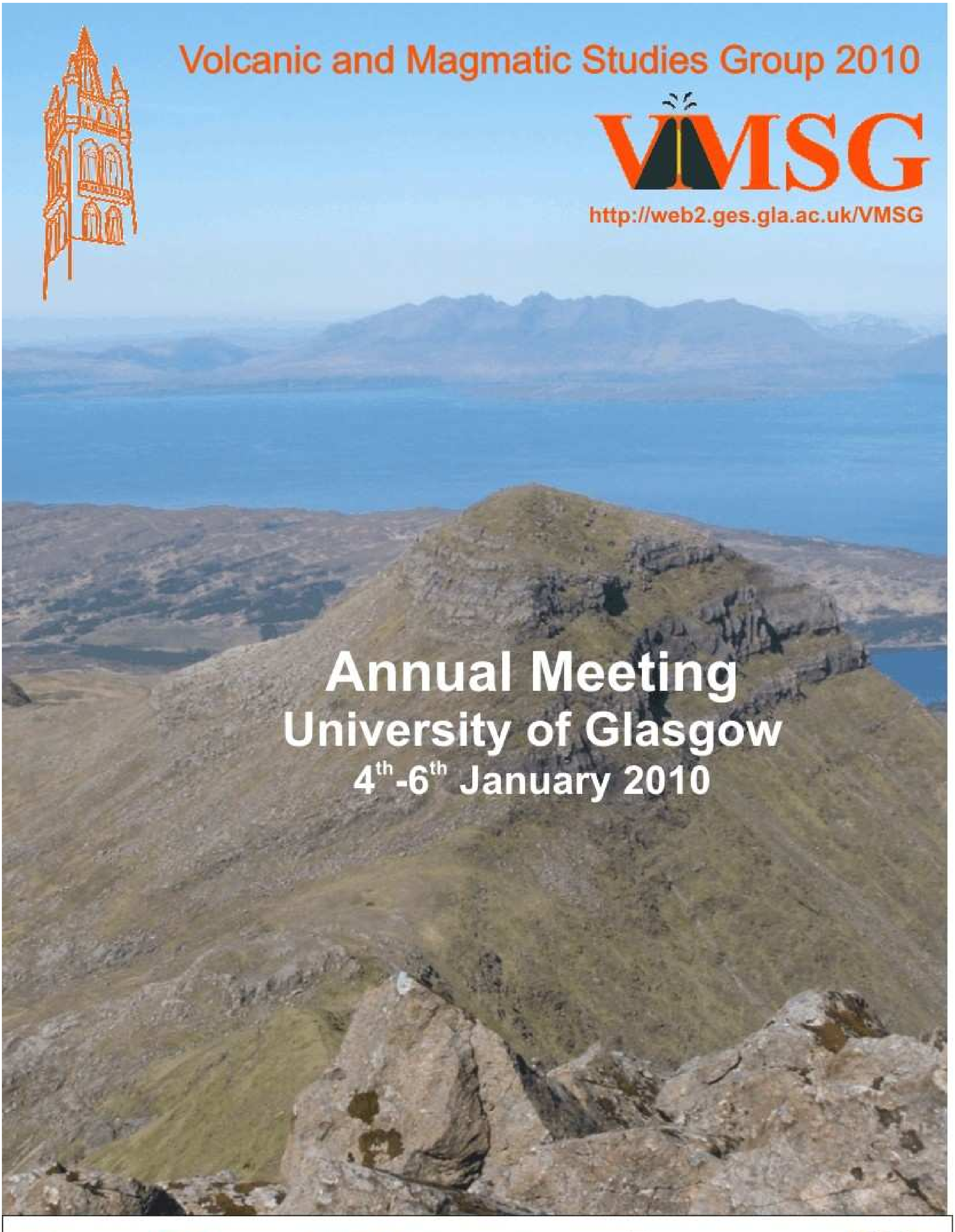
Volcanic and Magmatic Studies Group 2010

VMSG

http://web2.ges.gla.ac.uk/VMSG



Annual Meeting
University of Glasgow
4th-6th January 2010

ThermoFisher SCIENTIFIC
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University of Glasgow

The Geological Society

Welcome to VMSG2010, and welcome to Glasgow

The University of Glasgow was founded in 1451 and has been teaching Geology for over 100 years. We are the fourth oldest, and one of the largest universities in the UK, with ~ 15000 undergraduates. Over 1000 undergraduates are currently studying in the Department of Geographical & Earth Sciences, and our students report 100% satisfaction with the Earth Science degree.

The entire conference is being held under one roof, at the Glasgow University Union on University Avenue, in the West End of Glasgow. The Union was founded in 1885, and was the scene of Scotland's last ever duel in 1899, when swords were drawn and blood was spilled over the election battle of the University Rector. Fifty years later a group of nationalistic students "brought back" the Stone of Destiny from Westminster Abbey, and union members threw out several stone-shaped objects in an attempt to deceive the police. True to this history, politics have always played an integral part of the GUU and past presidents include Donald Dewar, Charles Kennedy and Menzies Campbell.

VMSG2010

We have 48 oral and over 50 poster presentations being given over the course of the meeting, and we would like to thank all of the presenters. There is a huge breadth in the areas of volcanic and magmatic research being presented at this meeting, as well as a full social programme, and we hope that everyone enjoys it.

In response to feedback from last years conference we have, once again, extended the times scheduled for the poster sessions. We have also squeezed in as many oral presentations as possible into the two days of talks. The conference therefore officially begins a little earlier than last year, with the first poster session starting at 4pm on the 4th Jan. We all know how much work goes into a poster and hope that everyone will attend. The registration desk will be open from 3pm.

Oral presentations will take place in the Debates Chamber, while the poster sessions and all refreshments will be located across the landing in the Reading Room. The Dining Room will be used for the conference dinner and the ceilidh. The whisky tasting will be held in the Debates Chamber immediately after dinner, while the staff clear the dinner tables and the band set up.

A ceilidh (pronounced "kay-lee", emphasis on 1st syllable) is many things. Derived from the Gaelic word meaning a visit, it is now used to describe an evening of informal Scottish traditional dancing and live music. "Ceilidhing" is fun, fast and informal, and requires absolutely no previous experience. The main thing is to have a go and have fun!

The GUU also contains a bar (in the basement), a shop (ground floor level), and a cash machine (basement).

VMSG2010 Organising Committee

Cover photograph: D. Brown. Hallival from Askival, Isle of Rum, Scotland. Taken on the VMSG Golden Rum Trip May 2007

General Timetable

Monday 4th January 2010

15.00	Registration Opens
16.00	Poster Session
17.30	Ice-breaker Reception & Poster Session

Tueday 5th January 2010

08.15	Registration & Coffee
08.45	Session 1 - Isotopes as Records of Volcanic & Magmatic Processes
10.30	Coffee & Posters
11.00	Session 2 - Isotopes as Records of Volcanic & Magmatic Processes
12.45	VMSG AGM
13.00	Lunch & Posters
14.00	Session 3 - Magma Transport versus Magma Storage
15.45	Coffee & Posters
16.15	Session 4 - Magma Transport versus Magma Storage
18.00	Wine Reception & Poster Session
19.30	Conference Dinner, Whisky Tasting & Ceilidh

Wednesday 6th January 2010

08.15	Coffee
08.45	Session 1 - Geochronology of Igneous Processes
10.30	Coffee & Posters
11.00	Session 2 - Research in Progress
13.00	Lunch & Posters
14.00	Session 3 - Transport, Dispersion & Deposition During Eruptions
15.15	Coffee & Posters
15.45	Session 4 - Transport, Dispersion & Deposition During Eruptions
16.45	Closing Remarks
17.15	Public Lecture by Jake Lowenstern, Scientist in Charge of Yellowstone National Park

Thanks

The organisers of VMSG2010 would like to thank Abigail Adams, Robert Gibb, Darren Mark, Jennifer Smith, Dawn Stewart, Marie Turnbull, John Ward, Ewan Webster, and the staff of the GUU for their assistance in organising and running the meeting. We thank ThermoFisher Scientific for their sponsorship of the VMSG Award and support of the 2010 meeting. We would also like to thank Tunnock's, who kindly supplied the chocolate.

Scientific Programme

08.15 am **Coffee & Registration**
08.45 am **Opening Remarks**

Time	*Title* **Presenting Author - * denotes student**	Page No.
	Isotopes as Records of Volcanic and Magmatic Processes	
Chair: Louise Thomas		
09.00	*Opening Soddy's Box: the Scottish roots of isotope geology* **Rob Ellam**	24
09.30	*Constraining magma sources and processes along the Lesser Antilles Arc* **Jon Davidson**	25
09.45	*Geochemistry and geochronology of Tobago Island: a preliminary re-appraisal* **Iain Neill***	26
10.00	*Earthquake-triggered crustal CO_2 liberation at Merapi volcano, Central Java, Indonesia* **Valentin Troll**	27
10.15	*Distinguishing between source and upper crustal volatile contamination along the Java-Bali segment of the Sunda Arc, Indonesia* **Lara Blythe***	28
10.30	**Coffee & Posters**	
Chair: Jon Davidson		
11.00	*Boron isotopes in feldspar: tracing magmatic processes on Gran Canaria* **Frances Deegan***	29
11.15	*Crustal contamination and anatexis on the Bolivian Altiplano* **Claire Mcleod***	30
11.30	*The nature and origin of the ~1.88 Ga Circum-Superior Large Igneous Province* **Matthew Minifie***	31
11.45	*Long-lived layered lithosphere? Fresh data from the Slave Craton – N.W.T., Canada* **Kathy Mather***	32
12.00	*The Öræfajökull Signature* **Christina Manning***	33
12.15	*Rhyolite volcanism at Öræfajökull volcano, Iceland – field relations, geochemistry & isotope geochronology* **Angela Walker***	34
12.30	*New insights into granitic magma complexity: Nd and Sr isotopic zonation in apatite in 300 Ma granites from southeast USA* **Scott Samson**	35
12.45	**AGM**	
13.00	**Lunch & Posters**	

