VMSG

The 51st Annual Volcanic and Magmatic Studies Group Conference

Norwich

5 – 7th January 2015

University of East Anglia

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Booklet Design: Anna Hicks, University of East Anglia

Contents

Welcome to the 51st Annual Volcanic and Magmatic Studies Conference!

As Chair of the Volcanic and Magmatic Studies Group, and on behalf of the VMSG committee, it is my great pleasure to welcome you all to the 2015 Annual Meeting. Now into its 51st season, the Group is one of the largest of the Special Interest Groups of the Geological Society and Mineralogical Society, with over 900 members worldwide. The activity is expressed by the vibrant annual meetings, each with around 200 delegates, many of whom are beginning their careers in this exciting and very diverse field. I look forward to this year's meeting in Norwich, which again promises to be a great success, and which I am sure will be a true testament to the efforts of the local organising committee.

I encourage everyone to participate in the AGM [7th January at 11:30) and student members to participate in the Student Forum (7th January at 10:15). The success of organisations such as VMSG depends not only on the activities of the various committees - and of course on excellent science - but on the continued input and contribution to the Group through the AGM and Forum.

I look forward to meeting you in Norwich in January.

Andy Saunders

CHAIR OF THE VOLCANIC AND MAGMATIC STUDIES GROUP

Foreword

It is a great pleasure to welcome you to the 2015 VMSG meeting in Norwich organised by the University of East Anglia. For many practical and aesthetic reasons, we thought it best to hold such a large meeting in the spectacular OPEN centre in Norwich rather than at UEA, and we hope that this location also gives you a chance to see a little of the city.

Although we are surrounded by sedimentary rocks in East Anglia, take heart that igneous rocks are only a few hundred metres away—albeit as intrusions in the buried Palaeozoic basement. Norfolk has some remarkable geological highlights, such as the Steppe Mammoth recovered from West Runton in 1995; palaeolithic hominid sites at Happisburgh and Lynford; and the vertebrate fossil treasure trove of the last interglacial at Shropham Pit.

We have a wide ranging programme with 125 presentations in the thematic sessions and the Research in Progress session. Colleagues at UEA have been developing research in aspects of volcanic risk and crisis behaviour and have organised a Panel Discussion on "The 21st Century Volcanologist". We are particularly pleased to welcome overseas panel members from the USGS, INGV, SRC and GNS to this meeting.

Richard Herd

CHAIR OF THE VMSG LOCAL CONFERENCE ORGANISING COMMITTEE

LOCAL ORGANISING COMMITTEE

Richard Herd, University of East Anglia

Anna Hicks, University of East Anglia

Amanda Hamer, University of East Anglia

Jenni Barclay, University of East Anglia

Katie Preece, University of East Anglia

Jonathan Stone, University of East Anglia

Roland von Glasow, University of East Anglia

David Litchfield, University of East Anglia

Charlotte Monteil, University of East Anglia

Peter Simmons, University of East Anglia

Russell Rajendra, Mineralogical Society

VOLCANIC AND MAGMATIC STUDIES GROUP

The Volcanic and Magmatic Studies Group (VMSG) is a joint specialist group of both the Mineralogical Society of Great Britain & Ireland and the Geological Society of London. The group, started in 1963-4, provides a focus for UK study of magmatic processes and volcanology through organisation and sponsorship of scientific meetings and fieldtrips. In particular, we organise an annual thematic and research in progress meeting, hosted at a UK based university venue.

The Volcanic Studies Group was initially formed at Birkbeck College, University of London, on 4 December 1963, at the instigation of Dr. A.T.J. Dollar and Dr. G.P.L. Walker. The Group became formally associated with the Society as a specialist group in January 1964, and a steering committee was formed under the chairmanship of Professor F.H. Stewart. The VSG appears to have been the first Specialist Group of the Geological Society, shortly followed by the Engineering Group.

The Group's first meeting in the Society's 'apartments', held on 18 March 1964, took the form of a one-day colloquium on pyroclastic rocks. A second one-day colloquium, on acid rocks in the North Atlantic Tertiary province, was held on 11 November 1964. The latter meeting was chaired by Professor Hawkes and included contributions from Sabine (Rockall), Dunham & Emeleus (the acid rocks of Rhum), Skelhorn (the acid rocks of Ardnamurchan and Mull), Moorbath & Bell (Sr isotope studies), Walker (the acid rocks of Iceland), Cann (Ascension Island) and Le Bas (Carlingford), among others.

Other one-day colloquia followed: Atlantic volcanoes on 19 May 1965; African volcanoes on 20 October 1965; 'volcanological topics arising out of the New Zealand symposium of the International Association of Volcanology' on 3 March 1966; and Alkali basalts and their associates on 2 June 1966. However, the meeting of 21-22 October 1966, on 'the Origin and Evolution of Basaltic Magmas' was unusual for two reasons; it was a 2-day symposium, and it was held in the Grant Institute at the University of Edinburgh – the first meeting of the VSG away from Burlington House.

This information was taken from the VMSG website. For further information about VMSG, visit www.vmsg.org.uk or visit our social media sites @vmsg_uk

CONFERENCE INFORMATION

Registration Desk

The registration desk for collection of your conference pack is based in **one of two** places, **depending on the day you arrive:**

- **Sunday 4th January** (17:00-22:00): Nelson Pub at the Premier Inn, Prince of Wales Road, Norwich, NR1 1DX (see map on page 106/back page for details)
- **Monday 5th January onwards:** OPEN Venue, 20 Bank Plain, Norwich, NR2 4SF (see map on page 106 for details)

Using Wifi

Our conference venue has designated wifi connection. Details will be easily accessible during the conference.

Information for speakers

- Presentations should last between 10 and 12 minutes, which allows for 3-5 minutes of questions. The session convener will notify you when you have three minutes left to speak. It is imperative that you keep your presentations to time in order for the conference to run on schedule.
- Presentations should be in one of the following file formats: *ppt, pptx, pdf.* The presenting computer will be running on Windows 7, and have MS Office 2010 or later installed.
- Two microphone options are available: fixed microphone at a lectern or radio mic headset. Speakers may choose either option to suit preference.

Information for poster presenters

- All posters will be displayed for the duration of the meeting in the Banking Hall. When you arrive, please put up your posters on your allocated numbered poster board (in your registration pack).
- There will be a dedicated poster session on Monday 5th January (poster session A) and Tuesday 5th January (poster session B). While you are encouraged to stand by your poster during your allocated session, you are of course welcome to invite people to discuss your poster at any time.
- Poster boards are size A0 (85cm by 115cm). **Portrait style only, please.** Posters will be fixed to boards using Velcro hooks provided.

Prizes

Prizes will be offered for: (1) the best student oral presentation in each session; (2) the best student poster presentation; (3) the best overall student oral presentation. Prizes will be judged by the local conference organising committee.

The OPEN venue

OPEN is a multi-purpose venue providing youth activities, live music, events and conferences all in the heart of Norwich. The OPEN Youth Trust was established to provide opportunities for young people in Norfolk including those who are most disadvantaged, with the longer term aim of making a positive difference to their lives. Through the commercial activities OPEN Conference, Live Music & CLOSED Secure Storage, the OPEN Youth Trust is able to offer a range of different activities, most of which are free to attend, for young people aged 7 – 25.

The OPEN Youth Trust also manages the SOS Bus. The history of the venue dates back to 1779 when Alderman Poole, a wine merchant, sold Barlett Gurney his premises. Gurney installed safes for bullion in the former wine cellars and the Gurney Bank was established. In 1896, 20 banks including the Gurney Bank were amalgamated under the name of Barclay & Co Ltd. However Barclays Bank outgrew its premises and in 1926 a new building was designed with a huge banking hall, offices and strong rooms.

Our venue was the regional head quarters of Barclays Bank until it was sold to the Lind Trust in 2003. Also during 2003 a Youth Forum was established to assess the needs of young people in Norfolk, and in 2005 the OPEN Youth Trust finally received charitable status.

Hudsons Architects worked with young people on how best to make use of the interior of the venue, both for young people and also conference users, and in 2009 a totally redesigned venue being handed back to the Trust.

(information and images taken from the OPEN Venue website: http://www.open247.org.uk/)

VMSG 2015 Twitter Policy

VMSG supports open science and welcomes discussion around its annual meeting on social media. All presenters have been asked to add a 'no Tweet' logo (see below) where they do not wish information to be shared on social media. Please respect this and tweet responsibly at other times, for example, do not Tweet photographs of talks or posters without permission. The official hashtag is #VMSG2015.

Meals & Refreshments

Your registration fee includes:

Monday 5th January

- Morning and afternoon refreshments
- Lunch
- Complimentary drinks for the poster session and pub quiz

Tuesday 6th January

- Morning and afternoon refreshments
- Lunch
- Complimentary drinks for the poster session
- Conference dinner (see page 9)

Wednesday 7th January

- Morning refreshments only **(no lunch)**

Note: All delegates were required to state dietary requirements during registration. Catering has been arranged according to these choices.

Conference Dinner

The Conference Dinner will take place on Tuesday 6th January at the "Top of the Terrace" at Norwich City Football Club starting with a drink on arrival at 19:00, and dinner at 19:30. Catering will be provided by Delia Smith's Canary Catering. The cost of the dinner is included in your conference fee, and includes a welcome drink (sparkling wine or a non-alcoholic option) and drinks during dinner. There will also be a cash bar. We will not be providing a seating plan. For your entertainment, a disco will follow dinner.

The evening ends at 01:00 but for those who wish to carry on, there are numerous clubs open at the nearby Riverside development and on the Prince of Wales Road.

Getting there

The venue is within easy walking distance from the Premier Inn (~1 km) and the OPEN venue.

For those who wish to take their own vehicles, ample free parking is available on site. The address is "Top of the Terrace", Barclay Stand, Norwich City Football Club, Carrow Road, Norwich, NR1 1JE

The venue is on the 2nd floor and unfortunately there is no dedicated lift. If you have problems negotiating stairs, please contact us via the conference registration desk or email vmsg.2015@uea.ac.uk and arrangements will be made for you.

MENU

Option 1

Roasted Mediterranean Vegetable Couscous Salad with Goats' Cheese and Harissa-style Dressing

***

Spanish Chicken with Butter Beans, Chorizo and Tomatoes; Oven-roasted Potatoes with Garlic and Rosemary; Crisp Green Salad with a Sharp, Lemony Dressing

***

Mini Pavlova with Strawberries, Vanilla Mascarpone Cream and Strawberry Sauce

Option 2

Caramelised Onion Tartlet with Goats' Cheese and Thyme

***

Spiced Chickpea Cakes with Red Onion and Coriander Salad

***

Mini Pavlova with Strawberries, Vanilla Mascarpone Cream and Strawberry Sauce

(Gluten free options are also available)

NORWICH INFORMATION

How to get to Norwich City Centre **(see Norwich map on inside back cover)**

By Air

Norwich International Airport is 4 miles from the city centre with connecting bus and taxi services available.

The closest London airport is Stansted (80 miles). Direct coach services to main London airports are available from National Express (www.nationalexpress.com).

By Rail

Norwich railway station is located in the city centre. Services are provided by Abellio Greater Anglia and by East Midlands Trains with a direct service to London Liverpool Street taking approximately 1 hour 45 minutes.

By Road

National coach services are provided by National Express (www.nationalexpress.com) with some limited services by Megabus (uk.megabus.com).

Main routes into Norwich are the A47 from the West and the A11 and A140 from the South. These connect to London via the M11, A14 and A12, with the Midlands and north of England served by the A14, A17 and A1.

For route planning see www.theaa.com/route-planner or google maps.

NORWICH RESTAURANTS

1. Artorio's Mediterrean Taverna
Unit 3C, Wherry Rd, NR1 1WX
01603 666165

2. Baby Buddha Chinese Teahouse
139 Ber St, NR1 3EY
01603 490889

3. Bella Italia
4aa Leisure Scheme, Riverside, NR1 1EE
01603 615584

4. Bella Italia
3 Red Lion St, NR1 3QF
01603 614676

5. Frankie & Benny's
2 Wherry Rd, NR1 1WZ
01603 617206

6. Frank's Bar
19 Bedford St, NR2 1AR
01603 618902 (Café bar)

7. La Tasca
24 Tombland, NR3 1RF
01603 776420

8. Last Wine Bar and Restaurant
76 St George's Street, NR3 1AB
01603 626626

9. Loch Fyne
39 St Giles St, NR2 1JN
01603 612790 (Seafood)

10. Mambo Jambo
14-16 Lower Goat Ln, NR2 1EL
01603 666802 (Mexican)

11. Namaste
2a Opie St, NR1 3DN
01603 662016 (Vegetarian Indian)

12. Nando's
23-25 Red Lion St, NR1 3QF
01603 633683

13. Nando's
7 Wherry Rd, NR1 1WS
01603 663930

14. Pedro's
Chapelfield Gardens, NR1 1NY
01603 614725 (Mexican)

15. Pizza Express
15 St Benedict's Street, NR2 4PE
01603 622157

16. Pizza Express
The Forum, Bethel St, NR2 1TF
01603 662234

17. Prezzo
2 Thorpe Rd, NR1 1RY
01603 660404 (Italian)

18. Roots
6 Pottergate, NR2 1DS
01603 920788

19. Shiki
6 Tombland, NR3 1HE
01603 619262 (Japanese)

20. Spice Lounge
8-10 Wensum St, NR3 1HR
01603 766602 (Indian)

21. Sugar Hut
4 Opie St, NR1 3DN
01603 766755 (Thai)

22. Thai on the River
Floating Restaurant, Riverside, NR1 1EE
01603 767800

23. The Belgian Monk
7 Pottergate, NR2 1DS
01603 767222

24. The Clipper
38-40 St Benedicts St, NR2 4AQ
01603 613444 (Indian)

25. The Edith Cavell
7 Tombland, NR3 1HF
01603 765813

26. The Iron House
1 St John Maddermarket, NR2 1DN
01603 763388

27. The Vine Tavern
Dove St, NR2 1DE
01603 627362 (Thai)

28. The Waffle House
39 St Giles St, NR2 1JN
01603 612790

29. Three Ways
4A Brigg St, NR2 1QN
01603 622814 (Lebanese)

30. Torero
19 Fye Bridge St, NR3 1LJ
01603 621825 (Spanish)

31. Trattoria Rustica
20 Princes St, NR3 1AE
01603 621043 (Italian)

32. Zizzi
25 Tombland, NR3 1RF
01603 765767 (Italian)

NORWICH PUBS

A. Adam and Eve
17 Bishopgate, NR3 1RZ
01603 667423

B. Compleat Angler
120 Prince of Wales Rd, NR1 1NS
01603 622425

C. King's Head
42 Magdalen St, NR3 1JE

D. Micawbers Tavern
92 Pottergate, NR2 1DZ
01603 626627

E. Norwich Playhouse
42-58 St Georges St, NR3 1AB
01603 612580

F. Take 5
17 Tombland, NR3 1HF
01603 763099

G. The Birdcage
23 Pottergate, NR2 1DS
01603 633534

H. The Champion
101 Chapel Field Road, NR2 1SE
01603 628148

I. The Coachmakers
9 Saint Stephens Road, NR1 3SP
01603 662080

J. The Lawyer
12-14 Wensum St, NR3 1HY
01603 633122

K. The Murderers
2-8 Timber Hill, NR1 3LB
01603 621447

L. The Norwich Tap House
8 Redwell Street

M. The Ribs of Beef
24 Wensum St, NR3 1HY
01603 619517

N. The Rumsey Wells
4 St Andrews St, NR2 4AF
01603 614858

O. Wildman
Bedford St, NR2 1AG
01603 614177

P. Wig and Pen
6 St Martin-At-Palace Plain, NR3 1RN
01603 625891

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The Geological Society

We would also like to thank the following organisations, institutions and research projects for their support of VMSG 2015:

University of East Anglia

Mineralogical Society

open CONFERENCE

STREVA
STRENGTHENING RESILIENCE IN VOLCANIC AREAS

delia's CANARY CATERING

Norwich City Football Club PLC

Premier Inn

CONFERENCE PROGRAMME

Sunday 4th January 2015

17:00-21:00	Arrival, registration and icebreaker (Nelson Pub, at The Premier Inn, Norwich). See page 106 for directions.

Monday 5th January 2015

08:00-08:50	Arrival at OPEN venue (see page 106 for map), registration & coffee
09:00-09:10	Welcome Address: Richard Herd, Chair of Local Organising Committee
09:10-09:15	Housekeeping & Questions: Anna Hicks, Local Organising Committee

Session 2: Tambora's legacy: volcanic emissions into the atmosphere

Convener: Jeremy Phillips, University of Bristol

09:15-09:45	Keynote: Clive Oppenheimer, University of Cambridge **"Global societal impacts of large eruptions"**	
09:45-10:00	Brendan McCormick	Improvements in volcanic gas emissions budgets enabled by satellite remote sensing
10:00-10:15	Anja Schmidt	Long-range transport and air quality impacts of volcanic sulfur emitted by the 2014 eruption at Holuhraun, Iceland
10:15-10:30	Roland von Glasow	Reactive plume chemistry and links to mercury deposition at Masaya volcano, Nicaragua
10:30-10:45	Catherine Hayer	Near real time observations of volcanic emissions
10:45-11:15	**COFFEE BREAK & POSTERS**	

Session 4: Research in Progress (Part 1)

Convener: Paul Cole, Plymouth University

11:15-11:30	Sebastian Watt	Volcanic edifice collapse and the reorganization of magmatic systems
11:30-11;45	Robert Jones	Developing a Probabilistic Method for Rain-Triggered Lahar Forecasting at Tungurahua Volcano
11:45-12:00	Vern Manville	Giant rafted pumice blocks from the 1.8 ka Taupo eruption, New Zealand: evidence for shallow subaqueous eruption processes at rhyolitic lava domes
12:00-12:15	Joel Gill	Development of Multi-Hazard Visualisations for Volcanic Environments in Guatemala
12:15-12:30	Jake Cibrowski	Did Mantle Plume Magmatism Trigger the Great Oxidation Event?

12:30-13:30	LUNCH & POSTERS	
Session 1: Geophysical, geochemical and petrological monitoring		
Convenor: Jessica Johnson, University of East Anglia		
13:30-14:00	Keynote: Marie Edmonds, University of Cambridge **“New perspectives on monitoring andesite volcanoes”**	
14:00-14:15	Tim Greenfield	Drumbeats from the Deep, Building the Crust through Melt Injection
14:15-14:30	Paul Jarvis	Crystal Transfer during Magma Mingling: Insights from Analogue Experiments
14:30-14:45	Janine Kavanagh	Tracking fluid flow and host-rock deformation during magma ascent: Insights from analogue models
14:45-15:15	**COFFEE BREAK & POSTERS**	
15:15-15:30	Giuseppe La Spina	Simulation of the Etna 2001 flank eruption with a steady-state numerical model of magma ascent
15:30-15:45	Manuel P. Queißer	Development of a remote sensing instrument to measure sub-aerial volcanic CO_2 fluxes
15:45-16:00	Christopher Kilburn	Emergency forecasts of volcanic eruptions
16:00-18:00	**Poster session (A) with refreshments**	
18:00-19:30	**Pub Quiz (at OPEN venue)**	

Tuesday 6th January 2015

Session 3: Important problems in applied volcanology		
Convener: Jenni Barclay		
09:00-09:30	Keynote: David Pyle, University of Oxford **“Volcanoes: Learning from the Past, Looking to the Future”**	
09:30-09:45	Jacqueline J. Ratner	Terrain mapping using structure-from-motion photogrammetry and crowd-sourced data
09:45-10:00	Sally H. Potter	Communicating the Status of Volcanic Activity in New Zealand
10:00-10:15	Luke Surl	Atmospheric Chemistry of Volcanic Plumes in WRF-Chem
10:15-10:30	Pete J. Rowley	Internal structure of a pyroclastic density current: Insights from spontaneous partitioning of experimental gas-fluidised powder flows.

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10:30-11:00	**COFFEE BREAK & POSTERS**	
11:00-12:00	**Panel Discussion 1: Being a good collaborator: collecting and sharing data**	
12:00-13:00	**LUNCH & POSTERS**	
13:00-14:00	**Panel Discussion 2 : Working with policy makers and sharing volcanic information**	
Session 4: Research in progress (Part 2) **Convener: Paul Cole, Plymouth University**		
14:00-14:30	**VMSG Award Winner Keynote: Jenni Barclay, University of East Anglia** **“Rocks, Risk and Robert Owen”**	
14:30-14:45	Samuel Bewick	A Comparison of Recent Post-Collisional Volcanism in the Lesser and Greater Caucasus
14:45-15:00	Eve Rooks	Structure of the off-craton lithospheric mantle beneath southern Gondwana: Constraints from Patagonian rare garnet-bearing mantle xenoliths
15:00-15:15	Alexandros Poulidis	Volcanically-Triggered Rainfall and the Effect on Volcanological Hazards at Soufriere Hills, Montserrat
15:15-15:45	**COFFEE & POSTERS**	
Session 5: Reconstructing volcanic and magmatic histories (Part 1) **Convener: Kathy Cashman, University of Bristol**		
15:45-16:00	Luke N. Hepworth	"Incremental construction of the Unit 10 peridotite, Rum Eastern Layered Intrusion, NW Scotland
16:00-16:15	Marina Valer	"The petrogenesis of plagioclase-phyric basalts from La Réunion Island
16:15-16:30	David A. Neave	"The evolution and storage of primitive melts in the Eastern Volcanic Zone of Iceland: the 10 ka Saksunarvatn tephra
16:30-18:30	**Poster session (B) with refreshments**	
19:00-19:30	Arrival at conference dinner venue (Norwich City Football Club “Top of the Terrace”) see page 9 for more details)	
19:30-late	Conference dinner	

Wednesday 7th January 2015

Session 5: Reconstructing volcanic and magmatic histories (Part 2)

Convener: Kathy Cashman, University of Bristol

09:00-09:30	**Keynote: Madeleine Humphreys, Durham University** **Magma degassing, crystallisation and the fidelity of plagioclase-melt thermometry**	
09:30-09:45	Michael J. Stock	A temporal record of magmatic volatile evolution through texturally constrained apatite analysis
09:45-10:00	Helena C. Moretti	The contributions of calcium carbonate assimilation and fresh fluids in the Pollara eruptions of Salina, Aeolian Arc, Italy
10:00-10:15	Nina Jordan	Volcanic history of a peralkaline caldera volcano: Pantelleria, Italy
10:15-10:45		**COFFEE, POSTERS & STUDENT FORUM**
10:45-11:00	Simon Groom	The Bejenado Effusive Phase lava flow field – insights into magmatic processes after a lateral collapse
11:15-11:30	Jenny Riker	Partitioning behaviour of CO_2 between apatite and basaltic melt: A new tool for tracking magmatic CO_2 contents
11:30-11:50	VMSG Annual General Meeting	
11:50-12:00	Prizes	
12:00-12:10	Closing remarks	

END OF CONFERENCE

For those staying on for the risk workshop at UEA, information is as follows:

Understanding Volcanic Risk: A STREVA scientific discussion meeting

Wednesday 7th January 2015 (Zuckerman Institute, School of Environmental Sciences, UEA)

14:00-19:00	Introduction to the STREVA forensic settings and exploring risk problems
19:00 -	**DINNER**

Thursday 8th January 2015 (Julian Study Centre, UEA)

09:00-15:00	Interdisciplinary approaches to tackling volcanic risk

PANEL DISCUSSION: Tuesday 6th January 11:30-14:00

"Challenges for the 21st Century volcanologist: gathering data, providing expert advice and sharing knowledge"

Chair:

Dr Sue Loughlin (British Geological Survey; Member Scientific Advisory Group for Emergencies (SAGE); UK Natural Hazard Platform, Advisor Civil Contingencies Secretariat)

Panel Members:

Professor Stephen Sparks (University of Bristol; Member SAGE, Member Scientific Advisory Committee for Montserrat (SAC))

Dr Richie Robertson (Director, Seismic Research Centre, University of the West Indies)

Dr Sally Potter (Joint Centre for Disaster Research, GNS Science, New Zealand)

Dr Cynthia Gardner (Cascades Volcano Observatory, United States Geological Survey)

Dr Anja Schmidt (University of Leeds; Member Scientific Advisory Group for Emergencies (SAGE))

Dr Chris Kilburn (University College London)

Professor Mike Burton (INGV Pisa, Italy)

Jonathan Stone (University of East Anglia; former Outreach and Education officer, Montserrat Volcano Observatory)

Objective: to stimulate discussion and thinking amongst the UK community about how we interact with other research teams, in-country partners, volcano observatories and wider public in volcanic regions.

Outcome: we will produce a discussion summary and some bullet guidelines for display and discussion on the VMSG website

We would like the discussion to follow three key **themes:**

1. **Ethics of data collection anywhere (rock samples, seismic data, interviews, online data streams etc.),**

2. **Collaboration. How would we define a good collaboration in any context. What works well during an eruption response (with reference to IAVCEI protocol)?**

3. **Provision of research advice to authorities and sharing information with the wider world.**

There will be two sessions and each will combine both short individual presentations by panel members with open floor discussions. Join the debate!

KEYNOTE TALKS

There will be five keynote presentations taking place during the conference:

Talk	Date/Time	Speaker	Presentation title
1	05/01/15 09:15	Clive Oppenheimer University of Cambridge	Global societal impacts of large eruptions
2	05/01/15 13:30	Marie Edmonds, University of Cambridge	New perspectives on monitoring andesite volcanoes
3	06/01/15 09:00	David Pyle, University of Oxford	Volcanoes: Learning from the Past, Looking to the Future
4	06/01/15 14:00	VMSG Medal Award Winner: Jenni Barclay, University of East Anglia	Rocks, Risk and Robert Owen
5	07/01/15 09:00	Madeleine Humphreys, Durham University	Magma degassing, crystallisation and the fidelity of plagioclase-melt thermometry

VMSG

ORAL ABSTRACTS:

Geophysical, geochemical and petrological monitoring

New perspectives on monitoring andesite volcanoes

MARIE EDMONDS

Dept. Earth Sciences, University of Cambridge, Downing Street, Cambridge, UK. CB2 3EQ; me201@cam.ac.uk

Our view of andesite magmatic systems has evolved dramatically over the past decade. The emerging picture of how andesite magmas are generated, stored and erupted, largely stimulated by studies of volcanic rocks and gas emissions from Soufriere Hills Volcano (Montserrat), has important and novel implications for the interpretation of volcano monitoring data. Geochemical studies of SHV and elsewhere illustrate that magma reservoirs are vertically protracted, extending throughout the upper and mid crust. Extensive regions of locked crystal mushes exist, as well as regions of felsic liquids. The erupted magmas are complex hybrids, consisting of crystal-rich magmas that have undergone protracted residence times in the crust, sporadically recharged by wet mafic melts. Interactions between recharging melts and resident mushes and liquids range from enclave formation at the interface to whole-scale destabilization and reorganization of mushes, liquids and fluids. Mafic enclave geochemistry shows extensive hybridization between mafic and felsic liquids in a foamy layer. The foam is rich in magnetites and probably also sulfides at the interface between mafic and andesitic magmas, made buoyant by heterogeneous bubble nucleation. In the shallow crust, there is segregation of water- and sulfur-rich fluids, resulting in extensive gas emissions during and after eruptions.

Volcanic gases are emitted in prodigious quantities at andesitic arc volcanoes, consistent with the volatile-rich nature of the recharging magmas and the extended periods of storage and crystallisation in the mid-crust. Sulfur may be supplied by flotation of sulphides, brought up through the crust by magma overturn events. Sulfur dioxide emissions at SHV, the mainstay of gas monitoring, are decoupled from lava fluxes, consistent with the idea of fluids being segregated from the bulk magma and utilising independent pathways to the surface. Ground deformation during and between eruptions is too small to fully account for the volumes of magma erupted, which can be reconciled by the presence of extensive amounts of exsolved, compressible fluids segregated into the upper parts of the magma reservoir. Studies to understand fully the architecture of complex andesite bodies are driven by an urgent need to understand volcano-monitoring data.

Drumbeats from the Deep, Building the Crust through Melt Injection

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Persistent seismicity recorded within the Askja segment of the Northern Volcanic Rift Zone of Iceland since 2007 by a network of up to 55 three-component broadband seismometers reveals melt transport in distinct regions at 20 km depth in the mid crust. The bulk of the seismicity occurs beneath the main central volcano but significant seismicity exists in two other, distinct, locations. The cluster located beneath Vadalda, a shield volcano to the east of Askja, experienced a swarm in December 2012 during which more 50% of the total earthquakes in this cluster occurred. Accurate earthquake locations have been generated using hand picked arrival times and cross-correlation techniques in combination with HypoDD. This has revealed that events within the seismic swarm all occurred at a single depth in the crust and migrated ~2.5 km to the southwest over a four week period. We interpret this as a sill intruding laterally into the mid-crust.

The swarm culminated in intense seismicity from the 23rd to the 27th December with periods where up to six earthquakes occurred each minute for ~2hrs. During an active period the waveforms are identical, like 'drumbeats' and locate in exactly the same place. This implies a repeating mechanism causing the earthquakes. Fault plane solutions are difficult to constrain due to the small size of the events, but for the largest cluster a thrust fault is the best fitting solution. This could be the ends of the injecting sill failing in a thrust sense as predicting by a Hill mesh. The stresses induced by the sill cause the fault to fail the same way every time causing the drumbeat seismicity. Another explanation is that the earthquakes are formed by melt moving to a higher aseismic layer which fails when the flow rate was sufficiently low to allow cooling of the melt through the glass transition and induce brittle failure.

Crystal Transfer during Magma Mingling: Insights from Analogue Experiments

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Mafic enclaves produced by the mingling of felsic and mafic magmas commonly contain xenocrysts; crystals akin to those in the felsic host. These crystals are interpreted as having crossed the interface between the two magmas during mingling. The preferential transfer of certain crystals could have significant consequences for the resulting hybrid compositions of the rocks. An understanding of the physical conditions that allow this exchange gives insight into the state of the system at the time of capture, providing information about the magmatic history of the rock. We investigate the fundamental problem of low Reynolds number gravitational settling of spheres through fluid-fluid interfaces is studied as an analogue to the magmatic process. Theoretical treatment suggests that the behaviour depends on four dimensionless parameters; Bond number, the viscosity ratio, a modified density ratio and the three phase contact angle. Spheres of various radii and density are allowed to settle onto a stable interface between silicone oil and a golden syrup/water solution for different values of the dimensionless groups. Here we will discuss the effects of interfacial tension and viscosity ratio on the identified flow regimes including under what conditions spheres pass through or are trapped at the interface, the volume of entrained fluid and how crystal dynamics are affected by the interface. We then explore the implications for magmatic systems.

