions, following different and variably complex heating and cooling cycles, the larger bubbles were found to have moved a greater distance than smaller bubbles, when the glass was in a molten state. Completing experiments for a range of bubble radii, we find that the final observed bubble positions agree with those predicted by the analytical model within experimental uncertainty.

The final model, which can predict bubble position when given a non-isothermal temperature profile, has a wide range of applications. In artistic or industrial settings, it could be used to help control processes that manipulate glass using kiln formed firing cycles. For volcanological settings our formulation could be used to estimate the critical bubble size for separated gas-magma flow in cooling volcanic conduits, or for conduits with a substantial vertical temperature distribution; both would aid understanding of bubble rise and its role in defining the eruptive behaviour of a volcano.

Volcanic Debris Avalanche and accompanying shear zone slip surface formed by a perched scoria cone collapse on Ascension Island, South Atlantic

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Volcanic debris avalanches occur when volcanic edifices collapse and flow as landslides. They are preserved in the geological record as volcanic debris avalanche deposits (VDADs). Analysis of these deposits can provide insight into the flow characteristics of the avalanche and its possible triggers.

Here we provide preliminary textural data on the shear zone layer at the base of a small-volume VDAD on Ascension Island, South Atlantic. The deposit has a volume of ~4 x 10^6 m^3, covers 2 km^2 and originated from the partial collapse of the northern flank of the 300ka Green Mountain scoria cone, which sits at 550 metres above sea level. The avalanche flowed 2 km down a ~10° slope, before stopping at in a small basin against a lava dome at 190 m above sea level.

Over most of its length the VDAD overlies an in-situ Green Mountain scoria fall deposit that was dispersed north during the eruption. The base of the deposit is marked by a fine-grained, ~2 cm-thick shear zone with slickensides. The shear zone is distinguishable in hand specimen from the rest of the deposit by being finer grained and indurated. The bulk of the VDAD is composed of semi-coherent, metre scale blocks of scoria with a poorly sorted volcaniclastic matrix composed of a hetereolithic clast population including randomly orientated clasts of basaltic scoria, pumice and lavas. The toe of the deposit is fractured and flame structures are abundant.

Preliminary Back-scattered Scanning Electron Microscope imaging of the shear zone reveal that porosity and pore interconnectivity decrease markedly towards the centre of the shear zone, and clasts become finer-grained, better sorted and more rounded. Experiments will be conducted on samples of Green Mountain Scoria using Rotary Shear Equipment to place constraints on slip rates and shear parameters. Ultimately, we hope to understand potential triggers of the failure and explore the hazards and potential for similar events on the island in the future.

A trachyte among basalts: assessing the ‘Shadow Zone’ hypothesis of São Miguel, Azores

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The island of São Miguel (Azores) comprises three active trachytic volcanic centres (Sete Cidades, Fogo, Furnas), separated by two basaltic fissure zones (the Picos and Congro basaltic fissure systems). The explosive eruption of a felsic magma within the Congro basaltic fissure system at ~ 3.8 ka, alongside the apparent cessation of basaltic volcanism in this area, led to the proposal of a recently-developed (< 5,000 years), laterally-extensive trachytic magma reservoir in the shallow crust between Fogo and Furnas, termed the ‘shadow zone’. This theory suggests that ascending basaltic magmas are unable to reach the surface, instead being mixed into trachytic magmas which may then be erupted.

This study investigates the potential of a single, laterally-expansive felsic magma reservoir in the shallow crust beneath eastern São Miguel. By targeting a pumice and ash fall deposit derived from the 3.8 ka Congro eruption, we aim to 1) determine the key petrogenetic processes responsible for its formation, and 2) establish any potential petrological links between the Congro trachyte and those erupted within the nearby Fogo and Furnas volcanic centres.

We discuss preliminary results which indicate that the Congro trachyte is geochemically comparable to the least-evolved, metaluminous trachytes of both Fogo and Furnas. This includes evidence for deposit-scale chemical zonation, depletion of elements including Cr, Ni, Sr, and Ba, similar Zr/Nb ratios, and Eu anomalies (Eu/Eu* = 0.59 to 0.72). These data imply petrogenesis via fractional crystallisation and may support the concept of a single, shallow crustal magma reservoir beneath eastern São Miguel. If this hypothesis is correct, the implications for future eruptive behaviour, frequency, and management of associated volcanic hazards in the Congro fissure system are considerable.

What can evolving seismic anisotropy tell us about the 2018 Kilauea eruption?

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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 anisotropy 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.

Seismic anisotropy is also affected by evolving stress and migrating fluids. Here, we use the unprecedented seismicity to complete the picture of seismic anisotropy in the Lower East Rift Zone (where it has not been imaged previously), investigate the transfer of stress between the propagating intrusion and the M6.9 earthquake that occurred concurrently on the décollement, and how stress and fluids affected the start and end of the eruption.

The effects of the rhyolitic eruption of 2008 at Chaitén and subsequent forest disturbance.

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The eruption of Chaitén in 2008 was the first rhyolitic eruption to take place in almost a century. This VEI 4 eruption inflicted damage on neighbouring endemic Valdivian temperate rain forest flora, setting up natural experiment conditions conducive for the study of early post-disturbance succession in a relatively pristine forest. The eruption was characterised by intense airfall tephra and PDCs both within and without the boundaries of the caldera. An extruded lava spine caused a further block-and-ash type PDC nine months after the eruption started sensu stricto – this came within 3km of the eponymous town of Chaiten. Further to this, lahars inundated the town and extended the coastline outwards by up to a kilometre for a period.

Lahar, PDC and extensive tephra airfall deposits combined to form gradients of disturbance with distance from the caldera – proximal reaches characterised by intense damage and distal reaches by minor. Close to the caldera rim in proximal reaches where PDC activity was intense, large block tephra airfall was prevalent, and some degree of directed blast took place, trees were either fully removed from the ground or were downed orthogonally away from the caldera. Further away in distal reaches – particularly in the northern and eastern directions – damage was limited to canopy removal from fine ash or lapilli tephra airfall.

The relatively instantaneous destruction of large swaths of forest, relative "natural" state of the landscape and unincumbered regrowth potential sets out a natural experiment that can be used to answer these questions.

The work of this project aims to establish primary succession dynamics within different zones of damage, characterised by prevalence of some disturbance agent. This will go on to address some key unknowns at the intersect of vulcanology and forestry, chiefly which mechanisms control early stage forest regrowth after an explosive eruption.

How does grain size distribution impact the mobility of aerated granular flows?

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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. They pose a catastrophic geological hazard, and have caused >90,000 deaths since 1600 AD[1].

PDCs are able to travel for tens of km, traversing topographic barriers hundreds of metres high. They are notably more mobile than other gravity currents of comparable size[2]. Gas fluidisation has been attributed as a major contributor to this high mobility.

Experimentation on dry (i.e. non-fluidised) granular flows has assessed the influence of grainsize on mobility, finding that the finer the grains, the larger the mobility of the mass[3]. Recent advances in analogue models of gas fluidised granular currents (where gas flowing through the material causes it to act like a fluid) have revealed the impact of aeration on current mobility, and how flow behaviour can control deposit architecture and morphology[4]. However, these experiments have so far largely used only a single grain-size. The impact of grain size variations on the mobility of aerated granular currents remains untested.

This project aims to investigate how grain size distribution affects current velocity and run-out distance, and how this distribution is preserved in the deposit. This will be tested in a series of analogue experiments using an aerated flume. Sediment of varying grain size and shape will be released from a hopper into a flume which can sustain fluidised currents, where a high-speed camera will be used to make observations and quantify velocity and run-out distance.

Improved understanding of the factors governing how PDCs behave and deposit will improve our interpretations of ignimbrite deposits and contribute to more realistic hazard assessments.

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A Machine Learning Approach to Magmatic Barometry Based on Multiple Saturation of Phases

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Petrological barometry is an important tool in magmatic studies[1]. Barometers are usually based on a combination of experimental results, thermodynamic reasoning, and statistical fitting of data. One key problem in barometry is the error associated with applying methods to inappropriate samples (e.g., using a method that assumes multiple saturation of a liquid with solid phases when the liquid was not multiply saturated). Another important issue is assessment and interpretation of uncertainty. Advances in machine learning techniques open a new range of possibilities for petrological barometry. Machine learning techniques allow the full range of data to be used without losing variables during dimensionality reduction or introducing any bias from incorrect thermodynamic assumptions. They can also allow errors to be quantified more accurately. Machine learning thermobarometers have shown to be of comparable accuracy to widely-used extant barometers[2]. We present a new melt-composition-based barometer that first assesses whether a melt is saturated in olivine, plagioclase, and augite (OPAM-saturated). This important step helps to mitigate the influence of application of the OPAM method to non-OPAM saturated natural liquids. Next, an algorithm estimates the pressure of pre-eruption storage. Multiple algorithms were assessed on training and testing datasets of experimental melt compositions by comparing the root-mean-square-error (RMSE) and the coefficient of determination. Following extensive testing and tuning of hyperparameters, the extremely randomised trees algorithm[3] performed best at classifying the saturation of input data, accurately predicting the saturation 83% of the time. The Super Learner algorithm[4] was the most effective at predicting pressures, with an RMSE of 1.5kbar. The algorithm was trained with experimental data in the 0-12 kbar range so is appropriate for probing crustal magma processes, potentially helping to differentiate between the stacked sills and trans-crustal mush models of oceanic crust generation.

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Simulations of foamy magma

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Magmatic foam -- characterised as a magma that is more than two-thirds gas by volume -- can be found in various parts of the volcanic plumbing system, particularly at shallow depths. Unusually, it lacks the surface-active compounds, known as surfactants, that prevent film rupture in most foams. Instead, magmatic foam is stabilised purely by its viscosity. This is a property vitally important to the mechanisms that drive eruptive phenomena. A fundamental understanding of viscosity-stabilised foams is therefore essential for a more complete model of volcanic eruptions and their subsequent impacts. However, while successful theory exists for surfactant-stabilised foams, few works detail their viscosity-stabilised counterparts. We aim to address this through the development of mathematical models, coupled with numerical simulations, that will be used to investigate and quantify a number of behaviours: porosity evolution, textural maturation, bubble decoupling, film rupture, and structural collapse. We anticipate that our results will provide novel insight into the conditions under which magmatic foam forms and breaks down, supporting the development of improved conceptual and numerical models of the behaviour of volcanic and magmatic systems.

Years of Deep Magmatic Unrest Prior to the 2021 Fagradalsfjall Eruption

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The 2021 Fagradalsfjall eruption provides a unique opportunity to quantify near-Moho magmatic processes. For the first time a detailed seismological and geodetic record of magmatic unrest can be linked to the petrology of deep-sourced erupted products. The inferred depth of pre-eruptive storage of 15-20 km is estimated from petrological barometry[1] and lies close to the seismically-determined Moho depth in the area[2]. After 8 centuries of repose, volcanism on the Reykjanes Peninsula recommenced on 19th March 2021. Eruption onset was preceded by 8 months of shallow unrest on the Fagradalsfjall system as recorded by seismicity. Upper-crustal deformation in the neighbouring volcanic systems was linked to shallow earthquake swarms and geodetic inflation/deflation sources from the end of 2019. Fresh lava and tephra from the first month of eruption contain a primitive crystal cargo of olivine (Fo_{84-89}), plagioclase (An_{78-90}), clinopyroxene (Mg# of 0.82-0.88), and Cr spinel (Cr# of 0.39-0.50). A 1D finite difference diffusion algorithm, *Autodiff*, was used to model Fe-Mg interdiffusion in 123 olivine crystals. *DFENS*, a diffusion chronometry method that combines finite element models with a Nested Sampling Bayesian inversion, was used to model 1D Mg diffusion in 51 plagioclase crystals. The recovered timescales from these methods are in good agreement, with medians close to 100 days. The timescales appear to record gradual disaggregation of crystals from a near-Moho mush into a new host liquid. The crystals are not initially in equilibrium with this liquid. The rate of initiation of disequilibrium profiles increases as unrest focusses on Fagradalsfjall alone. About 25% of the profiles, however, give initiation times that predate shallow unrest at Fagradalsfjall and are coincident with shallow deformation in neighbouring systems. Near-Moho storage zones that fed Fagradalsfjall were disturbed in synchrony with widespread unrest of shallow systems across the Reykjanes Peninsula.

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Who are the volcanologists?

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In this contribution, we reflect on the progress of Equality, Diversity and Inclusion (EDI) in volcanology by presenting accounts of witnessed and experienced discrimination from volcanologists around the world and statistical trends related to gender-identity, career stage and geographical distribution. We acquired membership data from the leading international organisations with a focus on volcanology (IAVCEI, AGU VGP division and EGU GMPV section). These data include self-identifying gender identity, career stage and geographical location of the members. Data from the leading volcanology journals (the Journal of Volcanology and Geothermal Research, and the Bulletin of Volcanology) is restricted to geographical location of the lead-author, but also documents the percentage of submission, rejection and acceptance of manuscripts. Our analysis also includes volcanology awards and positions on volcanology committees.

Collectively these data document the sobering current state of EDI within the volcanology community and should be a call to action for organisations, scientific journals, and individuals. We share suggestions and recommendations from other disciplines on how individuals, research groups and organisations can promote, develop, and implement new initiatives to call out and tackle discrimination in volcanology work and study, and advance EDI in the volcanological community.

Fundamental flow regimes during dyke propagation

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Scaled analogue experiments were conducted to explore the effect of magma flow regimes, characterised by the Reynolds number (Re), on the transit of magma through the lithosphere via fractures. An elastic, transparent gelatine solid (the crust analogue) was injected by a fluid (magma analogue) to create a thin, vertical, and penny-shaped crack that is analogous to a magma-filled crack (dyke). A vertical laser sheet fluoresced passive-tracer particles suspended in the injected fluid, and particle image velocity (PIV) was used to map the location, magnitude, and direction of flow within the growing dyke from its inception to its surface rupture. Experiments were conducted using water, hydroxyethyl cellulose (HEC) or xanthan gum (XG) as the magma analogue. The results suggest that Re has significant impact on the direction of fluid flow within propagating dykes: $Re > 0.1$ (jet-flow) is characterised by a rapid central rising fluid jet and downflow at the dyke margin, whereas $Re < 0.1$ (creeping flow) is characterised by broadly uniform velocities across the dyke plane. Re may be underestimated by up to two orders of magnitude if tip velocity rather than internal fluid velocity is used, meaning that turbulent flow in dykes may be more common than is currently assumed. In nature, these different flow regimes in dykes would affect the petrological, geochemical, geophysical, and geodetic measurements of magma movement, meaning that reconstructions of volcanic plumbing system architecture and their growth may need to be revisited.

Numerical modelling of crustal magma chamber dynamics: fractionation, assimilation, recharge

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Crustal magma chambers have long been proposed as the locus of magmatic differentiation as well as the source of volcanic eruptions. The dynamics of a magma chamber are thought to arise from a combination of fractional crystallisation, wall rock assimilation, mafic recharge, and volatile degassing. The time evolution and eruptability of magma chambers has previously been studied using 0-D box models[1]. These have, however, not resolved the spatial evolution or reactive transport dynamics of the complex mixture of magmatic melt, crystals, and vapour bubbles that give rise to the phenomena in question.

Here, I introduce a newly developed 2-D numerical model based on the three-phase fluid mechanics of crystals and bubbles suspended in melt coupled to the strongly simplified chemical thermodynamics of silicates plus volatiles, as well as the geochemical evolution of idealised trace elements and stable isotope ratios. The mathematical model is based on a recent theory framework[2], and its numerical implementation in Matlab utilises the finite-difference staggered-grid method[3]. Once published, the simulation code will be made openly available to the community.

Early results of fractional crystallisation, wall rock assimilation, and mafic recharge models demonstrate the utility of the numerical approach. Various expressions of stratified convection are observed under a range of conditions. Not surprisingly, the presence of an exsolved volatile phase has major implications on the internal dynamics. A key advance of the model is that it elucidates relationships between geochemical signatures and underlying magma chamber dynamics, hence providing new avenues of process-based interpretation of igneous rock geochemistry.

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Lithological controls on sill development in sedimentary basins: Field observations from the San Rafael Volcanic Field, Utah.

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Sills and dykes have been a studied topic for decades, and many studies have indirectly investigated sill propagation and architecture by using numerical models. Such studies are important to investigate how igneous intrusions behave at the time of the emplacement, but these often ignore the complexity observed in real magmatic intrusions.

Our study investigates how sedimentary and lithologic heterogeneity may infer strong controls on sill propagation and -evolution, which will significantly change distances ranging from e.g. 1 km- to 100 m. A key question is how such heterogeneity will influence the large-scale architecture of sills, and how the overall emplacement features in a single sill changes once it propagates into different lithologies. Understanding how sedimentary heterogeneity influence sill development on such scales may lead to better forecasting of volcanic eruptions, subsurface resources and general basin understanding.

Our dataset consists of three large localities: (I) *Cedar Mountains*, a 5.5 km long cliff-face showing complex sills with various geometries, (II) *Cathedral Valley*, a 250 m long cliff face showing a complex sill consisting of multiple splays, and (III) *Mussentuchit Valley*, a 1.3 km long meandering valley showing a 3D exposure of a 12 m thick sill . The first two field areas, the sills occur within red silty sandstones with interbedded mudstone, and for the latter mainly thinly bedded and cross-bedded sandstones.

Observations from the field area shows that the sills in San Rafael Swell prefers and exploits locally occurring discontinuities, such as flooding surfaces containing silt, and undulating anhydrite veins. This suggests that sill tips prefer weak discontinuities and will alter their initial propagation path to follow local lithology. This implies that certain local stratigraphic intervals exert strong controls on sill geometry and propagation.

Project PORO-CLIM initial results: A new oceanic crustal record of magma productivity throughout initiation of the North Atlantic Igneous Province

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In May 2021 project PORO-CLIM acquired a geophysical dataset across the little-known Porcupine and Rockall Plateau passive margins in the Northeastern Atlantic. The project aims to study the initiation of the North Atlantic Large Igneous Province, and test its relationship with the Palaeocene-Eocene Thermal Maximum (PETM) global climate change Event[1]. Profile 1, a 400 km long deep seismic (MCS and OBS) profile, contains a continuous latest-Cretaceous to early-Eocene oceanic crustal thickness record, spanning the full waxing-waning cycle of North Atlantic Igneous Province (NAIP) emplacement. Oceanic crustal thickness can be directly interpreted as a record of magma productivity and hence mantle temperature. The PORO-CLIM dataset represents the first continuous high-resolution record of the entire waxing and waning cycle of mantle temperature during the initiation of any of the world's Large Igneous Provinces. As such it presents a unique opportunity to study the processes involved in the initiation of Large Igneous Provinces. Profile 1 is also the first whole crustal seismic record across Eriador Ridge, thought to be the crustal trace of the anomalously hot mantle pulse that caused NAIP sill province emplacement, spanning the PETM. The new seismic dataset shows Eriador Ridge contains a previously unknown double peak in volcanic production. This presentation will outline the initial findings from seismic data analysis, including a preliminary magma production record spanning LIP initiation, the relationship between magma productivity and the PETM, and the significance of the previously unknown double peak of volcanic production within the Eriador Ridge structure.

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Turbulence and bubbles: acoustic observations of fire fountains during the 2021 Fagradalsfjall eruption, Iceland

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The 2021 eruption within the Fagradalsfjall volcanic system in south-west Iceland provided a rare opportunity to observe and describe eruptive activity from a persistent fissure event. The eruption, which began on 19th March, was characterised by persistent effusive activity punctuated by explosive fire fountaining events and produced lava flows covering an area of 4.85 km^2. On 21st April, a four-element infrasound microphone array was installed approximately 800 m north-west of the eruption site to track activity that was occurring across five active vents at that time. After 1st May, activity became focused at one vent which displayed remarkable rhythmic fire fountain eruptions throughout the rest of the month and into June. Here we detail the key observations derived from acoustic data recorded during this phase of activity, including complementary insights from seismic and observational data. Least-squares estimates for back-azimuths and apparent velocities from data recorded by the infrasound array provides a high-resolution time-series of activity occurring within the vent. Each fire fountain event can be divided into at least three key phases depending on their frequency of the recorded acoustics which correlate strongly with visual observations of activity. Two phases are defined by the peak lava fountaining followed by turbulent lava bubbling which can be distinguished using a quantitative comparison to jet noise spectra. The third phase is characterized by sequences of high amplitude acoustics generated by large, distinct bubble bursts within the vent. These sequences sometimes exhibit an upward 'gliding' of frequencies which may be linked to downward draining of lava after each fire fountain and can be used to constrain the cross-sectional shape of the vent. Such close and almost continuous acoustic recordings of basaltic fissure eruptions are rare and provide a unique insight into the dynamics of high-velocity multiphase volcanic eruptions.