Magma Transport versus Magma Storage - VMSG Award Session

Chair: Steve Sparks

14.00	*Thermal filtering of primary basaltic magmas through volcanic systems* **VMSG Award Lecture - Steve Blake**	36
14.30	*Melt segregation in Deep Crustal Hot Zones and its impact on timescales and composition* **James Solano***	37
14.45	*From Arthur Holmes to Harry Hess: how melting of the mantle controls amagmatic crustal accretion* **Samantha Unsworth***	38
15.00	*Antarctic lithospheric architecture and evolution: direct constraints from mantle xenoliths* **Lydia Gibson***	39
15.15	*Mixing of mantle melts recorded in Icelandic phenocrysts: the significance of clinopyroxene stability in depleted compositions* **Ben Winpenny***	40
15.30	*Channelised melt transport and the extraction of mantle properties from basalt compositions* **John Maclennan**	41
15.45	**Coffee & Posters**	

Chair: John Maclennan

16.15	*Magma sources and melt evolution during the 1875 volcanotectonic episode at Askja, north Iceland* **Margaret Hartley***	42
16.30	*Investigating magma plumbing beneath Anak Krakatau volcano, Indonesia: evidence for multiple magma storage regions* **Borje Dahren***	43
16.45	*Compositional variance in products of the 1998 and 2004 eruptions at the Grímsvötn central volcano, Iceland* **Tanya Jude-Eton***	44
17.00	*Emplacement and geochemical evolution of the Pilanesberg Complex, South Africa* **Grant Cawthorn**	45
17.15	*Large- and small-scale igneous layering in the Ben Buie intrusion, Mull* **John Faithfull**	46
17.30	*Physical behaviour of steeply dipping crystal mush* **Madeleine Humphreys**	47

Research in Progress

17.45	*Sulphide saturation and degassing in Reunion magmas* **Sarah Collins***	48
18.00	**Wine Reception & Posters**	
19.30	**Conference Dinner, Whisky Tasting & Ceilidh**	

Geochronology of Igneous Processes

Chair: Darren Mark & Dan Condon

08.45	*Reflections on half a century of accessory mineral U-Th-Pb geochronology* **Randy Parrish**	49
09.00	*On the cause of the Paleocene-Eocene hyperthermals (PETM and ETM2): New evidence for a tectonic-magmatic driver* **Dan Condon**	50
09.15	*Vulcano, Italy: the geochemistry of effusive and explosive activity in space and time* **Anna Todman***	51
09.30	*Dating Holocene basaltic lavas using cosmogenic isotopes* **Fin Stuart**	52
09.45	*Geomorphic evolution of composite complexes in a volcanic arc setting since 1 Ma: examples of the Axial Chain and the Grande Decouverte-Soufriere massifs (Guadeloupe, FWI), volume and extrusion rate estimations* **Agnes Samper***	53
10.00	*Eruptive history of western and central Aeolian Islands volcanoes (South Tyrrhenian sea): insights from K/Ar dating* **Erell Leocat***	54
10.15	*High-precision multi-collector $^{40}Ar/^{39}Ar$ dating of volcanic rocks* **Darren Mark**	55
10.30	**Coffee & Posters**	

Research in Progress

Chair: Valentin Troll

11.00	*Cone sheet emplacement in sub-volcanic systems: a case study from Ardnamurchan* **Craig Magee***	56
11.15	*Neogene plume-related magmatism of the Al Haruj volcanic field, central Libya* **Sarah Nixon***	57
11.30	*Volatiles in gases and melt inclusions erupted during the 2008-9 Halema`uma`u eruption of Kīlauea volcano, Hawai`i* **Isobel Sides***	58
11.45	*Continental-marine tephra correlations: linking the distal tephras of the Marsili Basin to the proximal source deposits of the Aeolian Islands, Southern Italy* **Paul Albert***	59
12.00	*Application of trace element chemistry to Holocene tephrochronology in the North Atlantic region* **Rhian Meara***	60
12.15	*Steep sided cones and their rapid collapse on the Mid-Atlantic Ridge, 45ºN* **Isobel Yeo***	61
12.30	*Widespread transport of pyroclastic density currents from a Skye volcano: correlation of ignimbrite lithofacies and the evolution of the Palaeogene Skye Central Complex* **Simon Drake***	62
12.45	*Can changes in caldera structure affect eruptive behaviour? An investigation in central México* **Chris Willcox***	63
13.00	**Lunch & Posters**	

Transport, Dispersion & Deposition During Eruptions

Chair: Richard Brown

14.00	*Granular segregation, levee formation and mobility of pyroclastic currents: new insights from sums, experiments and ignimbrites* **Peter Kokelaar**	64
14.30	*Ignimbrite reworking: experimental and field observations of remobilisation, shear instabilities and recumbent flames* **Pete Rowley***	65
14.45	*Modelling lahars at Galeras volcano, Colombia: a method for risk assessment* **Samantha Engwell***	66
15.00	*Infrasound generated by Strombolian eruptions – insights from laboratory experiments* **Amy Dabrowa***	67
15.15	**Coffee & Posters**	

Chair: Simon Passey

15.45	*The evolution of volcanic eruption columns* **Matthew Scase**	68
16.00	*Understanding the cessation of lava flows using remote time-lapse camera data* **Jane Applegarth**	69
16.15	*Graben-related volcanism and associated sedimentation, landscape evolution and palaeo-ecology during the early development of the Palaeogene Mull Lava Field* **Brian Bell**	70
16.30	*A Palaeogene, pre-flood basalt supervolcano in Co. Antrim? Evidence from the 'Clay with Flints.'* **Ian Meighan**	71
16.45	**Closing Remarks – Dave Pyle**	
17.15	*Magma intrusion, degassing, and hydrothermal setting of the Yellowstone Caldera* **Jake Lowenstern** Scientist-in-Charge of Yellowstone Volcano Observatory	72

The GUU will be open to collect/remove posters after the Open Lecture, and for social post-conference drinks and discussion.

Poster Presentations

(alphabetical order, * student presentation)

Contents

General Information

Underground

The underground links the West End to the City Centre (**Map B**). The closest stops to the conference venue are Kelvinbridge and Hillhead (both about 5 mins walk). A single journey ticket costs £1.20, and a two journey ticket costs £2.40

Taxis

Black cab taxi ranks can be found on Queen Margaret Drive just opposite Oran Mor (13, **Map E**), and outside Hillhead underground station (18, **Map E**). The Black Cab hire number is 0141 429 7070, but they are generally easy to flag down in the West End.

Taking a private hire cab to and from the airport will cost significantly less than a black cab. Two local West End companies are:

West End cabs: 0141 954 7070
Hyndland Cabs: 0141 954 2000

Or ask at your hotel

Cash Machines

Branches of all the major UK banks can be found on Byres Road and/or Great Western Road and the majority have 24 hour access cash machines outside. Around the GUU there are fewer cash points, but there is one in the basement of the building. The cash points closest to the conference hotels are shown on **Map D**.

Wireless internet

The GUU has a wireless internet service that all delegates may use. To get access you need to go to the security desk inside the front door and ask for a log in code. These are single use log in codes, so you will need a new one each time you log out.

Local amenities

The GUU is centrally situated in the West End of `Glasgow, and there are a large number of bars, pubs, restaurants, coffee shops and shops in the local area. Good public transport links to the city centre also make for easy access to the main shopping areas, and other bars, clubs, restaurants, museums and galleries.

The following pages contan a selection of maps for the local area. The recommended conference Hotels are shown on **Map D.** Restaurants and Bars etc. are shown on **Map E.**

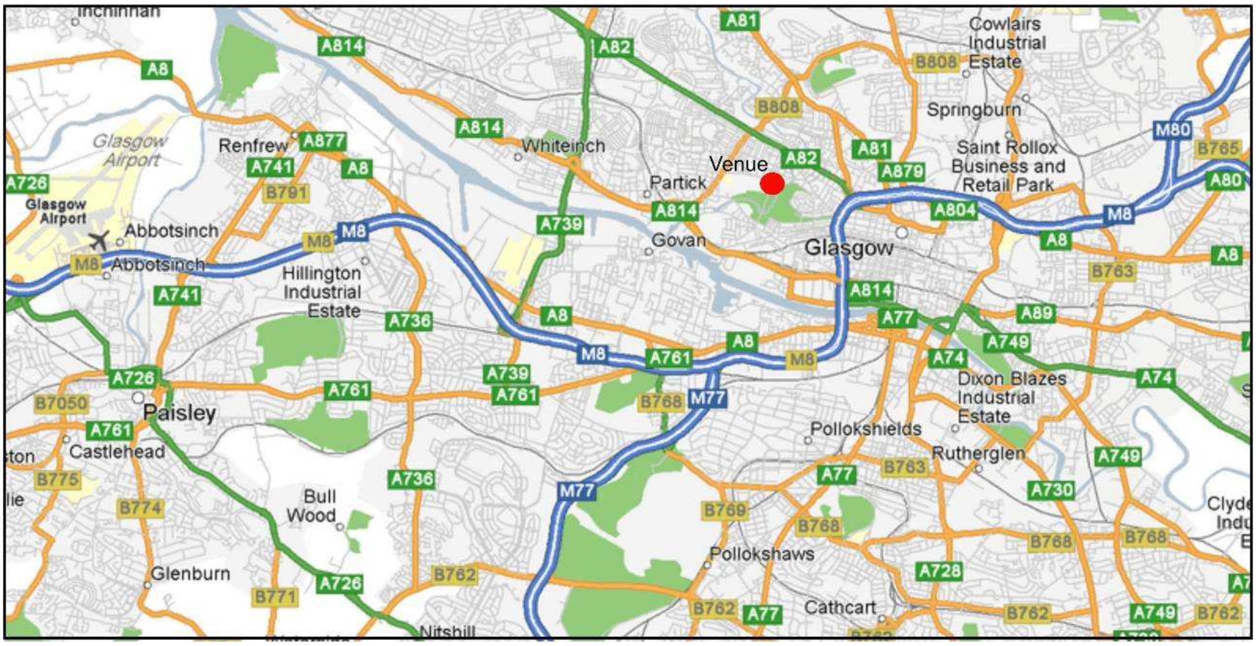
Local Attractions

The West End has a number of attractions that are all a short walk from the conference venue. The Hunterian Museum and Art Gallery, and the newly re-furbished Kelvingrove Museum are both worth a visit (**Map D**). The Hunterian Art Gallery also contains the The Mackintosh House, one of the many examples of the work of Rennie Mackintosh that can be seen around the city.