Tracking fluid flow and host-rock deformation during magma ascent: Insights from analogue models

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Models of magma ascent in the crust tend to either consider the dynamics of fluid flow within intrusions or the associated host-rock deformation. However, these processes are coupled in nature, and so to develop a more complete understanding of magma ascent dynamics in the crust both need to be taken into account. We present a series of gelatine analogue experiments that use both Particle Image Velocimentry (PIV) and Digital Image Correlation (DIC) techniques to characterise the dynamics of fluid flow within intrusions and to quantify the associated deformation of the intruded media. Experiments are prepared by filling a 40x40x30 cm^3 clear-Perspex tank with a low-concentration gelatine mixture (2-5 wt%) scaled to be of comparable stiffness to crustal strata. Fluorescent seeding particles are added to the gelatine mixture during its preparation and to the magma analogue prior to injection. Dyed water (the magma analogue) injected into the solid gelatine from below causes a vertically propagating penny-shaped crack (dike) to form. Two Dantec CCD cameras are positioned outside the tank and a vertical high-power laser sheet positioned along the centre line is triggered to illuminate the seeding particles with short intense pulses. Incremental and cumulative displacement vectors are calculated by cross-correlation between successive images at a defined time interval. Spatial derivatives map the fluid flow dynamics within the intrusion and associated strain and stress evolution in the host, both during dike propagation and on to eruption. Strain calculations correlate with stress as the gelatine-host deforms elastically at the experimental conditions. Models which couple fluid dynamics and host deformation make an important step towards improving our understanding of the dynamics of magma transport through the crust and to help constrain the tendency for eruption

Simulation of the Etna 2001 flank eruption with a steady-state numerical model of magma ascent

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Volcanoes exhibit a wide range of eruption styles, from relatively slow effusive eruptions, generating lava flows and lava domes, to explosive eruptions, in which very large volumes of fragmented magma and volcanic gas are ejected high into the atmosphere. Magma ascent dynamics in a volcanic conduit play a key role in determining the eruptive style of a volcano. However, due to the lack of direct observations in the conduit itself, numerical models, constrained with observational data, provide invaluable tools for quantitative insights into the complex magma ascent processes.

We have developed a 1D steady-state multiphase multicomponent gas-magma-solid mathematical model, consisting of a set of non-linear partial differential and constitutive equations. The governing equations used in this work are designed to model multiphase fluid with disequilibrium processes, represented through the formalism of thermodynamically compatible hyperbolic systems as a system of conservative partial differential equations with relaxation terms.

This numerical model has been used to reproduce the 2001 flank eruption at mount Etna. During this eruption, seven fissures at different altitude were active, showing different eruptive styles: fire fountains, Strombolian activities and lava effusions. From a mineralogical point of view, two different lavas were erupted. The vent higher than 2600 m a.s.l. (hereafter Upper vents, UV) erupted plagioclase-rich magma with an high crystal content. On the other hand, the vents located at 2550 and 2100 m a.s.l. (hereafter Lower vents, LV) produced a plagioclase-poor magma with a lower crystal content than UV magmas. With our numerical model we have investigated both eruptive events at UV and LV. Using the estimation for volume flow rate and for crystal content we are able to constraint the conduit radius and the temperature of the magma chamber. Furthermore, our numerical results indicate that UV and LV magmas are originated from the same magma, but with a different time available for crystallization. Our data show that LV magma is erupted before the crystals reach an equilibrium profile, while for UV the equilibrium is achieved. These conclusion are consistent with the presence of a shallow sill below UV where magma can circulate and reach the equilibrium crystal content, while for LV activities, magma ascends vertically without having enough time to completely crystallize.

Development of a remote sensing instrument to measure sub-aerial volcanic CO_2 fluxes

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The capacity to measure volcanic CO_2 fluxes is highly desirable, as such measurements would aid volcano monitoring efforts and help constrain the contribution of volcanic CO_2 emissions to the geological carbon cycle. Quantification of magmatic CO_2 in a volcanic plume is challenging since the signal is typically quite modest compared with the CO_2 concentration of the background atmosphere. It is for this reason that many magmatic CO_2 concentration measurements focus on in situ techniques, such as direct sampling Giggenbach bottles, chemical sensors, IR absorption spectrometers or mass spectrometers. Typically, such measurements are performed together with SO_2 concentration and flux measurements, allowing estimation of CO_2 fluxes. A further method to determine CO_2 fluxes is the step-ladder approach of flying a CO_2 concentration sensor in a raster-type pattern within a volcanic plume to produce a cross-sectional CO_2 concentration map, which may be used to determine CO_2 flux.

Here, we present a new instrument, developed with the ERC project CO_2Volc, which was designed to measure column amounts of CO_2 in the atmosphere with sufficient sensitivity to reveal the contribution of magmatic CO_2. By flying this instrument over a volcanic plume we will, in principle, be able to robustly and swiftly determine CO_2 fluxes. This opens the possibility of rapid, comprehensive surveys of both point source, open-vent CO_2 emissions, as well as emissions from more diffuse sources such as lakes and fumarole fields. The new instrument uses the differential absorption LIDAR technique (DIAL) to quantify the absorption, and therefore path amount, of CO_2 in the atmosphere. Collimated, multiplexed laser radiation at two precise wavelengths, produced with amplified fibre lasers, is emitted from the instrument, travels through the atmosphere and plume to the ground, where it is reflected back through the atmosphere and plume to a receiving telescope. The instrument has been optimised for ruggedness, low weight (20 kg) and low power (70W), making it highly portable. We present initial test results from the new instrument collected on the island of Vulcano, Italy. Whilst more refinement is required to fully realise the potential of the instrument, we believe that the CO_2 LIDAR could make a major contribution to volcano monitoring.

Emergency forecasts of volcanic eruptions

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Half of the volcanoes that have been active in historical time have reawakened after repose intervals of 100 years or more. Most such volcanoes are poorly monitored and neighbouring populations are rarely aware of their exposure to volcanic hazards. When signs of unrest are finally recognised, little background information is available for evaluating the potential for eruption. An urgent need therefore exists for improving the quality of short-term forecasts of eruptions at long-quiescent volcanoes, using emergency data obtained after the start of unrest.

Ground deformation and the numbers of short-period, or volcano-tectonic, seismic events are the phenomena most frequently monitored during unrest. Their changes with time can be detected as much as weeks-months before an eruption and show similar types of behaviour independent of tectonic setting, magma composition and style of eruption. The repetitive behaviour suggests that the unrest signals can be described in terms of a physical model that can be used to develop deterministic forecasts of eruptions during an emergency.

Deformation and short-period seismicity measure how the crust stores and consumes the mechanical energy being supplied, for example, by an increase in magma pressure. Two limiting regimes are: (1) when the storage of energy dominates, and (2) when the rate of energy supplied is balanced by the rate of energy lost by triggering short-period events. In the first case, the rate of occurrence of short-period events increases exponentially with deformation; in the second, the short-period event rate and mean rate of deformation increase in proportion to each other. The conditions yield quantitative constraints on the rates of occurrence of short-period events as the margins of a magma reservoir approaches bulk failure. The constraints, in turn, can be used to identify preferred times for an eruption.

ORAL ABSTRACTS:

Tambora's legacy: volcanic emissions into the atmosphere

Improvements in volcanic gas emissions budgets enabled by satellite remote sensing

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Accurate longterm records of volcanic gas emission rate and composition are essential for volcano monitoring and hazard mitigation; gauging the impact of volcanoes on Earth's environment and climate; and better characterising the role of degassing as a fundamental process for volatile transfer between major planetary reservoirs. In this study we show that significant improvements to emissions budgets can be made through wider use of satellite observations. The multi-year duration of satellite datasets enables measurements during a fuller range of degassing behaviour (eruptive cf. quiescent), while the global coverage of many satellite instruments allows characterisation of emissions at remote volcanoes currently inadequately constrained by ground-based measurement campaigns.

Anatahan (Marianas Islands) is a remote volcano in the SW Pacific whose first historical eruption was in 2003. Available ground-based measurements of sulphur dioxide (SO_2) gas emissions at Anatahan place it among the largest volcanic SO_2 sources worldwide. However, currently published data are restricted to eruptive intervals. Anatahan's activity since 2003—as compiled by the Smithsonian Institution Global Volcanism Program's Volcanoes of the World (GVP-VOTW) database of Holocene activity—has largely comprised sustained phases of quiescence, with relatively limited intervals of eruption.

Using ten years of satellite observations, we report highly variable SO_2 emissions within and between eruptive and quiescent intervals at Anatahan. Eruptive SO_2 emission rates have a mean value of 1900 td^{-1}, and a maximum of almost 20000 td^{-1}. Conversely, quiescent SO_2 emissions from Anatahan are below the detection limit of space-based sensors, and therefore are not likely to exceed ~300-400 td^{-1}. We show that while Anatahan occupies a quiescent state for 90% of the past ten years, only ~10% of total SO_2 emissions over this interval occur during quiescence, with the remaining ~90% released in short-lived but intense syn-eruptive degassing. We propose that multi-year satellite datasets in combination with activity histories from GVP-VOTW are a powerful complement to targeted ground-based campaign measurements in order to better characterise the longterm degassing behaviour of remote volcanoes for many volcanological applications.

Long-range transport and air quality impacts of volcanic sulfur emitted by the 2014 eruption at Holuhraun, Iceland

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During September/October 2014 the eruption at Holuhraun in Iceland emitted at least as much sulfur dioxide per day as is emitted from all European powerplant stacks together per day. Air quality measurement stations in Ireland and the UK reported the highest measured SO_2 concentrations since the late 1980s on two occasions in September 2014. I will present model simulations of the long-range transport and the air quality impacts of the Holuhraun eruption. Model performance is evaluated against satellite retrievals of SO_2 and ground-based measurements. I will also discuss whether or not this eruption affected low-level clouds and the climate.

Reactive plume chemistry and links to mercury deposition at Masaya volcano, Nicaragua

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Volcanoes are known to emit significant quantities of gases and trace metals including mercury. Some of these gases are involved in very fast reaction cycles in the atmosphere. This is especially true for chlorine and bromine which destroy ozone catalytically and also oxidise elemental gaseous mercury. Oxidised mercury is soluble and can be taken up by particles which can potentially increase the deposition of toxic mercury near the volcano.

In order to quantify these processes we conducted a field campaign at Masaya volcano, Nicaragua in March/ April 2011. We measured gaseous S, F, Cl, Br, I, total gaseous mercury and particulate mercury and particle size distributions near the crater rim and at a site ~2.5 km downwind fumigated by the plume. We also measured BrO and SO_2 near the crater rim and at two distances downwind by U.V. spectroscopy.

The BrO/SO_2 ratio was clearly elevated downwind compared to near-crater showing that reaction cycles to produce BrO are efficient on timescales of less than 10min. Changes in the mercury speciation (i.e., increased proportions of particulate Hg) were also observed at the downwind site, consistent with the links between reactive halogens and mercury discussed above.

A one-dimensional model was used to simulate the evolution of the volcanic emissions in the atmosphere, the comparison with the field data showed good model skill at reproducing the chemical processes. Details of the field data and the model results will be discussed.

Near real time observations of volcanic emissions

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Emissions of volcanic products are useful indicators of the activity level of a volcano. Many volcanoes are located in inaccessible regions, making remote observation the only regular method of monitoring. The emissions, particularly ash, also pose a significant hazard to passing aircraft through the damage caused to the engines. Evacuation of regions surrounding volcanoes, and cessation or diversion of air traffic around actively erupting volcanoes is costly and highly disruptive, but is sometimes required. Up to date information is of critical importance as to when to make these sensitive decisions. Since the volume of air traffic is constantly increasing, especially in regions with currently or recently active volcanoes, this need will also increase.

Rapid analysis of atmospheric composition can be used to detect volcanic activity. The IASI instruments, flying on board the MetOp-A and -B platforms, are used to produce Near Real Time (NRT) data using algorithms developed at the University of Oxford. The data is displayed on a website (www.nrt-atmos.cems.rl.ac.uk) within 3 hours of measurement. An archive of data is available to allow the study of previous events observed by IASI.

The IASI instruments provide global coverage twice daily (day-side and night-side), therefore jointly producing four measurements of the atmosphere per day. This is a significant advantage over the alternatives; geostationary instruments, with limited spatial coverage, or UV orbiting instruments, which can only make observations on the day-side of the orbit.

The website displays linear flags, denoting the presence or absence of ash and SO_2. In the near future, the website will be expanded to include flags for desert dust and biomass burning-derived species. The ability to produce near real time quantitative estimates of the mass loading of SO_2 and silicate ash within any volcanic cloud is also in development.

ORAL ABSTRACTS:

Important problems in applied volcanology

Volcanoes: Learning from the Past, Looking to the Future

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Despite considerable theoretical and technological advances of recent years, volcanology remains very much an empirical science. Volcanologists rely on developing an understanding of the prior behaviour of a volcano from observations, in order to develop conceptual models for how the volcano might behave in the future. For volcanoes that are frequently or continuously active, this approach works well, allowing the physical scientists charged with the monitoring of the volcano to build up their empirical expertise through careful continuous observation. For volcanoes that erupt only infrequently – once in a (human) generation, or more rarely - we need to use a different approach in order to develop our empirical expertise.

For volcanoes that have erupted in the 'historical' period, we can develop a rich understanding of past eruptions, and their wider impacts, by delving into what is left of both the physical deposits (if any exist), and the contemporary written and archival records relating to the event. In turn, these sorts of data provide the evidence base from which to develop scenarios and probabilistic models for future activity.

The Soufrière of St Vincent, in the Caribbean, makes an excellent example. St Vincent has a rich history of well documented eruptions (in 1812, 1902-3, 1971-2 and 1979). Diaries, newspaper reports, and colonial records outline the eruption of 1812 in sufficient detail that we can understand both the nature of the eruption, and its physical and economic impact: the eruption destroyed several major sugar plantations, which were subsequently rebuilt, and were soon back in production. They acted as hub for employment, and for a while the economy of St Vincent boomed.

Then, in May 1902 the volcano erupted again, with devastating consequences. The same plantations were once again destroyed, and at least 1600 lives were lost. Colonial records document in extraordinary detail the political response to the eruption, and efforts for immediate relief, and longer-term recovery. Volcanic ash samples, archived in collections around the UK, provide a remarkable petrological story of how the eruption unraveled – with ash samples collected hourly, or more frequently, as the eruption plumes rolled over Barbados. Put together, these materials give us not only an astonishing glimpse at the unfolding volcanic crisis; but also the clues to how the volcano might behave in the future.

Terrain mapping using structure-from-motion photogrammetry and crowd-sourced data

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Structure-from-motion (SfM) is a type of photogrammetry that triangulates points in digital photos to produce a 3D model. When applied to topographical modeling, SfM presents a powerful tool for rapid terrain mapping and it is robust enough to use crowd-sourced data as input while producing high-quality output terrain models. At little cost and on a timescale of hours, a metric-resolution digital terrain model (DTM) can be produced; the resultant DTM can be used for many types of hazard scenario modeling.

The robustness of SfM as a function of input data randomness was tested on the terrain of the Agios Georgios crater of Nea Kameni Island in Santorini, Greece. The experimental set-up was designed to yield datasets of photos from three groups: "laypeople" with no scientific expertise, a "general mix" of users with minimal expertise, and an "expert" group of SfM users. The three datasets of photos were collected by these groups, then analysed using SfM software VisualSFM, and the resultant terrain models were assessed and compared against one another for completeness.

The findings of this study indicate that while "expert" SfM users will collect data to a standard that creates very high-quality terrain models, the expertise is only marginally more beneficial to the end product than using data collected by a mixture of informed and uninformed participants. This shows that the SfM process is robust enough to withstand differences in data collection techniques, including uncalibrated camera set-ups, inconsistent methodologies, and incidental data collection; this indicates SfM as a technology that can confidently be used as a crowd-sourcing and community involvement tool.

The advantages of this study for emergency management are to provide a cheap and rapid metric-resolution alternative to low resolution or costly topography data sets, while simultaneously increasing stakeholder participation and understanding.

Communicating the Status of Volcanic Activity in New Zealand

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New Zealand has more than 12 active volcanoes; the most recent eruption occurred in 2013. The communication of scientific information to end-users is a critical component of an effective Volcano Early Warning System. In New Zealand, social science research is conducted on the communication of volcano-related information, and the findings are applied to contribute towards risk reduction.

Information about the status of volcanic activity and hazards is communicated by GNS Science using numerous means, including Volcanic Alert Bulletins, Volcanic Alert Levels (VALs), meetings and phone calls, blogs, public presentations, press releases, and social media are employed. End-users receiving the information include the public and media, civil defence and emergency management, lifelines and infrastructure sector, major land managers, tourist operators, and civil aviation.

Recent research explored the VAL system that was used between 1995 and 2014, and is an example of the application of research findings. A qualitative ethnographic methodology was utilised, involving semi-structured interviews of scientists and end-users, observations of the GNS Science volcanologists over three years, and document analysis. Participant’s opinions on the VAL system were integrated using thematic analysis. These findings were directly applied, resulting in a revised VAL system for all of New Zealand’s volcanoes. It was implemented on 1 July 2014 in collaboration with the Ministry of Civil Defence and Emergency Management.

Atmospheric Chemistry of Volcanic Plumes in WRF-Chem

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Volcanic eruptions are known to be a strong and concentrated source of reactive halogen species. The chemistry that these species are known to take part in include ozone-destruction cycles. Despite the potentially large perturbation to the chemistry of the troposphere that eruptions may cause, the magnitude of such impacts on global and regional scales is largely unknown.

We used WRF-Chem to investigate the influence of Mount Etna on the tropospheric chemistry of the Mediterranean region. The chemistry of bromine, chlorine and mercury has been added to the chemical mechanism CBMZ and we have coupled WRF-Chem with the emissions program PrepChem. We developed a simple parameterisation of the key multiphase reaction cycles involving halogens. Comparison with published field data shows that the model is able to reproduce the bromine explosion phenomenon seen in spectroscopic investigations of volcanic plumes.

From the model results we are able to determine a detailed picture of the chemistry of a volcanic plume; results are presented which show how the character of the volcanic plume evolves as it is advected downwind. We determine the magnitude of Mt. Etna's regional influence under typical conditions. We also present results which show how the variation in volcanic output, as well as meteorological variation within the region, can influence the extent of Mt. Etna's regional impact.

Additionally, these modelled results are supplemented with, and compared against, measurements of ozone depletion that we made within the plume at the summit of Mount Etna.

Internal structure of a pyroclastic density current: Insights from spontaneous partitioning of experimental gas-fluidised powder flows.

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Recent experimental studies have demonstrated the ability of dense air-particle flows with sustained high pore pressure, provided by continuous gas-fluidisation, to reproduce some aspects of long run-out pyroclastic density currents (PDCs) and their low aspect ratio deposits. The supplied gas simulates the extended pore-pressure diffusion timescales within thick natural flows, as well as processes including the exolution of gas from the juvenile components and air escape from rough natural substrates.

Similar experiments on flows generated by impingement of heated unaerated powder of 0-45 µm diameter silica beads, at a range of particle concentrations, onto a sub-horizontal surface show spontaneous formation of a two-layer particle transport system. This comprises a dense laminar flow over-ridden by a dilute turbulent powder suspension.

High speed video reveals that breaking-waves and sloshing features in the basal current provide a supply of material to the over-riding turbulent cloud, which in turn feeds some material back to the basal flow. The relative flux of these two processes is inferred to be a controlling factor on the growth rate of each flow layer.

This work provides insight into the flow structure of PDCs and suggests that mass-partitioning processes can lead to two discrete (dilute or dense) layers.

ORAL ABSTRACTS:

Research in Progress

Volcanic edifice collapse and the reorganization of magmatic systems

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Large-scale collapses of volcanic edifices are a widespread process, affecting composite volcanic structures across all volcano-tectonic setting. The largest such events mobilise tens of cubic kilometres of volcanic rock, producing debris avalanches that inundate large areas and which may potentially generate devastating tsunamis in coastal settings. A host of questions relating to these events remain poorly understood, including controls on the magnitude, frequency and timing of collapses, the progression of collapse, and the transport and mobility of resultant debris avalanches.

There is a wide range of evidence that collapses commonly mark transitions between major phases of activity at a volcanic system. This suggests that large collapses are either triggered by some change in the system, or that the collapse induces a step change in subsequent development of the magma storage and plumbing system. By making assessments from case studies at Montserrat and in Chile, we demonstrate that edifice collapse may promote the migration of deeper, more mafic magmas towards the surface. We suggest that this process is promoted by a mechanism that inhibits shallow magma ascent relative to deeper ascent, and may be associated with crystallization processes in shallow magma bodies. These investigations combine analyses of collapse deposits and their bounding volcanic stratigraphy with models of the impact of changing surface loads on stored magma. Our results can be used to better understand how surface processes are associated with major departures in the behaviour of a volcanic system. The specific response of magma systems to past changes in surface load, and the concomitant sub-surface pressurization conditions, can also provide constraints on the structure of the magma storage system, implied by the observed changes in volcanic activity.

Developing a Probabilistic Method for Rain-Triggered Lahar Forecasting at Tungurahua Volcano

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Ongoing intermittent strombolian, vulcanian and sub-plinian eruptions at Volcán Tungurahua (Ecuador) deposit pyroclastic material on the steep upper slopes of the volcano, creating a persistent rain-triggered lahar hazard. Hazardous flows threaten the popular tourist town of Baños (permanent population c. 18,000), c. 8 km from the crater, and other villages and vital infrastructure adjacent to the dense drainage network of Tungurahua.

This study focuses on the instrumented and lahar-prone northern drainages of the Vazcun Valley, which traverses the outskirts of Baños, and La Pampa quebrada, both of which are crossed by the primary road linking Baños to the Pan-American Highway. We analysed Acoustic Flow Monitor (AFM) records and rainfall gauge data between March 2012 and December 2013 to identify key factors influencing the timing and magnitude of lahar occurrence. Peak rainfall intensity (10, 30 and 60 minute timescales) is shown to be the main influence on the probability of a lahar exceeding a pre-defined flow discharge. A second factor is high levels of antecedent rainfall; particularly when peak rainfall intensity is also moderate-high. Peak rainfall intensity and antecedent rainfall have been used to construct three-dimensional lahar probability matrices for different data timescales, which can be used in conjunction with real-time rainfall data as lahar forecasting tools. Receiver Operating Characteristic statistical analysis of the performance of these matrices between July and December 2013 indicates consistently accurate prediction of lahar occurrence; with 92% of the matrices attaining a p-value below 0.05 over this time period and thus displaying strong statistical significance. Significantly, the technique also predicts the occurrence of lahars in this observation window an average of at least 20 minutes before their detection by the AFMs. Lahar travel times between the AFMs and the primary road bridges are currently estimated at 12-16 minutes in the La Pampa and 17-21 minutes in the Vazcun, therefore this technique has the potential to more than double effective warning times in these two drainages. Ultimately, this method could be adapted to any location with a significant rain-triggered lahar hazard and a basic monitoring set-up consisting of a rainfall gauge and an AFM.

Giant rafted pumice blocks from the 1.8 ka Taupo eruption, New Zealand: evidence for shallow subaqueous eruption processes at rhyolitic lava domes

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Giant blocks of vesiculated grey rhyolite glass, or pumice, lie strewn along a former transgressive shoreline of intracaldera Lake Taupo, New Zealand. Geochemically identical to material erupted during the complex and multiphase 1.8 ka Taupo eruption they post-date the main eruption by several decades. The blocks, some of which are >10 m long, show complex jointing patterns indicative of both surface chilling and continued interior expansion, as well as heterogeneous vesicularity, with dense rims, grading via a transitional zone into a more highly vesiculated interior. Thermal remnant palaeomagnetic evidence indicates significant reorientation of the blocks as they cooled through a series of blocking temperatures, with up to three orientations recorded: one in the dense pumice rim; another in the transition zone; and the third in the clast interior that matches the modern geomagnetic field. The blocks are believed to be derived from one or both of a pair of rhyolitic lava domes that developed on the bed of Lake Taupo several decades after the climactic Taupo eruption over the inferred vent area.

These, and similar giant rafted pumice blocks in other marine and lacustrine settings, raise a number of questions about how volatile-rich felsic magma can be erupted underwater without thermal fragmentation occurring. Furthermore, the prolonged flotation of out-sized fragments of vesiculated magma formed during subaqueous dome-growth contrasts with the rapid sinking of smaller pieces of plinian pumice under laboratory conditions.

At individual sites, giant grey pumice clasts occur over narrow elevation ranges (less than 1 m), implying emplacement during a single, short-lived stranding event. Correction for post-1.8 ka tectonic movements and grounding-line variations suggests emplacement occurred over a few months, implying either emplacement of the Horomatangi Reefs dome at a rate higher than the historically observed range for modern subaqueous rhyolite dome growth, or more prolonged dome growth and a restricted (?single) spalling event.

Development of Multi-Hazard Visualisations for Volcanic Environments in Guatemala

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Volcanic terrains are associated with multiple natural hazards, including volcanic eruptions, earthquakes, mass movements and floods. These processes are often not independent and it is therefore important to consider and understand the ways by which they interact to generate chains or networks of natural hazard events. Here we present a review of such interactions and chains in Guatemala, focusing on the volcanic environments around Pacaya, Fuego and Santiaguito. Interactions discussed are those where a primary hazard triggers or increases the probability of secondary hazards. Consideration is also given to interactions where two hazards combine to trigger a third hazard, or two concurring hazards result in impacts greater than the sum of components.

This work builds on earlier research which examined natural hazard interactions at a global level. Hazards were grouped into six categories (geophysical, hydrological, shallow earth processes, atmospheric, biophysical and space), with a total of 21 different hazard types. It identified 90 possible interactions through a wide-ranging review of grey- and peer-reviewed literature and case studies. As part of this initial work, a visualisation framework was developed to improve analysis, understanding and integration of interactions into hazard assessment and management programmes.

In order to assess the utility and approach of these published visualisations, semi-structured interviews with hazard and civil protection professionals in Guatemala were held. These interviews solicited feedback, assessing how visualisations can be modified for use in Guatemala and possible end users. Information was also gathered relating to participants' understanding of hazard interactions and their opinion of community understanding. Core themes emerging from these interviews are the importance of such tools in rapid response, preparedness and community education, and the need to integrate anthropic factors. It is hoped that the development of improved tools to understand natural hazard interactions and networks of interactions can support multi-hazard approaches to monitoring and responding to hazard events.

Did Mantle Plume Magmatism Trigger the Great Oxidation Event

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The Great Oxidation Event represents the first sustained appearance of free oxygen in Earth's atmosphere and was of fundamental importance in facilitating the evolution of complex multicellular life. This event has been dated to approximately 2450 million years ago, that is, hundreds of millions of years after the appearance of photosynthetic cyanobacteria. To explain this time lag between the onset of photosynthesis and atmospheric oxygenation, a variety of mechanisms have been suggested in the literature. These mechanisms include; a potential cessation of widespread ultramafic magmatism; a period of supercontinent assembly; or alternatively, widespread continental rifting.

Recently, it has been proposed that early-Proterozoic subaerial volcanism could have provided a significant pulse of sulphate to the ancient oceans, the reduction of which liberated the oxygen to drive the Great Oxidation Event. Here we show that the Matachewan Large Igneous Province, (which is now partially preserved in Scandinavia and North America) is both coincident with, and of sufficient magnitude to be the source of this sulphate. We therefore propose that Matachewan Large Igneous Province magmatism, interpreted to be the result of the melting of an early-Proterozoic mantle plume, to have been a significant driver of the oxygenation of our planet.

A Comparison of Recent Post-Collisional Volcanism in the Lesser and Greater Caucasus

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The Caucasus lie in the centre of the Alpine-Himalayan orogenic belt, and differ from their better studied neighbours by the presence of intense syn-post-collisional volcanism. The Lesser Caucasus (LC) represent a Jurassic-Cretaceous-early Palaeogene arc formed from the northward subduction of the Neotethys Ocean. The back-arc basin that opened behind this arc closed during the Oligocene-Miocene Arabia-Eurasian collision, forming the Greater Caucasus (GC). Miocene-Quaternary volcanism has erupted through the thickened crust (45-60km), tens of millions of years following continental collision. The source of magmatism in this region of thickened crust is poorly constrained. We present bulk rock major and trace element, and Sr-Nd-Pb isotope data to see through the complexity of the orogenic zone and assess the role of asthenosphere, lithosphere and crust in the contemporaneous GC and LC volcanism.

Rock types from the GC and LC cover a wide range of compositions from basalts to dacites, although only the youngest lavas show more evolved compositions. Enrichment in large-ion lithophiles and negative Ti and Nb-Ta anomalies are indicative of a source enriched by subduction related fluids. Flat heavy rare earths patterns ($(Dy/Yb)_N$ = 1.1-1.4) require shallow (<70km) melting for the LC, while the GC volcanics ($(Dy/Yb)_N$ = 1.2-1.6) require a small input from deeper melts. High Mg# cores of olivines and clinopyroxenes require a primitive source, and significant fractionation of the melts to produce the more evolved compositions. Variations in radiogenic isotopic compositions require interaction with local GC and LC crust.

Our results are consistent with subduction of Tethyan crust prior to collision. Our data do not support a crustal origin for these melts, but the shallow melting requires a mantle lithosphere source, close to the base of the thickened crust. Melting may have been triggered by an influx of heat from the asthenosphere, either by slab breakoff, or delamination. Assimilation fractional crystallisation processes must have occurred during melt ascent to the surface. Further investigation will allow sources of post-collisional volcanism across the Caucasus to be better constrained, allowing integration into a post-collisional tectonic model for the region.

Structure of the off-craton lithospheric mantle beneath southern Gondwana: Constraints from Patagonian rare garnet-bearing mantle xenoliths

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While mantle xenoliths are common throughout southern South America, only two localities in this region have produced garnet-bearing assemblages: Prahuaniyeu (North Patagonia) and Pali Aike (South Patagonia). This work focuses on a suite of fresh xenoliths from the 5000 yr – 5 Ma Pali Aike Volcanic Field, which predominantly comprises four or five phase lherzolites, with minor harzburgites, pyroxenites and wehrlites. Five phase lherzolites, containing both spinel and garnet, show good textural equilibrium, i.e. 120° grain boundaries. This is particularly common between adjacent olivine grains, and olivine-orthopyroxene grains. Rounded inclusions of clinopyroxenes and olivines within other minerals are common in some samples. Textures are granoblastic to equigranular mosaic (Mercier 1974). Spinel lherzolites (lacking garnet) are more variable in texture and some show evidence of extensive recrystallization, though re-equilibration appears to be incomplete. Where spinel and garnet co-exist, they share a characteristic relationship: spinels occur almost exclusively as irregular, blebby cores within garnet. The cause of this relationship is uncertain – suggested explanations are lithospheric thickening, growth in the presence of a melt and subsolidus cooling through the spinel-garnet transition.