Volcanic ash in jet engines: bouncing, sticking, and spreading of molten glass droplets.

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In the last thirty years there have been more than 250 incidents of aircraft encountering airborne volcanic ash. This volcanic ash can have a serious detrimental impact on the jet turbine engines on these aircraft, reducing the efficiency of the compressor and the airflow through the engine, making an engine failure more likely to occur. Historically the policy of aviation authorities is for aircraft to avoid all airborne volcanic ash. This leads to great disruption, as when in 2010 the volcano Eyjafjallajökull erupted in Iceland and the resultant ash cloud caused a shut-down of European airspace. Molten droplets of ash may bounce, stick, or spread on impact with engine surfaces, depending on the impact angle, impact velocity, particle rheology and various surface properties. Ash sticking to surfaces presents a serious problem because it can easily block the air ducts in the turbine and restrict air flow through the engine. In this project we will develop a quantitative understanding of molten ash droplet behaviour, which can be used to determine the threshold ash concentration beneath which a jet aircraft can safely operate. In progress so far, data from previous experiments has been analysed to determine whether they are appropriately scaled to capture the behaviour of volcanic ash in jet engines. To do this we recast the physical variables as dimensionless numbers, to facilitate comparison between laboratory and jet engine scenarios. Two of the numbers used were the Ohnesorge number and the Weber number. The Weber number is a ratio of inertial to surface tension forces the higher this is the more likely the droplet will spread out on impact and the Ohnesorge number is a ratio of the elastic to viscous forces in the droplet. We find that the dimensionless numbers calculated from the experiments are very different from those calculated for volcanic ash in a modern turbofan engine operating at cruise conditions. This suggests that previous laboratory experiments have not accurately replicated the real behaviour of volcanic ash in a jet engine. We will build on this finding to design and conduct new experiments to investigate this problem, in the correct regimes of all the relevant dimensionless numbers.

Outgassing of CO_2 reflected in trace element chemistry of mineral phases at Oldoinya Lengai, N.Tanzania

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The largest amounts of volcanic CO_2 outgassing from the solid Earth are associated with carbonatites. Oldoinya Lengai in the East African Rift is the world's only volcano currently erupting carbonatite and so places important constraints on the processes involved in the saturation of CO_2 in evolving silcate-carbonate systems. The Oldoinya Lengai natrocarbonatites are spatially associated with nephelinites but their relationship is controversial. While the presence of globules of nephelinite in natrocarbonatite ashes (from the 1993 eruption) and evidence from nepheline-hosted melt inclusions, indicate immiscibility between a natrocarbonatite and a peralkaline nephelinite melt before eruption[1,2] and at 750-800 ºC[3], it has also been proposed that: the natrocarbonatites form from a cognate alkali-rich fluid or; the injection of carbonatite into sub-volcanic clinopyroxene-rich crystal mushes results in CO_2-driven explosive eruptions at Oldoinya Lengai[4].

Experimental studies of trace element partitioning during silicate-carbonate liquid immiscibility show that Ta, Zr, Hf and the HREE fractionate into the silicate melt and Na_2O, CaO, Sr, Ba, Nb plus the LREE preferentially fractionate into the conjugate carbonate (Veksler et al., 2005). Here, we build on previous studies by undertaking detailed chemical mapping (QemScan) and *in-situ* analysis of major and trace elements (by EMPA and LA-ICP-MS) in co-existing phenocryst and groundmass phases in a combeite-wollastonite nephelinite dyke, found on the middle slopes of Oldoinya Lengai. These silicate magmas are isotopically indistinct from the natrocarbonatites and potentially represent conjugate pairs[2]. Using temperature-dependent trace element partitioning for sodic alkaline magmas, we show that an abrupt change in Nb, Ta, Zr, Hf and HREE concentrations occurs between the Ca-rich cores (diopsides) and Na- and Fe rich rims (aegirine-augites) of pyroxene phenocrysts formed at temperatures between 750-800 ºC. We also observe concomitant variations in Nb/Ta at the rims of wollastonite phenocrysts, where they form combeite during CO_2 loss at Oldoinya Lengai.

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Heterogeneity of the Hawaiian Mantle Plume

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Historically, the geochemistry of MORB and OIB lavas has been used to constrain the composition and heterogeneity of the depleted mantle and mantle plumes, respectively. However, research by Lambart et al.[1] on the isotopic composition of mid-ocean ridge lower crustal cumulates revealed that homogenisation via magma mixing in crustal magma chambers masks the true extent of depleted mantle heterogeneity. This study demonstrated that minerals from these lower crustal cumulates, which may have crystallised prior to mixing, preserve greater chemical heterogeneity than locally erupted MORBs. As such, analysis of trace element and isotopic signatures in cumulate minerals from other locations worldwide can provide further insights into the heterogeneous nature of the Earth's mantle.

This project focuses on the heterogeneity that is contained within upwelling mantle plumes, testing whether Hawaiian lower crustal xenoliths reveal greater heterogeneity than their corresponding lavas. To achieve this, major and trace element analysis and $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopic analysis of clinopyroxene and plagioclase crystals in cumulate xenoliths, brought to the surface during the 1800-1801 Hualalai eruption, will be used to characterise the heterogeneity of the Hawaiian plume.

Our initial results provide insight into whether OIB xenoliths contain greater heterogeneity than their host lavas, and whether the plume mantle source is indeed more heterogeneous than previously anticipated.

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Eruption explosivity revealed by volatile chemistry in apatite

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Melt volatile budgets and magma ascent rates are two key parameters directly related to volcano eruption styles. However, it is challenging to determine which of the two plays a larger role in any given eruption. Recent experimental and modelling work[1-6] show that apatite can reveal both parameters and we report here an application[6] to Merapi volcano (Indonesia). We used apatite-based thermodyncamic[4] and diffusion[5] models, and experimental data[3] together with natural observations of the Merapi 2006 (effusive) and 2010 (explosive) eruptions to explore what roles volatile contents and ascent rates played in the change in eruptive style.

Secondary ion mass spectrometry (SIMS) analysis of volatiles (H_2O, CO_2, Cl, F and S) in apatite shows that compositions of crystals from the same eruption deposit distribute bimodally: crystals in amphibole contain at least three times more CO_2 (≥2400 ppm), and twice as much H_2O (0.9–1.0 wt.%) as those in apatite in clinopyroxene/plagioclase/groundmass. Using the apatite-based hygrometry *ApThermo*[4], we found melt volatile concentrations that correspond to at least two volatile staturation-magma storage depths: in the upper crust, and near Moho respectively. These depths are consistent with geophysical tomography studies.

Apatite microphenocrysts from the 2006 effusive eruption mostly have rims zoned of Cl (with ca. 3–7 µm lengths), whereas those from the 2010 explosive are unzoned. Timescales acquired from modelling F-Cl-OH diffusion in apatite using *ApTimer*[5] show longer time for 2006 (12–16 days) than 2010 (at maximum 3 days). Assuming similar magma ascent distances and conduit geometry, the mean ascent velocity before the 2010 eruption should be at least 4–5 times faster. The more buoyant pre-eruptive magmas in 2010 may result from a larger volume of deep magma-volatile flux that ascended faster from depth before eruption. This is also supported by the volcano summit fumarole gas measurements showing larger and more abrupt increase in the gas C/H ratios before the 2010 eruption.

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The fingerprints of volcanism: secondary atmospheres on rocky planets

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The geology of Earth and super-Earth sized planets will, in many cases, only be observable via their atmospheres. In these scenarios, volcanism can be used as a key window into planetary geochemistry, in particular the planet's mantle fO_2 and bulk silicate H/C ratio. We developed a new C-O-H-S-N thermodynamic model to simulate volcanic degassing over a wide range in mantle fO_2. This is then coupled with atmospheric chemistry models to simulate the growth of C-O-H-S-N atmospheres in thermochemical equilibrium, aiming to establish what information about the planet's mantle fO_2 and bulk silicate H/C ratio can be determined after cooling and mixing of volcanic gases into warm, pre-existing atmospheres. Our results indicate that warm (800 K) volcanic atmospheres develop distinct compositional groups which are dependent on the mantle fO_2, which can be identified using sets of (often minor) indicator species (Fig. 1): Class O, representing an oxidised mantle and containing SO_2 and sulphur allotropes; Class I, formed by intermediate mantle fO_2's and containing CO_2, CH_4, CO and COS; and Class R, produced by reduced mantles, containing H_2, NH_3 and CH_4.

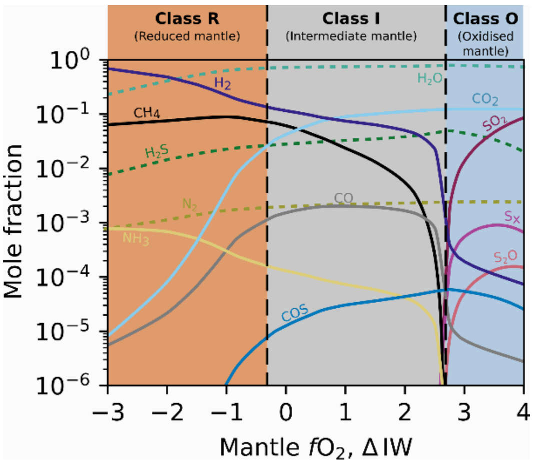

Figure 1: Chemical composition of a volcanic atmosphere after 1 Gyr of activity, split into 3 classes linked to their mantle fO_2

These atmospheric classes are largely independent of the bulk silicate H/C ratio. On warm, volcanically active planets, mantle fO_2 could be identifiable from atmospheric observations using JWST.

Farmers' perceptions of agriculture damage by the 1999-2014 eruptions of Tungurahua volcano, Ecuador, reveal the importance of tephra grain size, crop development stage and site-specific factors for assessing crop vulnerability to tephra hazard

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Agriculture is an economic pillar for the least developed countries. When these regions host explosive volcanoes, a serious risk for agricultural production arises as crops endure various injuries from tephra fall. However, our knowledge of crop vulnerability to ashfall is still fragmentary and new information is needed in order to strengthen the capacities of governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the agricultural impacts of a volcanic eruption. In order to gain new insights into the factors that govern tephra impacts on crops, we collected the farmers' perceptions of crop damage and production losses by tephra in 15 villages affected by the 1999-2014 eruptions of Tungurahua volcano, Ecuador. The level of tephra-induced damage depends highly on crop morphological characteristics and development stage; the timing of the latter is dependent, among other factors, on altitude. Using these observations, we illustrate how crop vulnerability fluctuates spatially and temporarily in the surveyed area. The study also reveals that fine tephra (< 63 µm) is more harmful to crops than tephra containing coarser particles. The farmers responded to the tephra hazard by favouring crops more resistant to tephra, a practice that has reduced crop diversity.

Intraslab Earthquake (M_w 6.8) heralds first detected unrest at Socompa Volcano, Northern Chile

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While unrest or eruption triggered by earthquakes has been suggested at many volcanoes around the world, such events tend to involve either megathrust earthquakes ($M_w \geq 7.0$) or shallow moderate earthquakes (M_w 5.0-6.5, depth < 70 km) very close to the volcanoes in the brittle crust. Intermediate-depth (70-300 km) earthquakes have not generally been linked to volcanic unrest or deformation.

Here, we test the evidence for an intraslab earthquake triggering a sustained episode of volcanic uplift using measurements from Interferometric Synthetic Aperture Radar (InSAR) and Global Navigation Satellite System (GNSS). On 3rd Jun 2020, a M_w 6.8 earthquake, whose centroid depth is 112 km according to the United States Geological Survey, occurred beneath Northern Chile, without notable subsequent aftershocks above magnitude 5. To capture the surface deformation signals and determine how surrounding volcanoes responded to this earthquake, we process both the ascending and descending Sentinel-1 InSAR time series data from Jan 2018 to Oct 2021 over this area. Our preliminary results find that the Socompa volcano, which neither has recent historical eruptions nor any other evidence of unrest, shows significant uplift signals above background noise levels after the earthquake event time. Given the distance - Socompa is located ~120 km south-southeast of the earthquake epicentre - the static stress change would be insufficient to trigger fluid movement. However, dynamic stress can act over greater distances, and may have affected a magmatic zone near Socompa. We use a combination of InSAR and GNSS time series analysis to assess the temporal relationship between the earthquake and onset of uplift, with the goal of establishing whether uplift was instantaneous or involved some delay. In addition, we investigate deformation signals from other nearby active volcanoes (such as Putana, Cerro Overo, and Lazufre).

Our work suggests that volcanic unrest can be triggered by deep intraslab earthquakes. Given the magnitude and depth of the earthquake in our study (neither considered as megathrust nor shallow), it implies that the earthquake-volcano interactions might be more universal than previously thought and thus similar intraslab events should be taken into account in the future studies.

Bubble chain phenomena in a shear-thinning magma analogue

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Passive degassing is a common process at many basaltic volcanic systems and consistently makes a greater contribution to total volcanic gas emissions than eruptive degassing. The exact mechanism for decoupled gas flow and open-system degassing is not fully understood, but may be related to permeable gas flow through connected bubbles or pathways. We test this hypothesis using experiments with hydroxyethyl cellulose (HEC), which is a non-Newtonian, shear-thinning solution that is well-characterised for magma analogue experiments[1]. We observe the formation of bubble chains[2] in HEC solutions that are sufficiently concentrated to show strongly shear-thinning behaviour, and across a range of flow rates, which we constrain. We combined these analogue experiments with rheological measurements and our analysis suggests that the shear-thinning and viscoelastic properties of HEC play a fundamental role in the observed bubble chain phenomena. We also concluded that the concentrations of HEC solution used in our experiments are suited for simulating shear-thinning and viscoelastic magmas, raising the possibility that bubble chain structures could form in magmas.

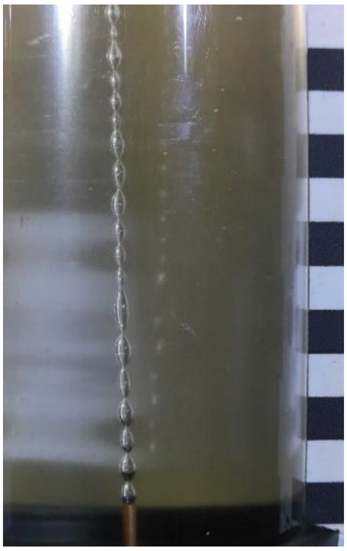

Fig. 1: bubble chain structure in 1.7 weight % HEC solution at 0.16 L min^{-1} gas flow rate in a 6.5 cm diameter pipe. Black and white ruler markings represent 1 cm each.

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Determining the vertical scale in videos of lava fountains from gravitational acceleration of single clasts at their zenith

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Videography is a popular tool for monitoring and characterising volcanic eruptions. Video records of lava fountaining episodes allow us to infer eruption parameters such as fountain heights, exit velocities, and pulse durations and frequencies, which may inform us on the subsurface processes that operate within the sub-volcanic plumbing system. However, the evolving shape and size of the natural features surrounding eruptive vent make it difficult to convert pixels in an image to meters in reality, due to the lack of fixed reference points with which to compare dimensions. In this poster, we present a new method for determining the vertical scale in videos of lava fountains. We measure the vertical pixel-position of clasts near their zenith, over successive frames, and convert this to an acceleration. By assuming that the only force acting on single clasts near their zenith is gravity, we use the clast motion to determine the scale – mapping pixels to metres. Geometric considerations around the viewing angle and lens distortions are discussed and corrected for. We validate this method with laboratory experiments using water fountains and vertically projected light plastic balls, which act as analogues for lava fountains and single clasts, respectively. An example of field application is then provided from the 2018 fissure eruption at Kilauea (Hawaii, USA). This approach will be useful to physical volcanologists for monitoring the dynamics of eruptions that produce fountains and/or ballistics from video records, which are becoming increasingly available both from scientific teams and from a wider community of tourists and volcano-enthusiasts.

Elements of sheet intrusions: building blocks of volcano plumbing systems

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Sheet intrusions such as dykes and sills are the fundamental building blocks of volcano plumbing systems. Networks of sheet intrusions are also capable of transporting magma across vast lateral distances, and may be intermittently active for millions of years. Yet most sheet intrusions are thin, typically centimetres to decametres thick, raising the question how can they transport magma over long distances, over long periods of time without solidifying? We know that many dykes and sills do not inject as continuous sheets, but rather comprise discrete isolated elements that eventually coalesce as magma input continues and they inflate. Here we explore how the preservation of these elements within sheet intrusions may act to channelize and insulate magma, allowing it to intrude further without solidifying. We will examine the geometry of these elements at various scales and use rock magnetic techniques to unravel how magma may flow within them. Our journey will take us to sills buried offshore NW Australia, to the Traigh Bhan na Sgurra sill on the Isle of Mull, and to magma fingers of the Shonkin Sag laccolith in Montana. Our work suggests that the evolution of magma flow within elements is complex, more so than flow within a continuous sheet intrusion. Preliminary observations indicate that even when coalesced, magma flow within elements may remain relatively isolated, serving to channelize intrusions. Such channelization raises questions regarding the role of elements in building volcano plumbing systems, and whether the mixing between elements is restricted and could limit the volume of magma available for eruption.

Variation of plagioclase shape with size in intermediate magmas: a window onto incipient plagioclase crystallisation

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Volcanic rocks commonly display complex textures acquired both in the magma reservoir and during ascent to the surface. While variations in mineral compositions, sizes and number densities are routinely analysed to reconstruct pre-eruptive magmatic histories, crystal shapes are often assumed to be constant, despite experimental evidence for the sensitivity of crystal habit to magmatic conditions. Here, we develop and use a new program for calculating 3D shapes from 2D crystal intersection data to study variations of crystal shape with size for plagioclase microlites (<100 µm) in intermediate volcanic rocks. The smallest crystals (<5 – 10 µm) tend to exhibit prismatic 3D shapes, whereas larger crystals show tabular habits. Crystal growth modelling and experimental constraints suggest that this trend reflects shape evolution during plagioclase growth, with nucleation as (prismatic) rods and subsequent preferential growth of the intermediate dimension to form tabular shapes. Plagioclase microlite shapes are therefore strongly dependent on the available growth volume per crystal, which decreases during crystallisation as crystal numbers increase. Our proposed growth model suggests that the range of crystal shapes developed in a decompressing magma is controlled by the temporal evolution of undercooling and total crystal numbers, i.e., distinct cooling/decompression paths. For example, in cases of slow to moderate ascent rates and quasi-continuous nucleation, crystals formed early grow larger and develop tabular shapes, whereas late-stage nuclei form smaller, prismatic crystals. In contrast, rapid magma ascent may suppress nucleation entirely or, if stalled at shallow depth, may produce a single nucleation burst associated with tabular crystal shapes. Such variation in crystal shapes have diagnostic value and are also an important factor to consider when constructing CSDs and models involving magma rheology.

St Vincent Eruption 2020-2021: Evaluation of the volcanic crisis communications campaign

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During the 2020-2021 eruption of La Soufriere, St. Vincent, the Seismic Research Centre at The University of the West Indies (SRC) played a major role in supporting communication of hazard and risk information to publics and stakeholders across St. Vincent. Due to COVID-19 restrictions, the communications campaign was heavily reliant on social media channels and TV and radio broadcasts, rather than in-person community education and communication sessions. Although the communications approach sought to be inclusive of all members of the affected communities where possible, it was considered possible that the more vulnerable residents, such as the elderly, children, and those with low levels literacy were excluded from the communication efforts.

In order to establish effectiveness of the crisis communications campaign at engaging communities and stakeholders with relevant information and to identify areas for improvement, a large-scale evaluation campaign was conducted in St Vincent in August 2021. Comprising an online and in-person survey, community focus groups and stakeholder interviews, the evaluations engaged over 700 residents. The results to-date demonstrate that radio broadcast are the most important communication tool for broad community reach, but that person-to-person information sharing was more important in the most exposed communities. Agencies such as the Red Cross and grassroots community disaster preparedness groups were instrumental in the spread of information to those most vulnerable within the most at-risk communities. However, social media was also found to be highly effective at communicating information to the diaspora, which in turn was communicated to family and friends on island through mediums such as WhatsApp.

Here we present some of the early findings of this research and provide suggestions and considerations to inform future crisis communication campaigns in St. Vincent and the wider Caribbean region.