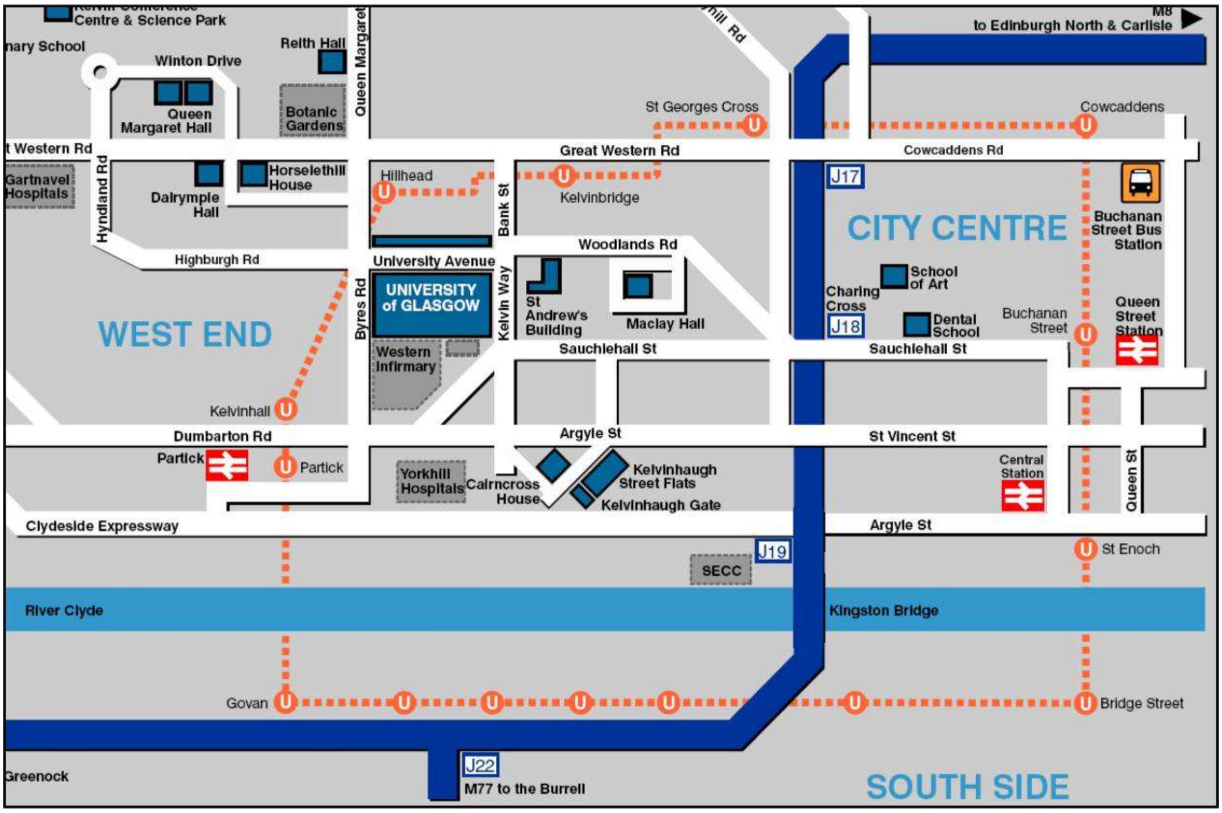
The main Univerity buildings, a short walk up the hill from the conference venue, are also worth investigating, and there is a stunning view of the city from the South Front (**Map C**).

Maps

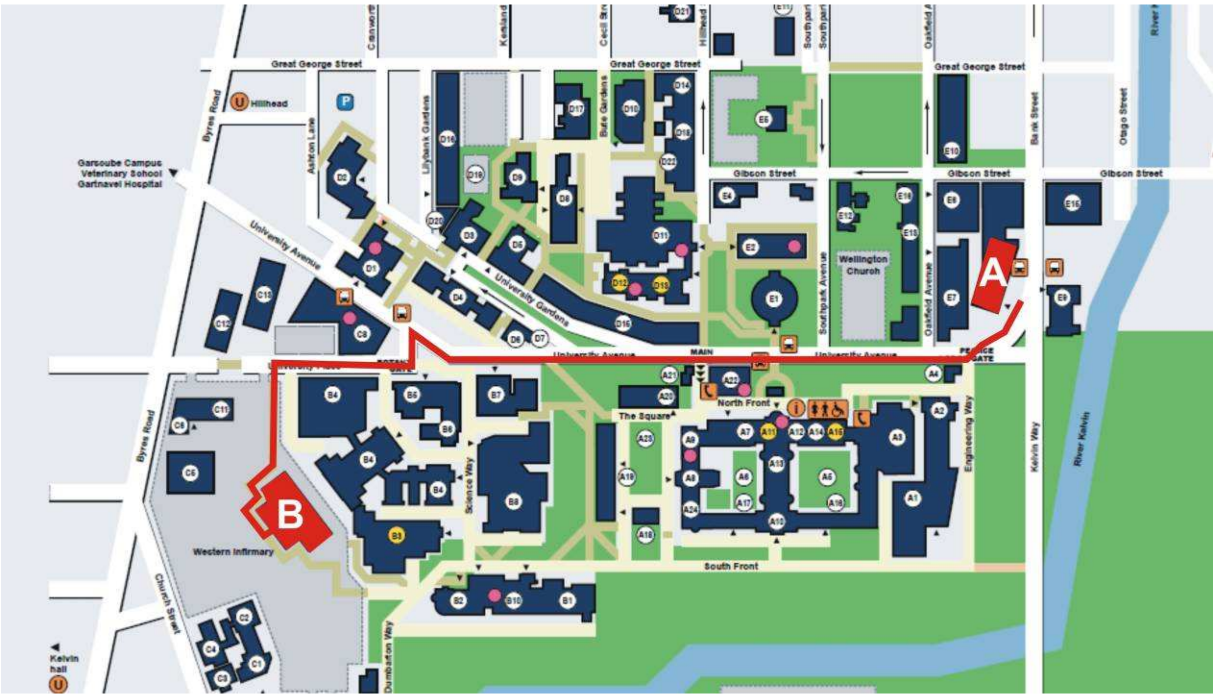
Map A - General map of Glasgow



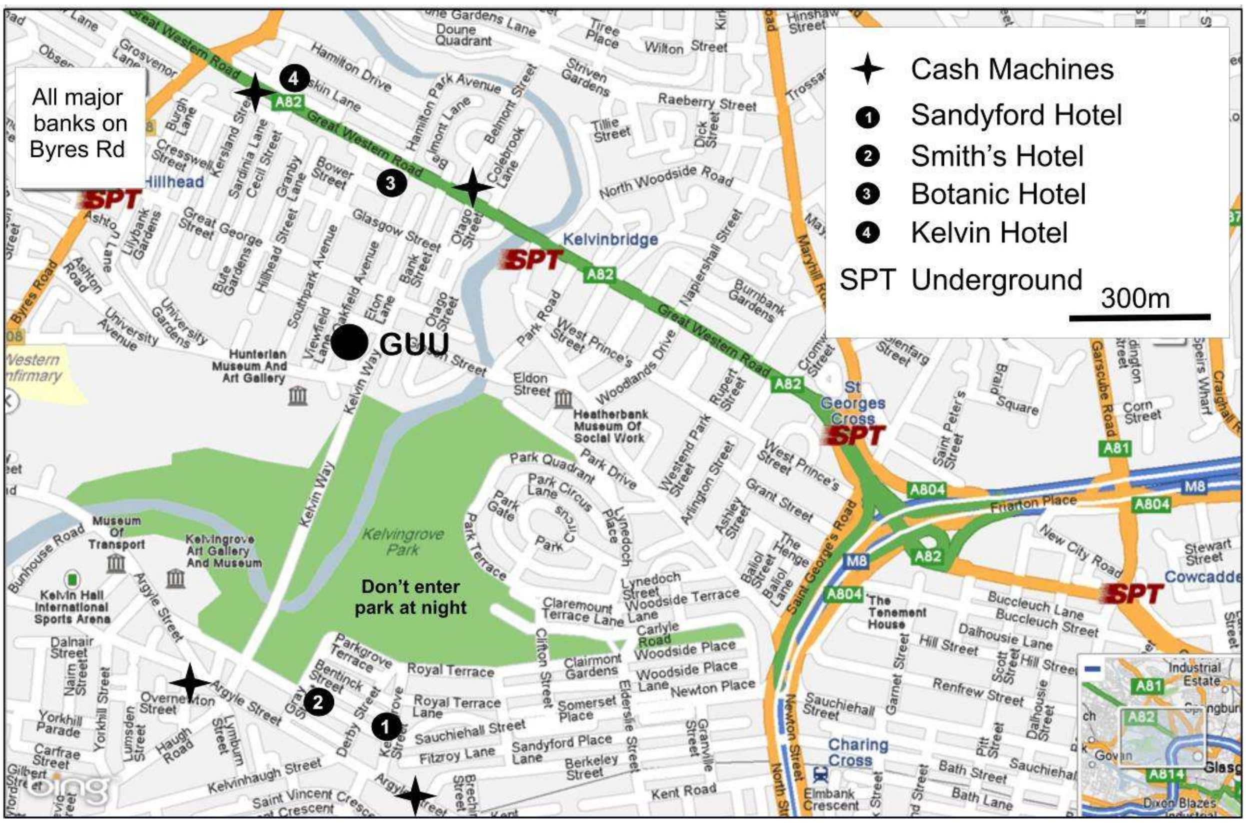
Map B - Glasgow University & Public Transport links