Pressures and temperatures (PT) of equilibrated garnet lherzolites have been calculated from major element data, using methods based on equilibrium between garnet & orthopyroxene (Nickel & Green 1985) and orthopyroxene -clinopyroxene (Taylor 1998). These PT estimates define an elevated continental geotherm with a surface heat flux of 56 mW.m-2, which is consistent with the expected heat flow of off-craton continental lithosphere. Many samples appear unmetasomatised – lacking characteristic LREE enrichment in both mineral phases and bulk-rock compositions. This suggests that the dominant process controlling mantle composition in this region is melting.

Xenoliths from Pali Aike provide an important insight into mantle processes operating beneath the southern margin of the Gondwana supercontinent – with a range of textures, depths & chemistry represented. Accessory phlogopite is more common in deeper samples, consistent with the concept of a metasomatic volatile front near the base of the lithosphere. Observations from this region will help to characterise the off-craton Patagonian mantle, and can be compared with xenoliths from other localities to investigate regional scale heterogeneities in the southern Gondwana lithospheric mantle.

Volcanically-Triggered Rainfall and the Effect on Volcanological Hazards at Soufriere Hills, Montserrat

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Atmospheric flow simulations over and around the Soufriere Hills volcano in the island of Montserrat in the Caribbean are studied, through a series of numerical model experiments, in order to link interactions between the volcano and the atmosphere. A heated surface is added on the top of the mountain, in order to simulate the dome of an active volcano that is not undergoing an explosive eruption.

A series of simulations with different atmospheric conditions and control parameters for the volcano will be presented. Simulations are made using the Weather Research and Forecasting (WRF) model, with a high resolution digital elevation map of Montserrat. Simulations with an idealised topography have also been examined, in order for the results to have general applicability to similar-sized volcanoes located in the Tropics. The model was initialised with soundings from representative days of qualitatively different atmospheric conditions from the rainy season.

The heated volcanic dome changes the orographic flow response significantly, depending upon the atmospheric conditions and the magnitude of the dome surface temperature anomaly. The flow regime and qualitative characteristic features, such orographic clouds and rainfall patterns, can all change significantly. For example, the orographic rainfall over the volcano can be significantly enhanced with increased dome temperatures. The implications of these changes on the eruptive behaviour of the volcano and resulting secondary volcanic hazards, such as lahars, will be discussed.

ORAL ABSTRACTS:

Reconstructing volcanic and magmatic histories

Magma degassing, crystallisation and the fidelity of plagioclase-melt thermometry

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Our ability to constrain the temperature and pressure of mineral melt assemblages in igneous rocks through thermobarometry is fundamental to understanding the conditions of magma storage, fractionation, ascent and eruption. Critical to this is the attainment of equilibrium between minerals and melt. We investigated plagioclase-melt thermometry in hydrous, subduction zone magmas using phase equilibria studies, thermodynamic modelling and previously published natural datasets to assess the controls on the resulting pH_2O-T patterns.

We calculated suites of data points in pH_2O-T space from published studies of melt inclusions and matrix glasses where the composition of the host or equilibrium plagioclase was well constrained. The natural data were for Soufrière Hills, Montserrat; Mount St Helens, USA; Unzen, Japan; Izu Oshima, Japan; and Shiveluch Volcano, Kamchatka. All datasets defined arrays of negative slope in pH_2O-T_{calc} space, which, taken at face value, could be interpreted as significant heating during decompression crystallisation (Blundy et al. 2006). Regressions indicate that 68-92% of the apparent temperature increase actually results from variations in H_2O content of the glass. In contrast, the anhydrous glass composition typically plays a minor role in controlling T_{calc}, while plagioclase composition is not a significant factor. Ruptured or leaked melt inclusions give anomalously high calculated temperatures.

Data from rapid, disequilibrium decompression crystallisation experiments also resulted in anomalously high calculated temperatures even though they were run at controlled temperatures. Importantly, the plagioclase-melt K_D(Ab-An) varies systematically with pH_2O, melt composition and plagioclase content, as well as with decompression rate. A fixed value of K_D therefore does not seem to be a good criterion for detecting attainment of equilibrium. We suggest that true temperatures for magmas undergoing decompression crystallisation lie below T_{calc} by a factor that is determined by the effective undercooling (i.e. distance from equilibrium conditions). Calculated temperatures should be considered as a maximum, unless there is clear evidence of equilibrium.

Incremental construction of the Unit 10 peridotite, Rum Eastern Layered Intrusion, NW Scotland

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The Rum Eastern Layered Intrusion (ELI) is the product of a ~60 Ma open system magma chamber. Its coupled peridotite/troctolite macro-rhythmic units represent crystallisation of multiple batches of basaltic and picritic magma. Within the ELI, Unit 10 has long been considered a classic example of batch fractionation of magma, successively producing peridotite, troctolite ± olivine gabbro. However, the Unit 10 peridotite contains numerous harrisite layers that are commonly associated with diffuse, laterally discontinuous platinum-group element enriched Cr -spinel seams (chromitite) occurring at their bases, tops and interiors. These features are inconsistent with simple batch fractionation of magma.

We present detailed logs of the Unit 10 peridotite, together with mineralogical and textural analyses of chromitites and their host peridotites. Critically, harrisite layers exhibit cm-scale flame-structures that suggest displacement of melt into the overlying cumulate and therefore indicate an intrusive origin for the harrisite. Quantitative textural analysis indicates all seams formed via *in situ* crystallisation under relatively similar conditions, with evidence of minor chemical and physical modification (e.g. postcumulus Fe^{3+} enrichment in coarsened harrisite-hosted Cr-spinel). Unmodified Al (+Mg)-rich Cr-spinels occur at some seam margins where porosity is effectively sealed, with increases in Cr-spinel Cr# and Fe^{3+} observed in the surrounding peridotite; a presumed effect of reaction with the intercumulus melt.

We suggest that harrisite in the Unit 10 peridotite is intrusive and that small volume replenishments are responsible for incremental construction of the body as a whole, similar to recent interpretations of parts of Unit 12 and Unit 14. An implication of this model is that the chromitites formed *in situ*, following injection of the picritic magma. The formation of intrusive chromitite in layered intrusions is also known from the platiniferous Merensky Reef of the Bushveld Complex, where 6 sill-like seams undercut the main ore body (i.e. intrude the footwall), highlighting the potentially important economic implications of our model.

The petrogenesis of plagioclase-phyric basalts from La Réunion Island.

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Plagioclase-bearing porphyric basalts (PPB) were episodically emitted during eruptive phases of Piton des Neiges and Piton de la Fournaise volcanoes (La Réunion Island). At least for Piton des Neiges, the PPB units coincided with major changes in the volcano dynamic. Here we provide further insights into the origin of this type of lavas. Special emphasis will be given to the processes acting in the magma chamber and plumbing system that led to the production of these rocks. Our work is based on a detailed study of the silicate melt inclusions trapped in plagioclase megacrysts in PPBs from the two volcanoes. Major and trace element compositions of plagioclase-hosted melt inclusions indicate that the crystals are inherited and their parental magmas are comparable to those of the host lava. Petrographic evidences indicate that plagioclase megacrysts could originate from fragments of a gabbroic "mush" ripped from the magma chamber walls, but our preferred explanation is that plagioclase accumulates in the melt by gravitational separation of phenocrysts at the top of the magma chamber roof. Accordingly, the periodic occurrence of the PPB and their association with specific periods of the volcano growth would reflect the effects of decreasing magma supply, which promotes plagioclase crystallization and its segregation by flotation.

The evolution and storage of primitive melts in the Eastern Volcanic Zone of Iceland: the 10 ka Saksunarvatn tephra

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Primitive eruptions whose mantle-derived geochemical signatures have not been overprinted by shallow processes are critical targets when investigating deep magmatism. Despite the Eastern Volcanic Zone (EVZ) being most volcanically productive region of Iceland, no primitive eruptions have been documented within it, and primitive melt evolution must be studied indirectly using melt inclusions. We present major element, trace element and volatile data from a suite of macrocrysts and melt inclusions in the voluminous (>15 km^3) 10.3 ka Saksunarvatn tephra collected from Hvítárvatn in central Iceland. Matrix glass compositions exhibit a strong affinity with the Grímsvötn central volcano, in line with previous studies. Many macrocrysts are normally zoned, with crystal cores (An83–An92, Mg#cpx = 82–87, Fo84–Fo87) defining a primitive assemblage, and crystal rims (An60–An68, Mg#cpx = 71–78, Fo70–Fo76) defining an evolved assemblage. The evolved assemblage is close to being in equilibrium with the matrix glass. Trace element disequilibrium between primitive and evolved components of the magma suggests that they were derived from different distributions of mantle melts, and become juxtaposed during disaggregation of primitive mushes. Primitive plagioclase -hosted inclusions have not been modified significantly by post-entrapment processes, and preserve records of fractional crystallisation and variable mantle melt supply. Extrapolating a mean liquid line of descent to compositions in equilibrium with Mg#melt = 70 indicates that near-primary melts supplied to the base of the EVZ are similar to high-Mg# melts erupted elsewhere in Iceland. Thermobarometry indicates that the evolved assemblage last equilibrated at 1140°C and 0.5 kbar, though this is unlikely to represent a depth of long-term storage given the large erupted volume. Barometry is equivocal on the depth at which the primitive assemblage formed: H_2O-CO_2 in melt inclusions and cpx-melt equilibria return conflicting results of ~0.65 kbar and 5.5–7.5 kbar respectively, thus questioning the validity of both techniques. New experiments in the crucial 1–7 kbar range are therefore required in order to reassesses mineral -melt barometer calibrations.

A temporal record of magmatic volatile evolution through texturally constrained apatite analysis

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Traditionally, magmatic volatile contents have been assessed through interpretation of phase assemblages or analysis of quenched glass or melt inclusions. However, the fidelity of these methods can be compromised by post-entrapment processes such as volatile leakage, devitrification or volatile exchange with their host. This inhibits the use of melt inclusions in determining magmatic volatile contents and restricts the range of systems and phases in which they yield meaningful data. Apatite has recently been identified as a potential volatile "probe" in magmatic and ore-forming systems, due to the F-Cl-OH exchange reaction and incorporation of trace C and S. Importantly, apatite analysis is subject to less preservation problems than melt inclusions.

We analysed apatite populations in different textural associations, with an aim to determine changes in magmatic volatile contents during magma fractionation prior to the Astroni 1 eruption of Campi Flegrei (Italy). The Astroni cone has produced many of the most recent Plinian eruptions in the resurgent Campi Flegrei system and knowledge of the pre-eruptive magmatic volatile evolution may therefore be of value to the on-going monitoring effort.

We find that F/OH ratios are generally lower in apatite inclusions hosted within clinopyroxene overgrowth rims than within cores, and that F/OH is lower in biotite-hosted apatite inclusions than in clinopyroxene-hosted inclusions. Apatite microphenocrysts (not contained within other phases) generally contain lower F/OH than either inclusion population. Similar trends are seen in Cl/OH ratios. Preliminary consideration of the thermodynamics of F-OH exchange between apatite and fluid indicates that decreasing F/OH could result from a small increase in temperature or a large increase in pressure, neither of which seems a likely condition for magma fractionation during crustal storage. We therefore infer that the apatites are recording a continuous increase in melt H_2O contents during volatile-undersaturated magmatic evolution, prior to the Astroni 1 eruption.

The contributions of calcium carbonate assimilation and fresh fluids in the Pollara eruptions of Salina, Aeolian Arc, Italy.

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The island of Salina lies at the intersection of an arcuate set of volcanoes and seamounts associated with the NW dipping Ionian subduction zone and a NW-SE trending set of large volcanic islands that follow the route of the Tindari-Letojanni fault. Volcanism from 244 ka to 15.6 ka was initially characterised by basaltic lavas and scoria in the NE, evolving over time to include andesites and rhyolites in the SE and SW, concluding with the Pollara sequence of eruptions in the NW of the island.

The bulk chemistry of the Pollara plot more deeply into the calcic field, with markedly less alumina and increased barium, potassium and rubidium than those preceding it and Harker diagrams show flat iron-enrichment. Ba/Nb ratios of mafic samples suggest a possible introduction of fresh fluids that correspond with geophysical evidence for a delaminated section of the subducting Ionian plate.

Microprobe analyses of cumulates show the increasing removal of ferric and ferrous iron into plagioclase-pyroxene adcumulates. Skarn mineralogy and microprobe analyses of grossular garnet, fassaite pyroxene, anorthite, diopside and magnetite suggest the coupled substitution of Fe^{3+} and Al for Si and Mg in oxidizing conditions of FMQ +1 to +2 and shallow depths around 2.6-2.7 kbar. Carbonate clasts are found to have no detectable barium.

Two pyroxene and amphibole-plagioclase thermometry places the skarn at 960-980˚C with magmatic temperatures of 1160-1180˚C. Melt inclusions suggest highly variable CO_2 within otherwise water-rich melts that may have allowed the earlier formation of plagioclase. The influence of calcium carbonate assimilation, from a shallow limestone atoll, is therefore suggested to have the major influence on magma chemistry with barium enrichment possibly caused by changes in bulk partitioning behavior in an aluminium under-saturated, high-calcium environment.

Volcanic history of a peralkaline caldera volcano: Pantelleria, Italy

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Pantelleria is a small rift volcano that has been active since at least 324 ka. Its volcanic history may be divided into three phases:

- Pre-ignimbrite phase (≥324 ka to ~200 ka): localised lavas, pumice cones, domes
- Ignimbrite phase (~200 ka to 46 ka): eight ignimbrite eruptions (with intervening localised eruptions)
- Post-ignimbrite phase (since 46 ka): localised lavas, pumice cones, domes

The ignimbrite stratigraphy and distribution have been determined making use of excellent sea cliff exposures. Individual ignimbrite volumes are thought be on the order of 1-13 km^3 although much is offshore and difficult to determine. Six of the ignimbrites are intensely welded and rheomorphic and five have lithic breccias that may indicate caldera collapse. Two have a basal pumice fallout layer and one has an upper pumice fallout layer. Most of the ignimbrites are chemically heterogeneous. This chemical zoning may be expressed in terms of the two most extreme compositions present in the deposit (enrichment factor). The ignimbrites have enrichment factors of at least ~2 (‘moderately zoned’), but two are strongly zoned with enrichment factors of 4.5 and 7 (SiO_2 ranges from ~63 to ~70 wt%; Zr ranges from ~300 to 2000 ppm). While whole -rock compositions overlap between formations, glass compositions are in most cases sufficiently distinct to differentiate between formations. The new glass compositions will be used to improve proximal-distal tephra correlations as Pantescan tephras have the potential to become marker horizons in the tephrachronology framework of the Mediterranean Sea.

Between the ignimbrite-forming eruptions and throughout the island’s history, small, localised eruptions of trachyte to pantellerite pumice cones, lava shields and domes occurred from >20 eruptive centres. The pumice cones record unsteady low strombolian to subplinian eruption columns at which activity fluctuated rapidly leaving varied deposits of pumice, spatter and rheomorphic agglutinate of evolved composition. Few localised basaltic lavas and scoria cones have occurred, but only in the northern part of the island.

Partitioning behaviour of CO_2 between apatite and basaltic melt: A new tool for tracking magmatic CO_2 contents

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CO_2 plays a fundamental role in the evolution and eruption of magmas, but its low solubility in silicate melts means that direct records of magmatic CO_2 concentrations remain elusive. The phosphate mineral apatite is unique among igneous minerals in its capacity to accommodate all major magmatic volatiles (H_2O, F, Cl, CO_2 and S). Although interest in apatite as a tool for tracking magmatic volatile contents – namely H_2O, F, and Cl – has increased in recent years, its potential as a record of magmatic CO_2 contents remains untapped.

We present the results of high-temperature, high-pressure experiments investigating the partitioning behaviour of CO_2 between apatite and basaltic melt. Experiments were run in piston cylinder apparatus at 1 GPa and 1250 °C, with a slow initial cooling ramp employed to facilitate crystal growth. Each charge contained the starting basaltic powder doped with Ca-phosphate and variable proportions of H_2O, CO_2, F, and Cl. Run products are glass-rich charges containing 5–25 vol% large, euhedral apatite crystals (± minor clinopyroxene). Experimental apatites and glasses have been characterised by BSE imaging, electron microprobe, and secondary ion mass spectrometry.

Apatite compositions range from near-endmember fluorapatite (3.0 wt% F), to near-endmember hydroxyapatite (1.7 wt% H_2O), to carbon-rich apatite containing up to 1.6 wt% CO_2. These compositions are near-stoichiometric if all anions (F–, OH–, and $CO3^{2-}$) lie in the channel site, suggesting that “A-type” substitution of carbonate dominates under these conditions (i.e. $CO3^{2-}$ + [] = 2X¯, where X is another channel anion and [] is a vacancy; e.g. Fleet et al. 2004). Importantly, we find that CO_2 partitions readily into apatite at all fluid compositions considered here. CO_2 is also more compatible in apatite than water at our run conditions, with calculated H_2O–CO_2 exchange coefficients close to or greater than 1. Our results indicate that when channel ions are primarily occupied by H_2O and CO_2 (i.e., halogen-poor magmatic systems), apatite can preserve higher absolute CO_2 concentrations than the surrounding melt. In this way, apatite may prove more sensitive than other direct records of pre-eruptive volatile contents, such as phenocryst-hosted melt inclusions. We therefore suggest that apatite has excellent potential as a tool for tracking magmatic CO_2 abundances.

List of Posters

Poster authors are asked to stand beside their poster for the duration of their allocated session

Poster Session A

Monday 5th January 16:00-18:00

Geophysical, geochemical and petrological monitoring

A1: Thorbjörg Ágústsdóttir et al.

Seismicity caused by dike propagation in the Bárðarbunga volcanic system, NE Iceland

A2: Rebecca L. Astbury et al.

A Petrographical and Geochemical Study of Mount Sorik Marapi, Sumatra, Indonesia

A3: Amy R. Donovan et al.

Volcanic gas measurements at the Holuhraun eruption in September 2014

A4: Kyriaki (Sandy) Drymoni et al.

Is Santorini Volcano ready to erupt? Insights from a multidimensional petrogenetical study of Nea Kameni recent lavas

A5: Thomas M. Gernon et al.

Volcanic development of the Boset-Bericha volcano, northern Main Ethiopian Rift

A6: Anthony Lamur et al.

Fracture and healing of silicic lava domes: relating stress/strain rate to eruption mode.

A7: Ryan Lloyd et al.

An Investigation into the temporal and spatial evolution of deformation at Corbetti volcano, Main Ethiopian Rift

A8: Craig Magee et al.

Lithological controls on igneous intrusion-induced ground deformation

A9: John M. Millett et al.

Approaches in borehole based volcanic stratigraphy analysis from the Krafla geothermal field, Iceland

A10: Melissa Plail et al.

Geochemistry of mafic enclaves illustrate quasi-continuous mixing and mingling at Soufrière Hills Volcano, Montserrat

A11: Tjarda Roberts et al.

Real-time in-situ sensing of volcanic gases (SO_2, HCl, H_2S) and size-resolved aerosol in Mt Etna plume

A12: Robert H. Sievwright & Jamie J. Wilkinson

Magnetite Crystallisation as a Control of Mineral -Melt Partitioning of Divalent Cations

A13: Rex Taylor et al.

The mixing, evolution and eruption history of a disaggregated magma reservoir

A14: Robert White et al.

Overview of Geophysical Constraints on the 2014 Bárðarbunga - Holuhraun Eruption, Iceland

A15: Jennifer Woods et al.

Dyke propagation mechanisms and the immediate pre- and syn-eruptive seismicity of the 2014 Holuhraun fissure eruption, Iceland.

A16: Nicola K. Young et al.

Shallow crustal mechanics of Soufrière Hills Volcano from volumetric strain data

A17: Woodhouse and Phillips et al.

Timescales of volcanic source unsteadiness observed in ash plume dynamics and tephra deposits

Tambora's legacy: volcanic emissions into the atmosphere

A18: Paul M. Ayris et al.

Volcanic ash leachate analysis: lessons for the future from Mt. St. Helens

A19: Ginevra Chelli et al.

Explosive magmatism underwater: insights from textural and geochemical study of volcanic ash and lapilli at the Mariana arc.

A20: Tom D. Pering et al.

Developing a low cost method for measuring volcanic water vapour emissions at high resolution

A21: John A Stevenson et al.

Physical volcanology of the prehistoric Hekla 3 and Hekla 4 eruptions, Iceland.

A22: Jodie Dyble & Rebecca Williams

Micro kinematic indicators in the Green Tuff Ignimbrite: can they tell us about caldera collapse?

Research in Progress

A23: Fabio Arzilli et al.

Processing of X-ray microtomography images to investigate crystallised volcanic rock textures

A24: Tiffany Barry et al.

3D numerical evidence for a process of separation in the mantle; explaining the DUPAL anomaly

A25: Daniel Beech

A Networked Approach to Seismic Activity: The Need for Communication and Cohesion

A26: David J. Brown et al.

“Hot and sticky” and “cold and moist” eruptions: lithofacies architecture of silicic ignimbrites in Ardnamurchan, NW Scotland

A27: John Browning et al.

Towards a new tectonic model of the Askja caldera

A28: L.S. Campbell et al.

Partial proxies for geochemical discrimination in Italian altered tuffs

A29: David E. Cavell et al

Active rear-arc seamounts in the South Sandwich Islands: Geochemical relationship to the main volcanic arc

A30: Arran Murch & Paul D Cole

Microlites and decompression crystallization from different styles of activity at Soufriere Hills Volcano, Montserrat

A31: Philippa J. Demonte et al.

Infrasonic analysis of geyser eruptions at Yellowstone National Park

A32: Andrew J. Dobrzański & Elizabeth E. Evans

Metallurgical Slag as a Suitable Analogue Material for Lava-Flow Fabric Studies

A33: Robert J. Gooday et al

The Arran central ring complex: a unique laboratory for caldera-forming processes

A34: Amy Gough & Ralf Gertisser

Chert formation in a volcanically influenced lake: The Timpone Pataso Formation, Lipari, Aeolian Islands, Italy

A35: Suraya Hilmi Hazim et al.

Linking Plutonism and Volcanism: Understanding the Development and Evolution of Large Magmatic Bodies

A36: William Hutchison et al.

A geological and geochemical overview of Aluto volcano, Ethiopia

A37: Fiona E. Iddon et al.

Hot, warm or cold? Disclosing the temperature of columnar jointing in lavas

A38: A. J. Jeffery et al.

A new occurrence of dalyite ($K_2ZrSi_6O_{15}$) from Terceira, Azores

Poster Session A cont'd

Monday 5th January 16:00-18:00

A39: Eleanor. S. Jennings et al.

Modelling the trace element characteristics of plume-derived partial melts of peridotite and pyroxenite, and the origin of Etendeka CFB primitive melts

A40: Jackie Kendrick & Yan Lavallée

Magma and rock friction

A41: Oliver Lamb et al.

Cyclic fracturing during spine extrusion at Unzen, Japan

A42: Philip T. Leat et al.

Bathymetry and Geological Setting of the South Sandwich Islands Volcanic Arc

A43: Lara Mani et al.

Improved volcanic hazard communication through educational video games: an example from St. Vincent, West Indies

A44: Simon Martin et al.

Magma flow within intrusions: Insights from field and petrographic studies

A45: Charlotte E. McLean & David J. Brown

Interactions and processes occurring in intra-diatreme fragmentation zones: field studies from Fife, Scotland and Reykjanes, Iceland

A46: Jonathan Moles et al.

Volcano-ice interactions at Tindfjallajökull volcano, Iceland

A47: Amy P. Parker et al.

Mineral lamination development in the Inner Layered Gabbros of the Skye Central Complex: Implications for cumulate rheology and magma chamber processes

A48: Lawrence Percival et al.

Mercury as a tracer for Large Igneous Province volcanism

A49: Kerry Reid et al.

Masaya Volcano: engaging Citizen Scientists in monitoring the environmental impacts of a persistently degassing volcano

A50: Peter Reynolds et al.

Deposition and evolution of basaltic agglutinate deposits along the Rauduborgir-Kvensödul fissure, Iceland

A51: Mel Rodgers et al.

Outstanding challenges in volcano seismology: Results from recent U.K. and U.S.A discussion workshops.

A52: J. M. Truby et al.

The rheology of three-phase basaltic magma

A53: Elliot P. Wood et al.

Magma ascent, damage zones and the location of volcanic vents

Poster Session B

Tuesday 6th January 16:30-18:30

Important Problems in Applied Volcanology

B1: Charlotte Birch et al.

The Volcanic Contribution to Stratospheric Sulphur

B2: Richard J. Brown et al.

The 29th December 2013 eruption of San Miguel Volcano, El Salvador

B3: Mike Burton et al.

Volcanic CO_2 emission from the Banda and Sunda arcs

B4: Danielle Charlton et al.

The importance of effective hazard communication and data sensitivity: hazard mapping of Campi Flegrei

B5: Carina J. Fearnley

Volcano Alert Level Systems: Managing the challenges of effective volcanic crisis communication

B6: Anna Hicks et al.

'Volcanomics'. Trialling analysis of eruptive scenarios via economic and probabilistic approaches on Tristan da Cunha and its application to decision support

B7: Marie Nolan et al.

Mechanical Properties of Levees and the Location of Breaches

B8: Jazmin P. Scarlett et al.

Volcanic risk perceptions of La Soufrière, St. Vincent

B9: Richard Wall et al.

Visualising volcanic risk

Reconstructing volcanic and magmatic histories

B10: Anna Barth et al.

Gas migration through crystal piles

B11: Karen Bemis & Margot Ferencz

A crater-centric view of cinder cones

B12: Liam A. Bullock et al.

A new classification for spherulites in obsidian lavas in the Aeolian Islands, Italy

B13: A.L. Chadderton et al.

High temperature permeability in volcanic systems: An experimental approach

B14: George F. Cooper et al.

Cumulates from Martinique: A window into the plumbing systems of the Lesser Antilles Volcanic Arc

B15: M. Coussens et al.

Investigating the long term evolution of an island arc volcano.

B16: Alessio Fabbrini et al.

Eruptive and magmatic processes within the shallow plumbing system of a small basaltic volcano: the example of Capraia Island (Italy).

B17: Andrew Gilbert & Marian Holness

The relationship between plagioclase aspect ratio and crystallization time in basaltic dykes

B18: Margaret Hartley et al.

Redox evolution of the AD 1783-84 Laki eruption, Iceland

B19: Stuart Hatter et al.

Marine sediments as an archive of arc volcanic history, Montserrat

B20: Adrian Hornby et al.

Ash generation at lava domes: from fracturing to fragmentation at Santiaguito, Guatemala

B21: Camilla L. Imarisio et al.

Plumbing systems interactions in the Torfajökull volcanic system, Iceland: an insight from mineral zoning

B22: Emma J. Liu et al.

The influence of near-surface magma-water interaction on magma fragmentation and degassing during the 2500BC Hverfjall Fires, Iceland

B23: Matthew P. Loocke et al.

An evolved axial melt lens in the Northern Ibra Valley, Southern Oman Ophiolite

B24: Christina J Manning & Matthew Thirlwall

Temporal evolution of magma storage beneath the Eastern Rift Zone, Iceland

B25: Peter E. Marshall et al.

The Volcanic Architecture of the Antrim Plateau Volcanics, Kalkarindji, Australia: A multidisciplinary study

B26: Euan J. F. Mutch et al.

A New Approach to Al-in-hornblende Geobarometry

Perkins

B27: Peter A Nicholls et al.

Pyroclastic Density Currents in the AD 1362 silicic eruption of Öræfajökull, Iceland

B28: Jacqueline Owen et al.

Bubble, bubble, toil and trouble: The degassing of Katla 1918 , a subglacial basaltic eruption

B29: Stephen G. Perkins

A new history of the Etive Granitoid Complex, Argyll, Scotland.

B30: Bethan A. Phillips et al.

The Origin and Evolution of the Siletz Terrane in Oregon, Washington and Vancouver Island: A geochemical perspective

B31: Katie Preece et al.

The eruptive history of Ascension Island: insights from stratigraphy, $^{40}Ar/^{39}Ar$ and cosmogenic ^{3}He dating

B32: Harriet Rawson et al.

Temporal geochemical evolution of Mocho-Choshuenco Volcano, Chile

B33: Brendon C. Rolfe-Betts et al.

Compositional variations in shield-stage volcanism, Fogo (Cape Verdes).

B34: Lois Salem et al.

Assessing hazards from the largest effusive eruption at Mt Etna, Sicily, 1669 using melt inclusion analysis and SO_2 outgassing models.

B35: Long Li, Frank Canters, M. Carmen Solana et al.

Discriminating lava surfaces and vegetation within Nyamuragira using spectral mixture analysis

B36: R.W. Tarff et al.

A re-examination of the Valentine et al (2014) model of diatreme evolution in the light of cyclic variations in explosivity in the Cova de Paul eruption, Santo Antao, Cape Verde

B37: Martina Tully et al.

Petrographic and Geochemical Investigation of Andesitic Arc Volcanism: Mount Kerinci, Sunda Arc, Indonesia

B38: Teresa Ubide et al.

Crystal-melt mixtures and their relevance to interpret geochemical data in magmatic systems

B39: Felix W. von Aulock et al.

Dehydration and rehydration of silicate melts

B40: Jing Zhang et al.

Recycling earlier-fractionated minerals through magma recharge: evidence from Mt. Lamington (Papua New Guinea)

POSTER ABSTRACTS (alphabetical by surname)

Seismicity caused by dike propagation in the Bárðarbunga volcanic system, NE Iceland

THORBJÖRG ÁGÚSTSDÓTTIR*[1], TIMOTHY GREENFIELD[1], ROBERT G. GREEN[1], ROBERT S. WHITE[1], BRYNDÍS BRANDSDÓTTIR[2], SVEINBJÖRN STEINÞÓRSSON[2], JENNIFER WOODS[1]

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The Bárðarbunga volcanic system lies in the Eastern Volcanic Zone in central Iceland close to the centre of the Iceland mantle plume. Iceland is situated astride the Mid-Atlantic Ridge with the geology characterised by the interaction of the ridge and the underlying hotspot. The Barðarbunga volcanic system consists of Bárðarbunga central volcano and a fissure swarm extending 115 km to the SW and 55 km to the NNE. The volcanic system is known to have experienced eruptions both in the SW and NNE part of its volcanic system (e.g. Veiðivötn 1477 CE, Holuhraun-I 1797 CE and Holuhraun-II 1860s CE) with the last significant eruption in Bárðarbunga central volcano in 1910 CE.