Global catastrophic risk from lower magnitude volcanic eruptions

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Currently the dominant narrative for global catastrophic risk (GCR) scenarios for volcanic eruptions considers a supersizing of the hazard element of the risk equation, with high magnitude eruptions of VEI 7+ considered the primary mechanism by which humanity is most likely to be substantially impacted. However, this current narrative fails to accommodate the vulnerability aspect of the risk equation, where supersizing the vulnerability element may mean that lower magnitude eruption (VEI 3-6) may constitute a GCR risk — events that might inflict damage to human welfare on a global scale.

Increased globalisation in our modern world has resulted in our over reliance on global critical system – networks and supply chains vital to the support and continued development of our societies (e.g. submarine cables, global shipping routes, transport and trade networks). We observe that many of these critical infrastructures and networks converge in regions where they could be exposed to moderate-scale volcanic eruptions (VEI 3-6). These regions of intersection, or *pinch points*, present localities where we have prioritised efficiency over resilience, and manufactured a new GCR landscape, presenting a scenario for global risk propagation. We present seven global pinch points, including the Strait of Malacca and the Mediterranean, which represent localities where disruption to any of these systems can result in a cascade of global disruptions. This is exemplified by 2010 Eyjafjallajökull VEI 4 eruption which resulted in the closure of European airspace and cascaded to cause global disruption to just-in-time supply chains and transportation networks.

We suggest that volcanic risk assessments should incorporate interdisciplinary systems thinking in order to increase our resilience to volcanic GCRs.

The origin of tachylite clasts in the 1959 Kīlauea Iki (Hawai‘i) eruption products

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Magma mingling and mixing are common at basaltic volcanoes and play a fundamental role in magma petrogenesis and eruption dynamics, yet there are rarely opportunities to constrain their mechanisms and consequences directly. Here we present textural observations of tephra from the 1959 Kīlauea Iki eruption at Kīlauea Volcano, Hawai‘i, where 16 discrete episodes of Hawaiian fountaining took place over five weeks. Each episode consisted of two parts: a high fountain and refilling of the lava lake, then lava lake drainage[1]. Analysis of melt inclusions[2,3] has shown that erupted products were progressively more volatile-poor through the 17 episodes, thought to reflect mixing of magma from shallow and deep reservoirs, with drained back, outgassed lava from the lava lake[2]. The erupted products are glassy scoria and Pele’s tears, with both sideromelane and tachylite components. The tachylite forms discrete clasts a few mm to cm in size, which are dark and highly microcrystalline, as well as convolute, thin mingled streaks. Tachylite is associated with large, coalesced vesicles. Here we present textural data for scoria erupted during episodes 1, 3, 15 and 16 obtained using scanning electron microscopy and optical imaging and analysed using ImageJ software. We quantify tachylite proportions and textures as well as the bubble size distributions for sideromelane and tachylite-rich samples. The nature of the tachylite component changes systematically through the eruption and its presence influences the nature of vesicularity. The tachylite may represent drained back, degassed magma and/or glassy ‘fallback’ fountaining scoria that has mingled with hotter melt in the conduit.

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Preservation of H_2O heterogeneity in the Icelandic mantle

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It is well established that the mantle is chemically heterogeneous on length scales of 10s of kilometres or less; a product of recycling melting residues and subducted lithosphere, followed by stirring and mixing during vigorous convective cycling. We might also expect these mantle components to have distinct H_2O concentrations, determined by their history of hydrous alteration near Earth's surface, devolatilization during subduction, or H_2O extraction during melting. However, the rapid diffusion of H^+ in mantle minerals will act to dampen or remove this H_2O heterogeneity during transport from the lower mantle. The persistence of H_2O heterogeneity can place a lower bound on the length scales of mantle heterogeneity.

Since subaerially erupted lavas lose most of their volatile element budget prior to or during eruption, volatile studies are limited to glasses quenched at high pressures, their eruption having occurred on the sea floor or at the base of glaciers. We combine new and existing H_2O, trace element, and radiogenic isotope analyses for glasses erupted on the submarine ridges adjacent to Iceland, subglacial glasses on Iceland, and olivine-hosted melt inclusions from 8 primitive Icelandic eruptions. To estimate pre-eruptive volatile concentrations, we develop methods for filtering melt inclusion datasets for the effects of H_2O degassing and H^+ diffusion.

Together, the datasets demonstrate pervasive small-scale H_2O heterogeneity is present throughout the mantle beneath Iceland and the surrounding spreading ridges, implying small-scale mantle heterogeneities are large enough that H^+ diffusion has not eroded their presence.

Variability of Slab Fluxes of Mobile Chalcophile Elements from Slab to Wedge: A Case Study of Popocatépetl Volcano, Mexico.

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Chalcophile elements are sulfur-loving elements many of which are considered economically important, such as copper and zinc, however our understanding of the processes which govern chalcophile element behaviour and accumulation into viable ore deposits at continental arcs, is lacking. In this study, we investigate the slab flux of mobile chalcophile elements into the volcanic system of Popocatépetl by utilising various element proxies.

Volcán Popocatépetl is an active Quaternary stratovolcano situated in Central Mexico. It lies along the Trans Mexican Volcanic Belt, approximately 70 km southeast of Mexico City [1]. This East to West trending continental arc results from the subduction of the Cocos plate and Rivera plate beneath the North American plate. Popocatépetl products consist predominantly of basaltic-andesites and dacites.

Pyroxene hosted melt inclusions from volcanic rocks spanning ~40 ka were measured using EPMA and LA-ICP-MS to obtain major and trace element concentrations. Selected melt inclusions measure 25 µm - 50 µm and have MgO contents between 0-2% and silica contents from 60-80%. These samples are andesitic-dacitic in nature and show a good compositional correlation with whole rock data.

Volcanism experienced by continental arc subduction zones is the result of mantle melting in response to the addition of one or more slab components into the mantle wedge. We can use material erupted from arcs to identify these different slab components through the use of element proxies, which behave similarly during mantle melting but have distinctly different solubilities in hydrous fluids e.g. Th, Ba and Nb [2]. When compared to American arcs, Popocatépetl melt inclusion Th/Nb ratios show a dominant melt component. Several chalcophile elements including Pb and Tl follow this trend, however others e.g. Cu are not so well constrained. The difference in trends between Popocatepetl and Mexican arc data highlight along-arc heterogeneities in slab flux.

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New U-Pb age constraints from plutonic enclaves preserved in alkaline volcanic rocks of oceanic islands - Fernando de Noronha Archipelago, Southwest Atlantic Ocean, northeast Brazil

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Plutonic enclaves provide evidence of magmatic processes in the deep feeder zones of volcanic edifices. Here, we present a petrographic, geochemical (whole-rock lithochemistry and isotopic Sm-Nd) and geochronological (U-Pb on zircon, apatite and titanite) studies on a plutonic enclave from a pyroclastic deposit of the Remédios Formation, a basal unit of the Fernando de Noronha Archipelago (FNA), Southwest Atlantic Ocean, Brazil. The FNA oceanic island shows a highly dissected upper portion of a Miocene-Pleistocene volcanic structure, rising 4 km above the ocean floor and reaching 323 meters above sea level. The Remédios Formation mostly occupies the central portion of the main island of Fernando de Noronha and consists of volcaniclastic deposits intruded by domes (mainly phonolite), plugs (essexite, trachyte, alkali-basalt). Dikes of ultrabasic composition to basic-intermediate composition cut those intrusions. The studied plutonic enclave mainly contains andesine, diopside, kaersutite, phlogopite, and minor amounts of magnetite and ilmenite, with accessory minerals such as apatite, titanite and zircon. Major and trace elements signatures from bulk-rock analyses show the enclave is under-saturated in silica and has a composition similar to the other rocks from the Remédios Formation, with typical REE enriched patterns (La/Yb_N = 13-14) The xenolith has ε_{Nd} = +1.7 to +2.2. The U-Pb zircon ages is 13.69 ± 0.14 Ma, while both titanite and apatite record a younger U-Pb age at 9.76 ± 0.94 Ma. The zircon age is interpreted as the crystallization age of the plutonic enclave, whereas the younger titanite and apatite ages are interpreted as reflecting the age of the explosive magmatism that formed the pyroclastic deposit of the Remédios Formation. These ages also indicate that the FNA magmatism was coeval with onshore continental magmatism found in northeastern Brazil.

Glaciovolcanism and geochronology of Late Pleistocene eruptions at Quetrupillán, Chile

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Quetrupillán is a volcanic complex in southern Chile (39°30’ S, 71°43’ W) and comprises a stratocone and a dispersed volcanic field on the stratocone’s flanks that is best developed south and west of the stratocone.

In combination with mapping and whole-rock geochemistry, the first Ar-Ar ages from the little-studied Quetrupillán Volcanic Complex indicate persistent trachyte-dominated volcanism during the last glacial period (Llanquihue). This corroborates and dovetails with recent studies of Quetrupillán’s trachyte-dominated Holocene volcanism[1] and indicates that for at least the past c.125 ka trachytes have been the main composition erupted at Quetrupillán.

A significant feature of Quetrupillán’s Llanquihue activity is glaciovolcanism, where eruptives encountered either ‘thin’ ice (<100 m) on the sloping flanks of the stratocone or thick ice (>300 m) filling a nearby glacial trough. Trachyte lava-ice interactions with different ice thicknesses and varying paleoslopes produced lava morphologies ranging from lava sheets less than 5 m thick to lava buttresses up to 150 m high. Exceptional exposure of proximal lithofacies enables the progression of lavas from vent to flow front to be investigated.

An unusual feature of Quetrupillán’s volcanism are the numerous fissure eruptions, and of particular note are two substantial fissure eruptions during the Llanquihue glaciation, along with smaller fissure eruptions during the Holocene[1].

The c.1,200 km long Liquiñe-Ofqui Fault Zone (LOFZ) is a major NNE-SSW strike-slip fault in Chile, and virtually all of the areas of active volcanism in the Southern Volcanic Zone of the Andes lie to one side of the LOFZ. However, Quetrupillán is different, as it lies between two strands of the LOFZ. Consequently, Quetrupillán’s flank eruptions may be more strongly influenced by LOFZ movements, and this may explain the relative abundance of fissure eruptions.

Given the unpredictability of fault movements on the LOFZ, there is potential for a sudden future fissure eruption at Quetrupillán, independent of any unrest and/or eruptive activity at the stratocone.

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Magma Reservoir Evolution Following Volcanic Sector Collapse

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Despite their relative infrequency, large-scale gravitational collapses can occur at all types of volcanic landforms from across all tectonic settings. Volcanoes are inherently unstable due to their construction and range of lithological properties. They also repeatedly undergo processes which further promote a variety of structural weaknesses, ultimately giving rise to an edifice prone to destabilisation.

Sector collapses can profoundly modify a volcano's morphology; the failing mass can be of the order of several cubic kilometres and in many cases cuts deeply into the edifice, including both the summit and portion of the volcano's central conduit. This results in the rapid removal and redistribution of a substantial volume of material across the surrounding landscape. Growing evidence suggests that this abrupt change in surface loading can significantly perturb the underlying magma reservoir, influencing pressurisation conditions and in turn, potentially manifesting as shifts in eruptive styles, rates and compositions on a range of timescales[1].

Difficulties in developing high-resolution reconstructions of pre- to post-collapse volcanic activity have resulted in a lack of detailed understanding of how magma systems are affected by edifice collapse. However, two unique sample sets which preserve the eruptive record spanning the major collapse of Ritter Island (Papua New Guinea) in 1888 and Anak Krakatau (Indonesia) in 2018, provide a rare opportunity to advance this understanding. This study builds on a body of preliminary investigations in which distinct changes in composition and behaviour of these volcanoes have been identified[2], therefore offering insights into the effect of rapid changes in surface loading on the activity of mafic arc-volcanic systems.

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Using seismology to probe the modern magma reservoir at Taupō volcano, New Zealand

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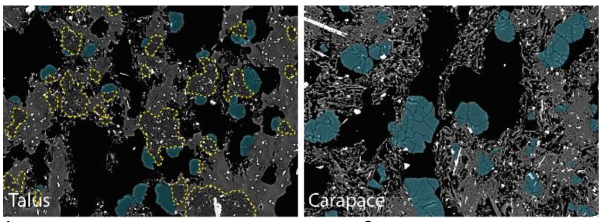
Taupō volcano, in the centre of North Island, New Zealand, is an active rhyolitic caldera volcano, now largely concealed beneath Lake Taupō. The volcano was the site of Earth's most recent supereruption (Oruanui ~25 ka)[1,2] and has erupted 28 times since then. It continues to display signs of unrest (seismicity and surface deformation), with periods of elevated unrest on roughly decadal timescales[3]. Any resumption of eruptive activity at the volcano would pose major hazards. Interactions between the magma reservoir and the regional tectonics that lead to unrest and possible eruption are thus a focus of current research. The likely location of the modern reservoir has been constrained by studies of past eruptive products and some geophysical imaging (gravity, broad-scale tomography). Earthquake patterns during a 2019 unrest episode have also been used to infer the location and size (>~250 km^3) of the modern-day magma reservoir[4], but its location and extent have not been directly imaged. Seismological methods are being used to investigate the Taupō reservoir, combining data from the national GeoNet seismic network with records from a 13 broadband seismometer temporary seismic network. Development of the temporary network approximately doubles the number of seismic stations within 10 km of the shore of Lake Taupō. We present here initial results on the characterisation of the seismicity in the Taupō region. These results include the improvement of earthquake locations with the addition of picks from the temporary stations and the use of automated machine learning phase picking and association techniques. We also present initial results of seismic tomography from the cross correlation of ambient noise between stations in the temporary network, with many of the paths between station pairs crossing the region most likely to contain the modern-day magma reservoir. We observe clear changes in the seismic signals across this region, with strong attenuation in local earthquakes and cross-correlations across the caldera.



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Vapor-phase cristobalite: Insights into cooling rates and outgassing in a submarine lava dome

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Vapor-phase (or metastable/secondary) cristobalite (VPC) is a silica polymorph commonly found in silicic lava domes with an outgassing hydrothermal system. While observations of VPC have been made in many dome systems, there is relatively little known about the exact temperatures and kinematics of vapor-phase cristobalite growth. In this study, we analysed ten samples acquired across a submarine rhyolitic lava dome at Havre volcano in the Kermadec Arc, New Zealand. Samples acquired from the *in-situ* carapace and dome flank talus show a variety of VPC-bearing groundmass textures (such as diktytaxitic void space between microlites), where *in-situ* samples from the top of the dome exhibit some of the most evolved VPC textures observed in any subaerial dome literature.

For each sample we determined: bulk porosity, pore space connectivity, and DRE density through He-pycnometry; VPC area fractions, size distributions and number densities through SEM image analysis; and major-element maps of VPC and surrounding groundmass through EPMA analysis. All VPC-bearing samples have near-fully connected pore space, even at porosities of 10-20%; samples with lower pore space connectivity have very little VPC, isolated in vesicles. The most evolved VPC-bearing samples (the carapace) have many, large vesicle-infilling VPC crystals, and in some cases, VPC re-filling diktytaxitic void space between microlites from prior glass dissolution. VPC growth also resulted in increases in bulk DRE from 2.38 up to 2.59 g cm^{-3}, which will have complex implications for dome strength and stability due to a combination of densification and hydrothermal devitrification. The extremely evolved VPC textures in a submarine dome may reflect the different cooling rates and outgassing environment in a more pressurized, fluid-rich, submarine system. The interior of a submarine lava dome may remain hotter for longer, with high-density, saline fluids trapped within the dome, creating an ideal environment for efficient glass dissolution and subsequent VPC precipitation and growth.

Ritter Island; recreating a volcano remotely

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The collapse of Ritter Island in 1888 removed 4.2 km^3 of material into the ocean[1]. This event has since become a key case study for similar events due to its well-documented catastrophic collapse and subsequent tsunami. Drone imagery data obtained by the scientific team of the So252 cruise in 2016 was used to create a 3D model.

The high-resolution structure from motion model of Ritter Island was produced using photogrammetry techniques. The resultant output of this model includes an orthomozaic image of the island (Figure a) and a digital elevation model (Figure b) both with a resolution of 15.7cm/pixel.

The orthomozaic image provides a detailed arial view of the island allowing high resolution digital mapping of the rock horizons. This includes mapping eastward dipping layered lava flows and cross cutting dykes at a meter scale. Various rock types, vegetation cover and erosional features were identified using colour variations in the data.

The elevation model gives us excellent detail on the topography of the island giving it a height of 119.7m at its peak and measurements of the eastern slope of 36.3° and western slope of 42.4°. The volume of the subaerial Island is 13202708 m^3. The elevation map was also used to create the base upon which a geological map was created.

This detailed information from Ritter Island will be important to further research about the nature of the volcanic collapse that occurred here.

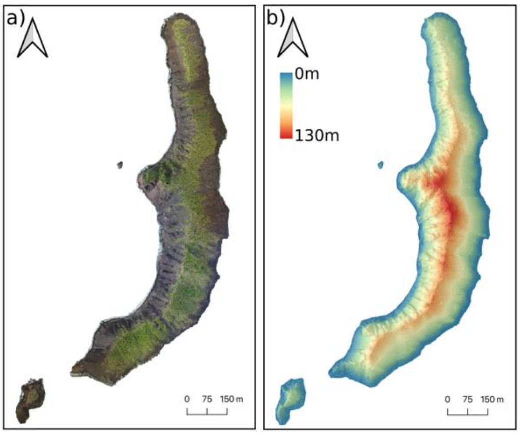

Figure: The outputs from the structure from motion model of Ritter Island; a) the orthomozaic, 15.7cm/px, b) the digital elevation model, 15.7cm/px

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Diffusion methods in volcanic petrology: where have we come from and where are we going?

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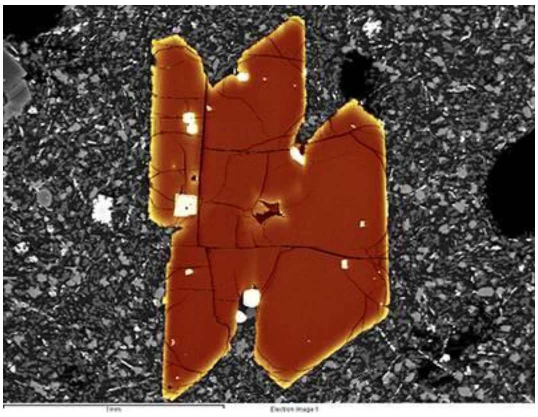
Diffusion chronometry methods have been applied to volcanic materials for some years in an array of different volcanic settings, from basaltic to rhyolitic, from monogenetic paroxysm to supervolcanic eruption.

These studies have progressed over the years from a handful of crystals taken from a single specimen to larger datasets acquired across hundreds of crystals from multiple samples spanning the products of an eruption sequence. Efforts to try and connect petrological chronologies with contemporary geophysical records show a mixed record of success which is consistent with the precise volcanic processes which are accessible to each technique and which may reflect the nature of the volcanic systems being studied.

As the techniques of diffusion chronometry become more widely integrated both within petrological studies and with external chemical or geophysical datasets it seems a good time to reflect on the evolution so far and the main questions that remain, both in terms of the technique itself but also the big questions that have been raised. One important question is how a magmatic system prepares for and evolves towards eruption. Another key question concerns the potential to use diffusion methods to extract monitoring-relevant information from erupted samples that are thousands or even tens of thousands of years old. Does this potentially unlock a wealth of previously inaccessible information?

Ultimately, though, the questions return to the crystals. Where have they been, what have they encountered, and what can they tell us?



This false-coloured BSE image of zoned Piton de la Fournaise olivine rests as a tribute to the various people I have been privileged to work with over the years, and whom I intend to be citing...

Evaluation of pyroxenite as a source of post-subduction alkali basalts in the Antarctic Peninsula

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A surprisingly common feature of both oceanic and continental destructive plate margins is the close spatial and temporal association between subduction-related calc-alkaline magmatism and 'within-plate' alkaline basalts; the latter having similar geochemical characteristics to ocean island basalts (OIBs). Examples of this association have been reported from locations along the Pacific margin of the Americas and the Antarctic Peninsula [1, 2], but their origin remains enigmatic.