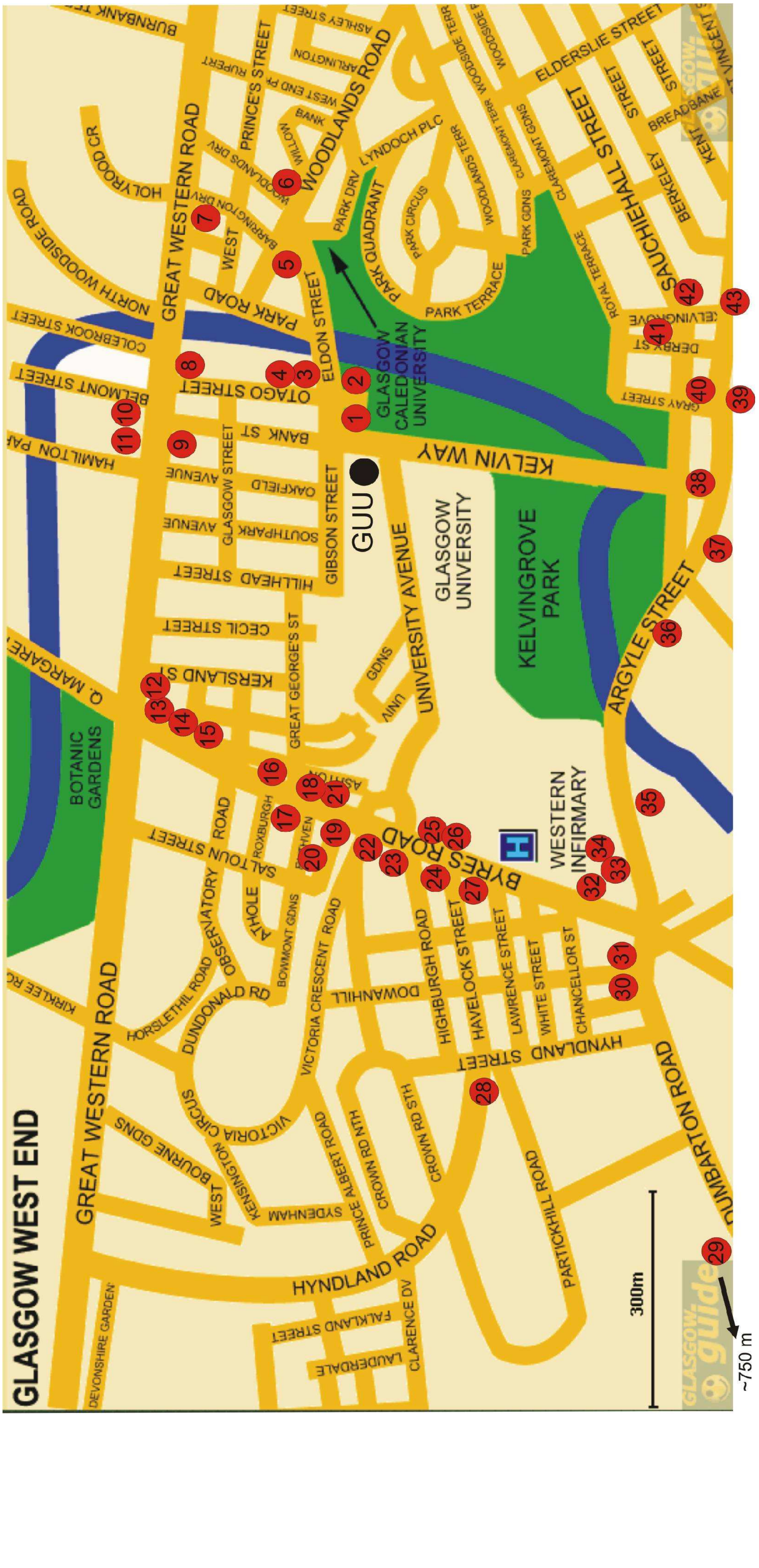
Map C - The University of Glasgow Campus. **A** - Glasgow Univsersity Union & Conference Venue. **B** - Western Infirmary Lecture Theatre, venue for Jake Lowenstern's public lecture



Map D - Conference Hotels and Conference Venue



Map E - Conference Hotels and Conference Venue



Restaurants

Food from almost every corner of the world can be sampled within a few minutes walk of the conference venue. Here are just a few suggestions

£ = approx < £10 per main course
££ = approx £10-15 per main course
£££ = approx > £15 per main course

03	**Stravaigin** *	0141 334 2665	Gibson Street	*Local & Scottish*	££-£££
07	**Gambrino**	0141 339 4111	Grt Western Rd	*Italian*	£
08	**Big Blue**	0141 357 1038	Grt Western Rd	*Italian*	£
08	**La Parmigiana** *	0141 334 0686	Grt Western Rd	*Italian*	£££
12	**Cail Bruich**	0141 334 6265	Grt Western Rd	*Local & Scottish*	£££
13	**Oran Mor**	0141 357 6200	Byres Rd	*Scottish*	£-£££
15	**La Vallee Blanche** ^	0141 334 3333	Byres Rd	*French*	£££
15	**The Salon**	0845 166 6008	Vinicombe St	*General all round*	£-££
16	**Café Andaluz**	0141 339 1111	Cresswell Lane	*Spanish*	££
17	**Mario's Plaice**	0141 334 6561	Byres Rd	*Fish & Chips*	£
18	**The Curry Leaf**	0141 339 3777	Byres Rd	*Curry Tapas*	£-££
19	**Paperino's**	0141 334 3888	Byres Rd	*Italian*	£
20	**Stravaigin2** *	0141 334 7165	Ruthven Lane	*Local & Scottish*	££-£££
20	**The Bothy** *	0854 166 6032	Ruthven Lane	*Local & Scottish*	££-£££
21	**Ashoka**	0141 337 1115	Ashton Lane	*Curry*	££
21	**Ketchup**		Ashton Lane	*Gourmet style burgers*	£-££
21	**Mimmo's**	0141 339 1848	Ashton Lane	*Italian*	
21	**The Ubiquitous Chip**	0141 334 5007	Ashton Lane	*Local & Scottish*	£-£££
21	**The Wee Curry Shop**	0141 357 5280	Ashton Lane	*Curry*	££
22	**Little Italy**	0141 339 6287	Byres Rd	*Italian*	£
22	**Sputini**	0141 339 4222	Byres Rd	*Italian Tapas*	£-££
26	**Amber**	0141 339 6121	Byres Rd	*Chinese*	£
28	**Cottiers**	0141 357 5825	Hyndland Rd	*South American*	££
29	**Bibi's Cantina**	0141 579 0179	Dumbarton Rd	*Mexican*	£-££
31	**Ichiban**	0141 334 9222	Dumbarton Rd	*Japanese Noodle Bar*	£
32	**No. 16 ^**	0141 339 2544	Byres Rd,	*Local & Scottish*	££-£££
34	**Balbirs** ^^	0141 339 7711	Church St	*Curry*	£-££
36	**Mother India Café**	0141 339 9145	Sauchiehall St	*Curry*	£-££
39	**Thai Siam**	0141 229 1191	Argyle St	*Thai*	££
41	**Konaki**	0141 342 4010	Sauchiehall St	*Greek*	£-££
42	**Mother India ****	0141 221 1663	Sauchiehall St	*Best curry in Glasgow*	££
43			Argyle St	*Korean*	££

*	booking reccommended
**	booking essential
^	small venue
^^	can accommodate large parties

Bars, Pubs & Clubs

There is a bar downstairs in the GUU, however if you wish to venture outside, here are a few suggestions…..

01	**The Left Bank**	Gibson St
05	**The Primary**	Woodlands Rd
06	**Uisge Beatha**	Woodlands Rd (good whisky bar)
09	**Coopers**	Great Western Rd
10	**Viper**	Great Western Rd (Club)
11	**Hubbards**	Great Western Rd (selection real ales)
13	**Oran Mor**	Byres Rd (selection real ales)
15	**Booly Mardy's**,	Vinicombe St (cocktails)
16	**Bar Budda**	Cresswell Lane
21	**Brel**	Ashton Lane (wide range of continental beers)
21	**Jinty McGuinty's**	Ashton Lane (Irish bar)
21	**Nude**	Ashton Lane (cocktails)
21	**Radio**	Ashton Lane (cocktails)
21	**The Lane**	Ashton Lane
21	**The Loft**	Ashton Lane
21	**The wee bar at the Ubiquitous Chip**	Ashton Lane
43	**Ben Nevis**	Argyle St (good whisky bar, sometimes live music)
21	**Upstairs at the Ubiquitous Chip**	Ashton Lane (good wine selection)
21	**VodkaWodka**	Ashton Lane
23	**Tennents**	Byres Rd (good selection of real ales)
27	**The Aragon**	Byres Rd
30	**Lismore**	Dumbarton Rd (good whisky bar)
33	**Gallus**	Dumbarton Rd
35	**Boho**	Dumbarton Rd (Club)
37	**Firebird**	Argyle St
37	**The Goat**	Argyle St
38	**Drawing Room**	Sauchiehall St
38	**Islay Inn**	Argyle St
40	**Park Bar**	Argyle St (sometimes live music)
40	**Snaffle Bit**	Argyle St

Coffee Shops

and if you have a little time to kill before catching your flight….