The dense seismic network of the University of Cambridge surrounding Askja and Vatnajökull has recorded the dyke propagation in unprecedented detail. The network consists of over 75 seismometers providing unique coverage of the volcanic and seismically active area. The dyke propagated 45 km to the NNE of Bárðarbunga central volcano to where it erupted in Holuhraun, reoccupying the old craters from the nineteenth century. The dyke propagated at depths of c. 6 km in sequences of rapid advance with intervening periods of little or no movement.

We show automated locations of over 30,000 seismic events recorded from the beginning of the seismic activity on 16.08.2014 to the start of the first eruption on 29.08.2014. We also present precise double difference relocations of a smaller subset of manually refined events that span the entire dyke in length and time. Fault plane solutions of the manually refined events show in detail the characteristics of the source of the seismicity caused by melt movement in the crust.

Processing of X-ray microtomography images to investigate crystallised volcanic rock textures

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X-ray computed microtomography has become a fundamental tool in geosciences to study rock textures directly in 3D. This technique is useful to study the vesiculation of pumices [1], but only recently there has been more interest to study the crystallisation process using volumetric datasets. Crystal and silicate glasses often have similar density and absorption contrast, therefore, image processing require more sophisticated procedures to separate them.

Feldspars are one of the most abundant crystalline phases of igneous rocks, hence their crystallization conditions and abundance are intensely investigated by geologists. Moreover, feldspar is one of the most difficult phases to segment during image analysis, making the separation of feldspars from the silicate glass a challenge.

Here we show that the crystallinity of natural pumice of Stromboli and synthetic trachyte can be studied using microtomographic datasets. Data were collected using the propagation-based synchrotron X-ray phase contrast microtomography technique at the SYRMEP beamline of the Elettra-Sincrotrone Trieste Laboratory (Basovizza (Trieste), Italy). Although X-ray phase contrast imaging can improve the visualization of weakly absorbing features, making visible the edge of feldspars, the segmentation of these crystals cannot be directly obtained from the raw phase contrast X-ray images. Phase-retrieval methods are needed for extracting phases of interest. A single distance phase-retrieval algorithm [2] was applied to the dataset to improve the contrast between feldspar and glass. Through this technique we are able to isolate feldspars both in natural samples and in synthetic ones, and to perform quantitative analysis of these phases using volumetric datasets. Our preliminary results have demonstrated that phase retrieval processing will be an invaluable tool for geologists to study rock textures.

[1] Polacci M. et al. (2009) J. Geophys. Res. 114, B01206. [2] Paganin D. et al. (2002) J. of Microscopy 206, 33-40.

A Petrographical and Geochemical Study of Mount Sorik Marapi, Sumatra, Indonesia

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The archipelago of Indonesia is formed from several highly active volcanic arcs, including the Island of Sumatra, located in the west Sunda Arc. Although thirty-four, mainly andesitic, volcanoes exist on Sumatra, most of the volcanological research in the area has been focussed on mount Toba, which produced the largest known volcanic eruption on Earth within the last 2 Ma. The ongoing eruption of Mount Sinabung coupled with continued unrest at Mount Kerinci, which erupted in 2009, indicates the need for further research into eruption timescales and the hazards posed by these volcanoes.

Along arc variation of whole rock andesite samples have been observed in Sumatra; Mg concentrations are high in the north of the island, yet low in the south. The data further stresses the need for detailed research into each separate volcano, in order to understand the genesis of each volcano.

Mount Sorik Marapi is a 600m wide stratovolcano, located around 200km south of the well-known Mount Toba. The edifice hosts a large crater lake, solfatara fields and a small parasitic volcano (Danau Merah) on its southeastern flank. Although it seemed quite active during the 19th and early 20th century, with several phreatic eruptions, it has not erupted since 1996. Seismic unrest was detected in late 2011, however no eruption occurred.

Samples taken from the area are moderately to highly vesicular with a porphyritic texture. They contain abundant plagioclase and pyroxenes, moderate Fe-Ti oxides, sparse olivine crystals and abundant crystals clots. Rare occurrences of amphibole are noted in some of the sampled lavas. Plagioclase, pyroxene and olivine are texturally zoned and often host melt inclusions. Multiple plagioclase populations are observed. Crystals and melt inclusions will be characterised for major and trace elements to investigate magma source and depth of crystallising magma body. In addition, diffusion modelling of pyroxene will provide insights into eruption timescales, in order to gain new understanding of the development of Mount Sorik Marapi and Sunda Arc volcanism as a whole.

Volcanic ash leachate analysis: lessons for the future from Mt. St. Helens

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Upon contact with water, freshly-fallen volcanic ash releases a pulse of readily soluble material, derived from dissolution of sulphate and halide salts formed on ash surfaces during transport through the volcanic eruption plume. Leachate concentrations, and S:Cl ratios, are often utilised to record spatial and temporal variations in salt loading across the deposit, and as tools to investigate the mechanisms of in-plume salt formation. Such investigations are subject to significant difficulties, as salts mobilised by leaching are the product of a complex and poorly understood interplay of ash-, plume- and environment-specific factors, mediated by the methods of leaching and leachate analysis. However, the influence of ash deposit sampling strategies on derived leachate datasets should not be overlooked, as studies often utilise small datasets with an uncertain capacity to adequately represent their parent ash deposit. Here we illustrate the significance of this limitation through the compilation and interrogation of a database of 96 published leachate compositions from 6 studies which investigated the May 18th, 1980 eruption of Mt. St. Helens. Utilising statistical analysis techniques, we identified biases and outliers between studies in order to produce a large and comparable ash leachate dataset. We sought to identify trends in S:Cl ratios and total S and Cl concentrations downwind of the volcano, with respect to the total mass, chemical composition and grain size distribution of erupted ash. Our analyses were significantly impacted by prior analytical error; inadequate documentation of sampling methods or environmental conditions; sparse and sporadic distribution of samples across the ash deposit; and even intra-deposit variability at ash sampling locations. Despite these difficulties, we identified weak spatial trends in S:Cl ratios, which reflect a complex composite of various volcanic and atmospheric processes. In order to disentangle such processes in leachate data from future eruptions, we emphasise the importance of standardised leaching protocols, and extensive and rigorous deposit-wide ash sampling campaigns with homogeneous spatial, and ideally temporal, distribution.

POSTER ABSTRACTS

3D numerical evidence for a process of separation in the mantle; explaining the DUPAL anomaly

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The DUPAL anomaly is a distinct isotopic signature found almost exclusively in mid-ocean ridge basalts along the Indian Ocean ridge system and ocean island basalts of the southern Atlantic, Indian Ocean, and SW Pacific (Hart, 1984). The isotopic signature has been recorded in Tethyan mid-ocean ridge basalts back to 350 Ma (Xu and Castillo, 1984), indicating that, contrary to our understanding of thorough mixing in the upper mantle, this is a long-lived mantle phenomenon, which has repeatedly been sampled at Tethyan and Indian Ocean ridges. The origin of the anomaly has been widely discussed (e.g. Castillo et al., 1996; Kempton et al., 2002, Regelous et al., 2009), with little consensus. Here, using 3D spherical numerical mantle circulation models, we explore the dynamics of how a distinct chemistry could be preserved in the mantle, but repeatedly sampled in the Tethyan-Indian Ocean region, but not the Pacific. Using well constrained plate motion history (Lithgow Bertelloni & Richards, 1995), we track passive particles placed into (1) the upper mantle (150-600km), (2) uppermost lower mantle (800-1200km) and (3) lowermost lower mantle (2400-2850km), into two geographic regions – one centred on the Indian Ocean and the other in an intra-Pacific location. After the equivalent of 119 My of convection and plate motion history, particles started beneath the Indian Ocean region all convected predominantly within the mantle beneath the Indian Ocean, whereas those placed beneath the Pacific region circulated in the mantle beneath the Pacific. There was no evidence for transfer of particles from one region to the other, though some particles from the Indian Ocean region spread to the southern Atlantic. Lateral restrictions appear to be caused by the presence of downgoing slabs and for the first time presents a mechanism for laterally isolating large-regions of mantle and restricting the extent of homogenization of the upper mantle.

Gas migration through crystal piles

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Eruption dynamics are often interpreted with reference to two-phase flow experiments. However, many volcanic eruptions involve three phases (solid, liquid, gas), and the crystals affect the physical properties of the magma. At low concentration, crystals act to increase the bulk viscosity and density. At high concentrations, close to maximum packing, the crystals can have a more dramatic effect on the motion of gas through the magma.

Strombolian explosions are attributed to the rise and bursting of large, conduit-filling gas bubbles (slugs) at the surface. This concept was developed as a way to explain the characteristic periodicity of Strombolian eruptions. However, recent petrological studies have indicated that the magma in the upper region of Stromboli's plumbing system is highly crystalline, with crystallinities above the threshold (~40-60 vol%) at which magma rheology becomes highly non-newtonian, and develops a yield stress This petrological data of a highly crystalline magma (Métrich et al., 2001; Landi et al., 2004) combined with numerical experiments (Suckale at al., 2010) of gas slugs rising in a conduit, suggests a new picture of Strombolian eruption mechanism.

Using analogue experiments, we explore the mechanism by which gas, issuing from a steady source, rises through a concentrated suspension of solid particles in a viscous liquid. We find that the crystal-rich 'plug' inhibits gas migration, causing bubbles to accumulate at its base. Once the bubble or foam reaches a critical size such that its buoyancy overcomes the plug's yield strength, ductile failure occurs and the bubble rises through a series of opening and closing 'fractures'. The results of these experiments suggest a new process which may regulate the periodic gas explosions at Stromboli, and we test this model by comparing our experimental observations with data on seismic activity and gas composition at Stromboli.

Suckale, J., Hager, B.H., Elkins-Tanton, L.T., Nave, J.-C., 2010. J. Geophys. Res. 115, B07410. doi:10.1029/2009JB006917

Métrich, N., Bertagnini, A., Landi, P., Rosi, M., 2001. J. Petrol. 42 (8), 1471-1490

Landi, P., Métrich, N., Bertagnini, A., Rosi, M., 2004. Contrib. Mineral. Petrol. 147, 213-227

A Networked Approach to Seismic Activity: The Need for Communication and Cohesion

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The management and mitigation of volcanic hazards requires a significant investment of cohesion, trust and togetherness. Interaction between hazard management agencies, academic institutes, communities and governments often constructs effective channels of communication, furthered through trusted and shared understandings of the threat posed to both society and aviation. An interdisciplinary perspective provides sufficient scope for research into how science, culture, technology and politics can become integral considerations in approaches to volcanic monitoring. This research specifically explores the case of Iceland as the geographical location, demography and socio-economic position ideally lends itself to seamless collaboration with overseas communities in Europe and North America.

Redesigning hazard management through the implementation of new technical protocols has led to increased interest in how channels of communication are formed, and how they function and evolve. European wide project's such as FUTUREVOLC and COSMIC thrive on newfound bridges between science and wider publics, and are often a means through which to distribute information and broaden awareness. The generation of data hubs epitomise the co-production of data, stretching disciplinary boundaries and furthering networked geographies.

Through observations of Icelandic and UK based seismic exercises and semi-structured interviews, communicative practises have been identified and critiqued. The research conducted has led to an envisioning of a hazard management network without boundaries, a fluid entity that changes shape, scale and configuration to create efficient communication channels. Findings outline the participatory characteristics of sophisticated networks; social media has provided new communication protocols through which those monitoring seismic hazards, and those affected by them, can share dialogue openly. Smartphone applications and tablets have enabled hazard information to become flexible in format, particularly with new methods of representation in virtual environments. Citizen science and the growth of open source data appears to have led to increased trust from communities to scientific experts, further enhancing the network's cohesive and collaborative abilities.

A crater-centric view of cinder cones

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The craters resulting from small mostly-monogenetic volcanic eruptions vary in considerable in size and shape. A statistical description of cinder cone populations in Guatemala suggests (1) crater elongation is highly variable, independent of substrate, and related to variability in summit elevation; (2) the ratio of crater depth to cone height varies from near zero to over one and shows little relationship to cone shape or age; (3) cone shape depends on both primary fragmentation and climatic (erosional) impacts post eruption. Clearly multiple factors influence the population distributions including primary eruptive processes (fragmentation may control original slope), syn-eruptive interactions with the surrounding country rock (conduit orientations may vary), and post-eruptive erosional processes (increasing variation in slope and size). This study considers the implications of population variability and the difficulties in separating the consequences of multiple factors determining cone and crater shapes

The Volcanic Contribution to Stratospheric Sulphur

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Volcanic emissions make an important contribution to the atmospheric sulphur budget. The volcanic contribution of sulphur to the atmosphere is poorly defined due to uncertainties in the amount of sulphur ejected, its distribution by sulphur species and the height of injection. Also there is little or no ground-based monitoring of many volcanoes, and little knowledge of sulphur emitted by degassing and other non-explosive volcanic processes.

Atmospheric sulphur compounds derive from a variety of sources. The largest direct source of SO_2 is from volcanic emission, though it also indirectly stems from conversion from carbonyl sulphide (OCS), the most abundant atmospheric sulphur species.

Altitude information is important for atmospheric chemistry, as SO_2 reaction rates vary hugely with height and atmospheric composition. SO_2 injected into the troposphere will relatively quickly leave the atmosphere as acidification of rainfall. However in the stratosphere, SO_2 is oxidised to H_2SO_4, which in aerosol form can remain and affect climate processes for many years. Sulphate aerosols affect the Earth's radiative balance through scattering of sunlight, and are therefore an important factor when considering climate change.

Satellite-based instrumentation is a vital tool for the analysis of volcanic eruptions. Here the IASI instruments, a Fourier transform spectrometer on the MetOp platforms, are used to study medium to large eruptions between 2008-2012. The total SO_2 injected into the atmosphere is estimated for each eruption and, for those eruptions visible to the IASI instrument, the contribution over each year in the studied range is derived.

The perturbation from the background sulphur profile is investigated through comparison of an atmospheric model with the vertical sulphur profile retrieved from the limb viewing instrument MIPAS. Due to the nature of the instrument, only carbonyl sulphide (OCS) exists in sufficient quantities to be observed in a “volcano-free” atmosphere. A background level of OCS is taken from the UMUKCA model developed at Leeds, from the pre-Pinatubo run.

“Hot and sticky” and “cold and moist” eruptions: lithofacies architecture of silicic ignimbrites in Ardnamurchan, NW Scotland

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The lithofacies architecture of a newly identified sequence of Palaeogene silicic ignimbrites in the Ben Hiant area of Ardnamurchan, NW Scotland, is presented here. These ignimbrites record high-temperature, low-fountaining, boil-over type eruptions, the incursion of PDCs into lakes, and the interaction of PDCs with palaeo-topography. Erosional surfaces indicate significant hiatuses between eruptive phases.

Five phases of eruption have been recognised in the sequence. Phase 1 was marked by the deposition of pumiceous welded massive lithic breccias in topographic depressions. Reworked clasts indicate that the PDC was eroding its earlier deposits.

Phase 2 was marked by the deposition of five valley-ponded, rapidly emplaced, glassy, lava-like ignimbrites. All units display a pervasive flow-banding and stretching lineation, indicating syn-depositional rheomorphism, except the uppermost unit, which displays complex folds and an upper autobreccia, indicating post-depositional rheomorphism. These units record high-temperature, low-fountaining, boil-over type eruptions.

Phase 3 was marked by the emplacement of a thin, localised, lava-like ignimbrite, similar to the Phase 2 material, but with abundant lithic lapilli. Its relationships with the Phase 2 deposits are unclear.

Phase 4 is marked by the emplacement of a localised sequence of stratified tuffs, lapilli-tuffs and breccias. The tuffs and lapilli-tuffs are planar- to cross-stratified and alternate with massive lapilli-tuffs and breccias. In the finer units, convolute laminae and ripples are present. Together they record the entry of a dilute PDC into a small lake and the aqueous reworking of finer pyroclasts.

Phase 5 is marked by the emplacement of a valley-filling crystal-rich massive lapilli-tuff. This unit unconformably overlies all earlier phases, and comprises up to 50% crystals of plagioclase feldspar in an ashy matrix, suggesting the the tapping of a crystal-rich slurry in the magma chamber.

The 29th December 2013 eruption of San Miguel Volcano, El Salvador

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On the 29th December 2013, San Miguel volcano (aka Chaparrastique volcano) in eastern El Salvador erupted after almost 40 years of quiescence. The flanks of the 2130 m-high volcano are covered in coffee plantations up to 1500 m altitude and the country's second city, San Miguel lies 12 km to the east. The 3 hour eruption produced a 7 km -high eruption plume that dispersed ash over >20 000 km^2 of El Salvador and Honduras. 5000 people were evacuated from a 3 km-wide radius of the volcano. The eruption ejected ballistic blocks into coffee plantations and produced a transient pyroclastic density current that flowed 700 m down the western flanks and knocked over trees. Proximally, the fall deposits can be divided into: A) 15 cm of poorly sorted, lithic-rich tephra; B) 4 cm of vesicular scoria of basaltic-andesite scoria. In medial regions (1-3 km from the volcano), the fall deposits are composed of A) a basal white ash layer containing ash-coated clasts and ash aggregates that is not seen in proximal parts, B) a grey lithic fine ash layer, and C) a layer of coarse ash to fine lapilli-grade scoria. The upper two layers can be traced >40 km from the volcano where they thin to < 0.5 mm thick. Initial phreatomagmatic explosivity is indicated by abundant hydrothermally altered lithic clasts, the presence of ash aggregates, ash-plastered rock surfaces in the crater and the absence of charred vegetation engulfed by the pyroclastic density current. The last phase of the eruption was predominantly magmatic and was driven by the vesiculation of basaltic andesite magma. Understanding hazards at San Miguel volcano is a priority due to the high population density and the commercialisation of the volcano's flanks. Reconnaissance fieldwork indicates that the volcano has produced substantially larger eruptions in the past.

Towards a new tectonic model of the Askja caldera

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The Askja volcanic system lies on the boundary between the Eurasian and North American tectonic plates and is an example of a multiple caldera formed in an extensional regime. Askja is composed of at least three calderas, the last of which formed during an explosive eruption in A.D. 1875. The caldera floor has been subsiding almost continuously since 1983; total subsidence in this period is around 1.1 metres. Perhaps surprisingly, there has been no slip or movement on the caldera bounding ring-faults during this subsidence period. Various models have been proposed to explain this unusual signal. A two magma chamber model appears to fit the observed displacements (Sturkell et al., 2006), with a shallow source at around 3 km depth and a much larger source at around 16 km depth. In this model, subsidence is caused by depressurisation in both sources as a result of cooling contraction and crystallisation. In other models subsidence results from magma being squeezed out of the shallow chamber laterally; or somehow draining back into a deep seated reservoir.

In this study we examine the contribution of regional extension and structural discontinuities to the current subsidence of Askja caldera. Using a finite element numerical analysis, we ascertain the state of stresses at Askja caldera over time based on several different magma body geometries. We calculate surface displacements expected from extension around a shallow magma body, and place these findings in the context of Icelandic calderas. In addition we investigate the likely stress effects of the Askja caldera on the associated part of the Northern Volcanic Zone. The proposed model seeks to understand the volcano-tectonic conditions at Askja during caldera formation, as well as during rifting episodes. The models presented will be useful in assessing likely future rifting events and fissure swarm activity in Askja caldera, and neighbouring volcanoes.

A new classification for spherulites in obsidian lavas in the Aeolian Islands, Italy

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Recent volcanism (< 42 ka) in the Aeolian Islands has been dominated by rhyolitic activity, and spherulite-bearing obsidian lavas are well exposed on both Lipari and Vulcano. Constraining spherulite nucleation and growth processes can provide key insights into obsidian cooling, crystallisation and emplacement history. Through combined petrological, textural and geochemical techniques, this study aims to decipher the conditions of formation of spherulites in obsidian flows on Lipari and Vulcano. The study contributes new compositional data for spherulites in the Aeolian Islands suite, expands on the use of CSD methods for interpretations of spherulite nucleation and growth, and proposes a systematic classification for spherulites.

Spherulites contain cristobalite, orthoclase, minor diopside, titanomagnetite and rhyolitic glass. Raman results indicate variable glass structure and degree of polymerisation (inherently affecting viscosity and rheology) in the samples. Spherulite CSD plots show distinct populations of smaller (< 0.5 mm) and larger spherulites. Based on the combined observations, spherulites can be classified as 5 types, based on physical characteristics, spatial distribution, composition and potential nucleation stimuli: Type 1 spherulites are small, radial and contain α- and β-cristobalite; Type 2 spherulites are elongate, with an oxidised rim, minor alteration and radial interior, often concentrated close (or within) multi-scale deformational structures such as folding; Type 3 spherulites are large, radial spherulites, often occurring individually in zones of low shear; Type 4 spherulites concentrate within fractures and faults; Type 5 spherulites are modified spherulites and lithophysae, with a non-radial interior.

This study shows that spherulites form due to a number of processes, pre- to post- emplacement, from high-temperature undercooling, through the glass transition and ductile deformation to late stage brittle deformation. Spherulites also form concomitantly in different parts of obsidian due to variations in rheology. Strain enhances crystallisation, whereby crystallites orient and stretch, facilitating flow-induced crystallisation; thus deformation may be an important catalyst for spherulite nucleation.

Volcanic CO_2 emission from the Banda and Sunda arcs

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The concentration of CO_2 in the atmosphere has a crucial role in controlling climate. Anthropogenic CO_2 emissions currently dominate natural CO_2 emissions, but this is a very recent development. Throughout Earth's history the geological carbon cycle has played a key role in controlling climate. There are large uncertainties [1] in the magnitude of the geological carbon cycle, due to difficulties in measuring global geological CO_2 sources and sinks. These uncertainties are relevant to climate studies and policy even in a high anthropogenic CO_2 emission scenario, as the speed of the geological cycle has a control on CO_2 lifetime in the atmosphere, and therefore recovery time from a peak in CO_2 emissions.

Volatile released at arcs are sourced from either the crust, subducting slab or the mantle wedge, and therefore the flux and composition of arc volatiles reflects the relative contributions of these two sources. The origin of volatiles is of paramount interest to better understand the geological carbon cycle.

The Banda and Sunda arcs are continent collision zones where the genesis and composition of the magma are affected by subducted oceanic lithosphere and continental sediments [2]. They contain ~150 volcanoes that have erupted in the last 10,000 years. They provide a valuable opportunity to quantify and model recycling of volatiles in subduction settings. This study presents a review of the petrological and geochemical features of Sunda and Banda arcs in order to highlight the possible mechanisms of magma genesis. The origin of volcanic CO_2 has three main sources, CO_2 dissolved in the mantle, recycled CO_2 from subducted crustal material [3, 4] and decarbonation of the crust [5]. Here we review our current understanding of the flux and composition of volcanic gases from the Sunda and Banda arc, and examine how novel results arising from planned surveys of gas emissions within the ERC CO_2Volc project could contribute to our understanding of volatile recycling in these important settings.

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Partial proxies for geochemical discrimination in Italian altered tuffs

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With well-constrained petrography and careful consideration of relevant mineral reaction paths and fluid evolution, zeolitized tuffs can help address the problem of accessibility to erupted melt compositions where there has been minimal preservation of glass. A new and robust microprobe protocol for the analysis of zeolite group minerals has recently been developed for this purpose, along with a trial adaptation of a high resolution LA-ICP-MS method for trace elements. A set of reference zeolites have been prepared, characterized and validated during the development of the WDS (microprobe) protocol, representing all compositional extremes of this mineral group (except for Cs in pollucite). The traditional problems of quantifying the light elements, confidence in the Si-Al ratio, and capability for analysis of Sr by WDS, have been resolved.

Mineral compositions for two Italian tuffs are presented, the Tufo Rosso a Scorie Nere (Vico, Sutri Formation), and the Tufo Lionato (Colli Albani). Volcanic-derived zeolites from the intra-plate Tanzanian Olduvai Gorge successions, are also included for comparison. Geochemical discrimination using zeolite compositions necessarily takes account of the wider alteration assemblage (paragenetically early smectites) and fluid inferences, but patterns of major elements, especially K2O and SiO2 for whole rock data of the same units are shown to be partially reflected in the zeolites. Data for T. Lionato indicates strong enrichment of Sr (mean SrO in chabazite: 4 wt%) as well as Si-undersaturation in the chabazite-precursor glass. Trace elements detected in zeolites, many assumed to be as micro-inclusions rather than as true substitutes in the mineral structures, might be preserving key petrogenetic information in the least mobile elements, most likely derived from precursor glasses than from reactive fluids. For example, the samples display Th/Nb and Ta/Nb ratios consistent with their appropriate contextual fields. REE patterns are also discussed, revealing possible alteration-stage fractionation behaviours.

Acks: Univ. Firenze and Roma3 teams for G'sch2013 fieldwork, and Univ. Berkeley for Tanzanian sample.

Active rear-arc seamounts in the South Sandwich Islands: Geochemical relationship to the main volcanic arc

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The South Sandwich Islands, located approximately 2200 km southeast of the Falkland Islands, are an intra-oceanic arc composed of nine major edifices and multiple submerged seamounts. Formed on back-arc crust from the nearby Scotia ridge generated in the last 10 Ma, the arc is influenced by ocean crust subduction, with no other major tectonic influences and is seen as the classic example of an intra-oceanic arc system. As such it is an excellent location to investigate early arc processes without biases[1]. The main edifices of the arc have been well studied geochemically over the last 30 years, but recent bathymetric has revealed new features that have yet to be fully examined[2].

In the centre of the arc lies Saunders Island, a dominantly tholeiitic edifice, to the west of which are submerged rear-arc seamounts. This study presents new and unpublished geochemical analyses of these seamounts, assessing their bulk compositions and relative trace element depletions as compared to the main arc, in particular Saunders Island.

Examinations of rear-arc magmatism in the arc have focused on Leskov Island, the only previously studied island edifice in the rear of the arc, with research showing that this has a calc-alkaline composition as well as a more enriched mantle source compared to the main arc[3]. For this study, rear-arc seamount geochemistry should be characterised by mantle less depleted than that of the main arc, in this case Saunders Island, as the source for Saunders would have been previously depleted by melt extraction beneath the rear-arc seamounts. Melting beneath the rear-arc may also be deeper and influenced by hotter mantle than that beneath the main arc. This study aims to test these hypotheses.

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High temperature permeability in volcanic systems: An experimental approach

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The permeability of magma exerts a major influence on volcanic activity and we have long held the ability to experimentally determine the permeability of volcanic material via various techniques. These observations have provided the basis for numerous theories of magmatic degassing. Recent enhancements to the High Temperature Triaxial Deformation Cell (HTTDC) at UCL have enabled us to make permeability measurements on 25mm x 75mm core samples at elevated temperature and elevated hydrostatic pressure (Gaunt et al, 2013). Specifically, we present here the results of several suites of permeability data on samples of dome dacite from Mount St Helens volcano, measured under an effective pressure of 5 MPa (confining pressure of 10 MPa and pore fluid pressure of 5 MPa) and temperatures up to 900oC. Most recently, the capabilities of the HTTDC apparatus have been further extended to enable permeability measurements to be made during triaxial deformation of test samples under similar temperature and pressure conditions. Initial results from this entirely new methodology will also be presented.

These new experimental results are being applied to enhance our understanding of the complex issue of silicic magma degassing. Two recent eruptions in Chile, at Chaitén Volcano in 2008-10 and at Cordón Caulle in 2011-12, allowed the first detailed observations of rhyolitic activity and provided previously hidden insights into the evolution of highly silicic eruptions. Both events exhibited simultaneous explosive and effusive activity, with both lava and ash plumes emitted from the same vent (Castro et al, 2014). The permeability of fracture networks that act as fluid flow pathways is key to such eruptive behaviour, and will be investigated systematically at magmatic temperatures and pressures in the presence of pore fluids, using our newly-developed experimental capability.

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The importance of effective hazard communication and data sensitivity: hazard mapping of Campi Flegrei

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Campi Flegrei is one of the most populated active calderas on Earth. Situated immediately west of Naples, in southern Italy, it has been in episodic unrest since the late 1950s. The unrest is the first recorded at Campi Flegrei since its last eruption in 1538 and suggests that the caldera may have re-entered a state with an increased probability of eruption.

Since the last caldera-forming eruption 15,500 years ago, approximately 60 eruptions have occurred across the caldera floor. These have mostly been explosive magmatic or phreatomagmatic events with VEIs of 3-5. Several hazard maps have been published, focussing on the expected distributions of pyroclastic density currents (PDCs) and tephra fall deposits. Although superficially similar, the maps show significant differences in detail, notably in the potential runout distances of PDCs and the distances and directions of major tephra fall. The civil authorities have thus a choice of hazard maps for designing their emergency response and, hence, the potential exists for a confused response.

We show here that the final forms of the hazard maps are sensitive to the starting assumptions of each study. Focusing on the hazards from PDCs, these assumptions include; the preferred location and size of a future eruption, the particular model used to determine heights of column collapse and the maximum potential runout distance of PDCs. The results illustrate the importance of highlighting the starting assumptions when communicating hazard information to the civil authorities, so that more-informed decisions can be made about the choice of hazard map to be used when preparing mitigating responses to volcanic unrest.

Explosive magmatism underwater: insights from textural and geochemical study of volcanic ash and lapilli at the Mariana arc.

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Lapilli and volcanic ash from the submarine volcano NW Rota-1, Mariana arc, were morphologically and geochemically analysed by reconstructing mechanism of fragmentation and magma ascent history during explosive subaqueous eruption.

Componentry and textural analysis reveals rare features of pyroclasts deposits underwater by investigating clasts morphology and frequency, area and distribution of vesicles in andesite basaltic magma as well as crystals, and microlite structure and expansion. Phenocrysts and microlite dispersion and orientation in clasts were observed as a proxy of fragmentation level and style of activity.

The use of SEM enabled the calculation of bulk vesicularity and crystallinity ranging between 0.1 to 0.3% in two different years of eruption, 2009 and 2010. Furthermore, microprobe analyses of SO_2 and chlorine content in matrix glass produced additional information about the magmatic fragmentation level, notably on NW Rota-1 degassing system. SO_2 content ranges between 0.01 and 0.02 wt% and chlorine content displays a wide range from 0.2 to 0.3 wt%.