Post-subduction alkali basalts from Seal Nunataks, Antarctic Peninsula (Fig. 1), exhibit very low CaO concentrations for a given MgO content (~8 wt% CaO at 9 wt% MgO). This feature, coupled with a lack of a recognisable subduction component in their trace-element geochemistry, has been cited as evidence that the basalts were generated by melting of pyroxenite hosted in a young, hot subducted slab following subduction of half of a spreading ridge [2]. Here, we report new high-precision electron microprobe and LA-ICP-MS data from olivine phenocrysts (Fo_{76-84}) in these basalts. Ca contents of olivine are significantly lower (~1230 ppm at Fo_{84}), and Ni contents higher (~1990 ppm at Fo_{84}), than those that would be expected from melting of mantle peridotite; the Seal Nunataks data exhibit a continuum with that for olivine in pyroxenite-dominated basalts from Koolau, Hawaii [3]. Similarly, Fe/Mn (70-90) are significantly higher than expected for peridotite-derived melts and again in the same range as Koolau basalts [3]. The olivine trace element geochemistry thus supports a hypothesis of a pyroxenite-dominated source for the basalts, and conflicts with recent findings for basalts from James Ross Island (JRI; Fig. 1), which is in a similar tectonic setting but 300 km to the north [4].

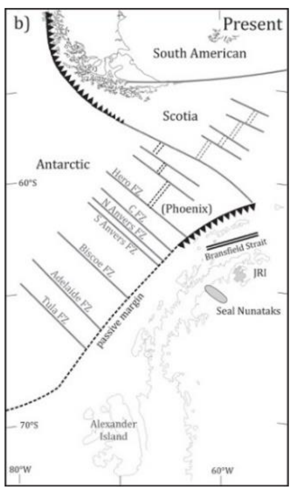

Fig. 1: Map of the Antarctic Peninsula showing locations of the Seal Nunataks and subduction zone to the west (black triangles) [2].

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Magnesium Partitioning in Plagioclase with Notable Implications for Diffusion Chronometry

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Plagioclase is a widespread phase in magmatic rocks and is an important archive of magmatic processes. Modelling diffusion of Mg in plagioclase is used to estimate the timescales of magmatic processes that operate weeks to decades before eruption. To do this, however, requires knowledge of how the anorthite composition of plagioclase influences partitioning of Mg.

Here we compiled a database of 904 calculated Mg in plagioclase partition coefficients using mineral rim-melt pairs from phase equilibria experiments and natural samples. The dataset includes a comprehensive range of plagioclase compositions (An_{15} - An_{90}), melt compositions (40 – 78 wt% SiO_2) and temperatures (75 –1400 °C). We find that Mg-in-plagioclase partition coefficients depend on these parameters, which is in agreement with previous studies[1]. Crucially, we find that the dependence on anorthite content has a major inflection at compositions that correspond to the C1́-I1́ structural phase transition (An_{60} at 1000 °C). Mg-in-plagioclase partition coefficients have a positive dependence on anorthite in the C1́ domain, and a negative dependence in the I1́ domain. We also find that this change in partitoning behaviour can account for Mg distributions in natural plagioclases observed in mafic to silicic systems including the Galápagos, Santorini, Krakatau and Toba.

The dichotomous nature of Mg-in-plagioclase partitioning has significant implications for diffusion chronometry. The shape of Mg 'quasi-state' equilibrium profiles will largely depend on the structural state of plagioclase. Crystals that have compositional zones on either side of the C1́-I1́ transition could potentially develop flat 'quasi-state' equilibrium profiles. The temperature dependence of the C1́-I1́ transition means that equilibrium profiles in these crystals could be used to estimate crystal storage temperatures. Our new empirical partitioning relationship is particularly important for interpreting plagioclase Mg profiles in intermediate and silicic systems, and for setting up initial conditions for modelling. Profiles that were previously interpreted to show little diffusion, may be close to equilibrium and *vice versa*. This will be highly significant for understanding thermal states and magmatic histories of at a range of tectonic settings.

[1]Dohmen, R., & Blundy, J. (2014). *American Journal of Science*, *314*(9), 1319-1372.

Experiments on Gas-Escape Pipe Formation in Pyroclastic Flow Deposits

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Coarse-enriched and/or fines-depleted gas-escape pipes (GEPs) or 'elutriation' pipes are common features of non-welded pyroclastic flow deposits. These structures are generally thought to form during deposition through hindered settling and channelised elutriation of fine and low-density particles out of a rapidly aggrading current. However, there are GEPs that cross-cut bedding and unit boundaries, suggesting post-deposition formation is feasible. We present experiments to explore the conditions conducive to GEP formation within a pyroclastic flow deposit. Bimodal and trimodal mixtures of spherical particles of varying size, proportions (ratio of coarse, intermediate, and fine), and grain densities were aerated in a tank with a porous base allowing an upward airflow through the mixtures. Experiments show that GEPs can form in (initially static) beds of particle mixtures via channelised bubbling and percolation, stemming from local variations in the minimum fluidisation velocity of the mixture. In coarse-rich beds, when the gas-flow exceeds the minimum fluidisation velocity of the fine component, fine particles are carried up (i.e. elutriated) by gas, percolating through the relatively large interstices of a coarse particle framework. This generates GEPs depleted in fines relative to the surrounding mixture. However, in fines-rich beds, particle percolation is inhibited with GEPs forming via channelised bubbling when the gas-flow exceeds the mixture minimum fluidisation velocity. Bubbling results in the sedimentation of coarse particles producing GEPs that are both fine-depleted and coarse-enriched relative to the surrounding mixture. In a second set of experiments, syn-depositional conditions were simulated by completely fluidising mixtures using a high gas flux and then allowing the particles to settle by turning off the gas input. With coarse-rich trimodal mixtures this produced a deposit with vertical coarse-enriched and fines-depleted structures. If gas was subsequently fluxed through, these structures acted as preferential gas-flow conduits and demonstrated how secondary gas flow can enhance syn-deposition structures. However, regardless of formation mechanism, GEPs collapse if the gas-flux exceeds the coarse component's minimum fluidisation velocity. Combining experimental results with analysis of pipe and host samples from the Xáltipan Ignimbrite (Mexico), we propose that percolation alone is insufficient to generate GEPs in pyroclastic deposits. Instead, when the gas flow exceeds the minimum fluidisation velocity of the deposit but not the minimum fluidisation velocity of the coarsest material, fines-depleted coarse-enriched GEPs form via channelised bubbling. We note that both syn- and post-depositional models of GEP formation require an understanding of gas-particle-particle interactions as fluidisation and hindered settling both involve upwards flow of gas relative to particles, albeit with different frames of reference.

Dynamics of deep-submarine volcanic eruptions

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This presentation will explore the dynamics of deep-submarine explosive eruptions, 1-4 km below the sea surface, and the dispersal of pyroclastic material in the water column. We show using a model of a turbulent fountain, that after rising 10’s m above the vent, the erupting particle-laden mixture entrains and mixes with sufficient seawater that it becomes denser than seawater. The momentum of the resulting negatively buoyant fountain only has sufficient momentum to rise a few hundred metres above the seafloor. We present a series of novel analogue experiments which shows that particle sedimentation at the top of the fountain can enable some buoyant fluid to rise above the fountain and carry with it a fraction of particles high into the water column. Simultaneously, dense material collapsing from the top of the fountain forms aqueous pyroclastic flows which spread along the base of the tank. From these experiments, we show that these processes can produce the far-reaching fall and flow deposits, 1000's m, observed at deep-submarine volcanic sites such as the Gakkel Ridge, the Arctic ocean,[1-3,] Marsili Seamount, Italy[4, 5] and the Havre volcano, the Kermadec arc[6]. We investigate the controls on the concurrent fall and flow deposits observed in our experiments and provide a framework to constrain the eruption rates of this important style of eruption.

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Iezzi, G. et al. Deep sea explosive eruptions may be not so different from subaerial eruptions. Sci. Reports 10 (2020).

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Magmatic interaction between mafic-ultramafic rocks and intruding syenites (São Sebastião Island, Brazil)

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Magma mixing is a common magmatic process that ranges from purely physical mingling to complete hybridization of chemically distinct magmas. Some of the typical pieces of evidence for mixing are magmatic enclaves and crystal disequilibria [1]. A coastal outcrop on the northside of the São Sebastião Island (SE Brazil) displays such evidence as an array of blocks and enclave swarms of mafic-ultramafic alkaline rocks and melasyenite wrapped and fragmented by syenitic rocks and veinlets. Melasyenite also hosts mafic enclaves that exhibit corroded contact and fragment dissemination. The geometry of the headland and well preservation of the rocks make it a great case study to understand the not-so-common instance of felsic magma intrusion into gabbroic rocks. We focused on detailed mineral chemistry guided by the field relations and textures with punctual analysis and X-ray compositional transect maps of the enclave and host rocks. One of the main mixing features of the outcrop, the melasyenite comprises alkali feldspar and recrystallized plagioclase grains with prevalent apatite-rich mafic clots. Previous whole-rock element compositional study [2] confirmed the hybrid nature of the rock. This is assumed as the assimilation of mafic-rock fragments into an initial syenitic magma pulse. The melasyenite were then brecciated alongside the mafic-ultramafic rocks by a later syenitic pulse, albeit not as intense. The amphibole-gabbros enclaves developed biotite-rich and fine granoblastic Na-plagioclase millimetric rinds, while clinopyroxene-laden haloes formed in the host rocks adjoined to the enclaves. The biotite was a reaction of amphibole with a hydrous K-rich fluid, and the high Ti content in the amphibole helped to develop Fe-Ti oxides and titanite in the rinds. Ca-Mg-Fe contamination of the surrounding host rock was responsible for the generation of the clinopyroxene, which has a syenitic signature, and possibly helped to decrease Ca content on the rind to promote less-calcic plagioclase recrystallization.

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Tephra sliding on roofs – insights from laboratory tests

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Near an eruptive vent, tephra deposits can significantly increase the load on roofs. Building standards routinely deal with snow loads but, in order to amend them to take account of tephra loads, we need to understand how and when tephra slides. This is the focus of our research.

We have conducted small-scale experiments on a tilt table (Figure 1) to test sliding of wet and dry tephra (low density pumice and high density scoria) on metal sheet, fibre cement and tile roof materials. For deposit depths of 10–30 cm, grains initially moved at tilts of 13–19 °, with sliding of the whole deposit occurring between 22 and 37 °, depending on the roof material, tephra density and presence of water. Tests using dry tephra on weathered roofing showed similar sliding angles to tests on new roofing.

The density of the wet tephra deposit did not increase as much as expected, as grain packing was less efficient, with the smallest particles clumping around larger ones rather than filling void spaces. The highest sliding angles occurred for dry tephra on a wet roof, with the finest grains forming a higher friction layer in contact with the roof.

From these results we aim to produce loading curves that can be used to design buildings to withstand tephra loads.

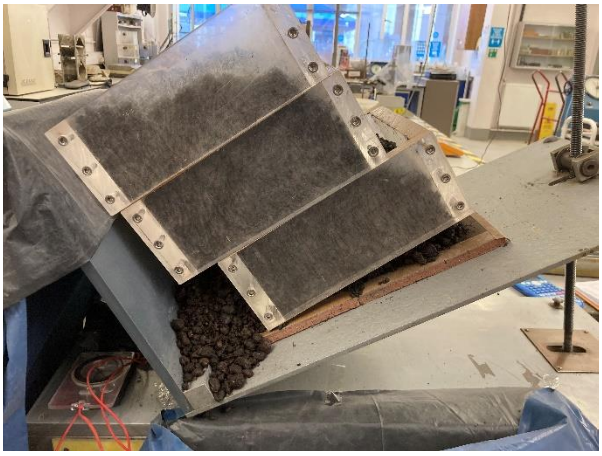

Fig 1: Wet scoria sliding over tiles

The case for volcanism as a major driver of Last Glacial millennial-scale climate change

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Paleoclimate records indicate a dynamic, highly variable climate during the Last Glacial Period (115 - 11.58 ka BP)[1,2]. Superimposed on an orbitally-forced gradual cooling trend, we see rapid and aperiodic large amplitude fluctuations between warm (interstadial) and cool (stadial) conditions referred to as Dansgaard-Oeschger (D-O) cycles[3]. The driving force behind these cycles remains unknown, and represents a key unresolved mystery of palaeoclimatology. Variations in surface temperature recorded in Greenland ice are coupled to ocean processes such as the Atlantic Meridional Overturning Circulation (AMOC)[4,5]. Over the last 50 years models have revealed how a sequence of non-linear feedbacks can produce the observed signals, assuming there is a driver that triggers the cycle in the first place. The trigger has not been identified, but should have the following features: (1) be aperiodic but with a return period that is, on average, similar to the observed occurrence of D-O cycles; (2) provide variable amplitudes of forcing to the climate system; (3) be causally linked to a plausible sequence of forcing-climate feedbacks that are consistent with established atmosphere-ice-ocean interactions for which models and proxy evidence exists (such as weakening of the AMOC). Here, we aim to explore whether volcanic eruptions meet these three criteria, and are a leading contender for the trigger mechanism.

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Why lacustrine mercury reconstructions might not be good records of large volcanic eruptions

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The impact of volcanism on the Earth system has been broadly linked to the release of chemical species such as volatile gases, and also trace metals. The latter includes mercury (Hg), which is highly toxic and mobile in the terrestrial environment. Time-averaged calculations suggest that 20-50% of naturally emitted Hg derives from volcanic activity[1]. Mercury shows promise as a marker for prolonged large-scale volcanism in the deep geological past (namely large igneous provinces), but studies have also hypothesized that lake sediment records may capture distinct Hg 'fingerprints' produced by individual volcanic eruptions [2-4]. However, the distance at which volcanic-derived Hg may be transported and sequestered in measurable amounts following a short-lived eruption is unclear, and the sedimentary conditions under which Hg signals may be favourably preserved are poorly defined[5].

Here, we present a reconstruction of Hg deposition in Lake Prespa, the Balkans (SE Europe) from 90 ka BP to present. Core Co1215 was sub-sampled at 2-cm-intervals; with a temporal resolution of ~50 years per sample. Identification of eleven tephra/cryptotephra layers within Co1215 (between 0.2 – 19 cm thickness) indicates the lake was recurrently affected by volcanic ash fall originating from Southern Italy[6]. Our measurements reveal high variability in sedimentary Hg concentrations and Hg/TOC ratios on <100-year timescales. Four of the tephra layers are followed by abrupt and short-lived peaks in Hg and Hg/TOC ratio. However, similar peaks are not seen following the other five layers, and we also see no evidence for Hg enrichment following the thickest layer corresponding to the largest eruption (Y-5). Our findings suggest that variable Hg concentrations measured in Co1215 cannot be unequivocally attributed to regional volcanic eruptions, and we posit this could be due to two factors: (1) lacustrine records may lack the resolution required to clearly identify signals produced by individual volcanic eruptions on <10-year timescales; and/or (2) the amount of Hg emitted by a single eruption might not be sufficient to leave a measurable signal in lake sediments.

Responsive Petrology update from the Cumbre Vieja 2021 eruption, La Palma, Canary Islands, Spain: An ongoing tale of urban volcanology

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On 19 September 2021, a new eruption began at Cumbre Vieja volcano, La Palma (Canary Islands) after almost a week of seismicity, ground deformation, and alterations to the normal soil degassing regime. It is the first subaerial eruption in the Canaries in 50 years, during which time the population has dramatically increased. The erupting fissure progressed into a cone-building phase characterised by lava effusion, strombolian activity, lava fountaining, ash venting and gas jetting. To date, >2000 structures have been inundated by lava, all north and south road access on the west side of the Island has been cut, and airport closures are common. At the time of writing, the eruption continues and is evolving with respect to hazard profile and emergency management on timescales of hours to days.

Also on 19 September, equipment for a petrology workshop/laboratory was scrambled from Tenerife, and within 48 hours, it began operations based within 5 km of the vent. Since those early days, a groundswell of international support, a number of key innovations in sample workflow, a change of address, three exclusion zone access systems, a pre-print paper[1], >300 tephra samples collected from permanent stations, >80 lava samples (many incandescent and a few 'toffee') collected with improvised equipment normally used for harvesting bananas, and media visits including those from BBC, Netflix, and the Surfing Channel(!) have highlighted both the potential and challenges of "Modern Petrology" in an urban volcanological crisis. In addition to the rich and varied petrological observations from these multi-mineralic products, given that many external aspects of this eruption are non-unique, Cumbre Vieja 2021- will likely represent a useful case study from both pure and applied volcano petrology. Efforts have been taken to capture lessons learned during the above experiences for community benefit.

This presentation seeks to provide an update to those efforts, a summary of the datastreams currently being combined, some initial interpretations, and initial recommendations to others that may find a volcanic eruption falling in their petrological laps.

One key finding is that modern petrology is not necessarily slow. Logistics and distance to instrumentation are identified as causing the most significant delays in quantitative petrological analysis during a volcanic eruption.

[1]Pankhurst et al. 10.21203/rs.3.rs-963593/v1

Analogue experiments of fissure eruption localization

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Fissure eruptions commonly localize from an elongated fracture into one or more discrete vents. The placement of these vents, and timing of their development, has a strong control over where lava is emitted and, by extension, where it will flow, and what it can damage. In our experiments, hot wax is injected into a narrow slot of predefined geometry, flowing due to a constant gravitational pressure head and cooling due to conduction. The geometry can be uniform in gap width, or with a vertical or lateral gradient, which we hypothesize can influence vent spacing and cause a flow pathway to spontaneously branch into smaller paths. Preliminary results show evidence of flow localization due to heat loss, in which some flow pathways become dominant and remain open and active. In contrast, smaller paths tend to solidify and close shut. By investigating the thermo- and fluid dynamics responsible for localization, we want to define characteristic behaviors, timescales and vent spacings. These results will improve our ability to interpret past fissure eruptions, and predict how future ones will evolve, by linking their evolution to their ability to flow and susceptibility to heat loss.

Is the mush model a giant with clay feet? A volcano tomography meta-analysis

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Our understanding of magmatic reservoirs is undergoing a paradigm shift. Petrological data indicate that most magma chambers are ephemeral and that magmatic systems are likely dominated both volumetrically and in time by mush reservoirs. Seismic tomography studies have been unable to detect any large magma chambers and are consistent with low melt fractions. Seismological studies are often cited as key evidence for mush dominated systems. A seminal review paper on volcano tomography by Lees (2007) concluded that “there is a general lack of strong evidence for large regions of pure melt below most volcanoes”[1]. The mush model has far-reaching implications for a wide range of phenomena, from volcanic hazard to the search for precious metal deposits. It is therefore of great importance that its foundations are established on robust observations. Are Lees’ conclusions still valid in 2022 or have more recent experiments uncovered large magma chambers? Can this lack of evidence be considered equivalent to evidence of absence?

To address these questions, I have assembled a comprehensive database of published volcano tomography studies. Over 270 studies have been published since 1975, 150 since 2007. Out of all these studies only 34 have attempted to rigorously estimate melt fraction. The remaining studies either found no clear evidence of melt or found clear low-velocity anomalies but did not attempt to estimate melt fraction. Melt estimates are available at only 20 active volcanoes. The average estimated melt fraction is 17% and the median is 12%. All but two studies reported a melt fraction below 40%.

Everywhere we have looked, we found no clear evidence of large high-melt fraction reservoirs. The evidence for mush dominated systems seems compelling. Very large magma chambers can be ruled out at most of the surveyed locations. However, when resolution limits are considered, it becomes apparent that significant melt bodies as large as several tens of cubic kilometres may have gone undetected. In addition, the estimation of melt fraction from seismic velocities is fraught with pitfalls and large uncertainties. Robust estimates of melt fraction remain scarce and the distribution of melt fraction in mush systems is poorly understood. The seismological community needs to keep striving to collect better data and use advanced methods to keep improving seismic resolution. There is also a clear need to improve the communication of uncertainties and limitations to enable confident interpretation of volcano tomography results.

1. Lees, J. M, JVGR 167 (2007), 37-56.

Volcanic processes and hazard assessment of the Torfajökull volcanic area, Iceland

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Throughout history, volcanoes have been a source of fascination to humanity. In the last decade, volcano tourism has boomed in countries like Iceland where people travel from all over the world to explore volcanic landscapes or, if they are lucky enough, experience an eruption first-hand. Consequently, eruptions may pose a greater threat to people than is commonly supposed and the need to understand volcanic processes to minimise volcanic risks to people's health and livelihood has never been greater or more pressing.

This project focuses on the Torfajökull volcanic area, a popular tourist destination in south-central Iceland and the largest silicic centre in Iceland. No hazard map or emergency response plan exists for the area to date. Even though there has not been an eruption in the area since 1477, Torfajökull volcano is still active. In the past, it has been activated by dyke injection from neighbouring Hekla and Bárðarbunga, two of the most active volcanoes in Iceland. We expect future eruptions will involve similar processes. Therefore, the project aims to understand the processes by which a stagnant rhyolite reservoir is activated by a laterally intruding basaltic dyke, as well as the triggering timescale and hazard implications of a next felsic eruption cycle.