02	**Offshore**	Gibson St	
04	**Tchai Ovna**	Otago St	
14	**Heart Buchanan**	Byres Rd	Eat in/take away Cakes, Lunches & Coffee
16	**Beanscene**	Cresswell Lane	
18	**Starbucks**	Byres Rd	
24	**Tinderbox**	Byres Rd	
25	**Kember & Jones**	Byres Rd	Eat in Cakes, Lunches & Coffee
25	**Peckhams**	Byres Rd	Deli & take away

Whisky Tasting

Scotch Malt Whisky is made from malted barley, water and yeast. The first stage of production is the malting of the barley. The barley is first steeped in tanks of water for 2 to 3 days before being spread out on the floors of the "malting house" to germinate. When the time is right the malted barley is dried in a kiln, fired by peat or more modern fuels. The dried malted barley is then ground and mixed with hot water in a vessel. This process converts the starch in the barley into a sugary liquid known as wort. The wort is transferred to a fermenting vat, where yeast is added and the fermentation process converts the sugary wort into crude alcohol. This is known as wash. The distillation process, which takes place in distinctive copper pot stills, then separates the alcohol from the wash. Malt whisky is distilled twice. The alcohol in the wash vaporises, rises up the still, through condensers, and reverts to liquid. This liquid is then collected in a receiver before being passed into the second spirit still where the process is repeated. During this stage considerable skill is required to judge the moment at which the spirit is ready to be collected. The spirit is now stored in a variety of wooden casks for the long period of maturation in cool, dark warehouses. Now time begins to work its magic. Some casks will previously have been used to mature oloroso, fino or amontillado sherries; some will have contained bourbon and some will be oak. The type of cask used for maturation will have been determined by the Master Blender who is seeking a particular character and continuity of the whisky. Only after a minimum of three years maturation can the new make spirit be legally defined as malt Whisky. In practice, most malt whisky matures for much longer, anything from five to thirty years and sometimes longer. It is during this time when Scotland's cool, clean air steals through the porous casks and contributes to the character of each distillery's unique creation. A proportion of the whisky in each cask evaporates annually and is lost to the heavens. This is known as the "angels' share".

The main malt whisky producing regions of Scotland

The four “original” malt whisky producing regions were: Lowland, Highland, Islay and Campbeltown. Whisky producing has declined in the Campbeltown region however, and it is now often grouped with other Highland whiskies. Speyside, originally a sub-division of the Highland region, is now typically recognised as a distinct group, and is home to over 100 distilleries making it the largest whisky-producing region. The Island whiskies (Orkney, Skye, Mull, Jura and Arran) are technically a sub-region of the Highlands, but are often thought of as another regional grouping. The Highlands can also be sub-divided into further northern, western, central and eastern regions.

Although each distillery is different, the main regions retain distinct characteristics. Islay malts are famous for their strong peaty smokiness, whereas Speyside whiskies are enjoyed for their sweeter taste. The Island whiskies are peaty and smoky but not as strong as their Islay cousins, while Campbeltown malts are full bodied and slightly salty. Highland whiskies are a mixed bunch due to their large geographical extent. They typically retain a slight whiff of smokiness, but with a sweet or spicy start and a dry finish. Lowland whiskies are dry, light and mellow and often enjoyed by those new to malt whisky.

We will be sampling 5 whiskies from the Lowland, Highland, Island, Speyside and Islay regions.

Auchentoshan, 12 year old (Lowland)

Auchentoshan is unusual as its whiskies are triple distilled.

Colour: Golden honey

Nose: Crème Brulee with a burst of citrus. A hint of nuts and green leaves

Taste: Smooth, fresh and sweet with hints of tangerine and lime

Finish: Gingery and slightly drying with a pleasant lingering nuttiness.

Dalwhinnie, 15 year old (Highland)

Scotland’s highest distillery at 326m, Dalwhinnie has a little bit of everything.

Colour: Yellow gold.

Nose: Wholemeal and honey quality to the nose and slightly smoky.

Taste: Smooth, soft and lasting flavours of heather, honey sweetness and vanilla followed by deeper citrus-fruit flavours and hints of malted bread.

Finish: Long smooth, lingering, surprisingly intense finish that starts sweetly, then gives way to smoke, peat and malt.

Talisker, 10 year old (Island)

The geologists’ favourite?

Colour: Deep gold.

Nose: Powerful peat-smoke with sea-water saltiness, the liquor of fresh oysters, a citrus sweetness.

Taste: A rich, dried-fruit sweetness with clouds of smoke and strong barley-malt flavours, warming and intense. At the back of the mouth is an explosion of pepper.

Finish: Huge, long, warming peppery finish with an appetising sweetness.

Balvenie Doublewood, 12 year old (Speyside)

Starts its life in oak whisky casks, before being transferred to oak sherry casks.

Colour: Amber.

Nose: The sherry comes through due to the second barelling. Full bodied.

Taste: Mellow, rich and smooth. An interesting complexity that will make you pay attention to detail as you taste this very unique malt.

Finish: Warming. Long-lasting, with the complexity still getting one's attention. The sherry is evident, with a most interesting fullness.

Laphroaig 10 year old (Islay)

Very intense – you either love it or hate it!

Colour: Full sparkling gold.

Nose: Huge smoke, seaweedy, "medicinal", with a hint of sweetness.

Body: Full bodied.

Taste: Surprising sweetness with hints of salt and layers of peatiness.

Finish: Lingering.

Abstracts

Oral Presentations

Presentation Order

Opening Soddy's box: the Scottish roots of isotope geology

Rob M. Ellam†

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This year VMSG meets in the city that gave the world the word "isotope". When Margaret Todd proposed the term to Frederick Soddy (in a house that now forms part of the University of Glasgow) she planted the roots of a sub-discipline that has become ubiquitous in the Earth Sciences. Philip Abelson's observation, "Today the mass spectrometer is probably the most ubiquitous and powerful tool in earth and planetary sciences" [1] remains apposite.

Soddy came to Glasgow having worked with the chemist William Ramsay at University College, London where they laid the basis of what is now (U,Th)-He thermochronolgy [2]. Ramsay was associated with the Glaswegian cyanide magnate G. T. Beilby who encouraged Soddy to Glasgow University with a dowry (literally since Soddy eventually married Beilby's daughter) of 50 kg of uranyl nitrate. It was at a dinner hosted by Beilby that Todd and Soddy discussed the discovery of substances of different mass that appeared to occupy the same place in the period table; i.e. isotopes.

Soddy, working with Rutherford, made the first determination of the heat generated by radioactive decay [3]. Immediately, they appreciated the immense significance of their observations for the cooling history of the Earth. Only a few years had passed since the retirement of Lord Kelvin from Glasgow University. Kelvin had made extensive calculations e.g. [4], concluding that only tens of millions of years had elapsed since the formation of the solar system. Rutherford and Soddy had a source of heat with which to prolong the cooling of the Earth. This in turn could reconcile the thermodynamics with the inference of great antiquity that emerged from geological observations. It is a delicious irony that the phenomenon of radioactivity provides both the energy to preserve a warm planet for aeons and the very tools that we have exploited as geochronometers to demonstrate that antiquity.

Subsequently, Edinburgh led the UK quest for the age of the Earth through the work of Arthur Holmes and much depended on Nier's contribution to mass spectrometry in wartime USA. In Glasgow, newly returned from the Manhatten Project, S. C. Curran invented the gas-proportional counter that greatly facilitated ^{14}C-dating. Curran eventually joined the Atomic Weapons Establishment until returning to Glasgow to found Strathclyde University. It was to former Harwell colleagues that Curran turned when he led the establishment of a nuclear reactor facility in East Kilbride. The Reactor Centre evolved into S.U.E.R.C. and the continued success of Isotope research in Earth, Environment and Biomedical Science is but part of Curran's extensive legacy in Scotland.

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Constraining magma sources and processes along the Lesser Antilles Arc

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The Lesser Antilles has long been recognised as an arc for which large along-strike variations in magma composition exist, and in which a strong continental crustal contribution is recognised [1, 2]. We wanted to explore 1) whether geochemical variations are largely controlled by changing differentiation processes along the arc, and 2) whether the crustal contribution is through source (subducted sediment) or through contamination during ascent. Two magma suites were compared; from Mt Pelée (Martinique) in the central part of the arc, and from The Quill (Statia) in the north of the arc. Differentiation trends are distinct and appear to be largely controlled by fractionation processes involving observed amphibole-plagioclase-dominated cumulate assemblages. Variations in isotopic ratios of Pb and Sr suggest open system differentiation with some crustal contamination during fractionation. Decreasing Dy/Yb with increasing SiO_2 is consistent with amphibole (but not garnet) fractionation at both volcanoes. However, the observed phenocryst assemblage (plag ± opx ± cpx + oxide) is virtually amphibole-free, so deep fractionation has been overprinted by a shallow level phase assemblage.