From these results, we propose further investigations into vesicularity and crystallinity as triggers and control factors of lapilli and volcanic ash generation, providing new insights into a process of explosive pyroclastic eruptions in the submarine environment.

The study of distinctive shapes of ash morphology underwater linked with vesicle behaviour and the relationship of vesicles with crystals, reveals unique results improving knowledge on underwater volcanic explosions, as well as sub-aerial activity and tephra deposits.

Microlites and decompression crystallization from different styles of activity at Soufriere Hills Volcano, Montserrat

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We undertook analysis of microlite populations on tephra generated by a range of different types of activity at Soufriere Hills Volcano (SHV), Montserrat between 2005 and 2010. The different styles analysed included Vulcanian explosions, precursory explosions, syn-extrusive ash venting, sampled from direct fallout and effusively erupted lava dome (sampled from block and ash flows).

We examined the microlite population in glassy semi-vesicular grains in the 500µm and 1mm size fractions. The dense crystalline fraction of the fallout was not studied. The microlite number density (MND) and several textural characteristics (Aspect ratio, mean size, plagioclase crystallinity etc.) of the microlite populations were quantified.

The MNDs measured plot in two main fields. Samples of the lava dome have the highest MND values and the largest range, whereas tephra from all types of explosive activity show notably lower MND values and a much narrower range. However the different explosive events analysed plot in distinct fields. Measurements of textural characteristics e.g. aspect ratio define a more continuous trend that is made up of smaller similar variation for each event measured. For the majority of the textural microlite characteristics the values measured from the lava dome were the most equant whereas the explosively derived tephra were more elongate.

The distinct nature of microlite crystallinity indicates that each style had quite different ascent rate histories. Nevertheless the variation in microlite crystallinity within glassy juvenile tephra from single events indicates that heterogeneity in the conduit was commonplace particularly within Vulcanian explosions and lava dome extrusion that was associated with syn-extrusive ash venting.

Cumulates from Martinique: A window into the plumbing systems of the Lesser Antilles Volcanic Arc

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The Lesser Antilles Arc is exceptional globally in respect to the abundance and variety of erupted plutonic nodules. The vast majority of studies on arc magmatism are restricted to samples of the extrusive products, which represent the end products of magmatic processes. These arc magmas are commonly highly differentiated, and rarely represent primary mantle derived melts. Cumulate xenoliths, representing erupted plutonic samples, provide a window into a deeper crystallisation history than is possible from lavas alone.

Here, we focus on a suite of cumulate samples from Martinique. The lavas are controlled by crystal-liquid differentiation, driven largely by amphibole, plagioclase and magnetite fractionation. Although amphibole is rarely present in the lavas, it is common in cumulate blocks, allowing us to directly test the involvement of amphibole on the petrogenesis of arc magmas.

Plutonic xenoliths from Martinique display both adcumulate and orthocumulate textures. Textural inspection reveals the general crystallisation sequence of ol, plag, spl, cpx, opx, amph. Amphibole may either be equant, crystallising earlier in the sequence, or interstitial, associated with the breakdown of cpx. The ubiquitous early appearance of plagioclase in the crystallisation sequence and a compositional offset between plagioclase (~An90) and olivine (~Fo75), suggests crystallisation under high water contents and low pressures from an already fractionated liquid.

Interstitial amphibole is enriched in Ba and LREE compared with early-crystallised amphibole and does not follow typical fractionation trends, suggesting the involvement of a reactive melt or fluid, which causes the breakdown of cpx and the crystallisation of amphibole. The normalised REE patterns of cpx and amphibole are nearly identical; suggesting trace element partitioning into amphibole is, in part, controlled by earlier crystallised cpx.

Geothermobarometry estimates and comparisons to experimental studies imply all Martinique cumulates formed at relatively low pressures (0.2-0.4 GPa) in the mid -crust. These cumulates may represent crystal-rich portions (crystal mushes) within an open system, through which melt can both percolate and be generated. The phase assemblages and mineral chemistry differ from cumulates found in Grenada and St. Vincent to the south, suggesting along arc variations in melt composition and magma storage conditions.

Investigating the long term evolution of an island arc volcano

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The long-term evolution of island-arc volcanoes is poorly understood due to poor preservation and the inaccessibility of the earliest volcanic products. This hampers the testing of models of how volcanic islands grow, and how their magmas evolve. IODP Expedition 340 provides some of the few long cores offshore from volcanic islands. Here we consider Sites U1394 to U1396 offshore Montserrat along with terrestrial field observations. This provides an unusually comprehensive data set for the last ~1 Ma, based on initial paleomagnetic dating. The advantage of using marine cores, located further from the volcano, is that the chronology of major events is better preserved because flows tend to erode or bypass more proximal locations on land. The study of these cores give valuable insight into the characteristics of the early volcanic behaviour of Montserrat, patterns of volcanic activity and volcanic flank collapse.

Montserrat consists of four volcanic centres. The only currently active centre is Soufrière Hills, which has been erupting since 1995. Activity has been characterised by explosive eruptions, dome building events, and dome collapse events. Previous studies have also identified large (~1-20 km^3) collapse deposits within the submarine record. On-land fieldwork conducted in 2013 focussed on the Centre Hills. Deposits comprised of tephra falls and flows generated by both eruptive and collapse events at Centre Hills. Thick pumice fall layers found within the subaerial Centre Hills record suggest that Centre Hills eruptions were much more explosive than the recent eruptions at Soufrière Hills. Preserved within IODP cores include >70 tephra layers and >60 mass flow deposits generated by explosive and collapse activity on Montserrat. Interbedded within the event deposits is hemipelagic mud, which has been dated using oxygen isotope stratigraphy and AMS radiocarbon dating. Combining both the submarine and terrestrial stratigraphic records has enabled the production of a uniquely detailed and unusually complete record of volcanic activity at Montserrat over the past ~1 Ma. Our aim is to eventually understand general patterns and trends in eruption style and the timing of major collapses to enable better prediction and management of future hazards.

Infrasonic analysis of geyser eruptions at Yellowstone National Park

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We investigated the effectiveness of characterizing and quantifying eruptive behaviours of geysers from their near-infrasound (1-20 Hz) and low frequency audible acoustic emissions. Data were acquired at Yellowstone National Park, USA, in August 2011 with three arrays of MEMS transducers temporarily deployed at near-source distances to Great Fountain Geyser (GFG), Sawmill Geyser (SMG), and Lone Star Geyser (LSG). Each geyser has distinct and diverse acoustic features. A comparison of these signals with each other and with time-synched video observations reveals how they relate to the geyser eruption dynamics.

GFG produces episodic, distinctly bimodal (compression-rarefaction) acoustic waveforms. We relate these to bubble or gas slug bursts leading to impulsive two -phase (liquid-steam) fluid ejections. The largest recorded excess pressure pulses correspond to calculated displaced atmospheric volumes of ~80 m^3. In contrast, SMG, a smaller fountain-type geyser, produces periodic acoustic waveforms that commence with a rarefaction. We interpret this acoustic signal as the collapse of steam bubbles with a calculated negatively displaced atmospheric volume of ~0.4 m^3. LSG's acoustic signals are characterized by ~2-4 minutes of low-amplitude tremor, followed by a rapid transition to higher-amplitude tremor, tapering to background levels after 10-13 minutes. These sonic emissions correspond to water-dominated flow and steam-dominated jetting respectively.

Spectral analysis of the aero-acoustic emissions from the fountain-type geysers shows the peak frequencies to be in the infrasonic range: 1.35 Hz at GFG and 1.46 Hz at SMG. In comparison, the aero-acoustic emissions from cone-type geysers are dominated by low audible frequencies: ~55-65 Hz at LSG.

Analysis of aero-acoustic emissions to determine and quantify baseline characteristics of geysers on active silicic volcanoes provides insight into distinguishing between shallow hydrothermal processes and magmatic processes.

Metallurgical Slag as a Suitable Analogue Material for Lava-Flow Fabric Studies

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Current X-Ray Computed Tomography (XRCT) studies of rotation and orientation fabrics of phenocrysts within samples of two- and three- phase lava flows are hampered by the low contrast between the groundmass of a lava flow and the phenocrysts contained within the groundmass. This is partly due to XRCT utilising both the density contrast and the atomic weight contrast of materials to resolve an image of a material that is essentially entirely composed of silicate minerals. As such the identification of a material that could both be used as an analogue for lava flows and also gives a strong contrast between all phases (liquid melt, solid crystals, gaseous vesicles) would greatly advance this area of study due to the possibility of automatic-recognition of phases and the removal of the need for manual recognition of each individual phase component. This initial study proposes industrial metallurgical slag as a prime candidate for further consideration as such an analogue material. Preliminary XRCT scans of slag samples have shown that there is a very strong contrast between the three-phases present (groundmass, metal blebs, vesicles) allowing easy computational thresholding of samples. Calculations of the Bingham flow law, Bingham Number and Reynolds Numbers as well as the physical morphology of the molten metallurgical slags have shown that the material displays a strong potential for being a suitable analogue for a range of lava compositions potentially opening its inclusion as part of controlled lava flow experiments.

Volcanic gas measurements at the Holuhraun eruption in September 2014

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This paper presents results from spectroscopic gas measurements made during the 2014 eruption of Holuhraun volcano, associated with the Bárðarbunga volcanic system. The eruption was associated with a dyke intrusion from underneath the Bárðarbunga volcano (IMO and IES, 2014; Hartley and Thordarson, 2013; Guðmundsson et al., 2014). The eruption began on 31st August 2014 and is ongoing at the time of writing. It has produced an extensive lava field and continues to degas very high concentrations of SO2, presenting a hazard to inhabited areas in Iceland (IMO and IES, 2014). Measurements were made during two field campaigns in September 2014. This paper presents the SO2 fluxes and trace gas ratios that were measured and analyses the implications of the results for the volcanic system of Bárðarbunga volcano and the dynamics of volcanic degassing from an extensive lava field. It also discusses some of the challenges that arise from spectroscopic gas measurements in the field, particularly when SO2 concentrations are very high.

Guðmundsson, A., Lecoeur, N., Mohajeri, N., & Thordarson, T. (2014). Dike emplacement at Bardarbunga, Iceland, induces unusual stress changes, caldera deformation, and earthquakes. Bulletin of Volcanology, 76 (10), 1-7.

Hartley, M. E., & Thorðarson, T. (2013). The 1874–1876 volcano□tectonic episode at Askja, North Iceland: Lateral flow revisited. Geochemistry, Geophysics, Geosystems, 14 (7), 2286-2309.

IMO, IES (2014) Status updates on the eruption at Holuhraun. www.vedur.is

Is Santorini Volcano ready to erupt? Insights from a multidimensional petrogenetical study of Nea Kameni recent lavas

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Santorini, the famous stratovolcano in the Aegean Sea, erupted during three periods in the 20th century (1925-1928, 1939-1941, and 1950). Since then, it has remained quiescent from eruptive activity, although periods of unrest have been experienced. This study combined new and published volcanological, petrological, geochemical, environmental and sociological data of the three most recent phases of Santorini's activity, all of which were restricted to the caldera centre on Nea Kameni. Samples and enclaves of dacite flows, pyroclastics and domes were collected and investigated. We conducted analysis of texture, mineralogy and chemical composition by polarizing light microscope, scanning electron microscope (SEM-EDS), XRD, Raman spectroscopy and ICP-MS.

The overall evaluation of the data obtained suggests notable consistency or slight changes in chemistry and mineralogy of lavas in the 20th century, the latter being mostly attributed to minor variations in the magmatic differentiation and magma chamber physicochemical conditions. On the other hand, the significant decrease with time in volume of all products, (solid: Dafni = 857x103 m^3, WW2 = 690x103 m^3, Liatsikas = 8x103 m^3) gases, (SO_2: Dafni = 647.400tn Liatsikas = 453,18tn), duration (Dafni = 949 days, WW2 = 711 days, Liatsikas = 24 days) and explosivity (VEI: Dafni <4, Liatsikas <1), can be ascribed to a slowing dynamic of the upper magma chamber and perhaps gradually limited feeding from a deeper reservoir. Based on the time over which the volcano has remained dormant (since 1950) and on all the above data, we consider with due caution that the restricted arrest and magma chamber movements noticed in Santorini during 2012 is rather a continuation of the decreasing volcanic activity during the 20th century than a start of a new cycle of explosive eruptive activity.

Eruptive and magmatic processes within the shallow plumbing system of a small basaltic volcano: the example of Capraia Island (Italy).

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Capraia Island, in the Tuscan Archipelago (Central Italy), is entirely made of volcanic rocks originated during two distinct volcanic episodes. The main part of the island is made of lava domes and pyroclastic flow deposits with andesitic and dacitic composition, emplaced in the time frame between 7.7 and 7.1 Ma. After about a 3 Ma hiatus, a new volcanic activity built the cone of Punta dello Zenobito in the southern part of the island around 4.3 Ma ago. The cone is formed by alternating basaltic lava flows and scoria beds emplaced with a Strombolian eruptive style. Marine erosion has completely exposed the inner part of the cone, allowing us to identify two units: Punta dello Zenobito Unit, probably representing a plug, and Cala Rossa Unit that consists of lava and scoria deposits. A new detailed mapping of Punta dello Zenobito and sampling of both lithological units has been conducted in order to study the structure of the internal part of the cone, its relationship with the eruptive products, the possible presence of compositional variations of feeding magmas and mixing phenomena. In this paper preliminary geological,minero-petrographical and geochemical data are presented. Punta dello Zenobito provides an example of the wide range of eruptive and magmatic processes that occur within the shallow plumbing system of a small basaltic volcano and allows us to understand how this processes works. This volcano provides also key information regarding processes that occur in active volcanoes with similar activity. The island shows well preserved geomorphological features that allow us to make inferences on geological and tectonic evolution at the regional scale of the Tuscan Archipelago.

Volcano Alert Level Systems: Managing the challenges of effective volcanic crisis communication

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Over the last four decades volcano observatories have adopted a number of different communication strategies for the dissemination of information on changes in volcanic behaviour and potential hazards to a wide range of user groups. These commonly include a standardised volcano alert level system (VALS), used in conjunction with other uni-directional communication techniques (such as information statements, reports, and maps) and multi-directional techniques (such as meetings and telephone calls). This research, based on interviews and observation conducted 2007-2009 at the five United States Geological Survey (USGS) volcano observatories, and including some of the key users of the VALS, argues for the importance of understanding how communicating volcanic hazard information takes place as an everyday social practice. Findings indicate that whilst VALS play a role in raising awareness of an unfolding situation, supplementary communication techniques are crucial in facilitating understanding of that situation, and the uncertainties inherent to its scientific assessment, as well as in facilitating specific responses. In consequence, 'best practice' recommendations eschew further standardisation, and focus on the in situ cultivation of dialogue between scientists and users as a means of disseminating useful information.

Volcanic development of the Boset-Bericha volcano, northern Main Ethiopian Rift

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The East African Rift—one of the most tectonically and volcanically active regions on Earth—is in the act of unzipping the African continent and slowly forming a new ocean basin. The northern Main Ethiopian rift (NMER) has the highest rates of extension and volcanism in the East African Rift System (EARS) and as such is an ideal setting to address how magma genesis and ascent occurs beneath rifts and how the morphology of rifts evolve. The Boset-Bericha volcanic complex (BBVC) is one of the largest stratovolcanoes of the EARS but very little is known about its eruptive history, despite the fact that 4 million people live within 100 km of the volcano.

A young fracture network at the BBVC dissects a variety of fresh lava flows, providing an extensive chronological record of interaction between tectonics and magmatism. The generation of silicic/peralkaline magmas in the BBVC has previously been attributed to closed system fractional crystallisation of basaltic parent magmas (Ronga et al., 2010). The occurrence of basaltic fissures, cones and lavas—many closely associated with peralkaline lava flows—suggests a complex relationship between the chemically distinct magma bodies. Based on available evidence, it is likely that juvenile basalt melts largely 'bypass' evolved upper crustal magma reservoirs, but through some mechanism promoted episodes of phonolitic volcanism. Our general understanding of the scale and recurrence of these processes in rifts is very limited.

Although volcanism at the BBVC was most recently dominated by lava emissions, the stratovolcano and remnant caldera suggest explosive volcanism played a major role in its development. We present a new high resolution Digital Elevation Model of the BBVC, acquired during a NERC ARSF LiDAR survey of the area (2012), together with some preliminary petrological and geochemical results, focussing on the numerous (~20) lavas blanketing the volcanic construct. Studies of poorly understood volcanoes such as the BBVC are critical given the high vulnerability and population growth, coupled with a very limited understanding of regional volcanism.

Ronga, F. Lustrino, M., Marzoli, A. and Melluso, L. 2010. Petrogenesis of a basalt-comendite-pantellerite rock suite: the Boseti Volcanic Complex (Main Ethiopian Rift). Mineralogy and Petrology 98 (1-4), 227-243.

The relationship between plagioclase aspect ratio and crystallization time in basaltic dykes

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The time taken for basaltic magma to solidify has a direct influence on the size and shape of plagioclase grains. The average apparent aspect ratio of plagioclase grains in dolerite sills (as viewed in thin section) varies systematically, with height, forming a symmetrical 'M-shape' in sills <200m thick, while in >200m thick sills a 'Z-shape' is seen. The lowest values are found in the centre of the sills. The average apparent aspect ratio in the central part of the sills (avoiding the legs of the "M") is a function of crystallization time. In this study we report the results of an examination of average apparent aspect ratio of plagioclase in a suite of basalt dykes of varying thickness.

The average apparent plagioclase aspect ratio is generally more constant across the dykes, with little evidence for the marginal reversals typical of sills. There is no simple relationship between crystallization time and plagioclase grain shape, with the central samples from thin (few metres) dykes having lower than expected aspect ratio while dykes thicker than ~10m have more elongate plagioclase than expected.

We suggest that these observations are consistent with significant vertical movement of plagioclase in thick dykes, with continuous convective scouring of sidewall material moving higher aspect ratio grains into the dyke centre. Our data suggest that this process becomes significant once dyke thickness exceeds ~10m, with the consequent slow cooling enabling the destabilization of the inwards-growing wall mushy layer.

The Arran central ring complex: a unique laboratory for caldera-forming processes

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The central ring complex (CRC) on the island of Arran in western Scotland is unique in its level of erosion within the North Atlantic Igneous Province (NAIP). Many processes occurring in modern calderas in Iceland are obscured by water and recent sedimentation (e.g., Askja). Other Palaeogene examples in Scotland are largely eroded down to their intrusive cores (e.g., Skye, Rùm). It has long been realised, however, that the Arran CRC shows the interplay between volcanic superstructures, pyroclastic rocks, and later intrusions (Tyrell, 1928; King, 1955).

The well-exposed Ard Bheinn area in the north west of the complex was mapped and described in detail by King (1955). It is perhaps testament to the rigorous and meticulous nature of this account that there has been very little research on the complex over the last 60 years. Some reconnaissance geochemistry and geochronology of the CRC granites has been attempted, but this did little more than identify differences with the Arran Northern Granite, and date the complex as late Palaeocene.

Recent studies of sedimentary and volcano-tectonic processes in the rest of the British Palaeogene Igneous Province (BPIP) have led to a re-evaluation of many lithologies in explosive volcanic settings (Brown et al., 2009). Initial fieldwork in the Arran CRC indicates that the ‘vent agglomerates’ may have formed by a combination of fluvial and mass-wasting processes, in addition to pyroclastic activity. Likewise, ‘felsites’, originally thought to be intrusive, may be re-classified as ignimbrites.

This study will use modern geochemical and geochronological techniques, which will be integrated with detailed mapping, sedimentological studies and volcanological work to re-assess the petrogenesis and volcanological history of this poorly understood complex. This work will enable us to relate the formation of the CRC to other centres in the BPIP, and currently active calderas in Iceland and the rest of the world.

Brown, D. J. et al. (2009) Geol. Mag. 146 (3)
King, B. C. (1955) Quart. J. Geol. Soc. 110
Tyrell, G. W. (1928) The Geology of Arran.

Chert formation in a volcanically influenced lake: The Timpone Pataso Formation, Lipari, Aeolian Islands, Italy

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Chert is a microcrystalline sedimentary rock that may form by direct precipitation due to silica oversaturation, secondary diagenesis caused by the dissolution of biochemical components within a rock, the replacement of primary material with silica, or biogenic or hydrothermal processes. In this study, we investigate chert within an unusual, volcanically influenced, chert-rich lacustrine system on the volcanic island of Lipari, one of the central islands within the Aeolian archipelago (Italy).

The lacustrine system, part of the Timpone Pataso Formation, is exposed along the western edge of Lipari and was deposited between approximately 114 and 105 ka [1]. The lake deposits consist of approximately 60 clearly defined, finely laminated chert layers (approximately 1 cm – 10 cm in thickness) with variable colouration, leaf bearing density current deposits (< 10 cm), and deposits from pyroclastic falls (< 1 cm) [1]. The overall section is approximately 100 m in thickness. Sedimentation in the lake appears to be influenced by episodic tectonic movement along the lacustrine margin, which causes alterations in bed thickness, extent, and internal sedimentary architectures, in addition to alterations caused by the intermittent influx of pyroclastic material into the lake, and, possibly, by seasonally-driven processes (varves).

Here, we present sedimentological field and FP-ED-XRF geochemical data, complemented by future Si and O isotopic analysis of the cherts, to shed light on the origin of the chert layers and sedimentation processes within the ‘Timpone Pataso’ lacustrine deposits.

Interbedded chert and volcaniclastic strata from the tpa Member, Timpone Pataso Formation, Lipari.

[1] Forni, F., Lucchi, F., Peccerillo, A., Tranne, C.A., Rossi, P.L., Frezzotti, M.L., 2013. *Stratigraphy and geological evolution of the Lipari volcanic complex (central Aeolian archipelago).* Geological Society Memoir, No. 37, p. 213-279.

Redox evolution of the AD 1783-84 Laki eruption, Iceland

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Crystal-hosted melt inclusions preserve information about geochemical diversity within magmatic systems, including information about the oxygen fugacity (fO_2) and redox evolution of their carrier melts. However, ferric iron proportions ($Fe_3+/\Sigma Fe$) in olivine-hosted melt inclusions are strongly influenced by post-entrapment processes such that inclusions may no longer preserve a record of the fO_2 at which they were trapped. Post-entrapment crystallisation (PEC), on the inclusion walls sequesters Fe2+ into olivine. Olivine-hosted inclusions also maintain H_2O and fO_2 equilibrium with their external environment via coupled proton and metal vacancy diffusion through the olivine crystal lattice.

We have measured $Fe_3+/\Sigma Fe$ by micro-XANES in a suite of 100 olivine-hosted melt inclusions and glasses from the AD 1783 Laki eruption, Iceland. The inclusions, hosted in Fo86-Fo68 olivines, have experienced up to a maximum of 7% PEC. Many of the inclusions have experienced diffusive modification of H+. Trace element depleted inclusions with low initial H_2O concentrations have gained H+ via diffusive exchange with a more H_2O-rich carrier melt, which is a consequence of concurrent mixing and crystallisation of diverse primary melt compositions in the Laki magmatic system. A strong correlation exists between melt inclusion H_2O and $Fe_3+/\Sigma Fe$. The most H_2O-rich inclusions are the most oxidised ($Fe3+/\Sigma Fe \approx 0.22$); these inclusions preserve the H_2O content and the redox conditions of the pre-eruptive Laki magma. By contrast, inclusions that have lost H_2O via diffusive re-equilibration with the degassed Laki lava during insulated transport are more reduced ($Fe3+/\Sigma Fe=0.14$), indicating that H_2O and fO_2 in olivine-hosted inclusions equilibrate over similar timescales. Laki matrix glasses preserve a range of ferric iron proportions, with the most oxidised glasses having the lowest sulfur contents.

Our data demonstrate the fundamental controls exerted by volatile diffusion and degassing over redox evolution within magmatic systems. Olivine-hosted inclusions can preserve the redox conditions of the pre-eruptive magma, provided they are rapidly quenched; however, redox heterogeneity present at the time of inclusion trapping is overprinted by the rapid re-equilibration of melt inclusion fO_2 with its external environment.

Marine sediments as an archive of arc volcanic history, Montserrat

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Understanding the long term evolution of arc volcanism from the on-land record alone is difficult; older deposits become progressively buried by successive activity, obscured by vegetation, or eroded out. A complimentary approach to this problem is provided by study of marine sediment cores. For example, Le Friant et al. (2009) calculated that ~75% of material erupted from Soufriere Hills from 1995-2005 ended up in the Caribbean Sea, thus marine sediments may contain a more complete record of volcanic activity. In March 2012 IODP expedition 340 obtained cores from ~30 km SW of Montserrat, Lesser Antilles, at site U1396. This core contains >150 tephra layers, extending back ~4.5 Ma. However, the first task in studying these sediments is to determine their provenance, because tephras of site U1396 might be derived from other nearby volcanic islands, particularly Guadeloupe. We show here that a combination of trace element and Pb isotope data can be used to distinguish the Montserrat tephra layers from those of other islands.

With the Montserrat tephra layers identified, we focus on those of the Silver Hills age range (c. 2.6-1.2 Ma), and make comparisons with terrestrial exposure studied during recent fieldwork. We reveal there is a discrepancy between the deposit types of the two records; the marine record is dominated by pumice rich fall-out and flow deposits, whereas the terrestrial record is dominated by pumice-devoid primary and re-worked flow deposits and lavas. Only one location within the Silver Hills contains a pumiceous sequence. This highlights the importance of examining both marine and terrestrial records in the development of a comprehensive eruptive history of an island or coastal volcano.

'Volcanomics'. Trialling analysis of eruptive scenarios via economic and probabilistic approaches on Tristan da Cunha and its application to decision support

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Preparing for a volcanic eruption during periods of quiescence is essential at any volcano where lives and livelihoods are threatened. This is a significant challenge at volcanoes where eruptions are infrequent and other more pertinent, recurrent risks are the focus of disaster management, mitigation measures and community concern.

One way to try and improve preparedness and aid decision making around highly uncertain and intermittent volcanic activity is to combine volcanological knowledge, economic analysis and probabilistic techniques. The strength of providing integrated information about what might happen, the probabilities of particular eruptive scenarios, and their economic consequences, is that decision maker(s) obtain a more complete suite of information. However, decisions do not solely refer to those made during a crisis, but also deciding on cost-effective measures to reduce risk in advance of an eruption.

Our case study focus is Tristan da Cunha. Tristan is one of 14 British overseas territories, which also include active volcanic islands of Montserrat and Ascension. Tristan last erupted in 1961 as a small dome and flow eruption, which by astonishing misfortune erupted adjacent to the only settlement (pop. 264), prompting the temporary evacuation of the population.

The uncertainty around location and style of future eruptions is severe, as Tristan has no central vent preference. Evidence suggests that there is no spatio-temporal pattern to eruptions, and, while small-volume leaks of evolved lava have been the norm over the last 300 years, eruptions of larger magnitude or different composition are also possible.

We present a methodology combining economics, probabilistic techniques and volcanology ("volcanomics"). More specifically, the impact (area affected and cost of losses) of plausible eruption scenarios are compared. The results of this integrated approach were communicated to national level decision makers during a scenario exercise aimed at improving preparedness and reducing risk to volcanic crises.

Linking Plutonism and Volcanism: Understanding the Development and Evolution of Large Magmatic Bodies

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Plutons are fundamental building blocks of the continental crust and are important in the development of magma chambers and construction of volcanic arcs. However, the mechanism of pluton formation and the relation between plutonism, volcanism and the development of magma chambers is unclear. Plutons are large bodies of unerupted magma, typically covering hundreds of square kilometres in aerial extent with an estimated volume of >104 km^3.

The mechanics of pluton formation are controversial, with contrasting hypotheses still active in the scientific community. It is somewhat a common belief amongst geologists that plutons once existed as predominantly molten magma bodies with the potential to feed volcanic eruptions.

However, recent petrographic and geochronologic studies of large granitie bodies reveal cryptic layering which suggests that plutons are assembled incrementally over millions of years. In this study we provide insight on the subject matter by using several integrated approaches; from field observation to recreating the formation of plutons in scaled laboratory experiments and thermal modelling.

We present preliminary results from analogue experiments where gelatine (the crustal analogue) is injected by dyed water (the magma analogue). Gelatine is a visco-elastic material whose mechanical properties can be determined using a rheometer. By varying the temperature and concentration of the gelatine, we are able to model magma intrusion dynamics in a progressively heated host. Particle Image Velocimetry (PIV) is used to provide additional details of the intrusion dynamics.

Ash generation at lava domes: from fracturing to fragmentation at Santiaguito, Guatemala

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Lava domes present challenges to existing models for the textural description of ash and the attendant formation mechanisms. Plug flow dynamics at lava domes introduce primary and secondary effects on ash texture, and prevent a simple nomenclature of ash provenance. Here, we describe textural features, morphology and petrology of ash collected before, during and after a dome collapse event at Santiaguito dome complex. We use QEM-scan, laser diffraction granulometry, optical imaging and SEM to characterise the samples. We compare these with granular textures produced during rock deformation experiments to help constrain formation mechanisms.

The ash samples show a range of textures and morphologies, however they do not contain a majority presence of pore walls, which have been attributed to magmatic fragmentation. Instead the ash is generally blocky (>70%). The ash samples show minor variation before, during and after dome collapse. Some ash particles present extraordinary evidence for disequilibrium melting. We compare these textures to ash experimentally generated by shear failure, abrasion and friction. We show that comminution and failure result in blocky ash. High-velocity friction can induce melting of dome rocks producing similar disequilibrium melting textures. This work shows the importance of deformation mechanisms in ash generation at lava domes and during Vulcanian activity. We compare these observations to similar studies at other lava domes.

A geological and geochemical overview of Aluto volcano, Ethiopia

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Volcanoes of the Ethiopian Rift are among some of most dangerous in the world, yet for many their eruptive history is poorly constrained and thus our understanding of the size and frequency of past eruptions is extremely limited. To address this we have undertaken a detailed multi-disciplinary study of Aluto, a typical young and restless silicic volcano, involving remote sensing, field mapping and geochemistry to reconstruct the volcanic history.

Using field and remote sensing mapping we have constructed a new geological map and eruptive stratigraphy for Aluto. Our results show that the development of Aluto volcano followed a period of regional basaltic fissure eruptions. Aluto was initially build up as a large trachytic complex (>8 km diameter), it subsequently underwent several large caldera-forming eruptions and developed a collapse structure (~45 km^2). Following caldera collapse several pulses of resurgent silicic volcanism have taken place, infilling the caldera and exploiting the pre-existing volcanic ring structure.