Initial field-based studies have allowed for collection, interpretation, and synthesis of geological data. Magma mingling has been identified in various volcanic deposits within the silicic caldera, as expressed in the form of mafic inclusions within felsic extruded material. Geomorphic exploration and characterisation of volcanic deposits have also revealed potential hazards from future eruptions such as: pyroclastic and lava flows, fissure and maar eruptions, as well as ash fallout and bomb fields; all of which represent an important risk to human lives and local infrastructure.

Sample characterisation and various geochemical and textural analyses are currently underway. The findings will be applied to constrain custom-built three-phase reaction-transport models in which the rhyolitic mush is represented as a dynamic mixture of crystals, melt, and bubbles. The models will track both convective flow and phase segregation and their effects on the thermo-chemical evolution of the mush body. Altogether, the cross-disciplinary approach of this project will enable us to test the key hypothesis of felsic mush rejuvenation by mafic injection, which will help develop realistic early warning scenarios that would aid the development of a much-needed hazard mitigation plan for the Torfajökull volcanic area.

Field evidence for the passage of a dyke tip cavity.

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Tip cavities are transient phenomena, being filled with magma as dyke emplacement progresses[1]. Stalled, breccia filled, cavities at dyke tips have been described [2, 3]. Descriptions of features at dyke walls that may record passage of the tip cavity are rare [4, 5]. Two dyke exposures on the SW shore of Loch Linnhe, Scotland, UK provide evidence for the passage of a tip cavity. The dykes are part of the Permo-carboniferous alkaline lamprophyre suite and are emplaced in low-greenschist facies phyllites. Isolated wall-rock clasts, clusters of clasts and bodies of fine breccia are trapped between the dyke chilled margins and the wall rock on the footwall and hanging wall. The outer margins of breccias are planar, lie directly on wall rock and are coplanar with the chilled margin in breccia free areas. Inner margins are curved or cuspate in section and reduce the thickness of igneous fill. Surfaces parallel to the dyke contact show breccia sheets and ribs in 3D. Ribs occur singly and as stellate, reticulate and subparallel groups. Breccia occurs in non-dilation recesses in the dyke walls, and can coat steps at the margins of recesses. Stubs of rotated and fractured bridges have breccia coating the stub end and filling the acute angled recess. Breccia clasts are mostly phyllite but some clasts of vein quartz or chilled igneous rock occur. There is no hydrothermal cement in the breccia, clasts within the breccia are pressed tightly together, eliminating primary porosity. Clasts at the breccia inner margins can project into igneous rock. Clusters of clasts have porosity invaded by the dyke chilled margin. The mixing of clasts shows transport and rotation. Igneous clasts show that magma was present somewhere in the fissure during breccia formation. The local chilled margin coats breccia, drapes over projecting clasts and in some cases penetrated between clasts showing that igneous fill formed after, or synchronously with, breccia accumulation. Relations at bridge stubs shows that initial dilation was followed by breccia accumulation. Relations at non-dilational recesses show that wall rock was removed after some dilation and prior to local breccia accumulation and magma arrival on site. The simplest interpretation of these relations is that breccia accumulated on the magma tip as it advanced into the tip cavity. This accounts for the occurrence of breccia and single clasts on both walls. The features allow interpretation of tip cavity evolution and magma arrival. They may be applicable to the structures reported from the Negev (Israel) and Ship Rock (USA) dykes [4, 5].

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Magma ascent and eruption dynamics at basaltic volcanoes by integrating 4D experimental petrology, numerical modelling and field observations: examples from Mt Etna, Italy

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Basaltic volcanism is the most widespread form of volcanic activity on Earth. The quiescent and eruptive basaltic activity that we observe at the surface is function of time-dependent processes, such as vesiculation and crystallisation, occurring in a 3D system in the subsurface. Investigating such processes requires real time 4D (3D space+time) studies integrated with a large-scale numerical model to capture the complex, non-linear dynamics of the physical behaviour of magma in volcanic conduits. Combining fast x-ray microtomography with an environmental cell at both high temperature and either ambient or intermediate (crustal) pressure, we have successfully captured, visualised and quantified crystallisation in basaltic magma from Mt Etna, mimicking both lava flow dynamics and the mobility of magmatic intrusions within the crust. Feeding results from the 4D tomographic experiments into a numerical model, we have ascertained the role of clinopyroxene and plagioclase crystallisation on magma ascent dynamics and constrained conditions leading to basaltic Plinian eruptions. Our results can explain field observations from Mt Etna eruptions implying they are fundamentally important to both advance our understanding and forecasting of basaltic systems, as well as benefit stakeholders/institutions involved with volcanic hazard assessment and risk mitigation.

Virtual Field Trips during a pandemic: application of virtual outcrop, lessons learnt and future use

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Virtual geological fieldtrips have become increasingly popular over the last decade, with the advent of remote piloted vehicles, such as drones, leading to progressively sophisticated photorealistic virtual outcrops (VOs). As the COVID-19 pandemic led to widespread international travel restrictions, virtual fieldtrips (VFTs) became practical and necessary substitutes for traditional fieldtrips, including the VMSG virtual fieldtrip 2021.

Here we describe the delivery of VFTs and examine participant perception, gauged primarily through student questionnaires across several VFTs. The VFT localities included several sills across the Henry Mountains Complex, Utah. Such localities are captured well in VOs, allowing detailed study of the large-scale intrusion geometries, to even intricate details such as flow banding within individual sills. The VFTs of this study were run in LIME, a software specifically designed for the interpretation of 3D models and the delivery of VFTs.

Overall, the student questionnaires reflect the satisfaction of group with the teaching method and feedback was more positive for the virtual fieldtrips than the equivalent real-world fieldtrips in earlier years. Our findings also highlight several notable advantages associated with VFTs, including the ability to examine geology data at a range of scales, financial and access inclusivity, and reduced environmental impact. Several disadvantages with VFTs were also highlighted, including a reduction in social cohesion, and missing out on the experience of travelling and being outdoors. Our findings highlight implications for future application of VFTs and the opportunity to utilise both traditional fieldtrips and VFTs within a blended learning approach.

Linking magma batch intrusion to the formation of geothermal systems and mineral deposits

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Granitic plutons are assembled over long time scales with the emplacement of smaller magma batches. Magmatic fluids generated from exsolution are transported away from the intrusion and may lead to the formation of geothermal systems and magmatic-hydrothermal mineral deposits. Given that we now know that plutons are established incrementally by magma batches, we want to study the link between magma batch emplacement-related deformation, fluid flow, alteration and mineralization.

The Slaufrudalur pluton is a layered granitic to granodioritic intrusion in a Miocene fossil rift zone of Eastern Iceland. The pluton was assembled by cauldron subsidence with magma batches being episodically injected from an underlying reservoir[1]. The pluton is in fault contact with the basaltic wall rocks. Hydrothermal alteration and brecciation occur locally at the wall rock contact.

Field mapping and sampling was carried out during a first field campaign in August 2021. We focused on the internal structure to identify individual magma batches, as well as alteration and deformation within and around the pluton. Furthermore, we carried out sampling for future analysis of the anisotropy of magnetic susceptibility.

Further work will aim at correlating magma batches in the Slaufrudalur area. The composition and source of fluids will be analysed using stable isotopes and fluid inclusions. Our study will shed light on the role of layered magmatic intrusions in providing fluids to geothermal systems and magmatic-hydrothermal mineral deposits.

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Mineral records of magma storage and crystallization in the basaltic systems on the Moon

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Lunar lavas mainly erupted between 4.35 to 3 billion years ago with some areas of the Moon thought to have been volcanically active as recently as a billion years ago1. Different lunar magmas are thought to have reached the surface via a range storage and crystallization mechanisms2 but the pressure and temperatures governing these processes remain uncertain. Many mineral thermobarometers calibrated for terrestrial magmatic systems are of limited applicability to lunar systems, owing (i) to the low pressure gradients (~4.5 MPa/km), (ii) lunar melt chemical variations from terrestrial systems (for example, lunar higher-Ti, -Fe and Na-poorer basalts), and (iii) the more reducing nature of the Moon. Some studies have shown the efficiency of the thermobarometers including the two pyroxene and olivine-spinel models applied to lunar highland breccias, cumulate rocks3,4 and troctolitic lunar meteorites5. We will exploit these further by refining the calibrations for and high-Ti and low-Ti mare basalt samples returned from the Apollo 17 and Apollo 15 missions respectively. The Apollo 17 mare basalts are divided into five types (A, B, C, D and U) based on their major and rare earth element variations. These basalt types are likely to be derived from distinct mantle source regions, as their compositional differences cannot be explained by near-surface crystal fractionation2. Through this work, we aim to compile and review published experimental data to investigate element partitioning into lunar minerals, conduct experiments to refine the mineral-mineral and mineral-thermobarometers calibrated specifically for lunar magma compositions. We then aim to combine these outputs to better understand what crystal records can tell us about subsurface magmatic systems and volcanic eruption styles on rocky planets.

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Volcanic particle-ice interaction: an experimental study

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The presence of volcanic particles can modify the thermodynamic behaviour of clean ice. This is predominantly due to an increase in solar radiation absorption. Ice with surface coatings of particles can be defined as 'debris-covered' or 'dirty' ice. Dirty ice refers to ice covered in a discontinuous, or very thin, layer of particles; under these conditions, melting of a glacier surface can be particularly efficient[1]. Therefore, the state of dirty ice is an important control on the energy balance of an ice system. Volcanic material can be deposited on ice via several processes (e.g. airfalls, pyroclastic density currents). Therefore, in ice-covered volcanically active parts of the world, a variety of layer thicknesses and particle properties is observed[2]. It is crucial to understand how this range of scenarios can influence particle-induced ice melt to (1) better understand the evolution of debris-covered and dirty ice in general and (2) forecast future ice-melt scenarios at individual ice-covered volcanoes.

We present laboratory experiments that systematically reviewed the impact of volcanic particles of a range of compositions and properties (e.g. thermal conductivity, diameter, density, and albedo) on ice. Experiments assessed single particles and a scattering of particles on optically transparent and opaque ice, subjected to visible light illumination from a light emitting diode in a system analogous to dirty ice. Automated time-lapse images and in-person observations captured the response of particles and ice to radiation. Particles investigated included trachy-andesitic cemented ash particles from Eyjafjallajökull (Iceland), basaltic-andesitic scoria from Volcán Sollipulli (Chile), and rhyolitic pumice from Mount St. Helens (USA).

The experiments demonstrated that all volcanic particles induced ice melt and drove convection systems within the meltwater. This convection resulted in heating beyond the immediate margins of the particles. The particles lost finer grained fragments to meltwater, further driving ice melt. In all experiments, the particles had a low thermal conductivity (relative to ice), although the density differed between particle types. Our experiments showed that the porosity and density of a volcanic particle can dictate the behaviour of particle-ice interaction; a dense particle can melt downwards through the ice (in similarity with the behaviour of iron-based meteorites[3]), whilst a less dense particle can become buoyant in meltwater, resulting in an extensive area of surface melt.

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Rapid formation and eruption of a silicic magma chamber

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Shallow magmatic reservoirs have been identified at many volcanoes worldwide. However, questions still remain regarding their size, dynamics and longevity. The Reyðarártindur Pluton exposed in Southeast Iceland provides a superb example to investigate the above questions. Here, we use field mapping, sampling, geochemistry, 3D pluton shape modelling and a numerical thermal model to reconstruct the assembly and eruptive history of the shallow magma body.

In 3D, the c. 2.5 km^3 pluton has a castle-like shape characterised by flat roof segments that are vertically offset along steep faults. The exposed pluton is constructed largely of a single rock unit, the Main Granite (69.9 to 77.6 wt.% SiO_2). Two additional units occur only as enclaves: the Granite Enclaves (67.4 to 70.2 wt.% SiO_2), and the Quartz Monzonite Enclaves (61.8 to 67.3 wt.% SiO_2). However, geochemistry clearly indicates that the units are related and hence were likely derived from the same source reservoir.

In two locations, the pluton roof displays depressions associated with large dykes. Within these two dykes the rock is partially to wholly tuffisitic, and geochemical compositions range from quartz monzonite to granite. We interpret these dykes as eruption-feeding conduits from the pluton. Additionally, we speculate that the mingling of magmatic units with compositional ranges from quartz monzonite to granite within the conduits indicates that injection of new magma into the reservoir triggered eruption.

Rapid pluton construction is indicated by ductile contacts between units in the pluton and a thermal model calculates the top 75 m would have rheologically locked up within 1000 years. Hence, we argue that the pluton was a short-lived part of the wider magmatic system that fed the associated volcano, and that timeframes from emplacement to eruption were limited to 1000 years.

Rhodes, E. Barker, A. K. Burchardt, S. et al. (2021). Rapid assembly and eruption of a shallow silicic magma reservoir, Reyðarártindur Pluton, Southeast Iceland. G-Cubed. DOI: 10.1029/2021GC009999

Deep Onset Sill Emissions and Their Impact on The Thermogenic Methane Flux Through the North Atlantic Igneous Province Formation: A Case for Constraining the Nature of Fracturing in Deep Sills

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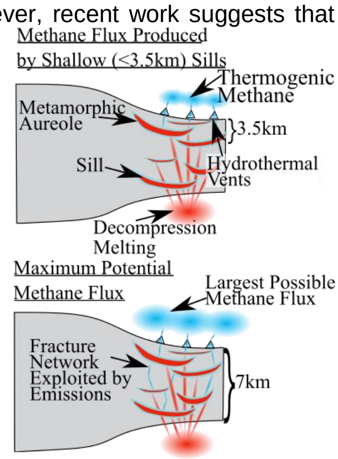
To fully understand how our climate and ecosystems will react to and recover from anthropogenic warming, it is important to look to the past. The Paleocene-Eocene Thermal Maximum (PETM, ~56Ma), an episode of rapid carbon emissions and global warming, can be used as a partial anthropogenic analogue. A likely cause for the PETM was rapid and extensive magmatism in the North Atlantic sedimentary basins, seen today as the North Atlantic Large Igneous Province (NAIP). Large scale thermal maturation of organic rich host rock, during the most intense periods of the NAIP formation, caused mass greenhouse gas production. These emissions can be expelled to the oceans and atmosphere via hydrothermal vents. It was originally suggested that venting is limited to shallow depths (<2 km) because increasing lithostatic pressure prevents hyrdro-fracking at deeper levels. However, recent work suggests that gases from deeper levels might escape the solid Earth through cooling joints within the sills themselves, in networks where deep sills are connected to shallow sills with vents. Adaptions of available NAIP methane production models[1] allow the depth potential to be doubled to a maximum depth of 7km (see figure), to calculate the total methane generated, an upper bound on the degree to which permeable sill networks can affect methane expulsion. Modelling findings suggest a potential maximum emissions of 37 EgC during the peak 50,000 years of the NAIP formation, compared to 27 EgC modelled from shallow sills alone. Additionally, this modelling highlights a region in the subsurface where maturation potential is greatest, irrespective of anisotropy, between 2.5km and 4km below sea floor. The work highlights the need to better understand permeability networks within and around igneous sill complexes to understand the climatic impacts.



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Volume and stratigraphy of the Cumbre Vieja 2021 eruption tephra fallout, La Palma Island

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On 19 September 2021, a new eruption began at Cumbre Vieja volcano, La Palma (Canary Islands). The ~1.0 km-length erupting fissure progressed into a cone-building phase characterised by lava effusion, strombolian activity, lava fountaining, ash venting and gas jetting.

Four field surveys on the tephra fallout deposit were carried out on 22-30 September, 1-20 & 24-30 October, and 12-20 November 2021, accounting 60 to 70 field control points each. By November, deposit thicknesses varied between 3 mm and 1.2 m at 13.5 to 1.1 km distance; isopach contours were elongated NE-SW. The thickest exposures show bedded architecture and at least 9 lapilli layers, with scarce lithic content (<2 %).

Juvenile fragments correspond to tachylyte and sideromelane scoriae with tephritic composition (44.6-45.0 wt. % SiO_2; 7.2-8.6 wt. % Na_2O+K_2O). Crystal phases consist of clinopyroxene, plagioclase, olivine, amphibole, and Fe-Ti oxides. These show vitrophyric, hyalopilitic, trachytic or glomeroporhyritic texture. Disequilibrium textures are observed in clinopyroxene phenocrysts as embayments and sieve texture. Rarely, restingolite xenoliths (partially melted oceanic sediments) are found in scoriae.

By late October, the bulk tephra volume was estimated to *c.* 8 x 10^6 m^3, while at the end of the November fieldwork nearly 22 x 10^6 m^3 were deposited. The newly formed pyroclastic cone reaches ~180 m height and similar volume (*c.* 23 x 10^6 m^3). The total pyroclastic volume (45 x 10^6 m^3) contrasts with the *c.* 170 x 10^6 m^3 of lava flows. Within this period, eruption columns averaged 2.9 km, and reached up to 5.6 km above the active vents. These values categorise the eruption with magnitude ~4.6 and intensity ~8.

Further research will investigate the fragmentation processes and eruption dynamics, source parameters, plume sedimentation and impact of these pyroclastic materials on the surrounding communities.

Flowability measurements and rheological investigations of volcaniclastic debris flows

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Volcaniclastic debris flows are hazardous natural phenomena that occur when a mixture of loose pyroclastic fallout and current deposits and water flow down slopes, very commonly after intense and/or prolonged rainfall. These phenomena represent a short and a long-term hazard in all the circumvolcanic areas, inducing dramatic changes in the territory and affecting population and infrastructures.

This is the case of the area surrounding the Somma-Vesuvius and the Phlegrean Fields volcanoes in Campania region (Southern Italy), where in the last five years more than 500 sites among archaeological excavations, stratigraphic trenches, drill cores and outcrops have been reviewed and analysed and several samples have been collected. The aim of this work is to combine field studies and experiments since few studies on the rheology of debris flows have been carried out, and very few using volcanic materials. The FT4 powder rheometer (Freeman Technology Ltd) is being used on several samples with the diameter of the particles less than or equal to 0.710 mm.

Shear tests have been performed to obtain physical parameters such as the angle of internal friction, that gives an idea of the viscosity of the sample, and the flow function coefficient, that gives information on the flow behaviour. Compressibility tests have been carried out to measure how the density changes as a function of the applied normal stress. Finally, the wall friction properties have been evaluated to understand how easily a powder flows against the material with which it is in contact. Shear test experiments with different applied shear rates in a Couette flow configuration are being performed. First results show that the angle of internal friction does not depend on the initial consolidation stresses and on the grain size, while the flowability and the compressibility of the powders are strongly affected by those features. The wall friction angle is affected by both grain size distribution and the roughness of the wall.

Reconciling physical & chemical fluid-fracture interface dynamics

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Geothermal energy accounts for less than 1% of the total global energy consumption, this should be rapidly increased to assist in reducing society's reliance on fossil fuels, help meet the rising demand in energy, and keep the 1.5°C climate change goal a reality. Many geothermal resources are reliant upon heat replenishment from below the surface, through fluid circulation in open, interconnected fractures. However, fluids transported through fractured hot rocks can also provide the ideal fluid-rock interaction conditions for minerals to nucleate and grow, causing fracture sealing that reduces permeability of the geothermal reservoir. Our research seeks to address the pressing issue of mineral scaling in geothermal reservoirs to enhance the productivity and longevity of geothermal power plants.

The real-time physical and chemical processes related to coupled fluid-rock interactions within fractured geothermal reservoirs are not well understood. An important control on fracture sealing processes is the nature of fluid flow within fractures. In particular, the spatial and temporal variations of fluid-fracture interface dynamics, and their impact on fluid rheology and flow dynamics, are grossly simplified, or even completely unaccounted for, in existing models. Such omissions have the potential for vast implications on the understanding of mineral nucleation and scaling processes within hydrothermal veins.

To reconcile how physical fluid-rock interactions effects chemistry (and vice versa) and mineral scaling processes, a combination of crustal analogue experiments and synthetic vein precipitation-dissolution experiments will be conducted. Fluids will be injected into a visco-elasto-plastic "crustal" analogue material hosting pre-existing fractures. Seeding the fluid and the crustal analogue with fluorescent particles will enable fluid flow vectors and incremental strain evolution of the deforming "crust" to be recorded, through the use of laser imaging, particle imaging velocimetry and digital image correlation techniques. Synthetic vein-generation experiments under variable fluid flows will then be conducted over a range of temperature/pressure conditions; their experimental products will be analysed using a range of microscope techniques, enabling atomic scale, chemistry and crystallography mapping, and morphological texture characterisation of fracture walls and synthetic geothermal minerals. This will quantitatively examine the relationships between microscale chemistry, structure and fracture fluid dynamics and their controls on mineral nucleation and growth mechanisms.