The differentiation trends at Mt Pelée and The Quill do not converge on a common parent and extrapolated primary compositions have distinct isotopic and incompatible element compositions. Different amounts and/or compositions of a subducted component appear to have been added to produce the distinct primary magmas at Mt Pelée and The Quill respectively. Bulk sediment-mantle mixes are not satisfactory. Moreover, a simple along-arc variation in source modification reflecting the known along-arc variation in subducted sediment composition [3] also fails.

So, geochemical diversity is established through variations in source composition which may be subsequently accentuated by differentiation processes, and the crustal contribution appears to be added both at source and during differentiation.

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Geochemistry and geochronology of Tobago Island: a preliminary re-appraisal

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A unifying model to constrain the sources, polarity and geometry of the Great Arc of the Caribbean during the Jurassic-Cretaceous remains elusive. The arc was the leading edge of the Caribbean plate prior to, and during, its late Cretaceous tectonic emplacement between the Americas [1, 2]. Tobago Island in the SE Caribbean has long been considered a partial cross-section through at least two generations of mid-Cretaceous Great Arc magmatism [3]. We combine ICP-OES/MS and Nd-Hf-Pb radiogenic isotope whole rock determinations with U-Pb zircon LA-ICP-MS and several existing mineral ages to present a geochemical and geochronological re-appraisal of the origin of the igneous suites on Tobago.

The North Coast Schist (>115 Ma [3]) is a suite of tholeiitic mafic-felsic tuffs and volcanic breccias with Nb-Ta, Ti and slight Th depletions indicative of an arc or back-arc origin. This suite was deformed and metamorphosed to greenschist facies prior to the formation of the Tobago pluton and volcanic suite. The pluton (104±1 Ma [3]) comprises peridotite cumulates, gabbro-diorites and hornblende pegmatites, cogenetic with the volcanic suite, consisting of mafic volcanic breccias, tuffs and lavas (~104 Ma [3]), and a suite of mafic dykes (~105-91 Ma[3]). The volcano-plutonic suite has a tholeiitic island arc composition and appears geochemically similar to the North Coast Schist. Two intrusive bodies remain enigmatic. A 6 km-long tonalite body cross-cuts the pluton and has an unusual composition, with high Si, Al, La/Yb and Sr/Y, low MgO, Y and Nb, consistent with a garnet-bearing source region. Similarly, several mafic to granitic dykes have highly enriched trace element signatures and positive Nb-Ta anomalies. The origin and significance of both shall be considered.

The data indicate a more complex magmatic history for the igneous rocks of Tobago than suggested by previous studies [3] and thus they require a more detailed tectonomagmatic interpretation. Radiogenic isotopes provide a unique opportunity to study in detail the changing nature of the mantle sources involved in arc magmatism on Tobago and to test potential links with arc outcrops of a similar age throughout the Caribbean. A vital test will be to place constraints upon whether or not subduction polarity reversal occurred between eruption of the North Coast Schist and the Tobago Volcanic Group, a key tenet of the work by Pindell et al.

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Earthquake-triggered crustal CO_2 liberation at Merapi volcano, Central Java, Indonesia

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High-temperature volcanic gas is widely considered to originate from ascending, mantle-derived magma. In the case of CO_2 at arc-related volcanoes, its provenance is thought to be predominantly subducted sediments from the down-going slab. Long-term monitoring (2001-2008) of Merapi volcano, in central Java, defines a baseline for the carbon isotope composition of fumarole CO_2 at around –4‰ (vs. PDB). In 2006, however, following the May 26th Yogyakarta earthquake (M=6.4, 10-15km deep hypocentre), carbon isotope ratios of Merapi volcanic gas rose to –2.5‰, implying that significant quantities of carbonate-derived CO_2 have been added. In 2007 and 2008, the data returned to background levels.

Prior to the 2006 eruptive activity, variation of fumarole carbon isotope ratios is limited ($\triangle\delta^{13}C_{2001\text{-}2006}$ = 0.5‰ ± 0.15), with a sharp rise from the baseline after the May 26th events (≥1.5‰ ± 0.15). This rise coincided with an increase in eruptive intensity and volcano seismicity by a factor of 3-5. The sharp increase in $\delta^{13}C$, its transient duration and the link with eruptive intensity is consistent with addition of CO_2 from mid- to upper-crustal depths. Such additions of crustal CO_2 to baseline fluxes may considerably modify volatile budgets of ascending magmas at Merapi. Furthermore, CO_2 liberation from long-term crustal storage reservoirs, such as the thick limestone basement that underlies Merapi, may be a process that is accelerated by external trigger mechanisms, such as seismic events. We postulate that such upper crustal volatile input can intensify ongoing eruptions and that late-stage volatile addition may potentially trigger explosive eruptions independently of magmatic recharge and fractionation.

Distinguishing between source and upper crustal volatile contamination along the Java-Bali segment of the Sunda Arc, Indonesia

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There is widespread consensus that the down-going slab adds volatile components to the mantle wedge through slab melting and/or fluid release. There is also strong evidence for an often little considered upper crustal input to the volatile inventory [1]. The ability to recognise, distinguish between and quantify these two sources of volatiles is necessary to constrain volatile cycles and thus provide realistic input parameters for atmospheric modelling [e.g. 2]. This information is also vital for hazard assessment, particularly for volcanoes underlain by carbonate crust that could potentially erupt more explosively due to late-stage crustal volatile additions [3].

Subduction along the Java Trench involves approximately 200-400m of down-going sediment, dominated by radiolarian and pelagic clays and clayey sand and silt. In addition, marine carbonate is subducted along the eastern segment of the trench [4]. Upper crustal lithologies across Java and Bali also vary and provide a variety of potential volatile contaminants. If source contamination (from subduction), is the predominant volatile input into the subduction factory, this should be reflected by systematic west-to-east changes in the composition of volatile emissions. Thus, any marked deviations from such trends have to reflect upper crustal additions.

We sampled hydrothermal gas and fluids from 11 selected volcanoes along a traverse from Krakatau through Java to Bali in 2008. Samples were analysed for helium and carbon isotope ratios and their relative abundances ($CO_2/^3He$). The data were filtered for air contamination and only high quality data were retained. The results show evidence for both source and upper crustal contamination. A distinct mantle signal is defined by the He isotope data (8 ±1 R_A), with varying amounts of upper crustal additions of radiogenic ^4He overprinting that baseline ($^3He/^4He = 5.5R_A$ at Slamet consistent with 33 % of the total He being of radiogenic, upper crustal origin). Carbon isotopes resolve a mantle source CO_2 signal at Anak Krakatau (-7.1 to -6.3 permil), however, $\delta^{13}C$ values progressively increase towards Bali. Superimposed on this trend is a late stage crustal signature shown by deviations from the baseline (e.g. up to -2.3 permil at Kawah Ijen). We are able to quantify source and upper crustal contamination using the approach of [5]. The data indicate that volcanic volatile budgets should consider an upper crustal component and that knowledge of input from upper crustal volatile sources may be of benefit to volcanic hazard assessments.

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Boron isotopes in feldspar: tracing magmatic processes on Gran Canaria

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Miocene peralkaline ignimbrite ‘A’ on Gran Canaria (13.63 ±0.04 Ma [1]) comprises three chemically distinct end-member magma types: a comenditic trachyte ($SiO_2 \approx 65\%$) and two comenditic rhyolites ($SiO_2 \approx 70\%$) [2]. Feldspar forms the main phenocryst phase and each end-member magma type contains a characteristic feldspar composition. Chemical variations (major and trace elements, $\delta^{18}O$‰, $^{87}Sr/^{86}Sr$) in ignimbrite ‘A’ feldspars record a history of fractional crystallisation, magma-mixing, and crustal assimilation within a shallow-level magma chamber [2-5]. To test the feasibility of boron isotopes as a tracer for magma chamber processes in evolved ocean island magmas, we have analysed a suite of ignimbrite ‘A’ feldspar separates for their B concentrations and $\delta^{11}B$‰ values. We also investigated a range of potential crustal contaminants, including the igneous and sedimentary portions of the ocean crust and hydrothermally overprinted plutonic rocks from the island’s core. Boron concentrations and $\delta^{11}B$‰ in feldspar from the three ignimbrite ‘A’ end-members ranges from 37.1 to 51.5 ppm and from –3.55 to +3.48 ‰ for trachyte to most evolved rhyolite compositions, respectively. Trends in the feldspar data suggest a combination of crystal fractionation/accumulation and progressive contamination of trachyte to rhyolite magmas by a contaminant that is best reflected by a mixture between sedimentary portions of the ocean crust and rocks of the island’s intrusive core. Considering the boron data in concert with existing oxygen and strontium isotope data for the same sample suite [2, 4, 5], it appears that ignimbrite ‘A’ has been contaminated by variable components of the proposed crustal mixture, arguing for selective contamination from the two main contaminants. The correlation between our new boron isotope data and the published data for ignimbrite ‘A’ feldspars demonstrates the applicability of boron isotopes to the study of magma chamber processes in dynamic ocean island systems.

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Crustal contamination and anatexis on the Bolivian Altiplano

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During ascent towards the earth's surface primary basaltic magma sourced from the mantle has the potential to interact with overlying crustal rocks. On the Bolivian Altiplano there are several volcanic centres where erupted lavas are hosts to partially melted crustal xenoliths. Lavas from monogenetic centres at Quillacas (QL) and Pampas Aullagas (PA) are (trachy)andesitic to dacitic in composition and porphyritic in nature. Xenoliths are gneissose and represent the otherwise unexposed metamorphic basement. In addition, they contain evidence for partial melting and melt loss in the form of intergranular glass (representing quenched crustal melt) and high bulk SiO_2 respectively.