Whole-rock major and trace element analysis of the erupted products of Aluto show that the youngest volcanic rocks are dominated by highly evolved peralkaline rhyolites. There is however, a large range in silica content of the sample suite (SiO_2 42 – 76 wt. %) and major element data are characteristic of protracted fractional crystallisation processes. Incompatible trace elements show smooth linear trends, and are indicative of a single magmatic lineage derived from a parental basalt. Simple closed-system Rayleigh fractionation modelling of trace element data suggest that the most evolved rhyolites of Aluto can be reached following 90 – 95% fractional crystallisation of the basalt rocks that preceded development of the complex.

This study offers some of the first detailed constraints on the volcanic and magmatic evolution of a silicic complex of the Main Ethiopian Rift and has clear implications for hazard assessment and more broadly for our understanding of volcanic edifice development within an evolving continental rift basin.

Hot, warm or cold? Disclosing the temperature of columnar jointing in lavas

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Columnar joints form by cracking during cooling-induced contraction of lava. The process, and resultant geometry, manifests a complex interplay between heat dissipation, contraction and tensile strength. However, the lack of direct measurements of the formation temperature of such joints has led to ambiguity about the exact mechanics of jointing and their role as fluid pathways.

Columnar joints from Seljavellir, a basaltic lava flow at the base of Eyjafjallajökull, produce quadratic to heptagonal cross sectional patterns with variable column widths. The fracture surfaces are characterised by striae that share a positive linear relationship with joint spacing. The fracture surface between each striae exhibit a smooth and rough portion. This is interpreted to express a change in deformation regime from a fully brittle response as stress overcomes the strength of rocks, resulting in a mode -I tensile fracture, which propagates and evolves into a rough, pervasive fracture as stress dissipates, suggesting a more ductile behaviour ending each fracture cycle.

To test the thermo-mechanics of columnar joints we developed an experiment to investigate the stress, strain-to-failure and temperature at which basalts undergo tensile failure during cooling from the solidus temperature of 980 °C. We find that microscopic fractures initiate at ~820 °C, which propagate into a localised macroscopic tensile fracture at ~670 °C. We interpret the two-stage fracture dynamics as the cause for the change in fracture surface roughness. This temperature window is supported by complementary analysis of expansion coefficient and tensile strain-to-failure during classic Brazilian tests.

We show for the first time that columnar jointing takes place well within the solid state of volcanic rocks. The findings have implications for the construction of permeable networks for fluid flow in volcanic, geothermal and hydrothermal environments.

Plumbing systems interactions in the Torfajökull volcanic system, Iceland: an insight from mineral zoning

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Recent seismic and eruptive events at Barðarbunga volcano, Iceland, have again highlighted the potential hazards related to linked plumbing systems between large volcanic centres. After the eruption onset in August 2014, a 45-km long dyke was quickly emplaced; it initiated close to Barðarbunga Volcano gradually extending towards the boundary between the East Volcanic Zone (EVZ) and the North Volcanic Zone [1]. This threatened to intersect the plumbing system, and trigger an eruption, at one of Iceland's major stratovolcanoes, Askja.

Iceland's volcanic systems are typically comprised of a central volcano and a fissure swarm [2]; Torfajökull, the largest silicic centre in Iceland, is located on the southern part of the EVZ, intersecting the southern tip of the neighbouring Veiðivötn fissure swarm; geochemical analysis of erupted products has shown evidence of mixing between fissure tholeiites and Torfajökull rhyolites [3]. This project aims to better understand the relationships that may exist between plumbing systems that feed Icelandic central volcanoes and their associated fissure swarms with the aim of assessing the risk of eruption triggering at volcanic centres.

Crystal cargoes hosted in lavas have been shown to provide detailed information on pre eruptive processes [4]. Plagioclase in particular is sensitive to changes in physical and chemical conditions of the system in which it crystallises, showing a variety of micro textures that relate to specific processes [5]; plagioclase is also present in a wide range of volcanic products thus is ideal where mixing occurs between very compositionally different end members.

Plagioclase phenocrysts in thin sections from Torfajökull and Veiðivötn show evidence for a dynamic plumbing system, subject to frequent changes affecting the growth of the crystals. In addition, abundance of sieved texture, resorbed edges and zoning within plagioclase crystals indicates substantial chemical variations. These grains particularly have been targeted during the initial SEM-EDS analysis, to assess the level of interaction between the plumbing systems feeding the fissures and that feeding the central volcano.

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A new occurrence of dalyite ($K_2ZrSi_6O_{15}$) from Terceira, Azores

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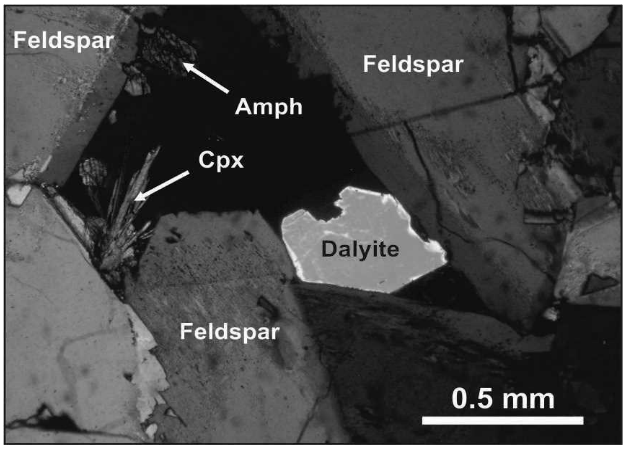
We report a new occurrence of the rare potassium zirconium silicate dalyite on Terceira, Azores, within syenitic ejecta of the Caldeira-Castelinho Ignimbrite Formation. By combining new quantitative major element analyses with available published analyses, as well as the application of solid state molecular modelling, we evaluate the mineral's compositional variability, assess the site allocations of substituting elements and discuss dalyites implications for the magma system.

The new analyses yield the average formula (K1.84, Na0.15) (Zr0.94, Ti0.01, Hf0.01) Si6.03O15, and highlight a bimodal variation in the degree of Na↔K substitution that can be related to the effects of pore size upon the composition of interstitial liquid. Model results predict the placement of substituting Hf in the octahedral site, Ti in either the tetrahedral or octahedral sites and small amounts of Fe in the polyhedral site, despite charge balancing difficulties.

The combined dataset reveals that dalyite from peralkaline granites and syenites is generally defined by higher Na↔K substitution and lower Ti↔Zr substitution relative to dalyite from potassic rocks. Substitution between the octahedral and tetrahedral sites (both Zr↔Si and Si↔Zr) is also highlighted, though the nature and degree of substitution does not correlate with rock composition. The absence of dalyite within the CCI trachyte itself implies that the syenites represent near complete solidification of trachytic melt, and that dalyite crystallised from significantly more evolved (peralkalinity index = 2 to 5) interstitial melts.



Modelling the trace element characteristics of plume-derived partial melts of peridotite and pyroxenite, and the origin of Etendeka CFB primitive melts

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Continental flood basalts (CFBs) are widely believed to be the products of high-temperature melting in an impacting mantle plume starting-head. Traditional models have focused on rising mantle plumes consisting of peridotites, but recycled oceanic crust (i.e. eclogite/ pyroxenite) may also be an important component. We use a new thermodynamic model to calculate melting phase relations at the relevant pressures in these lithologies, with calculations performed in THERMOCALC. This facilitates detailed forward modelling of the incompatible trace element composition expected of peridotite and pyroxenite partial melts produced in mantle plumes upwelling beneath continental lithosphere.

These models are used to examine the possibility of a recycled component in the mantle source of the ~133 Ma Paraná-Etendeka CFB province, which formed in response to the impact of the proto-Tristan plume. Here, primitive mantle melts (picrites and ferropicrites) are found in association with the main CFB pile. The ferropicrites were emplaced in the Etendeka region of Namibia immediately prior to the main flood basalt pulse and pre-date most lithospheric thinning in the region. Picrite melts - thought to form by high-temperature melting of a peridotite source – form dykes in the area and provide a useful comparison scenario for deconvolving the effects of pressure, temperature and source lithology on mantle melt composition.

Ferropicrite is a rare magma type found exclusively in a subset of global CFB provinces. It is characterised by high MgO, high FeO and low Al2O3, which cannot be the product of high-pressure melting of peridotite alone. Strongly fractionated rare-earth element patterns indicate the presence of garnet in the melt source region. The global association of ferropicrite with thick lithosphere and elevated mantle temperatures, alongside the 'garnet signature', implies that they are derived from high-pressure melting of a more fusible mantle lithology. We find that the Etendeka picrite trace element compositions are well matched by moderate-pressure, high-fraction melting of primitive mantle peridotite, whereas the ferropicrite trace element composition is better modelled by high- pressure, low-degree melting of a silica-undersaturated pyroxenite. This implies that recycled oceanic crust is indeed returned to the upper mantle in plumes.

Magma and rock friction

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Volcanoes are exceptionally dynamic settings which are particularly susceptible to strain localisation, failure and frictional processes. Damage accumulation is accompanied by the release of seismic energy which accelerates in the approach to failure. The failure stress is highly dependent upon strain-rate, which also dictates the slip-zone properties that pertain beyond failure.

High-velocity rotary shear (HVR) experiments demonstrate that at ambient temperatures, gouge behaves according to Byerlee's rule at low slip velocities. A non-linear reduction of the friction coefficient with slip velocity is observed; while textural analysis reveals that strain localisation and development of shear bands are more prominent at higher slip velocities. HVR experiments performed on solid samples of rock (Fig. 1), and at high starting temperature on magma for the first time, show that mechanical work induces comminution of asperities and heating which, if sufficient, may induce frictional melting and formation of pseudotachylyte. The viscosity of the melt, so generated, controls the subsequent lubrication or resistance to slip along the fault plane thanks to non-Newtonian suspension rheology. The silicate melt reveals a strong velocity-dependence and yields a tendency for extremely unstable slip thanks to its pivotal position with regard to the glass transition. This thermo-kinetic transition bestows the viscoelastic melt with the ability to either flow or fracture: with potentially drastic consequences for frictional slip dynamics.

In the conduit of dome-building volcanoes, the magma fracture and subsequent slip processes are further complicated: movement along the conduit margin fluctuates and is accompanied by characteristic repetitive seismic events generated by non-destructive, stick-slip source mechanisms. Frictional melt acts as an important feedback on the slip plane, accentuating stick-slip cycles that bring the magma, step-wise, to the surface. The bulk composition, mineralogy and glass content of the magma all influence frictional behaviour, which supersedes buoyancy as the controlling factor in magma ascent at some dome building volcanoes; hence it is of vital importance to recognise the frictional behaviour of volcanic rocks and magmas to understand the continuation of an eruption.

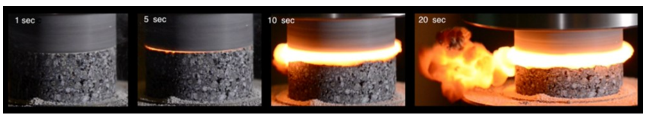

Fig.1: Freeze-frames of a HVR experiment performed on a basaltic-andesite; one sample applies axial load and the other rotates (here 2 MPa, 1.4 m/s).

Cyclic fracturing during spine extrusion at Unzen, Japan

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The 1990-1995 eruption at Unzen, Japan, was characterised by the continuous formation of a dacitic dome from May 1991 to February 1995. The period was punctuated by two phases of lava spine extrusion: at the onset of dome formation (20-21 May 1991) and near the eruption's end (October 1994 to February 1995). Using continuous seismic data collected during the latter period, this investigation seeks to identify and characterise seismicity associated with the spine extrusion.

Seismic events were automatically detected and characterized using a STA/LTA algorithm on continuous data. The data was recorded on a single short-period seismometer located roughly 600 m from the eruption vent. After filtering for false triggers, a total of 12,208 seismic events were detected between 1st October 1994 and 28th February 1995. Statistical analysis of hourly event counts was done using a combination of Multi-taper Method and Short-term Fourier transform. A strong ~41 hour cycle is detected during the first few weeks of spine extrusion, consistent with previous seismic and tilt observations. Temporal patterns in frequency and amplitude suggest that the fracturing processes associated with the spine dominate the record during the first few weeks of extrusion. Using waveform correlation, intense and long-lived clusters were identified during this period of extrusion and appear to form the basis of the strong cyclicity described previously. Source mechanisms will be inverted to obtain information on the state of stress and how it varies as the extrusion of the spine continued.

This investigation forms part of a broader project looking at seismogenic processes during the formation of lava domes. It is complemented by investigations of similar datasets from other volcanoes, including Mt St Helens (USA) and Volcán de Colima (Mexico). In addition, data are compared to acoustic emissions recorded during high-temperature magma deformation experiments.

Fracture and healing of silicic lava domes: relating stress/strain rate to eruption mode

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Active lava domes are a common occurrence and present a threat as their rapid destabilisation may result in a transition from effusive to explosive activity. The presence of interstitial glass is frequent in silicic dome lavas, and magma's response to an applied stress/ strain defines the type of eruption.

Because fractures have a tremendous impact on the dome permeability to gases, we have to understand how such features can develop and subsequently heal in lava dome and upper conduit settings.

This is investigated using three areas of study. First, by studying how cracks form, propagate and heal at high temperature in both synthetic (borosilicate glass) and natural samples (obsidian, basalts and rocks containing both glass and crystals). Further, field observations at Ceburoco volcano in Central Mexico complement these experimental data. Finally, because volcanoes are water saturated environments, the effects of water concentration and speciation on the physics of fractures within silicate glasses will be evaluated, using well constrained structure/ composition samples. I will then compare these results to simple glass failure tests and to failure of multiphase natural material.

Experimental deformation work is conducted on high -temperature uniaxial and triaxial presses at the experimental volcanology laboratory in University of Liverpool. Other experimental tools such as electron microprobe, Fourier Transform Infrared spectroscopy (FTIR) and differential scanning calorimetry (DSC) help to link the physical properties of magma failure and healing to their chemical signatures and response timescale in nature.

Bathymetry and Geological Setting of the South Sandwich Islands Volcanic Arc

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The South Sandwich Islands and associated seamounts constitute the volcanic arc of an active subduction system situated in the South Atlantic. A map at scale 1:750 000 is presented (side 1) which displays the bathymetry of the largely submarine volcanic arc, the associated back-arc spreading centre of the East Scotia Ridge, and the other tectonic boundaries of the subduction system. Satellite images of the volcanic islands at scales of 1:50 000 and 1:25 000 are also presented (side 2) with contours and main volcanological features indicated.

The South Sandwich arc is situated on the Sandwich plate in an intra-oceanic tectonic setting, far from any large fragments of continental crust, and the map demonstrates that the arc has a relatively simple tectonic structure controlled by the subduction of South American plate to the west below the Sandwich plate. The islands are entirely volcanic in origin, and most have been volcanically or fumarolically active in historic times. Many of the islands are glaciated, and the map forms a baseline for future glaciological changes caused by volcanic activities and climate change. Marine sedimentation around the islands is dominated by mass transport deposits and turbidite flows. The back-arc spreading centre consists of nine well-defined segments, most of which have rift-like morphologies. Submarine hydrothermal vents are confirmed at two sites in the back-arc spreading centre and two in submerged calderas on arc volcanoes.

The influence of near-surface magma-water interaction on magma fragmentation and degassing during the 2500BC Hverfjall Fires, Iceland

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Magma-water interaction (MWI) influences both eruption style and resulting pyroclast properties (e.g., grain size, morphology, and bubble/crystal textures). We explore the mechanisms and consequences of MWI by examining tephra deposits from the 2500BC Hverfjall Fires within the Krafla fissure system, northern Iceland. Here, contemporaneous fissure vents spanned sub-aerial to shallow lacustrine environments, causing both dry magmatic and variably wet phreatomagmatic activity. As all vents shared the same initial magma composition, the range of pyroclastic (ash fall, wet surge, dry surge and scoria) deposits record the effects of fragmentation under different near-surface conditions.

Samples from the opening phreatomagmatic phase show systematic changes in ash morphology with grain size. The proportion of dense blocky fragments increases linearly [from 8% (1φ) to 77% (>4φ)] with decreasing size fraction. The proportion of vesicular particles decreases concurrently, but shards comprise an increasing proportion of the vesicular size fraction [(from 6% (1φ) to 70% (>4φ)]. Free crystals, lithic and microcrystalline grains are ~10% of all size classes.

We compare these morphological data to (1) bubble size distributions (BSDs) and (2) the spatial distribution of preserved volatiles in matrix glass, which record the degassing history and pressure/rate of quenching, respectively. Elevated dissolved sulphur concentrations (≤ 550 ppm) in phreatomagmatic ash compared to magmatic scoria (~180 ppm) suggests either faster quench rates and/or greater fragmentation depths. To discriminate between these alternatives, we analyse BSDs in ash from both dry magmatic fragmentation and fragmentation modified by MWI. Finally, comparing BSDs to grain size distributions demonstrates the importance of bubbles in localizing thermal stresses during phreatomagmatic fragmentation.

An investigation into the temporal and spatial evolution of deformation at Corbetti volcano, Main Ethiopian Rift

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Corbetti volcano sits within the central Main Ethiopian Rift. Previously thought to be dormant, Biggs et al. (2011) identified several periods of cm scale uplift and subsidence centered on the volcano between 1994-2010, using interferometric synthetic aperture radar (InSAR). The Corbetti caldera, formed 300-100 ka, is elongated NWN-ESE, with a maximum diameter of 15 km. Within it there are two, younger, volcanic domes: Urji and Chabi, which are aligned with the long-axis of the caldera. This has lead to the hypothesis that there is a rift-perpendicular fault running E-W. Whether this is a pre-existing structure or a consequence of oblique rifting remains unclear.

The temporal deformation pattern observed has been likened to that at Campi Flegrei (Italy) (Vilardo et al., 2010) suggesting that components of the deformation may be partly due to deeper magmatic and shallower hydrothermal systems. Here we extend the time series using high resolution CosmoSkyMed data from 2011-2014 and investigate the link between the spatial pattern of deformation and the volcanic and tectonic structures or a possible hydrothermal influence. To do this we will make use of high-resolution digital elevation models, 2 m2 from airborne LiDAR over Chabi and 30 m2 STRM for the rest of Corbetti, as well as magnetotelluric and seismic data.

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An evolved axial melt lens in the Northern Ibra Valley, Southern Oman Ophiolite

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The axial melt lens (AML) is a common feature lying at the base of the sheeted dykes at fast-spreading mid-ocean ridges, and is thought to play a major role in the evolution of MORB and the accretion of the upper plutonic crust. In order to better understand the petrological nature and variability of the AML in the Oman ophiolite, we examine the plutonic section at the top of the lower crust to the east of Fahrah in the Ibra Valley. The plutonic complex separating the sheeted dykes and the foliated gabbros comprises 3 distinct units: an ophitic gabbro with pegmatitic patches (patchy gabbro; 70 m), overlain by a spotty gabbro (50 m), capped by a quartz-diorite (120 m). The sheeted dykes are observed rooting in the quartz-diorite, and contacts between the plutonic units are gradational and subhorizontal. All of the units are isotropic.

A total of 110 samples were collected for detailed petrographic and chemical analysis. With the exception of a small number of the diorites, all of the samples have a cumulate component. Primary igneous amphibole is ubiquitous across the units, present even as a minor phase in the foliated gabbros, indicating extensive differentiation and/or the presence of water in the primary liquid. We did not find patches of granoblastic material, suggested to represent the restites of partially melted pieces of the sheeted dykes, in the Fahrah section. Moreover, the composition of the quartz-diorite unit is inconsistent with partial melts of sheeted dykes. Hence, we rule out an origin of the quartz diorite by partial melting. Instead, preliminary geochemical modeling suggests that all of the units can be related by simple progressive fractional crystallization of a Geotimes melt composition. Along with the field relationships, as well as the basaltic andesite to dacite composition of the overlying sheeted dykes, this suggests that the AML accommodated the formation of highly evolved melts. This contrasts with the more primitive AML and sheeted dyke complex documented in Wadi Abyad, suggesting that there is lateral variability in AML compositions along the Oman ridge axis.

Lithological controls on igneous intrusion-induced ground deformation

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Ground deformation commonly precedes volcanic eruptions. It is typically assumed that the volume of intrusion-induced ground uplift or subsidence is equal to the volume of magma emplaced. However, the relationship between ground deformation and underlying intrusion networks is complex and difficult to quantify in active volcanic systems. Here, we examine the link between ancient sill intrusions and overlying forced folds imaged in seismic reflection data from offshore sedimentary basins. Seismic-stratigraphic relationships indicate that the forced folds developed at the contemporaneous palaeosurface in response to shallow-level sill emplacement. It may therefore be considered that these preserved ground deformation events are analogous to similar uplift patterns associated with modern-day magma movement in the subsurface. By analysing sill thickness and forced fold amplitude, seismic reflection data can thus provide unique insights into the relationship between shallow-level magma intrusion and ground deformation.

Our results highlight that the amplitude of forced folds may be up to 50 % less than the thickness of subjacent intrusions. Furthermore, where sills transgress stratigraphy, it is apparent from the forced fold geometries that magma ascent occurred passively in response to plastic deformation of the host rock and did not produce seismically resolvable uplift. These observations imply that the volume of sills may be greater than that of the contemporaneous ground deformation. We suggest that this disparity can be attributed to the accommodation of magma by multiple mechanisms. For example, several studies have demonstrated that magma emplacement can be accommodated by fluidisation of the host rock instead of overburden uplift. It is thus likely that the behaviour of the host rock during magma emplacement will dictate the surficial expression, if any, of an intrusion.

Although there is a resolution gap between seismic reflection data and techniques for monitoring active ground deformation (e.g., InSAR), our results suggest that: (i) many intrusions may be hidden from the traditional techniques usually employed to identify intrusion in real-time; and (ii) inversion models of ground deformation should acknowledge host rock behaviour during emplacement. We also highlight the importance of seismic reflection data to understanding igneous systems in three-dimensions.

Improved volcanic hazard communication through educational video games: an example from St. Vincent, West Indies

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Volcanic eruptions comprise numerous hazardous phenomena (e.g. tephra fallout, pyroclastic density currents, lava flows, volcanic mudflows). Often these phenomena are rarely, if at all, experienced or poorly understood by the communities that surround volcanoes.

On the Eastern Caribbean island of St. Vincent a generation has passed since the last eruption of Soufriere in 1979. Raising awareness of the potential for a future eruption of Soufriere presents a challenge.

Particularly when volcanic hazards are not as highly prioritised in day-to-day life as opposed to other natural disasters which occur more frequently (e.g. hurricanes, landslides & flooding). This research will develop a new engaging method of volcanic hazard education through the use of video games technology. Many creative medias (e.g. animations, puppet shows, cartoon strips) have already been used in volcanic hazard education however, video games create an immersive virtual experience and encourage learning by doing. The effectiveness of a player's progress can be measured by identifying their strengths and weaknesses and their knowledge gain throughout gameplay using inbuilt game analytics.

The video game developed will comprise realistic, interactive visualisation scenarios of hazardous eruptive phenomena, providing information about their formation and behaviour. The visualisation scenarios will be developed using historical records of both the 1902 and 1979 eruptions, helping to educate about the volcanoes eruptive history. Using scenes from within the main population centres surrounding Soufriere (Leeward, Windward and North), this will allow the players to visualise the eruption in a familiar setting. Activities and interactions will be embedded throughout the game allowing for a hands-on, active learning experience which can heighten engagement in a varied ability group of players. The game is designed to be included within existing volcanic hazard outreach activities and support education programmes.

Temporal evolution of magma storage beneath the Eastern Rift Zone, Iceland

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The Eastern Rift Zone (ERZ) is situated in south east Iceland. It trends in a NE-SW orientation from Vatnajökull glacier and is suggested to be propagating towards the SW with Heimaey representing the tip of the rift system [1]. The ERZ in its current position has been active since ~2Ma [2] and has been one of the historically most productive areas on Iceland.

A comprehensive suite of samples has been collected from the ERZ, spanning from Plio-Pleistocene (Siđa and Flotshevrí) to postglacial (Veiđivötn and Grímsvötn) in age. Bulk rock isotope analyses show the Plio-Pleistocene lavas to have essentially homogeneous isotopic compositions whilst the post glacial lavas show significant variability [3].

It is possible that the homogeneity in the Plio-Pleistocene lavas represents preservation bias, similar to that suggested to effect the Tertiary lavas [4]. However, the Tertiary lavas have since been shown to record periods of significant isotopic heterogeneity suggested to represent enrichment in the underlying mantle by pulses of fertile plume material[5]. Therefore temporal change in the diversity of magma chemistry erupted at the ERZ could represent changes in the heterogeneity of the mantle source.

However, it is also possible that these variations could result from, or be exacerbated by, changes in the magma storage systematics beneath the ERZ. Increased magma storage times or larger magma chambers could result in more homogeneous whole rock compositions, whilst shorter residence times or smaller chambers could result in more heterogeneous whole rock compositions. These variations could be a result of a change from rapid glacial/interglacial cycles during the Plio-Pleistocene to a period of major deglaciation [6].

We have used mineral chemistry; olivine chemistry to assess the degree of heterogeneity that could be attributed to mantle heterogeneity and plagioclase chemistry to assess the degree of homogenisation that is occurring within the crust. Together with plagioclase Sr isotopes we hope to better constrain the evolution of magma storage beneath the ERZ.

[1] Mattsson& Oskarsson (2005). JVGR, 147, 45–267.
[2] Stecher et al. (1999). EPSL, 165(1), 117–127.
[3] Manning & Thirlwall (2014). CMP, 167(1), 959.
[4] Hardarson & Fitton (1997 Geology, 25(11), 1043.
[5] Kitagawa et al. (2008). J. Pet, 49(7), 1365–1396.
[6] Hooper et al. (2011). Nature Geoscience, 4(11), 783–786

The Volcanic Architecture of the Antrim Plateau Volcanics, Kalkarindji, Australia: A multidisciplinary study

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The Kalkarindji Continental Flood Basalt Province (CFBP) is the oldest igneous province in the Phanerozoic. Erupted in the mid-Cambrian (505-510 Ma) [1], it is estimated volumes of lava up to 1.5 x 105 km^3 could have been produced, making this similar in size to the better known Columbia River Basalts, USA.

Relatively little is known about the province, due in part to its remote location, though large swathes remain well preserved (c. 50,000 km^2). This study, based on rigorous field investigations, utilises 4 different analytical techniques to construct a volcanic architecture for the Kalkarindji basalts, drawing together these complimentary datasets to generate a series of detailed stratigraphies from around the province.

Mineralogy and petrography form the basis while geochemical data aides in defining lava flow stratigraphies and distinguishing individual flow packages in disparate locations around the province. 40Ar/39Ar dating of key stratigraphic marker horizons support stratigraphical correlation across the province whilst the use of palaeomagnetism and magnetostratigraphy has allowed for correlation on a broader scale.

This study points towards an unusual eruption among CFBPs in the Phanerozoic; a lack of tumescence and immediate subsidence of the lava pile following cessation of eruption. We map a simple volcanic structure in the Antrim Plateau Volcanics, thinning to the east from source (s) in the west independent from other sub-provinces in the Kalkarindji CFBP.

1. L. M. Glass, D. Phillips, (2006). Geology. 34, 461–464.

Magma flow within intrusions: Insights from field and petrographic studies

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Investigating the factors that influence magma flow dynamics within intrusions is important for understanding how magma migrates through the crust and erupts at the surface. Studying extinct volcanoes where erosion has exposed their plumbing systems provides insights into the final stages of magma movement.

Fieldwork was conducted in a disused quarry near Invertote, Isle of Skye, Scotland to study how magma flow is preserved within intrusions. At this location a series of stacked olivine dolerite sills from the Little Minch Sill Complex (c.60Ma) intrude into Jurassic sediments. The sills are 0.5 to 8m thick, their contacts being defined by contrasts in jointing frequency, crystal layering, occurrence of gabbro lenses and variations in mineral proportion, size and composition. A series of five distinct sills crop out, with two N-S striking dykes cross-cutting the site. Pahoehoe ropes were found preserved on the exposed margin of one dyke, which helped to infer the magma flow direction. Closely-spaced sampling was carried out and petrographic thin sections analysed to describe the crystalline fabrics across the length and breadth of the intrusions. Samples of one sill and one dyke were analysed for their magnetic fabrics using Anisotropy of Magnetic Susceptibility and Anisotropy of Anhysteric Remenant Magnetisation techniques. These results are compared with the results from the petrographic study to provide an independent quantification of magma flow trajectories.

Interactions and processes occurring in intra-diatreme fragmentation zones: field studies from Fife, Scotland and Reykjanes, Iceland

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At shallow levels in maar-diatreme volcanoes, intra-diatreme dykes can be emplaced into water-saturated and unconsolidated diatreme fill. This occurs in intra-diatreme fragmentation zones [1]. Providing the hydrostatic groundwater pressure is below the hydrostatic pressure barrier (approx. 3 MPa), thermohydraulic explosions can occur at any level within the diatreme structure, resulting in highly fragmented juvenile material [2]. The unconsolidated nature and water-saturation of the diatreme fill supports a spectrum of sub-surface magma-sediment interactions from thermohydraulic explosions to non-explosive interaction including, peperite formation and thermal mobilisation of the tephra that surrounds the dykes, which can subsequently aid the disintegration of dykes upon emplacement.

In this study, we document basaltic dykes and inclined sheets that have been emplaced into the upper diatreme levels (Carboniferous maar-diatremes in Fife, Scotland) and tuff rings (Quaternary tuff-rings in Reykjanes, Iceland) of maar-diatreme volcanoes, and also provide evidence for these intra-diatreme dykes directly feeding "surface" extrusion events. The overall dyke geometries and degree of dyke fragmentation have been investigated at these two localities, to establish host-rock controls on dyke emplacement into maar-diatreme volcanoes and the stratigraphic level of dyke termination. A variety of interactions are seen, including: 1) complex dyke disintegration from coherent dykes, to dykes with brecciated carapaces, to coherent clastogenic bodies; 2) fluidal and blocky peperites (range of scales); and 3) fluidisation of tephra.

By studying the complexity, geometries and scales of these intra-diatreme dykes, this work will improve our understanding of the processes that occur in intra-fragmentation zones of maar-diatreme volcanoes, which at present are poorly understood [1].

[1] White & Ross, 2011, JVGR, 201, 1-29;

[2] Lorenz & Kurszlaukis, 2007, JVGR, 159, 4-32

Approaches in borehole based volcanic stratigraphy analysis from the Krafla geothermal field, Iceland

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Drilling for geothermal resources hosted within volcanic sequences has been pioneered in Iceland over recent decades. As part of the EU IMAGE** (Integrated Methods for Advanced Geothermal Exploration) project, the Krafla high temperature geothermal field in northern Iceland forms the focus of a number of ongoing geophysical investigations aimed at developing a better understanding of volcanic hosted geothermal systems.