First-hand experience and lessons learned from social media communication during a volcanic crisis

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On 27 December 2020 there was visual confirmation that a lava dome was forming at La Soufrière St. Vincent, East Caribbean. It had been 41 years since the last eruption in 1979. The effusive phase continued to 8 April 2021, transitioning to an explosive phase on the 9th. This lasted through to 22 May. As of 29 November 2021, a yellow alert remains in place.

The official authority responsible for providing scientific information to the English-speaking Eastern Caribbean governments and public is the University of the West Indies Seismic Research Centre (SRC) and in charge of disaster management on St. Vincent is the National Emergency Management Organisation of St. Vincent and the Grenadines (NEMO). Their communications strategies involve daily liaising with local authorities and stakeholders in-person and virtually (an added feature due to the COVID-19 pandemic) during crisis and sharing vital information through traditional (TV, radio) and social-based medias (Facebook, Twitter, Instagram) for public and diaspora.

The eruption attracted worldwide media attention, and in particular was of great interest to the Caribbean diaspora, overwhelming the communication channels of the SRC. Several experts of La Soufrière identified themselves to help reinforce messaging and answer questions online. From my own perspective, I learned the importance of identifying myself as an expert as soon as possible, communicating and sharing resources with other identified experts, working with the observatory behind the scenes to centre and reinforce official messages, and taking ownership of mistakes that occur during an evolving situation.

With increased attention of volcano observatories' presence on social media and the increasing task of managing effective communication, there is a need to understand the efficacy of social media usage. This talk aims to contribute a first-hand experience in utilising social media during a 21st Century volcanic crisis to the growing body of literature on crisis communication and management. Sharing personal experiences of communicating during a volcanic crisis[1] can be an important way to evolve best practise and develop effective strategies.

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Rapid response petrology for the opening eruptive phase of the 2021 Cumbre Vieja eruption, La Palma, Canary Islands

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How and why magmatic systems reactivate and evolve is a critical question for monitoring and hazard mitigation efforts during initial response and ongoing volcanic crisis management. Here we report initial integrated petrological results and interpretation provided to monitoring authorities during the ongoing eruption of Cumbre Vieja, La Palma, Canary Islands, Spain. The eruptive products comprised simultaneous Strombolian fountain-fed lava flows and tephra fall from near-continuous eruption plumes. From combined field, petrographic and geochemical analyses we infer low percentage mantle melts with a variably equilibrated multimineralic crystal-cargo and compositional fractionation by winnowing during eruptive processes.

Bulk chemical trends together with textural and mineralogical observations have been made within a few weeks of the samples' eruption, including sample transit and data processing, which both have potential for streamlining. It is plausible, therefore, that detailed and insightful petrological input can be delivered on a timescale that is useful for initial response and ongoing volcanic crisis management. We suggest that state-of-the-art petrology is now more time-limited by logistical elements than those inherent in its practice.

The first eruptive volcanic products studied here provide an initial benchmark for understanding the evolution of the eruption. Hence 'rapid response' petrology can untangle complex magmatic and volcanic processes for this eruption, which combined with further study and methodological improvement can increasingly assist in active decision making.

Re-evaluating magma storage beneath Tenerife using cumulate mush

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Understanding the pre-eruptive assembly of magma prior to large eruptions is key to understanding the processes acting to trigger large eruptions and informs our ability to monitor and predict them. Cumulate nodules ejected during three Early Pleistocene eruptions on Tenerife: the Gaviotas (1.84 Ma), Morteros (~1.75 Ma) and San Juan (1.50 Ma), provide a unique window into magma reservoir architecture and dynamics prior to these eruptions. 51 cumulates were classified, ranging from ultramafic clinopyroxenites to felsic monzonites, with the cumulates containing between 0 – 77% quenched interstitial melt. Petrological analysis revealed three distinct domains within the reservoir: ultramafic, mafic-gabbroic, and felsic. However, trace and major element chemistry from 19 samples of interstitial melt do not correspond with these three domains. Investigation into the relationship between the interstitial melt and cumulate crystals revealed no correlation between the more primitive cumulates having more primitive liquids. This supports the hypothesis that the interstitial melt may be the carrier liquid of the nodules and not the crystals parent liquid. Interstitial melt compositions range from tephrites/basanites to basalts and trachy basalts and are characterised by high Al2O3 and high Nb at a given Zr. This study identified unusual uninflated phonolite and trachyte glass compositions in the Gaviotas and Morteros that have not been previously recognised on Tenerife. The major elements of the intercumulus glass were measured in 8 places on sample TR027-08 from the Gaviotas formation. A mixing line between the average compositions of the intercumulus glass and the interstitial melts reveal that the trachyte compositions are a product of the mixing of the phonolite and basanite liquids. This highlights the prevalence of magma mixing and hybridisation between reservoirs. The mixing of the phonolite and trachyte compositions is clearly visible in thin section, suggesting that magma mixing occurred imminently prior to eruption and may have acted to trigger the eruption. This study has built on previous work and supports the presence of a lower crustal mafic, commonly basanite, mush zone with a poorly connected upper crustal phonolite reservoir, consistent with previous models of the Magma reservoir beneath Tenerife. This work could have wider global applications for magma storage beneath ocean islands atop low flux plumes.

Plutonic insights into shallow magma systems beneath the central Taupō Volcanic Zone (New Zealand) and their relationship to the magma-hydrothermal interface

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The central Taupō Volcanic Zone (TVZ) is an area of vigorous Quaternary silicic volcanism accompanied by an exceptional geothermal heat flux reflected by 23 high-temperature (>250 °C) geothermal systems[1]. It is challenging to observe processes occurring in modern magmatic systems underlying the central TVZ, and most knowledge about such processes comes from past eruptive products. Geophysical studies can inform on the location, extent and movement of magma in real-time, but cannot provide detailed information on magma or fluid compositions, or processes occurring within magma chamber(s).

Within the central TVZ, however, rare plutonic fragments have been ejected in several silicic and mafic eruptions. These fragments offer vital insights into young magmatic systems underlying the central TVZ and their relationship to overlying hydrothermal systems. A collection of granitoids from several central TVZ eruptions will be used for petrographic (mineralogical and textural), geochemical and isotopic analysis. These data will be used to constrain the crystallisation environment of these granitoids, in terms of pressure (depth), temperature constraints, and the processes contributing to their petrogenesis. Integrating these data with recent geophysical observations[2,3,4] will allow for a better understanding of the present-day magmatic system[5].

In addition, residual fluids in these granitoids will be assessed via fluid inclusion studies of quartz phenocrysts and hydrothermal quartz that have grown within vugs. Assessment of the temperature, salinity and composition of fluids circulating during and after granitoid crystallisation and the formation of miarolitic cavities will help constrain processes occurring in the magmatic-hydrothermal interface. These data will provide insights on the origins of 'deep' hydrothermal fluids and their magmatic components, which are sampled in modern TVZ geothermal wells. This combination of petrological and fluid inclusion analyses of the granitoids, will address if/when meteoric fluids reach the granitoid bodies, indicating the presence or absence of significant permeability that can guide future utilisation of supercritical geothermal resources.

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Magma stalling weakens eruption

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Volatiles fundamentally modulate magma characteristics from generation to eruption, driving changes in crystallinity, density, viscosity, and buoyancy – each of which can produce transitions in eruptive behavior. At open-system basaltic volcanoes, these transitions between effusive and paroxysmal activity can occur unexpectedly with significant hazard. We investigate the run-up to the 2018 VEI 3 eruption of Volcán de Fuego, Guatemala, by constraining magma storage conditions using olivine-hosted melt inclusions (MIs) and timing magma mixing using Fe-Mg diffusion chronometry.

MIs may preserve volatiles from entrapment but can also experience diffusive re-equilibration of H_2O through olivine on the timescales of minutes to months. We oriented olivine crystals along the (010) crystallographic plane, measured MI volatile contents by FTIR with reference to fastest H_2O-diffusion along the a-axis, and obtained Fe-Mg profiles by EMPA and LA-ICP-MS along the a- and c-axes. MIs from the 2018 eruption average 2.8 ± 0.3 wt. % H_2O, distinctly offset by 1.1 ± 0.7 wt. % compared to those from the more explosive 1974 VEI 4 eruption[1]. Nearly identical trace elements ratios and S-SiO_2 support a common parent to the two eruptions, including initial volatiles. The offset in H_2O can be explained by re-equilibration during shallow stalling at 3.4 ± 0.6 km for at least two months. Shallow stalling and H_2O loss may have weakened the 2018 eruption (relative to 1974) by reducing overpressure and/or increasing cooling, crystallization, and viscosity, leading to lower magma ascent rates. Olivine rims record events more proximal to eruption. Reversals of 1-2 Fo units within 40 microns of the rim are recorded solely in profiles along the c-axis (not along the a-axis, due to slower anisotropic diffusion) and reflect a final input of magma – through recharge or destabilization – into the storage region weeks prior to eruption. Notably, RSAM also increased in the week before eruption[2]. While previous work has de-emphasized juvenile inputs and recharge and emphasized top-down behavior, forensic chronometry places constraints on syn-eruptive magma storage and mixing, crucial to understanding explosivity and to interpreting geophysical signals.

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A historic multi-segment volcanic episode in the Main Ethiopian Rift

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Magmatic continental rifts show evidence for episodic intrusive and eruptive events. However, due to the paucity of well-resolved rock ages we have only few constraints on the time-scales of recent magmatic events that cause rift opening. In addition, whether the surface rift segmentation of the volcanic system is maintained at depth is poorly constrained. To address this issue, we combine new radiocarbon and historical dating with the chemistry of young fissural flows from the Boset, Kone, and Fantale segments of the Ethiopian rift. Combined radiocarbon dates of charcoal from the Boset-Bericha volcanic complex indicates the most recent mafic lava flow likely occurred between 1681 and 1938 CE. These dates allow us to relate Boset’s most recent eruption to those recorded in historical accounts, from the neighbouring Kone (~1810 CE) and Fantale (~1770 to 1808 CE) segments, and therefore glean a snapshot of magmatism in different segments at an equivalent time. The geochronology coupled with geochemistry is best explained by the occurrence of three discrete, segment-scale rifting episodes within about a century of each other.

A unified approach to measuring plume composition with emission OP-FTIR

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Volcanic gas measurements are a major component in most monitoring network around the world. They provide invaluable information for informing mitigation strategies during eruptions and are crucial to our understanding of eruption mechanisms. Most volcano observatories rely on ultraviolet (UV) spectroscopy (e.g., COSPEC, DOAS) for continuous measurements of the emission rate of sulphur dioxide (SO_2). While the method has proven extremely reliable, it does come with a series of disadvantages, most notably the fact that it is limited to daytime use only, and the lack of information about other volcanic gases. Open Path Fourier Transform Infrared (OP-FTIR) instruments offer an alternative and can be used to measure the concentrations of many volcanic gases, in daytime or at night. However, traditional retrieval methods require a specific viewing geometry with a strong source of IR radiation in the background (such as an effusive feature or the sun). This fact, among other factors, has limited their use to sporadic measurement campaigns during episodes of volcanic unrest. OP-FTIR can also be used to measure the self-emission of IR light by a volcanic plume against a colder sky background, a method hereby referred to as "emission mode", and which provides the significant advantage of much more flexible viewing geometries. We developed a simplified 3-layer iterative retrieval algorithm, which allows us to retrieve concentrations of multiple gases (SO_2, SiF_4 and in some cases CO_2), as well as sulphate aerosols (SA) and ash within a single broadband spectral window (700-1300 cm^{-1}). Starting with a well-defined viewing geometry and local atmospheric conditions, we use the Reference Forward Model (RFM) to generate reference transmittance and radiance spectra for the atmosphere directly below and above the plume, considering a range of volume mixing ratios for the main atmospheric gases. A plume layer containing only volcanic species is inserted at a given plume height, and in-plume spectra are evaluated using their difference compared to a clear sky spectrum taken at the same location in order to isolate the spectral features of the volcanic species. Here we present results from measurements performed in emission mode on plumes at Stromboli, Vulcano and Etna. We show that a simple retrieval scheme can be implemented in real-time to monitor changes in plume composition (e.g., using SA/SO_2, CO_2/SO_2, and ash/SiF_4 ratios) and suggest that long-term deployment could significantly enhance the scientific return from costly and often underused OP-FTIR instruments during periods of relative unrest.

The Evolution of the Galapagos Mantle Plume: an Fe Isotope Perspective

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In recent years, stable Fe isotopes have been suggested as a tool to complement existing tracers of mantle geochemical heterogeneity (particularly in ocean island basalt, OIB, sources), because mineral- and redox-specific equilibrium fractionation effects link the melt isotopic composition to source mineralogy and melting degree.[1,2,3] Among OIB, Fe isotope variability relative to mid-ocean ridge basalts (MORB) – in particular, the observation of isotopically heavy basalts associated with some mantle plumes including Samoa, Pitcairn, Galapagos, Azores – has been attributed at least partly to the presence of a pyroxenite lithology in the OIB mantle source.[4,5,6,7]

Here we present new Fe isotope data for well-characterised samples throughout the evolution of the Galapagos mantle plume, which at present has a mantle potential temperature (T_p) of around 1500°C[8] and is inferred to sample a pyroxenite mantle component.[6] We include samples from the Caribbean Large Igneous Province (CLIP) associated with the hot plume head (T_p < 1800°C; Tortugal, Gorgona, Curaçao)[9], transitional CLIP to steady-state plume track terranes which record evidence for pyroxenite entrainment and secular plume cooling[10] and modern Galapagos basalts from multiple radiogenic isotope domains. This sample set allows us to explore the sensitivity of Fe isotopes to mantle temperature and lithological heterogeneity in natural samples, and test how well quantitative models of equilibrium Fe isotope fractionation during mantle melting can match observations.

Preliminary results suggest that CLIP basalts and picrites corrected to their primary liquid MgO content have lower δ^{57}Fe than later-stage plume tracks and modern Galapagos. This result is consistent with high plume head temperatures resulting in large degrees of melting of ambient peridotitic mantle (diluting the signature of any lithological heterogeneity, if present) and small partial melting isotope fractionations.

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The petrology, geochemistry, and geochronology of St. Barthelemy – implications for the geodynamics of the Lesser Antilles island arc

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The Lesser Antilles island arc (LAA) is a Cenozoic intra-oceanic convergent margin formed through the west-directed subduction of the Atlantic plates beneath the Caribbean plate[1]. Above the central island of Martinique, the arc bifurcates into an active segment known as the Volcanic Caribbees (VC) and an extinct segment known as the Limestone Caribbees (LC). The islands of the VC (< 25 Ma) have been the focus of detailed petrological investigations but those of the LC (55 – 25 Ma) are little studied, leaving the origin of the VC and its relationship to other Caribbean arc suites poorly constrained.

St. Barthelemy is a small (~ 25 km^2) volcanic island situated at the far northern end of the LC. Although St. Barthelemy has been mapped in detail[2], there are no published geochemical datasets and existing K-Ar and biostratigraphical dating is imprecise. Here we report a novel petrological, whole-rock major and trace element geochemical dataset, and U-Pb zircon geochronology for a suite of magmatic rocks from St. Barthelemy.

Samples form a continuum from relatively primitive basalts to highly fractionated rhyolites, with distinct calc-alkaline affinities and arc-like trace element signatures. Modelled primary magmas can be reproduced through melting of a spinel-lherzolite source following 2 – 3% bulk-sediment addition. Sediments found on the incoming Atlantic plate fail to reproduce the composition of our modelled primary magmas, and instead require the addition of Cretaceous sediments found in the north Atlantic basin. Closed-system fractional crystallisation of the modelled primary magmas using a gabbroic assemblage ± amphibole can reproduce the trace element variability of the studied samples. U-Pb zircon geochronology demonstrates that magmatism is upper Oligocene to lower Eocene in age, and is older than previously suggested.

By comparing the age, chemistry and tectonic history of other Caribbean arc suites with St. Barthelemy, we demonstrate that the LC likely represents an eastern extension of the Cretaceous-Paleogene Greater Antilles arc system, but was physically separated from it during the Miocene. The islands of the LC show a distinct evolutionary history from those of the modern VC.

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Over a decade of SO_2 measurements made with the IASI satellite instrument

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Satellite data on the emissions of SO_2 from volcanoes is valuable for studying trends in volcanic activity and for investigating the impacts of these plumes on the environment and climate. The Infrared Atmospheric Sounding Interferometer (IASI) is a hyperspectral sensor onboard three meteorological satellites. Within this instrument's spectral range is sensitivity to SO_2 and volcanic ash. Retrieval schemes which exploit the sensitivity within the IASI spectra to SO_2 have been developed by the Earth Observation Data Group (EODG) at the University of Oxford, to detect and quantify information about these plumes. The first of these tools is a linear retrieval which is able to quickly flag pixels which contain elevated amounts of SO_2. The second method, is an iterative retrieval which can quantify the amount and height of SO_2. In addition, the iterative retrieval also generates a comprehensive error matrix which helps to interpret the results.

The first IASI instrument was launched in 2006 with data first becoming available in mid-2007 and since then two more instruments have been launched. The Oxford SO_2 retrievals have now been applied to over a decade of IASI spectra. This extensive dataset has been used to generate global total SO_2 masses: the largest mass recorded being associated with the 2011 eruption of Nabro in Eritrea. The dataset also includes emissions from smaller eruptions and more persistent emissions from both volcanic (e.g. Popocatepetl in Mexico and Etna in Italy) and anthropogenic (e.g. in South Africa, Russia and China) sources. Using the iterative retrieval results it is possible to explore the distribution of SO_2 emissions with latitude and height: important criteria for understanding the hazard as well as for determining the lifetime of the gas, dispersion across the globe and the atmospheric impacts. The aim of this study is to archive the IASI SO_2 products to make them easily available to other researchers.

Constraining Neogene Mantle Dynamics of Western Mediterranean Region Encompassing Iberia by Quantitative Modeling of Basalt Geochemistry

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Dynamic topography is the surface expression of sub-plate mantle convective processes. In recent years, there has been considerable interest in combining a wide range of geophysical, geological and geomorphic observations with a view to determining the amplitude, wavelength and depth of mantle thermal anomalies. Here, we are interested in exploring how quantitative modelling of major, trace and rare earth elements can be used to constrain the depth and degree of asthenospheric melting for a mantle peridotitic source. Our focus is on a region that encompasses the Iberian Peninsula where previous research suggests that long-wavelength topography is supported by a significant sub-plate thermal anomaly which is manifest by reduced shear-wave velocities. Stratigraphic and fluvial studies imply that this dynamic support is a Neogene phenomenon. We analyzed 48 Neogene basaltic rocks that were acquired from Iberia in September 2019 and combined these analyses with previously published datasets. Both major element thermobarometry and rare earth element inverse modelling are used to determine the asthenospheric potential temperature and lithospheric thickness. These values are compared with those estimated from calibrated shear-wave tomographic models. Our geochemical results indicate that potential temperatures and lithospheric thicknesses are 1300-1375 °C and 50-80 km, respectively. These values broadly agree with calibrated tomographic models which yield values of 1300-1360 °C and 45-70 km. We conclude that a region encompassing Iberia is dynamically supported by a combination of warm asthenosphere and thinned lithosphere.

Critical assessment of pressure estimates in volcanic plumbing systems: the case study of Popocatépetl volcano, Mexico

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Most geobarometers use chemical compositions of minerals and their host melt to estimate crystallization pressures. Crystal structural parameters such as cell and site volumes are not usually considered despite their known sensitivity to pressure. Here, we compare two clinopyroxene geobarometers based upon electron microprobe analysis alone and coupled with single-crystal X-ray diffraction data. The case study is the plumbing system of Popocatépetl volcano (Mexico), which consists of three distinct magma reservoirs in upper, middle and lower crustal depths, represented by three compositionally and texturally distinct clinopyroxene populations (T1, T2, and low-Ca). These clinopyroxenes are augites of limited compositional variability, although yielding a significant increase in cell (V cell) and M1 site (V M1) volumes from low-Ca and T2 core to T1 (core and rim) and T2 (rim) clinopyroxenes. This variation is not due to chemical or temperature effects but is linked to their depth of crystallization. The application of the geobarometer based on chemical composition alone is unable to distinguish the three different reservoirs postulated on volcanological and petrological grounds. In contrast, the application of the geobarometer based on both structural parameters and chemical composition yields a remarkable correlation between the calculated cell volume and the estimated depth of crystallization of the different clinopyroxenes, including core to rim differences.