Lavas are enriched in incompatible trace elements as a result of crustal contamination with PA lavas displaying higher degrees of enrichment than QL. This is further reflected by higher $^{87}Sr/^{86}Sr$ ratios which are the most enriched Sr-isotopic signatures reported for Central Andean volcanics. Xenoliths are relatively depleted in incompatible trace elements reflecting melt loss and QL xenoliths generally exhibit lower $^{87}Sr/^{86}Sr$ than PA xenoliths.

Lavas typically display similar Pb isotopic compositions to those of their entrained xenoliths suggesting that the Pb budget of the volcanics is crustally derived. This is unsurprising as reported crustal thickness for the Central Andes is ~75km. No involvement of an enriched mantle source and/or old mantle lithospheric source is therefore required to account for the enriched isotopic signatures of the lavas. Entrained xenoliths are likely to have originated from geochemically heterogeneous and/or various crustal lithologies.

Intergranular glasses range from peraluminous (PA) to near granitic minimum melt compositions (QL). They exhibit Sr-isotopic disequilibrium with their bulk host xenoliths which suggests that the composition of anatectic melts is controlled by the incongruent melting of variable Rb/Sr phases and not by the bulk $^{87}Sr/^{86}Sr$ of the source.

Current models of crustal contamination (e.g. AFC modelling) use bulk rock compositions in calculations however, this may be an oversimplification. Further *in situ* studies (EMP, LA-ICPMS, microdrill-TIMS) aim to improve knowledge of mass transfer during crust-magma interaction and models of crustal contamination.

The nature and origin of the ~1.88 Ga Circum-Superior Large Igneous Province

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The Circum-Superior Large Igneous Province (LIP) is composed of a discontinuous belt of magmatic rocks, predominantly mafic-ultramafic in composition, circumscribing the cratonic margins of the Superior Province in the Canadian Shield for >3000 km. In addition to the cratonic margin magmatism, magmatic rocks of the same age are found in the interior of the craton in the form of mafic-ultramafic dykes and also carbonatite complexes along the Kapuskasing Structural Zone. Recent U-Pb geochronological studies have shown a tight age grouping for these magmatic rocks between 1885 and 1864 Ma.

Previous studies have treated the various segments of the Circum-Superior LIP individually and models on the origin of the magmatism include seafloor spreading, back-arc basin rifting, foredeep basin flexure, volcanic arc activity, transtension in pull-apart basins, and mantle plume activity. This study is the first to create a cohesive geochemical and Sr-Nd-Pb-Hf-Os isotopic database for the whole of the Circum-Superior LIP and to assess its petrogenesis as a single entity.

The geochemical and isotopic evidence strongly favour a mantle plume origin for the Circum-Superior LIP magmatism. A common trace element signature, very much like that of the Ontong Java oceanic plateau, is persistent throughout most of this LIP. Most samples possess Zr/Y and Nb/Y ratios almost identical to Ontong Java and other oceanic plateau lavas. Utilisation of computer software shows that the parental magmas of the Circum-Superior LIP were derived from ~30-35% pooled fractional melting of a source composition similar to that of primitive mantle with 1% continental crust extracted from it at mantle potential temperatures ranging from 1515 to 1610° C. Basalts from islands in Hudson Bay possess slightly enriched trace element profiles with small positive Nb anomalies and highlight a degree of heterogeneity within the plume source. The Circum-Superior LIP magmatic rocks possess similar isotopic compositions which further support the notion of a common mantle source for the whole LIP. The isotopic composition of this source is distinct to that of N-MORB which precludes the role of ambient upper mantle in the petrogenesis of the Circum-Superior magmatism suggested by previous studies.

Ni-Cu-PGE sulphide deposits are associated with some regions of the Circum-Superior LIP. Subtle differences in the geochemistry of the volcanic rocks in areas which are fertile with respect to Ni-Cu-PGE deposits and areas which are barren may have implications for ore prospecting in other LIPs around the world.

Long-lived layered lithosphere? Fresh data from the Slave Craton – N.W.T., Canada

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During the last decade, the Slave craton (Northwest Territories, Canada) has emerged as an important global diamond resource. Recent work on the sub-continental lithospheric mantle (SCLM) beneath this craton has yielded tantalising suggestions about its structure and composition that are of interest to the diamond mining effort. Geochemical studies of xenoliths, sulphides, diamond inclusions and mineral separates, together with teleseismic interpretations have indicated that the Slave SCLM has a uniquely stratified structure. This consists of a high-Mg #, 'depleted' mantle layer above ~110km, most pronounced in the Central Slave Lac de Gras region, with a relatively lower-Mg# 'fertile' layer of mantle beneath that extends to the base of the lithosphere. However, the data are thin for most localities. As diamond mining and exploration in the Slave craton matures, more xenolith samples are becoming available for study. These will allow testing of earlier models of lithosphere structure and refinements on existing geotherm estimates.

This study provides new major element, thermobarometric and Re-Os isotope data for a suite of peridotite xenoliths from the Central Slave craton, together with new Re-Os isotope data for a suite of xenoliths from the Southern Slave. Major element data from both localities are used to calculate a new geotherm for the Slave Craton, using the method outlined by McKenzie et al[1]. The average mineral compositions, Mg#, and Rhenium-depletion ages (T_{RD}) for individual xenoliths from the two localities are plotted on this new geotherm. The resulting pattern of T_{RD} with depth is used to evaluate the suggestion by Irvine et al.[2] that the Slave lithosphere is stratified in age as well as composition. The distribution of average mineral compositions and Mg# with depth is used to comment on the apparent layered nature of the continental lithosphere beneath the Slave province, and possible mechanisms for its formation.

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The Öræfajökull Signature

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Öræfajökull exhibits a geochemical signature unique to that of other Icelandic basalts. Published data show it to have anomolously high $^{87}Sr/^{86}Sr$, $\Delta^{208}Pb$ and $\Delta^{207}Pb$ values compared to other Icelandic samples [1, 2]. Mixing with an EM type component has been suggested as the source of this enrichment [1,2]. Until now research has suggested that this EM type component is not present in other basalts elsewhere on Iceland [1].

A comprehensive suite of lavas from Öræfajökull, rift tholeiites from the Eastern Rift Zone (Grimsvötn and Veiðvötn), Síða and Fljótshevrfi and the tertiary formations of Skaftafell, were analysed for high precision Sr-Nd-Pb-Hf-O isotopic ratios and REE elemental concentrations [1]. The Eastern Rift Zone, Síða and Fljótshevrfi and the Skaftafell basalts lie on distinct negative correlations on Sr-Nd plots. The Eastern Rift Zone, Síða and Fljótshevrfi lavas lie on a shallower trajectory to the main Icelandic array and trend owards the Öræfajökull lavas. Similar relationships are seen on $\Delta^{207}Pb$ and $\Delta^{208}Pb$ vs. $^{206}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ vs. $^{206}Pb/^{204}Pb$ indicating a possible mixing relationship between the rift tholeiites and Öræfajökull. The Skaftafell lavas lie on a steeper trend and extend to considerably more enriched $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$. If this is also interpreted as a binary mixing relationship then the end-member lies to considerably more enriched $^{87}Sr/^{86}Sr$ than any Icelandic lavas, with the exception of Öræfajökull which lies to the right of the trend. It is possible that the differences in the Sr-Nd trends for the rift tholeiites and Skaftafell lavas reflects a temporal change in the composition of the Öræfajökull source. Calculations, assuming a maximum age of 5Ma for the Skaftafell lavas [3], show that a $^{87}Rb/^{86}Sr$ of ~ 2.535, considerably higher than those seen within the Oraefajokull basalts ~0.04-0.14, is required to form the present day Öræfajökull $^{87}Sr/^{86}Sr$ from the most enriched tertiary lava. This indicates that the change in the Öræfajökull source cannot be explained through isotopic growth over time. Mixing models have indicated a temporal change from the binary mixing seen within the Skaftafell lavas to a three component mixing relationship which can account for the range in compositions seen in the younger lavas from the Eastern Rift zone, Síða, Fljótshevrfi and Öræfajökull. This possibly suggests a change in the magma plumbing or melting regime during the evolution of the Eastern Rift Zone which led to the tapping of a third mantle component.

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Rhyolite volcanism at Öræfajökull Volcano, Iceland - field relations, geochemistry & isotope geochronology

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Öraefajökull Volcano is a partially ice-covered stratovolcano situated in the southeast of Iceland which has erupted both basaltic and silicic products throughout the mid to late Quaternary and Holocene. This area of Iceland has been completely glaciated at least 16 times in the last 5 million years [1] , which makes Öraefajökull an ideal location to study the evolution of a bimodal stratovolcano in an environment dominated by fluctuating levels of ice thickness and the associated hazards of volcano-ice interaction.

A multidisciplinary approach, combining field observation, geochemistry and isotope geochronology, is being utilised in order to establish a geological history of Öraefajökull and a record of regional minimum ice thicknesses during the development of Öraefajökull's volcanic edifice throughout the varying climatic conditions of the mid to late Quaternary.

Once identified, Individual eruptive units are being dated using $^{40}Ar/^{39}Ar$ method. However, obtaining robust Ar-Ar ages for Quaternary eruptions can be a challenging process as only a small amount of radiogenic ^{40}Ar will have had time to develop in rocks of this age. To complicate matters further, Icelandic silicic rocks of all ages have been found to contain relatively high levels of atmospheric argon [2, 3] and some feldspar phenocrysts give unrealistically old apparent ages, possibly from long-term pre-eruptive storage below their closure temperature, in partially crystallised magma chambers.

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New insights into granitic magma complexity: Nd and Sr isotopic zonation in apatite in 300 Ma granites from southeast USA

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A wealth of information concerning magma chamber complexities has been gathered in recent years based on the observation of chemical and isotopic zonation in phenocrysts from volcanic rocks. Sr isotopic variations in particular have been noted in feldspar phenocrysts from volcanic rocks (e.g. [1] and references therein). Although fewer studies have explored isotopic variations in crystals from plutonic rocks, such variations have been noted in K-feldspar in granite [2].