The Krafla geothermal field contains very high temperature wells due to the presence of magma at shallow depths in the area with some wells actually drilling into magma (e.g. IDDP Iceland Deep Drilling Project, web: iddp.is). Geophysical investigations include both passive and active source seismic imaging including a VSP (vertical seismic profile) experiment with goals including the imaging of magma at shallow levels, supercritical fluids and high permeability zones.

As with any subsurface investigations well constrained geological models at both the individual borehole and wider field scales are important for effective exploration and exploitation of geothermal resources. The geology in the area around Krafla comprises a mixture of both basic and evolved composition volcanic deposits, with basic compositions dominating. These cover a wide range of eruptive facies from sub-aerial effusive flows to sub-glacial explosive hyaloclastites and tephra.

Deriving coherent velocity models for borehole studies in volcanic sequences is challenging and requires close integration of lithology and geophysical based data. In this contribution we present results of recent ditch cutting analysis developments along with provisional velocity data from well K-18, aimed at providing a robust volcanic facies model for the subsurface.

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Volcano-ice interactions at Tindfjallajökull volcano, Iceland

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Tindfjallajökull central volcano is situated in the non-rifting Southern Flank Zone of Iceland. As is common for high-latitude Quaternary volcanoes, diverse lithologies can show evidence of magma-meltwater interaction and/or confinement by ice. We present field investigations from the south west upper flank of Tindfjallajökull on the inferred interaction of six small basaltic eruptions with ice.

Lithologies emplaced during the early development of three of the six eruptions are exposed, and consist of phreatomagmatic tuffs. This is indicative of an abundant supply of water which is interpreted to be ice derived and ice confined, given the lack of any topographic depressions for holding water. The transition to scoria, welded scoria and agglutinate lavas marks the emergence of the eruptions into a subaerial (water-free) environment.

Agglutinate lavas have draped cone flanks, and where they have entered valleys they have formed steeply dipping lobes. These lobes have either become disaggregated or retained coherence, and they display cooling fractures indicating interactions between lava and water. It is interpreted that the agglutinate lavas encountered ice-filled valleys and flowed down the ice-edifice interface where they were cooled from above by infiltrating glacial meltwater.

The minimal degree of glacial erosion may suggest that the six vents were active during the most recent glacial period, although their relative ages are unknown. Future geochemical work will attempt to establish whether the eruptions were part of one volcanic event or multiple distinct events. If the volcanism was synchronous, the architecture of ice cover at that time can be reconstructed over an area exceeding 20 km^2.

A New Approach to Al-in-hornblende Geobarometry

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Geobarometry based on the total Al content of igneous hornblende (Al^{tot}) has long proven popular for quantitatively constraining emplacement depths of calc-alkaline granitoid intrusions, and several Al-in-hornblende geobarometers currently exist [1]. However, most of these require an extensive low variance phase assemblage to be thermodynamically valid, and many have not been successfully calibrated to depths less than ~7 km (~2 kbar). Not only does this restrict the applicability of the barometer to low variance, calc-alkaline plutons; but it also means that caution should be used when applying it to shallow magmatic systems, such as those associated with porphyry copper deposits (PCDs) (typically < 4 km deep).

We present a reformulation of the Al-in-hornblende geobarometer with a greater focus on the relationship between octahedral Al in hornblende (Al^{VI}) and the composition of associated feldspars as described by the reaction:

$$\text{Phl} + 2\text{Qtz} + 2\text{An} = \text{Kfs} + \text{Ts}$$

This relationship has been experimentally calibrated using a combination of cold-seal and piston-cylinder experiments followed by quantitative geochemical analysis of appropriate phases. The experiments used natural granitic and monzonitic compositions sampled from the Chilean magmatic arc, and were conducted in close proximity to the water saturated solidus (685-760°C) over the pressure range 1-10 kbar. This new calibration of the geobarometer can be applied to a much wider range of granitoid bodies, helping to inform our understanding of crustal and magmatic processes in tectonic settings around the world.

[1] Anderson, J. et al. (2008) *Reviews in Mineralogy and Geochemistry,* 69(1), 121-142.

Pyroclastic Density Currents in the AD 1362 silicic eruption of Öræfajökull, Iceland

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Öræfajökull is Iceland's largest stratovolcano. In 1362 it was the source of a silicic pyroclastic eruption (2 km^3 DRE), which ranks as Iceland's largest historical explosive eruption (Thorarinsson 1958). Although it has long been suspected that pyroclastic density currents (PDCs) played a part in the eruption, no compelling evidence for these has hitherto been given. Here we present the first detailed account of two phases of PDC activity during this eruption.

Field mapping and logging of an eastern catchment of the volcano identified five main units of proximal deposit (i.e. within 8 km of the suspected vent) along with lithofacies variation within them. Unit A comprises layers of fine to medium lapilli and ash 16 to 20cm thick. Unit B comprises massive tuffs coarsening up in massive pumice bomb tuffs ranging in thickness from 160 cm valleys and to 50cm on ridges. Unit C comprises clast-supported pumice lapilli and bombs. Unit D consists of massive lapilli tuffs and diffuse-bedded layers, and displays rounding of pumice lapilli. Unit E consists of massive, clast-supported pumice lapilli.

Units A, C and E are interpreted as fall deposits due to their lack of lateral thickness variations and the angular clast-supported nature of the deposits. However Units B and D show evidence such as lateral thickness variation, poor sorting, and rounding of clasts which indicates a PDC origin. Accordingly, Unit B is interpreted to have been deposited by a fully dilute density current, with pumice bombs being incorporated via fall out from a coeval eruption cloud. Unit D is interpreted to have been deposit via a PDC whose flow boundary conditions switched between fluid-escape dominated and more granular fluid based.

Better characterisation of past PDCs at this volcano will enable more accurate hazard forecasting of future explosive rhyolite eruptions.

Thorarinsson, S. Acta Naturalia Islandica (1958) 2: 5–96

Mechanical Properties of Levees and the Location of Breaches

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The capability to predict the final dimensions of an 'a'a flow-field and the timeline for emplacement is key to effective lava hazard management. Levee breaching and the subsequent generation of secondary flows has been recognised as an intrinsic process in flow-field development. However, the conditions, locations and mechanisms for levee failure are not fully understood.

Uniaxial compression tests show that the strength of levees changes with direction according to the orientation, size and distribution of the vesicles. Levee samples where vesicle alignment is oblique to the direction of principal stress were consistently weakest and failed in a brittle manner. In contrast, levee samples with vesicles aligned parallel or perpendicular to the principal stress appeared to fail in a more ductile manner.

Vesicle size distribution analyses have shown that the shape and size distribution of vesicles appear to have a greater control on rock strength than the overall percentage of vesiculation.

Investigation into the mechanical properties of levees through uniaxial compression tests, porosity and density measurements and vesicle size distribution analysis have highlighted a number of interesting trends in rock strength which may, with further study, be used to identify locations along a flow where breaches are more likely to occur.

Bubble, bubble, toil and trouble: The degassing of Katla 1918 , a subglacial basaltic eruption

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The subglacial 1918 eruption of Katla was one of Iceland's most powerful of the 20th century, producing ~five times the total eruptive volume (DRE) of both Eyjafjallajökull 2010 and Grímsvötn 2011. However, little is known of the factors that made it such an explosive eruption e.g. was fragmentation fuelled by meltwater interaction or magmatic volatiles?

We have collected both jökulhlaup and airfall tephra from the 1918 Katla eruption. In both deposits, stratigraphy was observed, which has allows us to evaluate different periods during the eruption.

The matrix glass water content, measured using Fourier transform infrared spectroscopy (FTIR), was used to infer loading pressure. Jökulhlaup samples suggest quenching pressures of 0.4 to 1.2 MPa. Although this suggests some loading, it is considerably lower than the 3.6 MPa which is the inferred glacial load, based on an ice thickness of 400 m. There is also evidence of clast welding which suggests that post-fragmentation quenching was not instantaneous and may indicate that fragmentation occurred within the conduit. The H2O content of the air-fall tephra is consistent with degassing under atmospheric conditions.

Total volatile contents measured using Thermo-gravimetric analysis (TGA) suggest that degassing became more efficient as the eruption progressed .

All clasts have a high bubble number density. Vesicles are often spherical with some evidence of coalescence. However, both vesicle size and microlite contents are varied suggesting a variety of cooling rates.

Hotstage experiments, performed at eruptive temperatures, indicate bubble growth rates in the order of 0.8-1.6 µm s-1 . Based on models of pyroclasts cooling within meltwater, this suggests that there would be insufficient time for significant post-fragmentation bubble growth within the jökulhlaup samples. This agrees with vesicle textures as there is often no correlation between bubble size and position within the clast. However, some clasts within the airfall deposit seem to have rapidly quenched margins and significantly larger vesicles in the clast centre consistent with continued post-fragmentation degassing, suggestive of slower cooling rates which may indicate little or no interaction with meltwater.

Future work involves quantification of bubble textures, further volatile and geochemical analysis and evaluation of clast morphologies and grain size distributions to infer the degree of water interaction.

Mineral lamination development in the Inner Layered Gabbros of the Skye Central Complex: Implications for cumulate rheology and magma chamber processes

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The upper portion of the basic-ultrabasic Skye Cuillin igneous centre (NW Scotland; ~58.91 ± 0.07 Myr[1]) consists of a sequence of exceptionally well-layered adcumulates and mesocumulates, known as the Druim Hain layered gabbros. The gabbros host an abundance of autoliths and xenoliths, whose interaction with the layering and a pervasive mineral lamination has the potential to offer insights into cumulate rheology during solidification of the crystal mush.

Rhythmic layering comprises plagioclase-clinopyroxene- and magnetite-rich mesocumulates, typically 2-30 cm thick. A strong planar fabric (mineral lamination) is carried by primary cumulus framework-forming lath-like plagioclase (typically 40-60 vol. %). Magnetite (10-20 vol.%) pseudomorphs the pore space, with localised overgrowth onto the cumulus framework[2].

At the outcrop scale, ductile deformation of rhythmic layering is common close to xenoliths and autoliths. In addition, elongate beerbachite xenoliths have asymmetric shapes, wrapped by layering and the mineral lamination, suggesting solid-state deformation. Anisotropy of Magnetic Susceptibility (AMS) fabrics reveal that magnetic foliations are parallel to the macroscopic silicate lamination. The magnetic lineation is well-defined and plunges gently to the north. Such an orientation (i.e., not parallel to magnetic foliation dip or strike) cannot be easily resolved in the context of supra-solidus magma chamber processes. However, combined with field observations that suggest solid-state deformation, the AMS data point towards enhancement, if not whole-sale formation, of the Druim Hain mineral lamination in the sub-solidus. Ongoing investigation seeks to further elucidate the timing of fabric formation at Druim Hain by combining detailed petrographic observations with quantitative textural techniques such as AMS and crystal size distribution (CSD) analysis.

[1] Hamilton et al. (1998). Nature. 394, 260-263.

[2] O'Driscoll et al. (2008). Journal of Petrology. 49 (6), 1187-1221.

Mercury as a tracer for Large Igneous Province volcanism

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Large Igneous Provinces (LIPs) record the emplacement of millions of cubic kilometres of magma over a geologically short time. The majority of known provinces date to the Mesozoic Era, and almost always coincide with episodes of mass extinction or major environmental change, such as Ocean Anoxic Events (OAEs). This study explores the use of mercury as a possible direct tracer between a number of Mesozoic LIPs and coeval episodes of mass extinction and major environmental change, with initial results focussing on the Toarcian OAE (T-OAE) and its coincidence with the Karoo –Ferrar LIP. Mercury is emitted to the atmosphere as a trace constituent of volcanic gas, and may be distributed globally before being deposited in sediments. Modern marine deposits show a strong linear correlation between mercury and organic-matter content. We find that such a linear relationship was absent during the T-OAE, likely complicated by a strong affinity between mercury and sulphides. A number of depositional settings evidence an increased Hg concentration in sediments that record the T-OAE, suggesting a rise in the depositional flux of this element. Increased Hg concentrations are particularly prevalent in sections where terrestrial organic matter is preserved, likely caused by the direct uptake of atmospheric mercury by trees, suggesting enhanced atmospheric mercury during the Early Toarcian, which is most easily explained by a rise in volcanic Hg output. We therefore suggest that the Karoo–Ferrar LIP caused increased mercury flux to the Early Toarcian sedimentary realm, supporting this element's potential as a proxy for LIP volcanism. However, the Karoo–Ferrar represents only one style of LIP volcanism (subaerial emplacement which intrudes organic-rich sediment). We therefore plan to compare Hg concentrations from sediments recording three events coincident with differing styles of LIP volcanism: the end-Triassic mass extinction, coincident with the Central Atlantic Magmatic Province (subaerial and intrudes organic-rich sediment); the end-Cretaceous mass extinction, coincident with the Deccan Traps (subaerial and does not intrude organic-rich sediments); and Cretaceous OAE 2, coincident with a multitude of subaqueous LIPs emplaced in the mid-Cretaceous.

Developing a low cost method for measuring volcanic water vapour emissions at high resolution

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The most voluminous of emissions from volcanoes are from water vapour (H_2O) (Carroll and Holloway, 1994), however, measurements of this species receive little focus due to the difficulty of independent measurement, largely a result of high atmospheric background concentrations which often undergo rapid fluctuations. This is in stark contrast to SO_2 which is routinely measured at volcanoes globally (e.g. see Burton et al. In Press). A feasible method of measuring H_2O emissions at high temporal and spatial resolutions would therefore be highly valuable.

We describe a new and low-cost method combining modified web cameras with measurements of relative humidity to produce high resolution measurements (≈ 0.25 Hz) of H_2O emissions. The cameras are affixed with near-infrared filters at points where water vapour absorbs (940 nm) and doesn't absorb (850 nm) incident light. Absorption is then determined by using Lambert-Beer's law on a pixel by pixel basis, producing a high spatial resolution image. The system is then calibrated by placing a Multi-GAS unit, within the gas source and camera field-of-view, which measures; SO_2, CO_2, H_2S and relative humidity. By combining the point measurements of the Multi-GAS unit with pixel values for absorption, first correcting for the width of the gas source (generally a Gaussian distribution), a calibration curve is produced which allows the conversion of absorption values to mass of water within a pixel. This technique is demonstrated in detail at the active fumarolic system on Vulcano (Aeolian Islands, Italy).

The technique is also demonstrated for the plume of the North-East Crater of Mount Etna (Sicily, Italy). Here, contemporaneously acquired measurements of SO_2 using a UV camera, combined with gas ratios in the plume, allow for the first comparison between CO_2, SO_2 and H_2O emissions at high resolution, however, calibration and conversion to real H_2O values in this instance is more complex and problematic. Despite this and in tandem with recent observations (Tamburello et al. 2013; Pering et al. 2014), H_2O emissions demonstrate defined oscillation and periodicity over similar periods to those previously observed for other gas species at Mount Etna.

A new history of the Etive Granitoid Complex, Argyll, Scotland.

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This is developed from detailed mapping of a part of this Late Caledonian complex, linked to modal and plagioclase and biotite grain-size sampling, carried out mainly between 1968 and 1985, with associated geochemistry (Unpub PhD CNAA, Kingston 1986).

The complex is bisected by a SSW extension of the Laggan sinistral wrench fault, with ~0·8km of displacement. Other features, listed in age order, are as follows.

1. Relics of an ash-flow caldera, including unerupted ignimbrite, emplaced into fractures created by initial tumescence.

2. A sequence of five flat-topped cauldron subsidence intrusions with compositionally stratified tops. Successive intrusions were derived from different sources, and each was supplied via an individual underlying temporary laccolith.

3. Parallel sygmoid-sectioned synplutonic sheets of mafic monzodiorite in the last of these five, with geometry determined by simultaneous tilting of the foundered interior block.

4. A leucogranite, the Hilltop Meall Odhar Granite (Hilltop MOG) forming a laccolith at upper levels, with earlier underlying mainly low-angle sheets. Dips of its initially horizontal floor confirm an interior depression of the pre-MOG rocks, and show a graben depression along the Laggan Fault. Absence of marginal chilling confirms the adjacent Meall Odhar ring-dyke as the feeder conduit.

5. Emplacement of granitoid magma into the central position now occupied by the Starav Granitoids. ~0·6km of the Laggan Fault displacement preceded Starav Granitoid crystallisation.

Most of the intrusive stages, with chemistry termed "Main Trend", are formed by fractionation and assimilation in an evolving Lower Crustal magma chamber from an average composition of the adjacent Lorn Plateau basalts. Mafic additions by mixing accompanied each of these stages. Of other, "Off-trend" stages, two match the more potassic part of the Lorn Plateau range better as parents, with higher K2O and Ba. A third, with ~8,000ppm Ba. It corresponds to shoshonitic Lorn Plateau basalts with >3,000ppm Ba.

A means of generating the MOG by partial melting of downwardly displaced caldera rocks is proposed.

The complex and the Glencoe Caldera and associated granitoids are a contemporaneous caldera/pluton pair.

The Origin and Evolution of the Siletz Terrane in Oregon, Washington and Vancouver Island: A geochemical perspective

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The Siletz Terrane is located in Oregon, Washington and Vancouver Island and consists of a series of accreted basaltic rocks, including pillow lavas, massive flows and intrusive sheets. It represents a late Paleocene – Eocene oceanic large igneous province, previously proposed to have formed either as an accreted oceanic plateau, or accreted hotspot island chains or as the product of marginal rifting during ridge subduction producing slab window volcanism.

The different parts of this expansive terrane have previously been studied in isolation, however, this project will conduct a province-wide geochemical and geochronological study of the terrane and our results will be integrated with the available structural and geophysical data, in order to develop a coherent model for the origin, age and petrogenesis of the Siletz terrane.

Initial geochemical data supports an oceanic plateau origin for the terrane. Oceanic plateaus are vast areas of over thickened oceanic crust (10–35 km), the majority of which was erupted in a relatively short period of time (1–2 Ma). The acquisition of new radiogenic isotope data for the Siletz rocks will enable us to further test the oceanic plateau model and will be used to assess possible mantle source heterogeneity. It has been suggested that the Siletz Plateau represents melting of the mantle plume head phase of the Yellowstone hotspot and comparison of our new data, with data from the Columbia River flood basalts will aim to test this hypothesis.

Timescales of volcanic source unsteadiness observed in ash plume dynamics and tephra deposits

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Many explosive volcanic eruptions are characterised by unsteadiness on a wide range of scales. Recent focus on airborne volcanic ash hazard and associated direct observations of explosive eruptions has provided numerous observations of short-timescale fluctuations in source conditions for eruption plumes, leading to suggestions that source unsteadiness could form a component of eruption classification. However, important questions remain about the extent to which fluctuating source conditions are preserved in eruption plume dynamics or tephra deposits.

We have investigated the influence of source unsteadiness on plume dynamics using a new time-dependent integral model for volcanic plumes in the atmosphere. We used the model to characterise the timescales over which source fluctuations are expressed in measurable fluctuations of plume properties, and explored the influence of the wind strength. We found that source fluctuations shorter than a few minutes cannot be identified in direct observations of the plume dynamics, and consequently exert no influence on airborne ash transport.

We also investigated timescales of marked fluctuations in grain size in the Fogo A Plinian pumice fall deposits of Sao Miguel, Azores. Fine-grained pumice layers are seen within thick and coarser homogeneous layers of the fall deposit. The ratio of the grain size distributions from two outcrops at different distances from the vent was used to determine the volumetric flow rate of the umbrella cloud, the plume height for each layer and to quantify the duration of each layer forming event. Here we calculate that the thin, finer-grained layers formed in 2-5 hours and so must be a result of changes in the source conditions of the eruption. We propose that the fine layers observed in Plinian fall deposits are not inherently associated with processes of eruption column collapse and may be formed due to the non-linear dynamics of magma flows within the conduit during explosive eruptions.

The use of volcanic plume models and field observations enables constraints to be placed on the timescales and mechanisms of unsteadiness that influence tephra dispersal.

Geochemistry of mafic enclaves illustrate quasi-continuous mixing and mingling at Soufrière Hills Volcano, Montserrat

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The andesitic Soufrière Hills Volcano (SHV), Montserrat has been active since 1995, with five phases of dome growth to date. Erupted andesites exhibit evidence for recharge by mafic magmas in the form of basaltic to basaltic andesite enclaves. An ongoing andesitic eruption involving magma mixing is a unique opportunity to examine geochemically the temporal evolution of mafic magma supply and interaction with the host andesite over the course of an eruption. We present new whole rock major and trace element data (XRF and ICP-MS) for SHV mafic enclaves and andesite from the latest eruptive phase (2009-2010) and compare them to those from earlier eruptive phases.

Mafic enclaves sampled from all eruptive phases have a wide range of bulk compositions (48–57 wt % SiO2) whereas SHV andesite has a narrower range (58–61 wt % SiO2). Mixing between a mafic end member and up to 67% of andesite can explain the range in mafic enclave major and trace element compositions for phase 5 (2009-2010) erupted products. This mixing model is consistent with the observed high percentage (15–25%) of phenocrysts and rhyolitic melt incorporated from the SHV andesite present in the evolved mafic enclaves. The range of mafic enclave compositions may reflect the sampling of a hybridised layer at the interface between the two magmas.

However, there is evidence that the mafic end member has changed in character through the eruption. Systematic offsets in major element compositions such as Fe and Mg, and trace element compositions, such as V and Sc, between the eruptive phases show that the mafic end-member composition progressively altered from phases 1 to 3, but was constant from phases 3 to 5. The variability in Fe, Mg and HREE are consistent with variable cryptic fractionation of amphibole and magnetite.

These observations illustrate that the intruding mafic magmas have undergone significant fractionation in the lower crust prior to interaction with the andesite. The geochemical variability of the mafic end member is consistent with a quasi-continuous supply throughout the eruption, consistent with geophysical observations.

The eruptive history of Ascension Island: insights from stratigraphy, $^{40}Ar/^{39}Ar$ and cosmogenic ^{3}He dating

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Ascension Island, located in the South Atlantic Ocean, ~ 90 km west of the Mid-Atlantic Ridge axis, is the sub-aerial portion of an ocean island volcano rising to 859 m above sea level. Discovered in 1501, but only occupied since 1815, Ascension has no historical record of activity despite having several deposits that appear geomorphologically young, potentially late Holocene [1]. The volcanic rocks of Ascension define a transitional to mildly alkaline basalt-hawaiite-mugearite-benmoreite-trachyte-rhyolite sequence that spans an astonishing range of eruptive styles across only 98 km^2 of land. The central and eastern parts of the island are predominantly composed of pyroclastic deposits, trachyte and rhyolite lava flows and domes, and several mafic lava flows. The northern, southern and western areas comprise mafic lava flows punctuated by scoria cones [2]. The oldest exposed rocks on Ascension are ~ 1 Ma [1, 3].

This study aims to develop further understanding of the volcanic history of Ascension via a combination of field -based investigation, remote analysis and geochronological data to inform assessment of future volcanic hazards. Physical characterisation and stratigraphy of tephra deposits will place constraints on the dispersal, volume and intensity of felsic volcanism on the island. A comprehensive new set of mafic and felsic samples will be used for $^{40}Ar/^{39}Ar$ and cosmogenic 3He dating to shed light on timescales of both explosive and effusive volcanism on Ascension. This forms part of a larger project to integrate the timing and style of volcanic activity with the timescales over which magmatic processes occur and to examine the control that magmatic processes exert over eruption duration, style and magnitude.

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Temporal geochemical evolution of Mocho-Choshuenco Volcano, Chile

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Mocho-Choshuenco (39°55'S 72°2'W) is a large stratovolcano located in the Southern Volcanic Zone (SVZ), Chile. To better evaluate the hazards we have reconstructed a high resolution eruptive history, the most detailed to date for a volcano in Chile, which includes ca. 75 post-glacial (<18 ka) explosive eruptions. We utilise this high resolution stratigraphy and chronology to understand, in greater detail, the temporal geochemical evolution of the magmatic system.

During the last 18 ka Mocho-Choshuenco has ejected tephra over a broad compositional range, basalt through to rhyolite, with no apparent gap in the glass or whole rock chemistry. The total post-glacial volume of tephra preserved is estimated at ≥20 km^3 (ca. 50% with a dacitic or rhyolitic glass composition) making Mocho-Choshuenco one of the most productive (ca. 1 km^3/kyr) and active volcanoes in the SVZ during post-glacial times.

To investigate the geochemical evolution we use major element glass chemistry (ca. 2200 analyses), major and trace element whole rock analyses (ca. 120 samples) and geothermometry (ca. 600 temperature and fO_2 estimates from Fe-Ti oxide pairs) of all eruptions. These data provide a complete understanding of how the system evolved over time, providing constraints on storage and pre-eruption processes.

Masaya Volcano: engaging Citizen Scientists in monitoring the environmental impacts of a persistently degassing volcano

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Masaya Volcano, Nicaragua, displays a cyclic pattern of activity, associated with periods of intense persistent degassing. This results in periodic degassing crises where substantial environmental deterioration takes place, triggering poor agricultural yields and reducing the quality of life in this area. This research will investigate the relationship between sub-surface behaviour and environmental impact with the aim of a better understanding of cyclic behaviour of heightened degassing periods to allow for warning and time to initiate preventative measures. Geophysical measurements including microgravity, ground deformation, gas flux and sulphur particle deposition will be made to identify this relationship.

Citizen Scientists include the local population and volunteers from further afield. Both have a role to play in data collection and analysis and both have a stake in the results although the impact on the local community is more obvious. Long term studies are well suited to Citizen Scientist participation because of the opportunity to engage large numbers of people and because incremental developments in the understanding of the volcanic system can be regularly disseminated.

This project will build on and extend previous work by the Open University Volcano Dynamics Group at Masaya and other persistently active volcanoes.

Deposition and evolution of basaltic agglutinate deposits along the Rauduborgir-Kvensödul fissure, Iceland

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Basaltic agglutinate deposits along a Holocene fissure in Iceland reveal complex internal architectures and lateral facies variations. Field observations demonstrate that these deposits are constructed during the high rate accumulation of pyroclasts from a sustained lava fountain. Observations indicate that the agglutinate evolved texturally with time, initially developing a crust then vesiculating and in some cases auto-brecciating. These deposits then deform via a combination of syn- and post-depositional modification processes. Three mechanisms by which the agglutinate can deform are recognised: 1) gravitational spreading; 2) reconstitution and flow of viscous deposits and; 3) brittle failure. The field observations give insights into the mechanisms of growth and deformation of agglutinated volcanic deposits that may build edifices. In particular, these deposits may commonly form along spatter ramparts and within the initial parts of scoria cones. We also show that these agglutinates form in a dynamic and evolving environment. The features recognised in this study may also be useful for identifying vent proximal locations in ancient successions.

Real-time in-situ sensing of volcanic gases (SO_2, HCl, H_2S) and size-resolved aerosol in Mt Etna plume

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A suite of in-situ sensors were used to characterise aerosols and gases in Mt Etna plume in October 2013, at both crater-rim and in near-downwind grounding plume. A LOAC (Light Optical Aerosol Counter) for size-resolved particle measurements was deployed alongside two Multi-Gas instruments ('direct exposure' and 'pumped instrument') measuring HCl, SO_2, H_2S, CO_2, H_2O, and an ozone sensor.

These high frequency measurements (gases: 1-0.1 Hz, aerosol: 0.1 Hz) provide a detailed in-situ dataset for time-resolved plume characterization and volcano monitoring. The LOAC measurement of sized-resolved aerosol (over a 0.2 – 50 μm particle diameter range) alongside SO2 (10's ppbv to 10's ppmv) provides a valuable dataset for determining the volcanic aerosol emission specifically aerosol surface area loading. This parameter is presently poorly defined but is important for atmospheric models of the multi-phase plume reactive halogen chemistry that converts volcanic HBr into reactive bromine, including BrO. The role of volcanic aerosol is shown by PlumeChem simulations of Etna plume chemical evolution (Roberts et al., ACP 2014). The LOAC's patented optical design can also provide insights into particle properties. Finally, analysis of the total aerosol volume alongside SO_2 is performed to provide an estimate of plume SO42-:SO_2.

The two Multi-Gas instrument SO_2 time-series show good agreement, detecting co-varying plume fluctuations in the downwind plume, which also correlate with the LOAC total aerosol volume. HCl alongside H_2S and SO_2 was detected by Multi-Gas electrochemical sensor, using a 'direct-exposure' design to limit absorption/desorption effects. Electrochemical sensor response times are not instantaneous, particularly for sticky gases such as HCl (T90 ~min), but also even for "fast"-response (T90 ~ 10-30 s) sensors such as SO_2 and H_2S. Further, in a near-source volcanic plume environment, Multi-Gas instruments are exposed to very rapidly fluctuating gas concentrations. It is shown (Roberts et al., JVGR, 2014) that the combination of these effects can introduce measurement errors and bias in the derived Multi-Gas ratio. This emphasizes the need for improved data analysis e.g. sensor response modelling (Roberts et al., Chem. Geol. 2012) for accurate determination of Multi-Gas volcanic gas ratios.

Outstanding challenges in volcano seismology: Results from recent U.K. and U.S.A discussion workshops.

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Observations and interpretations of volcanic seismicity are a crucial part of any volcano-monitoring effort and accurate forecasting of volcanic activity relies heavily on observations of seismic activity. Studies of volcanic seismicity and of seismic wave propagation also provide critical understanding of subsurface magmatic systems and the physical processes associated with magma genesis, transport, and eruption. However, our ability to successfully forecast volcanic eruptions and to fully understand subsurface volcanic processes is limited by an incomplete understanding of the generation and behaviour of volcanic seismicity, limited data, and the non-standardised terminology used to describe seismic waveforms. Progress in volcano seismology is further hampered by inconsistent data formats and standards, lack of state-of-the-art hardware and professional technical staff, as well as a lack of widely adopted analysis techniques and software. Addressing these challenges will not only advance scientific understanding of volcanoes, but also will lead to more accurate forecasts and warnings of hazardous volcanic eruptions that would ultimately save lives and property world-wide.