These results have twofold implications. First, the determination of the structural parameters of clinopyroxenes is the only method to resolve the actual distribution of Mg, Fe^{2+}, Fe^{3+} in the M1 and M2 structural sites and, given the sensitivity of cell and site volumes to pressure, permits to improve geobarometric estimates in volcanic plumbing systems. Second, the quantitative determination of the crystallization depth of the different clinopyroxenes has permitted to rescale the depth of the three different reservoirs in the plumbing system of the Popocatépetl Volcanic Complex located from ~30 km b.s.l. (low-Ca clinopyroxene) to ~18 km b.s.l. (T2 clinopyroxene core) and ~10-0 km b.s.l. (T1 clinopyroxene core and rim, T2 clinopyroxene rim) within the crustal structure of the Morelos platform. This provides further support to the complex plumbing system of the Popocatépetl Volcanic Complex consisting of polybaric storage layers of variable interconnected and interacting transient magma reservoirs.

Tommasini et al. (2021), *Lithos,* https://doi.org/10.1016/j.lithos.2021.106540

Petrogenesis and geochronology of volcanic rocks from the Sierra de San Miguelito Volcanic Complex, San Luis Potosí, Mexico.

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The Sierra de San Miguelito Volcanic Complex (SSMVC) is located in the southeastern part of the Mesa Central province, Mexico. The SSMVC consist dominantly of three volcanic successions: (a) mafic magmatism composed of trachybasalt and basaltic lavas; (b) intermediate magmatism composed of basaltic-trachyandesite, basaltic andesite and andesitic lavas and (c) felsic volcanism composed mainly rhyolitic domes. $^{40}Ar/^{39}Ar$ ages data demonstrated that SMMVC volcanism was active during Oligocene to Early Miocene (34-21 Ma) in three main episodes. Rare-earth element (REE) chondrite normalized patterns for mafic and intermediate magmatism have relatively flat light REE and large ion lithophile elements patterns, whereas felsic magmatism display enrichment in light REE and high field strength elements. In each volcanism style, total REE concentrations increase from mafic to felsic and Eu anomalies become progressively negative from mafic to felsic magmatism (Eu/Eu* = 1.03-0.03). These variations are consistent with the effects of crustal contamination where lower crust may have contribute to evolved magmas. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotope ratios suggests that magmatism from the SSMVC derived from a mantle source and evolved through magma mixing associated with crustal assimilation. Geochemical modelling reveals that intermediate volcanism experience ~ 45% of mixing process between mafic and felsic end-members. In contrast, partial melting model display that felsic volcanism were generated through melts from the upper continental crust. Multi-dimensional discrimination and isotope-isotope diagrams indicate an extensional system prevalent in the area.

Automated Petrography using Machine Learning

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Recent successes in extracting petrological constraints from chemical[1] and textural[2] observations of volcanic rocks now necessitate an improvement in the processing of optical and electron microscopy data obtained from thin sections. Advances in detector technology mean that data acquisition is rapid but also that data processing time is an increasingly important limitation.

Inspired by large-scale textural analysis of volcanic rocks using software such as QEMSCAN[3], we aim to showcase an automated approach to data-driven analysis of rock textures. Using a machine learning approach we are able to extract maps of phases and their internal zonation for entire thin sections using only SEM chemical data.

The mapping is achieved through the application of non-linear dimensionality reduction methods similar to PCA (principal component analysis) but more powerful. We are able to map our multidimensional compositional datasets, where each dimension corresponds to a given element, to only two dimensions (the 'latent space' representation) using 'autoencoder' neural networks[4].

These mappings are performed by mathematical functions and lead to the key result that similar data points will map to similar locations of the latent space; whereas highly dissimilar data will occupy an entirely different region altogether. Different mineral phases are expected to only exist in narrow compositional ranges, which appear as distinct clusters in the latent space representation. By applying a suitable clustering algorithm, each data point is labelled and the sample microstructure may then be reconstructed – ready for extracting physical and chemical information.

The method is applied to gabbroic nodules from Icelandic volcanoes, and shows the potential for automated extraction of petrologically-useful textural and compositional quantities.

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Reconstructing rhyolitic conduit dynamics at Húsafell, Iceland: sintering, alteration, and permeability evolution within a plugged pyroclastic pathway

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Volcanic conduits act as pathways for pyroclast passage from subsurface to atmosphere, and their evolution both reflects and influences transitions in eruptive style. Despite intense interest in silicic conduit dynamics, few studies have directly characterised ancient, dissected systems. Knowledge gaps include how conduit wall permeability changes through time, and how conduit-plugging dense lava is assembled.

To address these, we characterise an exceptionally exposed ~3 Ma rhyolitic conduit at Hringsgil, Húsafell, Iceland, dissected to ~500 m depth and emplaced within basaltic country rock. Poorly-sorted, heterogeneous pyroclastic breccia envelops ≤150 m-long, dense lava plugs. Intra-breccia contacts reflect repeated pyroclastic injection on a fissure becoming locally blocked by plugs of sintering, compacting magma. Magma ascent ended with localised deformation on plug shear zones.

In order to reconstruct conduit evolution, we document spatial variations in componentry, grainsize, alteration, and matrix connected porosity and permeability across a 15 m transect of lithic-rich pyroclastic breccia between outer country rock and interior dense plug. Towards the plug, the juvenile proportion and degree of sintering increases, and alteration minerals change from zeolite to near-plug smectite dominance. The connected porosity decreases from >0.25 to <0.1, due to pore-filling smectite and strong matrix sintering close to the plug. However, matrix permeability increases from ~10^{-17} to 10^{-15} m^2, as smectite is less effective than zeolite at sealing fluid flow pathways, and fracture pathways become more important. The plug has a very low matrix permeability (<10^{-18} m^2) and fluid flow is fracture-controlled.

We develop a model in which the conduit wall effectively shifted inwards from country rock to the final compacted plug, as magma flux waned and focussed, and examine how sintering, compaction, and alteration influenced fluid flow and thus pressurisation. A key factor is the relative timescale of porosity and permeability change occurring at near-magmatic temperatures through sintering and cristobalite precipitation, and that occurring at lower temperatures via interactions with the hydrothermal system. Our study provides new insights into magma focussing on rhyolitic fissures, and emphasises the continuum between pyroclasts and densified silicic lava.

Multisource remote thermal monitoring of Hasandağ volcano (Central Anatolia, Turkey)

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Hasandağ is a double-peaked stratovolcano system located in the Central Anatolian Volcanic Province. Geophysical evidence indicates hydrothermal activity on both of the Greater and Lesser Hasandağ summits. On the western flanks between 3000 and 3100 meters (a.s.l.) of Greater Hasandağ summit, weak fumaroles and water vapor emissions were observed at several vents. The highest temperature measured in those vents is ~70 °C and IR CO_2 readings exceed 100,000 ppm.

In order to test the remote thermal monitoring options for the summit fumarole zone, we used multisource remote sensing data with varying spatial and temporal resolution.

MODIS surface temperature (ST) data was tested for its analysis capability in high-temporal resolution. Daily (nighttime) ST data were analysed for a period of 18 years. A statistical procedure, Seasonal Decomposition of Time-series was used to decompose the surface temperature data to separate the seasonal variations and thermal anomalies. Results were evaluated with respect to the decomposed meteorological temperature data. 56 nighttime ASTER Thermal Infrared (TIR) imagery covering a period between 2001 and 2018 were used to generate Surface temperature, Surface temperature anomaly, and Relative radiative heat flux images. Lightweight drones were used to collect airborne thermal and visible data for the inspection of the thermal radiation over the fumarole zone. A stereo-photogrammetric model of the summit area was constructed. A thermal map of the fumarole zone was created using high-resolution, ground-based, and aerial thermal mosaic images.

Anomalies observed over the fumarole zone using MODIS and ASTER TIR imagery exhibit a significant correlation with the meteorological temperature trends. Hence, the observed thermal variation may be considered as a baseline reference value for the volcano. Higher the resolution, mapping, detection, and monitoring potential of the TIR dataset increases on the weak fumarole zone. The current risk associated with Hasandağ volcano is poorly known and needs to be evaluated. We envisage that it is compulsory to install a permanent ground-based station for direct and remote thermal monitoring of the fumarole zone.

Tracking volcanic conduit wall stability during evolution of the Mule Creek Vent, USA

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Silicic volcanic eruptions typically begin with the explosive ejection of pyroclastic material from the conduit, before transitioning to more gentle effusive activity. This transition is controlled by a shift from closed-system degassing – promoting rapid magma ascent and fragmentation – to open-system degassing, allowing gas escape.

Well-preserved dissected silicic conduits are scarce, but provide an opportunity to examine the structures and textures of the conduit interior to reconstruct their evolution. The Mule Creek Vent, New Mexico, USA, is the best-known location for examining the wall of a silicic conduit and its intersecting tuffisites[1.] Here we present a detailed characterisation of the margins of the Mule Creek Vent, focusing on a large outcrop of pyroclastic breccia that records the early stages of conduit filling as explosivity wanes. Pyroclastic material can either erode or accrete on to the pre-existing conduit wall, recorded by erosive surfaces. Gas-ash mixtures can flow through the conduit wall along pathways of connected porosity, or open new fractures to increase wall permeability. Sintering during conduit evolution will increase the resistance of the conduit walls to erosion, allowing them to become more stable through time. The reduction in permeability caused by sintering will increase the importance of localised, fracture-controlled outgassing.

Strong similarities between the conduit structure and its intersecting tuffisites add to evidence that the conduit is a larger more evolved tuffisite, reaching a sufficient temperature for its centre to weld significantly. Tuffisites injected into different host rocks therefore give an insight into how the morphology of the conduit wall might have changed during conduit evolution, from a poorly defined migrating pathway to one much more stable and constrained through time.

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Pyroclastic Density Currents Over Ice: An Experimental Investigation of Microphysical Heat Transfer Processes

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Pyroclastic density current (PDC) interactions with ice are common at high altitudes and high-latitude stratovolcanoes. Ice-melt lahars can be produced when PDCs propagate over ice, generating and incorporating melt and steam into the PDC. The hazardous and temporally unpredictable nature of these flows limits field observations. Conceptual models of PDC-ice interactions for hazard assessment and modelling exist, but quantifications of the microscale physical processes that underpin these interactions are lacking.

A set of experiments was conducted in which a heated granular layer was instantaneously emplaced onto a horizontal ice layer, to characterise the processes of heat transfer and melting. The experiments were conducted in different configurations and scales, and were parameterised by particle type, temperature, and layer thickness. The particle types used were glass ballotini, pumice, and Ruapehu PDC samples, covering a diverse range of grain characteristics. The particle layer was varied in thickness up to 45 mm and across temperatures up to 700 °C. In each experiment, the mass of melt and steam were quantified, and the time evolution of temperature through the particle layer was measured.

Melt and steam production were observed to consistently fit to a function of the proposed parameters. Increasing particle mass and temperature were observed to increase melt and steam production. For different particle types, different parameters were shown to be dominant. For example, Ruapehu and pumice melt masses showed much greater sensitivity than ballotini to particle temperature for any given layer thickness. Conversely, steam production was much greater for the ballotini for any given layer thickness and was more sensitive to ballotini particle temperature.

Localised steam escape, fluidisation, capillary action, and particle sinking, were observed to varying extents in the experiments. These phenomena altered the thermal diffusion properties of the particle layer through physical mixing, and increased particle bulk diffusivity due to incorporated melt and steam.

A further set of experiments characterised the mobility of the particle types over frozen and non-frozen substrates. Fluidisation of Ruapehu particles was observed above 400 °C particle temperatures, and enhanced the particle layer mobility over ice.

These observations will form the basis of a microphysical model for parameterising melting and flow mobility into a dynamic model of PDC flow over ice.

Frequent late Holocene volcanic activity in glaciated Southern Patagonia

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The Andean Austral Volcanic Zone (AVZ) of Southern Patagonia hosts both active volcanoes and the southern hemisphere's largest non-polar ice cap. Due to their remoteness and difficulty of access, the background frequency and magnitude of eruptions from these volcanoes is currently poorly constrained. Previous work has identified a small number of Holocene eruptions, but the lack of an extensive and high preservation dataset limits our understanding of the AVZ volcanoes. In this study, we collect 47 lacustrine sediment cores from a large proglacial lake, Lago Argentino, that is within 100 km of the three active volcanoes of the Southern Patagonian Icefield: Lautaro, Aguilera and Reclus. We combine the 5000-year varve chronology with single-grain electron microprobe analysis of tephra glasses to evaluate Southern Patagonia's eruptive record.

We find that 47 of the 56 individual tephra layers analyzed are rhyolitic in composition (77 wt% SiO_2, 7.5 wt% Na_2O+K_2O), with occasional trachytic layers (63 wt% SiO_2, 9 wt% Na_2O+K_2O). The rhyolitic tephras are derived from eruptions of local volcanoes Aguilera and Lautaro and suggest that their eruptive frequency is greater than previously considered. Trachytic tephra layers are likely sourced from large eruptions of Hudson volcano, in the better studied Andean Southern Volcanic Zone. The high volcanic output from Lautaro and Aguilera suggests that they host active magmatic systems. With the Southern Patagonian Icefield thinning at a rate of several metres per year, changes in subsurface stress fields and overburden pressure may affect the future eruptive potential in the region.

Why people reoccupy volcanoes after eruptions: implications for risk management in the southern Andes

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Immediate reoccupation of volcanic territories after eruptions by communities reveals their tendency of recovering a former daily life. However, this process faces renewed exposition to volcanic hazards. Identifying problematic or beneficial aspects of living with volcanoes accordingly to local populations, may reveal contradictions or agreements between management priorities and those of communities at risk.

From an anthropological approach, this process may be analysed through an *emic* perspective (focused in the *native* point of view). This allows the underlying socio-cultural dimension understanding which explains the decision-making at a community level.

We documented this dimension at three human settlements influenced by the activity of both Carran-Los Venados and Cordon Caulle volcanic systems (southern Andes, Chile). Three factors that interfered with the reoccupation decisions, despite four past eruptions, were identified: 1) a *stratigraphy of memories*, 2) the reproduction of a peasant *habitus* and 3) the *acceptability* of volcanic risk. Memories show up in a *stratified way* that involves the past experiences facing eruptions and its differentiated impacts, as *layers* that recall "beneficial" and "harmful" eruptions. The second relates to the *habit of living in a volcanic environment* reproducing a culture and maintaining a heritage difficult to replicate in another place. Finally, accepting volcanic risk involves the hierarchy of hazards against which communities seek to be better prepared, informed and cautious.

In this scenario, volcanic risk management has to resolve relevant subjects related to the assessment of threats and impacts of future events. Also decisions of multiple stakeholders, including communities that value volcanoes as part of their culture should be addressed. Understanding the priorities that lead people to choose the volcano over another *safer* place (with little or no exposure to volcanic hazard), can help to design mitigation actions that are consistent with the inhabitant's expectations towards the future. In this sense, a people-centred management can be developed to reduce people's risk by making them part of the solution. Finally, we propose that risk communication and planning efforts should focus on the hazard assessment as well as the *stratigraphy of memory* of past eruptions, from where determine what communities already know and what they *need* to learn to be prepared for volcanic uncertainty.

Refining tephra dispersal in Japan and understanding the impact of past volcanic eruptions

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The East Asia-Pacific region has been the source of some of the largest magnitude eruptions during the Quaternary, and now it is home to >20% of the global population. Accurately evaluating the eruptive histories of these volcanoes is essential for hazard assessments. By identifying volcanic ash (tephra) layers in distal environments more comprehensive eruption stratigraphies can be constructed as records near these large volcanoes are incomplete records due to burial and erosion.

We are conducting a cryptotephra study on the Lake Suigetsu sedimentary sequence, a high-resolution core from central Honshu, Japan, which is widely regarded as a key palaeoenvironmental archive from East Asia. Volcanic glass shards are being extracted from the section of the core which spans 50-115 ka that has not previously been investigated to identify cryptically preserved volcanic ash layers.

This project aims to refine the understanding of timing and dispersal of large eruptions in Japan and improve the tephrochronological framework for the East Asia/Pacific region between 50-115 ka. Another objective of this project is to assess the environmental impact of large explosive eruptions and their associated impacts upon global and regional climates, environments and ecosystems. The use of cryptotephra layers offers the potential to overcome issues associated with comparing palaeoenvironmental records on independent timescales, and thus gain a more detailed understanding of the spatio-temporal nature of environmental response to climate forcing.

Experimental investigation of trachydacite magma storage prior to the 1257 eruption of Mt Samalas

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The 1257 eruption of Mt Samalas, Indonesia, stands as one of the most explosive (VEI 7) and sulphur-rich (158±12 Tg SO_2) eruptions in the Holocene[1,2]. The intermediate alkaline type of magma that was erupted during the Samalas event is comparable to other powerful volcanic eruptions (e.g., Tambora 1815, El Chichón 1982), yet these magma compositions remain relatively understudied.

In this study, we perform cold-seal pressure vessel experiments on natural Samalas trachydacite pumice to investigate phase relations at various P-T conditions as well as magma storage before the eruption. All experiments are partial equilibrium experiments, run at an oxygen fugacity fO_2 of NNO/NNO+1 log units under water-saturated conditions. The investigated pressure and temperature range extends from 850-1000°C and 25-200 MPa, with experimental run times varying between 2-21 days. Experimental products were analysed for compositional and textural changes in the matrix glass and minerals and subsequently compared to natural results. Natural matrix glass and mineral compositions could be replicated at experimental conditions of 875-930°C and 100-150 MPa (4.5 ± 1 km), indicating likely reservoir conditions. Strong constraints on the Samalas trachydacite phase stability field can be derived from mineral breakdown textures in experimental plagioclase and amphibole at 950°C/100 MPa and pressures below 75 MPa. The geochemistry of the natural plagioclase, amphibole, orthopyroxene, and the matrix glass could be experimentally replicated with the overall best match at 900°C and 100 MPa. The experimentally grown mineral rims could not reproduce the compositions of high-anorthite plagioclase ($An_{>64}$) and clinopyroxene, suggesting that these compositions were inherited from a deeper part of the Samalas plumbing system. Preliminary water contents of experimental glasses, measured with FTIR, point towards high H_2O-solubilities (about 3.73 wt.% at 50 MPa) in trachydacite magma.

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The Climatic Impact of the 1257 Samalas Eruption.

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The 1257 Samalas eruption was one of the largest eruptions of the Holocene epoch. With a VEI of 7, the eruption column is estimated to have reached altitudes of 43km and ejected an estimated 119 Tg of SO_2 into the stratosphere, ten times that of the 1991 Mt Pinatubo eruption[1]. Whilst proxy data from tree ring chronologies suggest a Northern Hemisphere Summer cooling on the order of -0.7 to -1.2°C[2], previous attempts to model the climatic impact of the eruption have tended to overestimate the eruption's radiative forcing with a global surface cooling of -4°C[3]. Proxy and historical data also suggest significant regional heterogeneities in temperature and precipitation anomalies, with the eruption's climatic impact being invoked to account for a range of historical phenomena during the 13th century[4,5]. Uncertainties also remain over the timing of the eruption, with dates being suggested from between May 1257 to January 1258[6,7].

Using the UK Earth System climate model, simulations were run for the eruption starting in either January or July with initial conditions that sampled different states of the Quasi-Biennial Oscillation (QBO) and El Niño Southern Oscillation (ENSO), and the climatic impact investigated. This includes an analysis of global mean and regional stratospheric aerosol optical depth, and surface temperature and precipitation anomalies. A database of proxy and historical data has also been complied and utilised to place additional constraints on eruption impact and model accuracy.

Initial results show that model runs of a July 1257 eruption successfully capture both the Northern Hemisphere summer cooling and regional surface temperature anomalies when compared to proxy and historical data. This strongly favours the eruption having occurred in the summer of 1257 and thus places a convincing constraint on eruption timing. The eruption is shown to perturb both ENSO and QBO state, although the role of prior atmospheric conditions in modulating the eruption impact remains under investigation.

The PDC flow units problem: Deposit heterogeneity from varying cohesive behavior and sediment flux.

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Pyroclastic Density Currents (PDCs) are rapidly moving, high-temperature currents of heterogeneous volcanic material and gas that can surmount topographic barriers and can form extensive deposits (ignimbrites) far away from source. They are a highly destructive, and a deadly hazard (~100 million people live at risk from PDCs[1]).

Flow units are interpreted as deposits of individual PDCs and are defined by markers of hiatus in activity (such as ash fallout, reworking or paleosols). However, it has been shown that the arrangement of flow units can vary spatially within a deposit (from proximal to distal exposures, and laterally across drainages), recording a contradictory picture of PDC activity during a single eruption at different locations[2].

The stratigraphic record of flow units within an ignimbrite may have been influenced by a number of factors, such as current unsteadiness or syn-depositional processes. Formation of ash within a PDC can be from magma fragmentation and/or by comminution processes as the current propagates. Entrainment from both internal and external environments can decrease temperatures and introduce water vapor (e.g. exsolving juvenile magma, external hydrological factors, combusting plant matter, water-laden sediment). These factors will likely affect cohesive and frictional behaviors within the flow causing internal variations affecting both the current dynamics and resulting deposits.

This project will investigate how cohesive and frictional behaviors within a PDC may impact its ability to transport, deposit and erode material. Thus, impacting the flow unit record and determining the extent to which single pulsatory currents can be misinterpreted as separate flow events during major eruptions. Flume experiments[3] will explore the significance of cohesion in influencing flow dynamics and resulting deposit behaviors, by exploring the role of fines and water vapour. Fieldwork will be undertaken to consider bedform and stratigraphic relationships of flow unit marker beds to ground-truth the experiments. This research will improve our understanding of the dynamics of PDCs, how they react to variations in internal and external conditions and factors that control the depositional record of PDCs. Better interpretation of ignimbrite successions is pivotal in improved volcanic hazard assessment.

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Temporal magmatic evolution of the Mull lava succession, Palaeogene Igneous Province, western Scotland.

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The Mull Lava succession (MLS), western Scotland, is part of the remnants of the early Palaeogene (62-58 Ma.) North Atlantic Igneous Province. This stratigraphically well-constrained sequence consists of basaltic lava flows, progressively becoming more evolved, with the youngest lavas regressing to more basic compositions [1]. The sequence begins with the Staffa Lava (oldest), overlaid by the Mull Plateau Lava, and the Mull Central Lava (youngest) stratigraphically above, but this temporal evolution has not been considered in detail in previous geochemical studies. Here we attempt to identify a clear lithostratigraphy based upon the mineralogy of the rocks using field observations and petrography, to interpret the magmatic evolution of the sequence through time.

The main field observation prevalent throughout the stratigraphy was the continual transition from basaltic into more evolved, intermediate and trachytic flows, with distinct mineralogical changes. In several sections of the MLS, basaltic lava flows containing olivine (≈3-5%), plagioclase (≈4-8%) and some clinopyroxene (≈2-4%) were succeeded by more evolved flows with distinct prismatic amphibole (≈5-8%), slightly higher amounts of plagioclase (≈5-10%) and some lavas presenting trachytic texture. These intermediate to evolved flows are overlain by basaltic flows containing the former minerals. The preliminary field results suggest that fractional crystallisation, geochemically modelled by Kerr [2,3] was the main magmatic process governing the successions development, but with a higher magma mixing contribution than previously thought [2].

In a small number of sample locations, outcrops differ in rock type from those reported in the literature. A previously undiscovered outcrop in the area close to the summit of Ben More is suspected to be more evolved based on field observations, interbedded between basic basaltic flows. The outcrop has slight trachytic texture of plagioclase with a minor mafic mineral visible. These observations give new details regarding the temporal magmatic evolution of the MLS and show clear stratigraphic patterns of evolution, complementing the detailed geochemical stratigraphy established by Kerr [2,3].

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Tracing recycled lithosphere in the mantle: insights from heavy halogens

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Heavy halogens (Cl, Br and I) are concentrated in oceanic crust and lithosphere which are returned to the mantle during subduction. Retention of heavy halogens in nominally anhydrous minerals following dehydration of the subducting slabs means they are potentially excellent chemical tracers of recycled oceanic lithosphere in the mantle[1].

The Icelandic mantle is chemically and lithologically heterogeneous with a with a recycled pyroxenite component[2]. We measure the heavy halogen composition of a suite of sub-glacial and sub-aqueous basaltic glasses from the Reykjanes Ridge and Iceland to investigate if they can trace the influence of pyroxenite-derived melts from the Icelandic mantle plume and across Iceland.

The halogen content of glasses from the Reykjanes Ridge increases on the approach to Iceland, along with other chemical indicators of melt enrichment. Across Iceland the highest halogen concentrations are measured in glasses from the flank zones where influence from pyroxenite-derived melts is greatest. Halogen concentrations can be used to spatially map the influence of recycled lithosphere on erupted melt composition.

Ratios of halogens to elements of similar incompatibility do not appear to track the influence of recycled lithosphere on melt composition. A shift in ratios is apparent between north and south Iceland, which maps spatially with variation in Pb isotope compositions. These ratios can be used to identify heterogeneous ratios in mantle sources. These heterogeneous ratios may reflect the presence of two enriched recycled domains in the Icelandic mantle with differing halogen/K, Br/Cl and I/Cl ratios. Br/Cl and I/Cl ratios vary in different lithologies within subducting slabs. If these heterogeneities are preserved following subduction they may detectable before long-term cycling of recycled material has occurred[3].

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Determining the depths and timescales of pre-eruptive processes at Campi Flegrei caldera, Italy

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Campi Flegrei is one of the most dangerous volcanoes on Earth and a detailed understanding of the sub-volcanic magma system and pre-eruption processes is essential for effective hazard mitigation. Of particular interest are the depths and timescales of magma storage, as this information can inform the interpretation of volcano monitoring data at the Earth's surface and improve civil protection. This study places new constraints on these critical aspects of the magmatic system through detailed petrological analysis of clinopyroxene crystals produced in the most recent, AD 1538 Monte Nuovo, eruption.

Through backscattered electron imaging (BSE) of >200 erupted crystals, we identified four texturally distinct clinopyroxene populations in Monte Nuovo eruption deposits, with a range of zoning patterns. A small number of crystals preserve a thin, evolved zone at their rim. Using BSE images as a guide, we characterised the full compositional diversity of these clinopyroxenes by electron microprobe analysis (EPMA). This data was input into the into the Python tool Thermobar to find equilibrium matches with published Monte Nuovo whole-rock and glass data, and to determine clinopyroxene crystallisation pressures and temperatures using a geothermobarometer calibrated for alkali systems.

The compositional zoning preserved in the Monte Nuovo clinopyroxenes is consistent with an open magmatic system where mafic and felsic magma periodically mix. Our barometric modelling suggests that all the erupted clinopyroxene crystals formed at temperatures and pressures averaging at 1000°C and 2-2.5kbar. These pressures correlate with a deep magma storage region at ~7.5 km, which has also been identified by seismic tomography. The crystals do not display evidence for crystallisation at shallow depths, suggesting the magmas that go on to erupt are not fuelling the bradyseismic activity at Campi Flegrei. Hence, our data agrees with previous studies, which suggest that recent Campi Flegrei eruptions are fed by magmas ascending directly from the mid–lower crust and have minimal interaction with magmas that have stalled at shallow depths. The next stage of the project is to extract profiles across compositional zones and use Mg-Fe diffusion modelling to characterise the timescales of pre-eruptive processes.

Thermobar: An Open-Source Python3 tool for Thermobarometry

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The chemistry of erupted minerals and melts are commonly used to determine the pressures, temperatures and H_2O contents of magma storage regions beneath volcanic centres. In the last few decades, more than 100 empirical and thermodynamic expressions have been calibrated using measurements of phases in experimental studies where these intensive parameters are known. However, users wishing to apply these expressions to deduce storage conditions in natural samples have to format their mineral and melt data in specific ways, and perform calculations using a number of different tools (e.g. multiple Excel spreadsheets, Matlab, R, Python), some of which are not publicly-available. Here, we present Thermobar[1,2], a user friendly open-source tool written in Python3 that requires no prior coding experience. Thermobar allows users to perform calculations for equilibrium involving liquid, olivine, spinel, pyroxene, feldspar, and amphibole based on oxide data provided in an excel spreadsheet within minimal user-formatting required. We also provide a number of functions for mineral-melt matching (e.g., Cpx-Liq[3]), plotting mineral classification (e.g., feldspar and pyroxene ternaries) and equilibrium diagrams (e.g., Ol-Liq Fo vs. Mg#). Perhaps most importantly, Thermobar provides tools for propagating analytical errors using Monte-Carlo approaches. As an example of this functionality, we show that the precision of barometry involving Cpx equilibrium is heavily affected by the count times and beam conditions during analysis of Na_2O by EPMA. These analytical conditions, resulting in imprecisions of 20-40% for Na_2O, can introduce ~3-5 kbar of random error into Cpx-only and Cpx-Liq barometry calculations. We show that Na migration is not an issue in natural pyroxenes, even at 100nA, indicating that Cpx-based barometry could be greatly improved by re-analysis of existing experimental charges to improve Na precision. Thermobar can be downloaded via pip and on Github[1]. Extensive documentation, example videos and example Jupyter Notebooks are available at Read The Docs[2].

1. https://github.com/PennyWieser/Thermobar
2. https://thermobar.readthedocs.io/
3. Neave and Putirka. (2017), Am Min. 102.

From microstructures to regional scale flow indicators – evidence of magma flow in a mafic sill

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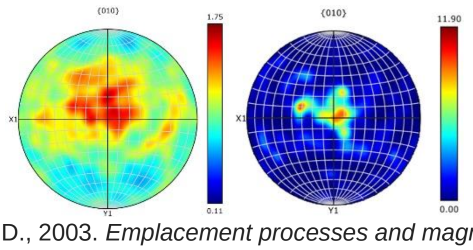
3D geophysical studies have identified sill complexes responsible for the lateral transport of magma hundreds of kilometres. Understanding how magma is transported through sills is key to quantifying the potentially eruptible magma volumes within volcanic plumbing systems, as well as the locations of mineral deposits associated with igneous intrusions. Structures on a range of scales (meso- to micro-scale) are interpreted as flow indicators, and they can be used to quantify variations in flow that could indicate small-scale flow variations.

Two field campaigns were conducted during the autumn of 2021 and 2021 to the Whin Sill complex, which provided an excellent opportunity to explore how dynamic processes have been in a mafic intrusion on a range of scales. The Whin Sill is a quartz-microgabbro sill that intruded 295±6 Ma into Carboniferous strata. The Whin Sill outcrops across northern England, with excellent outcrops along the coast, and reaching a maximum thickness of 81 m. Previous anisotropy of magnetic susceptibility studies have shown different regional flow directions for large areas of the Whin Sill, which were interpreted to be fed by different feeder dykes[1]. Our field observations document individual flow units, magma fingers and ropy flow structures as flow indicators at multiple locations and suggest that flow variations on a km-m scale were recorded.

Preliminary scanning electron microscopy (SEM) and electron back-scattered diffraction (EBSD) analysis of unoriented samples of quartz-microgabbro composition from the Whin Sill have identified two groupings in the crystallographic preferred orientations (CPO), with the coarsest plagioclase crystals orientated differently to the finer crystals (Figure 1). Stresses associated with magma flow could also be recorded through plastic deformation of the crystal lattice, and this proof-of-concept studies provides a first insight into quantifying the crystal plasticity associated with magma flow through misorientation angles.

Figure 1 – pole figure of all (left) plagioclase grains and coarse (right) plagioclase grains in sample.



[1]Liss, D., 2003. *Emplacement processes and magma flow geometries of the Whin Sill complex* (Doctoral dissertation, University of Birmingham).

Contrasting eruption styles at the intermediate composition, Devil's Ink Pot fissure, Ascension Island.

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Ascension Island is an active volcanic island in the South Atlantic Ocean. The volcanic material on Ascension Island exhibits a wide compositional range of basalt-hawaiite-mugearite-benmoreite-trachyte-rhyolite[1]. Here, we focus on the 1.3 km long Devil's Ink Pot fissure, located in the south east corner of the island and, one of the youngest and best-preserved intermediate deposits on the island. We use a combination of detailed field associations and petrographic and geochemical data collected for the juvenile components, in order to elucidate the nature of the volcanic eruption(s). The fissure, which was fed by benmoreite magma, is composed of 18 craters, 3 lava flow fields and tephra fall deposits up to 2 m thick, with no evidence of a time break in the deposits.

We find evidence for two contrasting eruption styles that occurred along the fissure. First, some craters are characterised by abundant moderately to densely welded spatter and appear to have fed lava flows. Second, other craters are characterised by weakly agglutinated spatter, loose lapilli and bomb clasts and an abundance of lithic and ballistics clasts. Fall deposits are relatively coarse grained and are composed of scoria clasts, pumice clasts, dense clasts, and lithic clast components. Despite these morphological and lithological differences, Whole rock major and trace element analyses show that the erupted magma is chemically uniform. Initial analysis of microlite textures and groundmass feldspar anorthite contents lead us to infer variations in ascent rates for the tephra and lava/spatter samples, respectively, suggesting that bulk magma ascent rates may have controlled the eruption style.

Moving forward, crystal chemistry and volatiles in melt inclusions and groundmass glass will allow us to better constrain how ascent rates affect the variability of eruption styles in this low-magnitude eruption. In particular, we aim to explore the dynamics by which along-fissure variations in eruption intensity and explosivity can occur in close spatial association.

1. Weaver, B., Kar, A., Davidson, J. and Colucci, M., 1996. Geothermics, 25(4-5), pp.449-470.

Immobile elements trapped as precipitants in magmatic fractures

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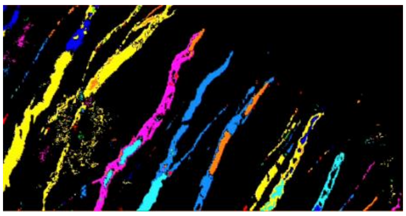
Useful minerals containing rare Earth elements (REE) and metals are sourced from magma bodies, but exactly how these elements initially leave the magma is not well known. Here we describe systematic bands of cm-scale tensile fractures found in the rhyolitic Sandfell laccolith exposed in eastern Iceland. These magmatic fractures are filled with comb, laminate, and radial textures of primarily FeO, MnO, and carbonate, and are enriched in REEs. The filling material also appears reworked into clastic textures pushed into the fracture tips. Microtomography images of hand-samples show the fractures to be stretched-penny shaped, and contain 80 vol% fillings and 20 vol% void space. The connectivity within one band is limited to 1-3 neighbouring fractures. µXRF measurements revealed distinct halos of 0.8 wt% Fe depletion surrounding each facture, and within the fractures a strong enrichment in an unusual suite of elements including Fe, Mn, Cl, Zn, Cr, Y, Ce, and La. This assemblage is puzzling, as many of these elements are typically immobile during hydrothermal processes. Our working hypothesis is that the formation of the fractures provided a degassing pathway through the impermeable magma. However, the nature and the composition of the magmatic volatiles are as yet unknown. The minimal connectivity between fractures (at hand-sample scale) suggests fluid would have travelled through the length of the crack until reaching an intersection with another fracture band system, precipitating minerals along the way. Given the ubiquitous occurrence of the fracture bands within the laccolith, this small-scale process compounds into large amounts of mass transfer overall. The fractures at Sandfell may be a snapshot of the initial process of removing incompatible elements from silicic magma.



Tomography slice of fracture band showing connectivity of phases by colour. Field of view is ~4 cm.

Petrological evidence for focussed mid-crustal magma intrusion in the Main Ethiopian Rift

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Rifting in Ethiopia is predominantly driven by magmatic intrusion into the rifting crust. Unravelling the dynamics of lithospheric melt migration and storage is paramount to understanding the late-stage development of continental rifts. In particular, extensive geophysical observations of the structure and composition of rifting crust must be supported by petrology to provide a complete picture of rift-related magmatism. We present major element, trace element, and volatile element compositional data for olivine-hosted melt inclusions from the Boku Volcanic Complex (BVC), a monogenetic cone field in the north Main Ethiopian Rift. Through combined CO_2-density-calibrated Raman spectroscopy and secondary ion mass spectrometry we assess the total CO_2 concentrations within the melt inclusions allowing us to estimate pressures of entrapment via CO_2-H_2O solubility models. Our results show that primitive BVC melts carry up to 0.58 wt% CO_2 (mean ~0.2 wt%), with as much as half of the CO_2 in the melt inclusion present within shrinkage bubbles. Volatile solubility models suggest that these melts are stored over a narrow range of depths (10-15 km), consistent with geophysical data and implying the existence of focussed zone of magma intrusion at mid-crustal depths. The expansive range of trace element concentrations in the inclusions illustrate that, at the time of entrapment, compositional heterogeneity remains extant, and melts must therefore be stored in discrete magmatic bodies with limited mixing. Our results have implications for understanding the interplay between magma intrusion and extensional tectonics during continental break-up, such as magmatic compensation of crustal thinning and the thermo-mechanical effects of melt emplacement into the rifting crust.

Pre-eruptive exsolved volatiles: Implications for volcanic deformation and degassing

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Reconciling multi-parameter satellite observations of volcanic eruptions is important for global volcano monitoring. While integrating observations of volcanic deformation and degassing have improved our understanding of magma storage conditions, we still lack quantitative models to link these observations. Here we develop models based on melt inclusion data and thermodynamics to reconstruct magma properties such as compressibility. We calculate the weight fraction of exsolved volatiles, and its composition using solubility laws and partitioning models, and this is then used to make an estimate of co-eruptive SO_2 degassing. The exsolved volatile phase increases magma compressibility, which is a key parameter controlling the change in magma volume during eruption and intrusion, since compressible magmas can accommodate pressure changes with little change in volume. Using a thermodynamic framework, we perform sensitivity analyses to explore the effects of changing magmatic volatile content (H_2O, CO_2, S), oxygen fugacity and pre-eruptive exsolved volatile segregation (e.g., exsolved volatile accumulation at the reservoir roof, or the formation of a 'degassed plug') on volcanic deformation and degassing of basaltic and rhyolitic magma. Our model shows that increasing magmatic H_2O content increases the co-eruptive sulfur dioxide yield and decreases the magnitude of observed deformation at the surface; and that rhyolitic eruptions are likely to show less co-eruptive deformation than basaltic eruptions (owing to their higher volatile content). We have collated a large database for natural eruptions, which show that in general our model predictions are borne out: ground deformation during water-rich arc eruptions, which generally erupt more evolved magmas, is muted compared to water-poor ocean island eruptions. We analyse the temporal variation of SO_2 degassing and deformation during a number of case study eruptions to understand pre-eruptive magma storage conditions and the evolution of magma properties, namely compressibility. Integrating deformation, degassing and extrusion data from the 2004 eruption of Mount St Helens reveal that the bulk magma compressibility increases following the removal of a degassed plug. In contrast, the bulk magma compressibility of the 2011 eruption of Cordón Caulle decreases following the removal of a gas-rich cap.

Insights from a bizarre silicic "flow", Mt. Changbaishan, China/DPRK

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Silicic volcanism has long been considered to be either explosive or effusive. Silicic volcanic deposits have, therefore, long been interpreted under this dichotomy. The distinction between intensely-welded explosive deposits and truly effusive deposits is not always apparent and often controversial[1]. Following detailed observations of hybrid eruptions at Volcán Chaitén (2008-09) and Cordón Caulle (2011-12), Chile, it was recognised that obsidians – previously thought to be effusive – can form via rapid in-conduit sintering of melt-rich glass fragments. This may be the underlying genetic mechanism of all obsidians, via which the explosive-effusive transition of silicic volcanism is modulated[2].

The QXZ formation is a ~8ka, apparently flow-modified pantelleritic unit, situated on the north flank of Mt. Changbaishan/Paektu, on the border between China and DPRK. It is the only apparently-effusive silicic unit observed on Mt. Changbaishan and is compositionally similar to the climactic Millennium Eruption (ME, VEI~6-7, 946-947 CE)[3]. Understanding the eruption dynamics of the QXZ, especially any differences from ME, is vital to volcanic hazard assessments of Mt. Changbaishan. However, the formation is texturally complex and has been variously identified as a rheomorphic ignimbrite or a purely-effusive flow.

Here we present our preliminary findings, including major element compositions, glass volatile contents, and microtextures of the QXZ and potentially associated products, including a suite of clastogenic obsidian pyroclasts. We see this as a first step in re-interpreting this unit in the developing new paradigm of sintering-controlled silicic explosive-effusive transition, and comment on its potentials for future research.

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2. Wadsworth, F., Llewellin, E., Vasseur, J., Gardner, J. & Tuffen, H. Explosive-effusive volcanic eruption transitions caused by sintering. Science Advances 6, (2020).

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