Two recent community-wide discussion workshops held in Oxford, UK and Anchorage, Alaska, USA, represent important steps towards developing a shared, long-term vision for volcano seismology. The key challenges identified during these two workshops can be categorised as either 'scientific questions' or 'technical challenges', and in many cases technical challenges strongly limit efforts to address the scientific questions. We outline six recommendations that can be regarded as a road map for scientific and technical progress over the next 5-10 years: 1) Continued community-wide discussions, 2) Improved data, metadata and derived data sharing (using e.g. WOVOdat, the GVM, or another established platform), 3) Code development and sharing, 4) Development of resources for more comprehensive data mining, including standardisation of processing methodologies, 5) Enhanced strategic seismic data collection, 6) Enhanced integration of multiple datasets (including seismicity) to better understand volcanic activity.

Compositional variations in shield-stage volcanism, Fogo (Cape Verdes)

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Fogo is a highly active shield–stage oceanic island volcano in the Cape Verdes islands. The arid climate and excellent geological exposure have allowed the stratigraphy of Fogo to be determined by flow-by-flow mapping of lavas and pyroclastic rocks erupted both from summit vents and from flank vents in broadly radial volcanic rift zones. This mapping has shown that, during the shield stage of growth, Fogo has erupted a wide range of magmas at different times, producing well-defined chronostratigraphic units. Some of the broad compositional changes coincide with changes in volcano structure, both before the major Monte Amarelo lateral collapse (volume 150-200 km^3) and in more recent times. In both periods the structural change was from three broadly radial volcanic rift zones to one N-S trending zone. Rock samples collected during the detailed mapping of the island, yield tightly controlled stratigraphic relations.

Preliminary electron microprobe analysis indicates that samples investigated to date have complexly zoned clinopyroxene megacrysts, smaller haüyne and olivine phenocrysts with a crystalline groundmass of clinopyroxene, biotite, Ti-oxides, apatite and a variety of feldspathoids. The latter include nepheline, leucite, nosean and analcite. X-ray fluorescence (XRF) analyses of fourteen samples indicate that the rocks are highly alkaline and exhibit a near vertical trend on a TAS diagram. Initial interpretations of the data suggest that these magmas have had a complex history of fractionation and magma mixing that in future work will be used to understand the evolution of the complex multi-level magma reservoir and supply system beneath the island, and to relate this evolution to the structural history of the Fogo volcanic edifice.

Assessing hazards from the largest effusive eruption at Mt Etna, Sicily, 1669 using melt inclusion analysis and SO_2 outgassing models.

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The melts feeding Mt Etna, Italy, are rich in volatiles and drive long-lasting powerful eruptions of basaltic magma in both effusive and explosive styles of activity. The historic 1669 eruption is unique for the large volume of lava erupted ($607 \pm 105 \times 10^6$ m^3), the relatively low elevation (800-850m a.s.l) of the vents and high average lava effusion rate (58 m^3/s) (Branca et al., 2013). The eruption posed severe threats to the local population: pahoehoe lava flooded populated areas, destroying part of Catania. Large volume eruptions are likely to occur again at Etna and local populations are at significant risk. However, very little is understood about the detail of magma volatile sources, the outgassing budget and the environmental impacts of the eruption.

Using the geochemistry of olivine-hosted melt inclusions, we show that the melts feeding Mount Etna are mixtures: the end members are sulfur and - LREE-enriched with sulfur and depleted. In order to explain the mixing array illustrated by the melt inclusions, the enriched end member must have been supersaturated with respect to both carbon and sulfur upon entry into shallow reservoir where mixing took place, suggesting that emplacement was rapid.

We develop a volatile degassing model for Etna using observations of gas emissions and compositions during present-day activity, combined with a thermodynamic model to describe volatile degassing during decompression. We incorporate the effects of kinetic control on exsolution of volatiles. We use the model to estimate the sulfur output of the 1669 eruption. We show that the heat flux provided by the extensive lava flow fields may have lofted the tropospheric SO_2 and aerosol plume into the lower stratosphere via penetrative convection (Kaminski et al. 2011). We evaluate the potential effects of this large effusive eruption on central Europe.

Volcanic risk perceptions of La Soufrière, St. Vincent

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The community and personal perceptions of volcanic hazard, risk, vulnerability and resilience of those living in close proximity to an active volcano is poorly understood because of a lack of empirical evidence on the subject. However, it is understood that this data is becoming increasingly important and is a growing field of research (Laksono, 1988; Barberi et al., 2008; Ricci et al., 2013). A volcanic risk perception study of the population exposed to the volcano La Soufrière, on St. Vincent, was carried out in June 2014 in order to explore current perceptions of the volcano.

A total of 100 questionnaires with 39 questions were distributed to the general population across the red (highest risk), orange, yellow and green (lowest risk) designated hazard zones, with a 100% return rate.

Results indicated there is a lack of hazard saliency towards the volcano and there are misperceptions of the most likely volcanic hazards. People are willing to learn more about the volcano, its dangers and how to prepare. However, the majority also transfer their responsibilities in personal resilience and vulnerability reduction to those in authority. The study also revealed a lack of confidence in self-preparedness, but moderate feelings of self-efficacy and moderate confidence in the government and scientists to provide information. People want to see more done to raise awareness of the volcano's dangers and guidance in individual preparedness measures.

There seems to be a generation gap in knowledge, whereby school children are well informed through school education, however, those that are 30 and over years of age have a lesser understanding of the volcano and its hazards. On the other hand, the experiences of those who remember the last eruption in 1979 determine their preparedness for future events.

From these results it is clear that hazard awareness education should be targeted to everyone in the community in order to reduce a generation gap in knowledge resulting from the history of volcanic activity, and to boost the community's overall resilience and preparedness in facing a future volcanic crisis on the island.

Magnetite Crystallisation as a Control of Mineral-Melt Partitioning of Divalent Cations

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There is increasing interest in the use of magnetite as a geochemical proxy to interpret ore forming processes in magmatic systems. However, in order to utilise magnetite as a petrogenetic indicator, a comprehensive understanding of how different factors affect magnetite chemistry is required. Magnetite/melt partitioning of a large range of elements has been investigated experimentally as a function of oxygen fugacity (fO2) and temperature (T) in an andesitic bulk-chemical composition. In this bulk system, at constant T, there are strong increases in the magnetite-melt partitioning of the divalent cations, Mg2+ and Mn2+, with increasing fO2 between 0 and 3 log units above the fayalite-magnetite-quartz (FMQ) buffer. At first sight, this could be viewed as related to changing redox condition; however, we suggest this is actually controlled by a coupling between magnetite crystallisation and melt structure.

At constant T, with increasing fO2 the proportion of magnetite and plagioclase increases, whereas the melt proportion decreases. The increased crystallisation of magnetite notably results in a decrease in FeOmelt, which causes a silica enrichment in the residual liquid. This leads to an increase in the degree of melt polymerisation at a given temperature. It has been suggested that more polymerised melts contain less potential sites onto which divalent cations can partition. Consequently, between FMQ < fO2 < FMQ + 3, increasing the fO2 drives an increase in the degree of melt polymerisation into a critical range where small increases in polymerisation result in large increases in the mineral-melt partitioning of divalent cations. In an andesitic bulk system, the enhanced crystallisation of magnetite with increasing fO2, and associated repercussions on melt structure, will have significant implications for mineral-melt partitioning, phase relations and the physical properties of melts, and should therefore be considered when studying natural andesitic systems.

Discriminating lava surfaces and vegetation within Nyamuragira using spectral mixture analysis

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In this study, Spectral Mixing analysis (SMA) is used to characterize lava flow fields from Nyamuragira volcano (DRC), where vegetation and lava flows are the two main land covers. We aim at estimating fractions of vegetation and lava using satellite remote sensing data. Datasets for fraction estimation include 30 m resolution Landsat Enhanced Thematic Mapper Plus (ETM+) and Earth-Observing 1 Advanced Land Imager (ALI). Pleiades 1A data of 2 m is used here as validation dataset. In addition to vegetation, three lava spectral endmembers are identified from feature spaces built up by components resulted from a minimum noise fraction transform. Fraction images show that these lava endmembers correspond to lava flow surfaces of different ages. It is suggested that lava of different ages is spectrally distinguishable due mainly to vegetation colonisation. Comparison of the mean endmember fraction for each lava flow shows that the majority of them have a dominant endmember (fraction > 0.5). Vegetation fractions for lava flows erupted from 1938 to 2002 increases with their ages. In Nyamuragira's tropical environment, vegetation starts to significantly colonize lava flows about 25 years after eruption, and occupy over 50% of the lava surfaces roughly 3~4 decades after eruption. Validation highlights the high correlation between the modelled vegetation fraction from the ALI image and vegetation mapped derived from the Pleiades dataset although the modelled vegetation fraction is generally slightly lower on the latter Spectral unmixing demonstrates its capability in characterizing lava flow surfaces and vegetation colonization, which is particularly useful for volcanoes not accessible in the field. This study also demonstrates the application of less used ALI and Pleiades images in volcanology.

Physical volcanology of the prehistoric Hekla 3 and Hekla 4 eruptions, Iceland.

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Hekla is the third most active volcano in Iceland, with 18 eruptions since the island was settled around 871 AD. Furthermore, having produced at least 9 of the 22 most prominent and widely-distributed ash marker layers found in European soils and lakes, it is the primary source of volcanic ash fall within the UK. The Hekla 3 (2879+/-34 14C BP) and Hekla 4 (3826+/-12 14C BP) are the two largest explosive eruptions of the Holocene. Both deposited at least 1 cm tephra over 80% of the surface of Iceland and are important teprochronological markers in Europe.

We present the first results from a modern re-evaluation of the eruptions. New isopach maps give freshly -fallen volumes of 11.2 and 13.3 km^3 for Hekla 3 and Hekla 4, respectively. This contrasts with previous estimates of 12 and 9 km^3. In general, Hekla 4 tephra is notable for being much finer-grained than that from Hekla 3. Hekla 3 can be divided into 3 phases, whose axes rotate from NE to NW as the eruption proceeds. Hekla 4 is divided into 4 phases. The first three phases were deposited to the N, NE and E of Hekla. The fourth, which represents a less powerful but long-lasting eruption of less-evolved 'gunmetal blue' tephra, is dispersed in all directions around the volcano.

Ongoing analysis will resolve isopachs, isopleths and plume heights for each phase of both eruptions, leading onto calculation of their total deposit grainsize distributions. Some of these results will be included here.

A re-examination of the Valentine et al (2014) model of diatreme evolution in the light of cyclic variations in explosivity in the Cova de Paul eruption, Santo Antao, Cape Verde

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Valentine et al (2014) have proposed a quasi-steady-state model for the growth of maar/diatreme volcanoes in phreatomagmatic explosive eruptions. They propose that most ejected material from the diatreme fill is sourced from numerous near-surface phreatomagmatic explosions, whilst deep explosions from within the fill rarely breach its surface to eject material out of the crater. They infer that these deeper explosions produce subsurface mixing in the fluidized crater fill and move wall rock clasts upwards from depth, to be ejected by subsequent near-surface explosions. Their model predicts that deposits from maar/diatreme type eruptions should be dominated by many thin beds from shallow explosions with rare thicker and coarser beds from the more energetic deeper explosions.

Whilst this may be true for many maar/diatremes, our study of deposits from the Cova de Paul Crater maar/diatreme on Santo Antao, Cape Verde islands, indicates that growth of the crater was in two distinct cycles that terminated in violent phreatomagmatic explosive phases. These were by far the most hazardous feature of the eruption, and deposited low-temperature phreatomagmatic ignimbrites that extend several kilometres from the vent and contain many deep-sourced, hydrothermally altered wall-rock clasts. Compositional and textural variations in the two cycles indicate that the diatreme fill evolved from a coarse and permeable fill that allowed gas escape, to a much finer grained, poorly sorted, and less permeable fill. As a result of the reduced permeability, pore fluid pressures are inferred to have built up to produce the two violent explosive phases. We infer that the first of these largely emptied the crater, so that the second cycle began with emplacement of breccia beds rich in scoriaceous clasts of juvenile magma from the feeder intrusion beneath the crater. We conclude that there is a need for non-steady-state models of maar/diatreme eruptions that include the cyclical effects of progressive grain size reduction in the fluidized vent fill upon the violence of the eruptions.

Valentine, G. A., Graettinger, A. H. and Sonder, I. (2014). "Explosion depths for phreatomagmatic eruptions." Geophysical Research Letters. 41(9): 3045-3051

The mixing, evolution and eruption history of a disaggregated magma reservoir

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Sampling material from a range of depths within an actively-forming magma chamber beneath a major volcano is a dream scenario for volcanologists. This has been made possible by numerous major Plinian eruptions on Tenerife, which ejected melt-rich nodules that were entrained into the pyroclastic deposits flanking the Las Canãdas volcano. Individual eruptions expelled a suite of “mushy” nodules that span the entire range of proto-cumulate material: wehrlites and lamproites, through pyroxenites and hornblende gabbros, to monzonites and nepheline syenites.

Each suite of nodules represents a catastrophic disaggregation of a partially molten magma reservoir during a caldera-forming eruption. As quenched magma is present in nodules originating from all levels of the stratified reservoir, we are able to examine the compositional diversity of melt in the chamber at the moment of eruption. Nodules were effectively “frozen” on eruption and have escaped post-crystallisation hydrothermal alteration.

Melt within the nodules is tephrite to phono-tephrite, but has trace element ratios covering the fractionation range of Tenerifian magmatism. High-resolution and ultra-high resolution Pb isotopes indicate that the cumulus phases and the entrained melt are isotopically different, but lie along a well-defined mixing trend between two mantle-derived end members. This cumulate-melt Pb isotope trend is distinct from juvenile phonolitic material and accidental syenite blocks within the host pyroclastic deposit.

These characteristics indicate that eruption was preceded by permeation of an isotopically distinct magma throughout the crystallising mush. A separate phonolitic magma body then instigated explosive activity, potentially by conjoining with the mush reservoir. The result was the disaggregation and excavation of the complete cumulate stratigraphy of the tephrite/phono-tephrite reservoir.

The rheology of three-phase basaltic magma

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The transport of magma is controlled by its rheology which, in turn, is a function of its crystal and bubble content. We develop the first empirically-validated model for the rheology of a three-phase magma (i.e. one containing both bubbles and crystals). The model is valid at low bubble capillary number (where bubble deformation is small) which is typical of basaltic magma. We adopt an 'effective-medium' approach in which the bubbly melt is treated as a continuous medium which suspends the crystals. The resulting three-phase model combines separate two-phase models for bubble suspension rheology and crystal suspension rheology, which are taken from the literature. The model is validated against new analogue experimental data for three-phase suspensions of bubbles and spherical particles, collected in the low bubble capillary number regime. Good agreement is found across the experimental range of particle volume fraction ($0 \leq \Phi p \leq 0.5$) and bubble volume fraction ($0 \leq \Phi b \leq 0.3$). Consistent with model predictions, experimental results demonstrate that, at low capillarity, bubble growth in a crystal-poor magma increases its viscosity, whilst bubble growth in a crystal-rich magma decreases its viscosity.

The validity range of the model makes it particularly applicable to the transport of magma in the sub-volcanic plumbing system. The model is trivially extended to account for variations in crystal shape, and for the high capillarity regime; these extended models await experimental validation.

Petrographic and Geochemical Investigation of Andesitic Arc Volcanism: Mount Kerinci, Sunda Arc, Indonesia

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Knowledge of the chain of dominantly andesitic volcanoes, which span the Sumatran portion of the Sunda Arc is extremely limited. Previous studies have focused on Toba and Krakatau, although over 13 further volcanic edifices are known. Recent explosive eruptions in Sumatra such as that of Mt. Sinabung, 2014, have highlighted the potential hazard that these volcanoes pose to the local and regional communities. Mount Kerinci - located approximately mid-way between Toba in the North and Krakatau in the south - is one of the most active of the volcanoes in this region, yet little is known about the petrogenesis of the magma by which it is fed.

Along arc variations are observed in the major, minor and trace elements of whole rock analyses. However, bulk rock approaches produce an average chemical composition for a sample, potentially masking important chemical signatures. Examination of whole rock chemistry indicates its location may be key to unravelling the petrogenesis of the arc as significant chemical changes occur between Kerinci and Kaba, 250 km to the south.

Kerinci samples are dominantly porphyritic with large crystals of plagioclase, pyroxene and Fe-Ti oxides, rare olivine crystals are observed. Plagioclase and pyroxene crystals are chemically zoned and host melt inclusions. Multiple plagioclase populations are observed. A combination of in-situ micro-analysis techniques will be used to characterise the chemical composition of melt inclusions and crystals in considerably more detail. These data can be used along with extant geothermobarometric models to help determine the magma source, storage conditions and composition of the evolving melt. Integration of the findings from this study with existing data for the volcanic chain will enable along-arc variations in magmatic processes in Sumatra to be assessed more thoroughly, providing fundamental insights into the evolution of not only Kerinci, but magma genesis in Sumatra in general.

Crystal-melt mixtures and their relevance to interpret geochemical data in magmatic systems

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There is an increasing awareness that large mineral phases in porphyritic rocks are commonly not in equilibrium with their host glass/groundmass. Large crystals traditionally referred to as phenocrysts, are shown in many cases to be antecrysts recycled from earlier stages of the magmatic system, reflecting open-system magmatic histories that involve events of magma mixing and crystal recycling.

In this contribution we explore the influence of recycled phases on magmatic bulk rock compositions. We have carried out detailed petrographical and geochemical studies on a variaty of magmatic environments: 1) basaltic lava flows and dykes from the Azores archipelago; 2) subvolcanic lamprophyre sills from northeast Spain; 3) mafic-felsic composite dykes from the Pyrenees, intruded in a plutonic environment.

In the studied mafic systems (1-volcanic and 2-subvolcanic), samples with high volume fractions of mafic antecrysts (mainly clinopyroxene and olivine) have highest concentrations in MgO and compatible elements and lowest concentrations in incompatible elements. These samples are not closest to the parental melt composition, but represent mixtures of partly evolved melts and mafic antecrysts. Similarly, linear geochemical trends represent antecryst-accummulation trends towards more apparently-primitive compositions, rather than magma fractionation trends.

In the studied mixing systems (3-plutonic), samples with high volume fractions of phases inherited from the original end-members have compositions that deviate from the theoretical hybrid line. These samples are enriched in elements with high concentrations in the inherited phases relative to ideal hybrid compositions.

According to our results, the interpretation of geochemical trends needs to be revisited to account for the effect of recycled mineral phases. The interpretation of primary petrogenetic processes needs to be led by the understanding of the petrography of the samples and their crystal cargo.

Dehydration and rehydration of silicate melts

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Magma loses most of its water during depressurization and bubble growth. The resultant volume/pressure increase in the volcanic system leads, in extreme instances, to fracturing and fragmentation unless pathways for gradual degassing open up. Therefore the study of dehydration and permeability within the volcanic conduit is essential to the understanding of eruptive behaviour at volcanoes. The solubility of water in silicate systems increases if the melt cools, permitting the diffusive motion from hydrous vapour into melt. Recent studies have shown that diffusion of water is indeed not unidirectional and rehydration is common once water-saturated silicate melts cool and become under-saturated. Water drastically reduces the viscosity and thus, the glass transition temperature of silicate melts. We present a series of experiments that highlight important aspects of dehydration and rehydration in volcanic processes: 1) dehydration during bubble growth; 2) rehydration during cooling of bubbly magma; 3) formation of dehydrated skins at foam boundaries (in anhydrous atmospheres); 4) high-temperature hydration of degassed glasses/melts and shift of their glass transition temperature; and 5) shortening of sintering timescales due to melt hydration. Volcanic materials at the Earth's surface frequently undergo a complex degassing history and our data show that both dehydration and rehydration have to be considered to reconstruct degassing pathways in a volcanic system. The (de)hydration patterns observed in experimentally produced glasses provide first-order proxies for degassing processes within the volcanic conduit which control the eruptive behaviour and emplacement processes of deposits.

Visualising volcanic risk

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Identifying and visualising risk is critical for improving disaster risk reduction and communicating it to different end users. To this end we initially adapted and applied ImpactOnDemand®, a commercial software platform developed by Aon Benfield, to address the needs of the humanitarian and development sectors. We have also applied the same methodology in more commonly used Geographical Information System (GIS) software to enable different stakeholders to create their own visualisations. This methodology assesses the risk of communities to volcanic hazards by identifying the individual population centres that are exposed to a range of hazard footprints. Volcanic hazards may be represented by hazard maps of past events or satellite images of ongoing activity. Populations are drawn from census data, but these are often of variable quality and resolution and may compromise the accuracy of the estimation of risk.

To aid decision makers in response to volcanic disasters, or for long-term planning, we have combined the visualisations with a social vulnerability index, which can be used to prioritise locations for relief efforts. This index is created by combining census data with community-based participatory vulnerability and capacity assessments and thus enables the communities themselves to define vulnerability.

The creation of these visualisations for communities threatened by volcanic hazards shows that census and hazard datasets can be used to communicate risk quickly and effectively and at low cost. The methodology allows information on risk to be presented in bespoke formats to different stakeholders and highlights the mutual benefit of collaboration between academic research, the commercial sector and humanitarian and development organisations. Providing a methodology that can be used within a range of software is also key in enabling stakeholders to create their own visualisations and tailoring them for the requirements of specific organisations.

Overview of Geophysical Constraints on the 2014 Bárðarbunga - Holuhraun Eruption, Iceland

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We present an overview of geophysical data from the propagating dyke intrusion from the subglacial Bárðarbunga (Bb) central volcano, which 12 days later resulted in effusive magmatism at the Holuhraun lava field in northern Iceland some 45 km away. The Bb volcano is located above the centre of the Iceland hot spot within the Eastern Rift Zone, beneath the Vatnajökull ice cap in central Iceland.

Local magmatic intrusions can be tracked through the swarms of micro-seismicity accompanying dyke propagation, arising from crustal failure and fracture of both the country rock and solidifying magma. Fortuitously, Cambridge University had a large array of 55 broad-band seismometers deployed around Vatnajökull and the Askja volcanic system to the north at the onset of seismic unrest. A team in the field was able to deploy an extra 15 seismometers both on the Vatnajökull ice cap above the propagating dyke and on the Holuhraun lava field near the tip of the dyke. The last deployment was completed just 2 hours before the eruption started close to that position. We subsequently had to rescue two of the seismometers from the advancing lava flows, so close was the deployment. This dense seismic array gives unprecedented coverage of the location of seismicity caused by the magma movement. GPS and InSAR measurements provide control on the crustal deformation caused by the intrusion.

By the end of October 2014 approximately 1 km^3 of lava had been erupted over an area of > 65 km^2, while the Bardabunga caldera had subsided over 42 m.

Micro kinematic indicators in the Green Tuff Ignimbrite: can they tell us about caldera collapse?

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The Green Tuff ignimbrite (c.45 ka) formed as a result of a catastrophic but short-lived pyroclastic density current which engulfed the island of Pantelleria, Italy. The eruption is reported to have been a caldera-forming eruption, though the Green Tuff Formation lacks significant lithic breccias. Furthermore, the Green Tuff ignimbrite drapes some of the exposed caldera scarps attributed to this eruption. There are two different calderas which have been proposed to have formed as a result of the Green Tuff eruption: (1) The Monastero caldera1 which has buried, unidentified northern scarps and (2) the Cinque Denti caldera2 which shares its northern scarps with the older La Vecchia caldera.

The Green Tuff ignimbrite is welded, rheomorphic and contains a well-developed welding fabric, flow folds, and elongation lineation. The emplacement of the ignimbrite has been reconstructed using detailed mapping of the zoned deposit sheet3. An oblique fabric (e.g. imbricated fiamme) gives a sense of the current direction. Some features, such as asymmetric folds and rotated phenocrysts, can also be used as kinematic indicators, and may have formed either by the over-riding current exerting shear upon the aggrading deposit, or as the hot, ductile deposit slumped downslope.

Here, we investigate the use of micro-kinematic indicators to help inform when the caldera scarps draped by the Green Tuff ignimbrite were formed. Analysis of thin sections from draping sections on two caldera scarps reveals both an upslope and downslope sense of movement. The upslope sense of movement must record shear exerted upon the deposit by the over-riding current and therefore is interpreted to mean that the current flowed up an existing caldera scarp. The downslope sense of movement then records rheomorphic slumping of the deposit. Therefore we show that these scarps do not likely form part of the Green Tuff caldera. They were more likely to have been formed during a previous eruption.

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Magma ascent, damage zones and the location of volcanic vents

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Understanding the controls on volcanic vent formation is important for hazard assessments, which rely on accurate constraints on the expected location and eruptive style of future vents. Magma travels through the crust as a network of fractures that are either discordant to stratigraphic layering (dykes) or concordant (sills). The propagation dynamics of these magma-driven fractures and how they reach the surface to erupt will be largely controlled by the properties and response of the host rock to the intrusion of magma. This project aims to constrain the controls of magma ascent in the crust using a field, laboratory and analogue modelling approach.

The tip region of magmatic intrusions is thought to comprise a series of fractures that propagate ahead of the ascending magma forming a “damage zone”. The extent and orientation of these fractures and their role in controlling the dynamics of magma intrusion is not well constrained. As dykes approach the surface they tend to break into a series of en-echelon segments; the host-rock at the tip regions and between individual dyke segments becomes increasingly fractured and brecciated. This weakening of the host rock has been shown to have important implications for controlling the geometry of magmatic intrusions as they solidify. However, questions still remain as to the role damage zones play in controlling the dynamics of intrusion. Highly fractured and weak regions of host-rock provide weak channels through which magmatic gases can permeate, cause alteration and further weaken the host-rock. This has been suggested to be an important preconditioning mechanism in the focusing of magma ascent and ultimately for the localisation of volcanic vents.

Samples collected from a strike slip fault within the Atacama Fault System in Northern Chile, will be used to study the formation of host-rock damage zones without the added complexity of intruded magma. Detailed microscopy will be used to map the fracture density along the length of the fault. This work will be complemented by fieldwork carried out on the Colorado Plateau, USA, which will investigate the nature of host-rock damage zone formation at the dyke tip-region during magma intrusion. Detailed observations and measurements of the extent and nature of interaction between magma and host-rock will be documented in an exceptionally well-exposed shallow volcanic plumbing system.

Dyke propagation mechanisms and the immediate pre- and syn-eruptive seismicity of the 2014 Holuhraun fissure eruption, Iceland.

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We present data from our dense seismic array which captured the micro-seismicity associated with the propagating dyke intrusion from the subglacial Bárðarbunga volcano, during the 24 hours preceding and following the onset of effusive magmatism at the Holuhraun lava field in central Iceland. The Bárðarbunga volcano is located at the centre of the Iceland hot spot within the Eastern Rift Zone, beneath the Vatnajökull ice cap.

Local magmatic intrusions can be tracked through the swarms of micro-seismicity accompanying dyke propagation, arising from crustal failure and fracture of both the country rock and solidifying magma plugs. August 2014 saw the beginning of a period of unrest of Bárðarbunga volcano during which a dyke propagated first out of the caldera and then towards the northeast. It continued north of the Dyngjujökull outlet glacier and resulted in a fissure eruption in the old Holuhraun lava field on 29 August 2014. At time of writing it has erupted ~1km^3 of lava covering over 64km^2, making this the largest eruption in Iceland for 150 years.

Our extensive, local seismic network covers the numerous volcanic systems beneath the Vatnajökull glacier and their transecting fissure swarms (rifting units) along the divergent plate boundary. This work focusses on the immediate pre- and syn-eruptive seismicity of the 2014 Holuhraun fissure eruption. Rock fracture mechanisms are determined from fault plane solutions of these seismic events, produced as the magma migrated from beneath the surface to the eruption site.

Shallow crustal mechanics of Soufrière Hills Volcano from volumetric strain data

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Volumetric strain data from the July 29th 2008 Vulcanian explosion of the Soufrière Hills Volcano provide an excellent opportunity to explore the mechanical properties of the shallow crust beneath Montserrat. We find that simple models neglecting topography and mechanical heterogeneities may substantially underestimate conduit pressure drops. We use Finite Element Analysis to implement sub-domains within our model representing i) a mechanically compliant rock halo around the conduit, and ii) a mechanically compliant edifice and shallow crust. These complexities allow us to obtain geologically and mechanically acceptable pressure changes which fit the volumetric strain signal. Our results indicate much larger conduit dimensions than have been suggested previously i.e. a radius on the order of several 10s of meters and a length of 1500m. In order to fit the syn-eruptive volumetric strain data for a conduit pressure drop of <10 MPa, the conduit needs to be surrounded by a tens to hundreds of meters wide halo of mechanically compliant rock material with a Young's modulus of between 0.5 to 1 GPa. Our best-fit models find that the conduit contracted by a maximum of 0.34m during the eruption with a corresponding volume loss of ~0.16 Mm3, implying only partial emptying of the conduit upon the explosion. Invoking mechanical complexities is a necessity to obtain mechanically acceptable conduit pressure drops to fit the observed volumetric strain signals.

Recycling earlier-fractionated minerals through magma recharge: evidence from Mt. Lamington (Papua New Guinea)

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Mt. Lamington is an intermediate composite volcano in Papua New Guinea, sitting on the Papuan Ultramafic Belt (PUB, ophiolite). The 1951 eruption produced andesitic dome lavas with numerous mafic enclaves. We carried out petrological, mineralogical and geochemical studies on these eruption products to identify processes that shaped Mt. Lamington magmas. The mineralogy of enclaves is dominated by amphibole and plagioclase, similar to andesitic lava hosts. Textures of the enclaves vary from fine-grained diktytaxitic to coarser-grained plutonic. We interpret this variation to result from variable cooling rates in enclave-forming magma body when it invades the overlying andesite. One particular enclave is basaltic but contains up to 69% amphibole and 22% plagioclase. This mineral assemblage is not consistent with recent equilibrium crystallization experiments carried out on natural basalt. Therefore we infer that this enclave has accumulated amphibole and does not represent a magmatic liquid. The diktytaxitic enclaves contain various proportions of host-derived amph+plag antecrysts, and xenocrysts of ol+sp±cpx±amph with disequilibrium textures, indicating interaction with host lava and assimilating foreign materials. A previous study argued that the olivine xenocrysts with chrome spinel inclusions are derived from PUB, and this resulted in contamination of PUB to Mt. Lamington magmas. We demonstrate this is highly unlikely on the basis of morphological and compositional discrepancies between PUB ol+sp, sampled in nodules, and the xenocrysts. Mass balance indicates that whole-rock Ni contents of enclaves and andesitic hosts can be explained by olivine incorporation and does not require any PUB involvement. The xenocrysts are considered to represent crystal mush fractionated from precursor(s) of andesitic and/or pre-1951 shoshonitic lavas. Their presence in enclaves represents recycling earlier-fractionated components through magma recharge; this is an important process in shaping arc magmas which might be underestimated previously.

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