To test further the potential for intracrystal isotopic variation in plutonic rocks we determined the initial Sr and Nd isotopic composition of apatite from ~ 300 Ma granitoids in the southeastern USA. Apatite was chosen because diffusion experiments have shown that Sr and rare earth elements remain virtually closed to diffusion up to ~ 600ºC. Two approaches were taken to compare compositions of crystal cores and rims. The first method involves the physical abrasion of apatite. This technique destroys crystal rims, but allows for a simple method to analyze cores. The second method involves acid leaching of annealed apatite to dissolve rim material leaving residual cores to be dissolved and analyzed separately. Annealing was done at 300ºC for 5 hours to anneal both fission and alpha tracks which might otherwise allow the leaching acid access to the internal portions of the grains rather than just rims. Results of the experiments can be grouped into two categories: apatite with high $^{87}Sr/^{86}Sr$ rims and relatively lower 87Sr/86Sr cores (five plutons) and apatite with the exact opposite behaviour (two plutons). The composition of apatite cores were identical using the two preparation methods. For example, for the Harbison granite the $^{87}Sr/^{86}Sr$ for cores from two batches of leached apatite were 0.70473 ± 2 and 0.70474 ± 2, indistinguishable from the values obtained from physical abrasion (0.70474 ± 2 and 0.70474 ± 2). The rim $^{87}Sr/^{86}Sr$ values for the two leaching experiments were 0.70490 ± 2 and 0.70501 ± 1. Other plutons, such as the Merriweather Granite, displayed much larger Sr isotopic differences between core (0.70500 ± 2) and rim (0.71030 ± 2). Nd isotopic variations in core and rim are consistent with the Sr isotopic data.

The core-rim relationships are evidence that in some plutons crystallization occurred in an evolved environment followed by crystallization after interaction/mingling with juvenile magmas. Other plutons record the exact opposite set of conditions. More detailed information might be gleaned if smaller samples, ideally single grains, were analyzed. Much smaller samples are planned for analysis using the new Orion® mass spectrometers developed by IsotopX. Results of those new data will be discussed.

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Thermal filtering of primary basaltic magmas through volcanic systems

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The sizes, depths and longevities of transport and storage areas beneath a volcano influence the rate and extent of magma evolution that occurs between magma generation and eruption. These factors also influence volcanic eruption patterns and the geophysical and geochemical signals associated with volcanic unrest and eruption. Understanding how transport and storage affect volcanic systems is therefore of theoretical and practical importance. Although lithospheric magma storage chambers are typically seen as the principal sites of magma evolution, here we consider volcanic systems that are inferred to lack such chambers and therefore serve to reveal the significance of transport-related magmatic processes in volcanic systems in general.

Specifically we investigate the role of high pressure fractional crystallization within dykes in preventing primary basaltic magmas from leaving the mantle. This work is motivated by studies of small volume monogenetic basanite to alkali basalt eruptions in the Auckland Volcanic Field (AVF), New Zealand [e.g., 1]. Individual eruptions yield compositionally variable magmas linked by high pressure fractional crystallization, with different eruptions sourced by parent magmas generated by different degrees of partial melting. There is no geophysical evidence for a storage system between a zone of reduced S-wave speed at 70-90 km and the surface [2].

The rarity of primary basalts (Mg# ~70) in the AVF and elsewhere can be explained if these magmas are filtered out by (i) encountering a density barrier (a density filter [3, 4]) or (ii) fractionating in response to heat loss to the country rock (a thermal filter). Whether or not a density filter acts, the rarity of erupted primary magmas indicates that they seldom reach the surface without some cooling-induced fractionation. Initially, the primary magma lies within a region where the liquidus temperature of the melt is the same as that of the ambient mantle. But from the moment the magma leaves the source region it must pass through cooler rock, making it prone to fractional crystallization. Modelling of the thermal history of magma rising in a dyke reveals regimes wherein magma can travel in a superheated state, undergo fractional crystallization on the dyke walls, or rise without evolving within a dyke sheathed by a chilled margin. Differences between the local magma, country rock, and magma liquidus temperatures influence which regime is appropriate, and are related to the plate tectonic setting through its influence on melting depth and the shape of the geotherm. The results highlight the inevitability of high-P fractional crystallization in the early history of most basalts before they undergo shallow magmatic evolution, and the consequent formation of refractory veins in the uppermost mantle.

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Melt segregation in Deep Crustal Hot Zones and its impact on timescales and composition

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Hot, mantle-derived magmatic sills emplaced in the lower crust provide a mechanism for the generation of evolved magmas in deep crustal hot zones (DCHZ). Within these zones, partial melt sourced from the crust, and residual melt sourced from the sills, may both be present over timescales which allow melt segregation processes to occur. The evolved magmas, which are produced from these coupled melting and melt segregation processes, can leave the DCHZ to be emplaced in the shallow crust or erupted at the surface.

The aim of this study is to characterise the impact of melt segregation processes on the timescale and composition of evolved magmas formed in DCHZ. The impact of emplacement rate and style on the generation of evolved magmas and their influence on melt segregation is also quantified. The model presented couples together repetitive emplacement of sills with buoyancy-driven melt segregation to describe the generation and subsequent mobilisation of magmas in DCHZ. The system is modelled numerically via an enthalpy-based heat transfer equation and porosity-based mass transfer equation.

The model results suggest that the emplacement rate and style of the intruded sills have the largest impact on evolved magma formation, influencing the time required for melt to accumulate, and also the depth and temperature at which the magma forms. This controls the composition of the magma. Fast emplacement rates lead to the generation of a large partially molten zone in the crust above the intruded sills into which melt can percolate, leading to the generation of high porosity melt lenses. At slower emplacement rates, the hot zone evolves differently depending upon whether the intruded sills accumulate by over- or under-accretion. Under- and intra-accretion of sills does not produce a large partially molten zone in the overlying crust, so the melt is contained within the intruded sills. Over-accretion continues to melt the overlying crust for all emplacement rates.

At high emplacement rates, and during over-accretion at lower emplacement rates, the partial melt sourced from the crust and residual melt sourced from the sills are able to mix, leading to the formation of evolved magmas with mixed geochemical signatures involving both crust and mantle contributions. However, during under- and intra-accretion at low emplacement rates, crustal contamination of the residual melts will be minimal. In all cases, the buoyant melt migrates upwards into cooler regions of the DCHZ before accumulating to form a magma, leading to the formation of evolved magmas which can leave the source region. Models which neglect melt segregation predict that magma formation requires much longer timescales of melting (up to an order of magnitude) and also that less evolved magmas form and leave the DCHZ.

From Arthur Holmes to Harry Hess: how melting of the mantle controls amagmatic crustal accretion

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Slow-spreading ridges are often characterised by variable volcanic cover, with some regions experiencing little volcanism, and spreading instead via extension along detachment faults. Whilst this form of spreading is well recognised, little is known about the mechanisms which initiate the transition between axial volcanic spreading, and spreading via extension on detachment fault planes.

We investigate these mechanisms in detail on the Mid-Atlantic Ridge (12º60'N-15º20'N), examining normal spreading areas, which receive a rich supply of melt and form robust volcanic cover, and also fault-dominated regions. Here, axial volcanism is sporadic, and a significant proportion of plate separation is accommodated on low-angle detachment faults, exposing mantle peridotite on the seafloor in oceanic core complexes (OCCs). The melt supply to a specific area may vary as a result of 'crustal plumbing,' melt focusing in the mantle, or melt production beneath the ridge. Melt production along the segment may vary as a result of differences in local concentrations of 'meltable' components in the mantle. Geochemical analyses reveal that major and trace element concentrations are broadly stable along the axis, with no evidence to suggest that melt production is reduced at the axis adjacent to active core complexes, despite the lack of volcanism expressed at the surface. However, analyses of basalt samples from the OCC surfaces off-axis reveal significant variations between compositions of axial basalts and those associated temporally with OCC formation. Incompatible element enriched, CPX bearing basalts are found at dredge sites associated with the onset of faulting on the OCC at 13º32'N, -44º95W. Element [8] and trace-element ratios indicate that these variations exist independent of fractionation processes.

Yb/Lu ratios, taken as a proxy for residual garnet in the melting zone, suggest that these sites are characterised by high-pressure, low melt fractions. This indicates a short, deep upwelling path (mantle cold spot?) as an explanation for low melt fraction produced in these regions. Skeletal olivine and CPX textures in these rocks support a theory of rapid eruption from a deep source. Along segment, Pb isotope ratios show a wide variation in initial source compositions over a limited (~15km) geographic extent, but basalt samples associated with core complex formation have Pb ratios which lie significantly off the local ridge trend, indicating that at the time of core complex formation, a geochemically distinct combination of mantle sources was providing melt to the ridge.

We conclude that low melt production at amagmatic regions, resulting directly from mantle compositional characteristics, drives the transition from magmatic to tectonic spreading. During this period, detachment initiation may be aided by decreased mechanical strength on the fault plane due to increased alteration and serpentinisation of underlying peridotite, made possible by the paucity of volcanic cover. Fresh dolerites cross-cutting the hydrothermally active toe of the OCC have compositions similar to those erupted at the axis today, but unlike those associated with OCC initiation. We suggest therefore that low F melts form prior to detachment initiation, but do not necessarily persist at the axis during amagmatic spreading. The melt beneath the axis today is partially intruded along the fault plane, reducing the amount of volcanism expressed at the axis, and giving the impression that magma starvation continues during the active lifetime of the core complex.

Antarctic lithospheric architecture and evolution: direct constraints from mantle xenoliths

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Our understanding of the tectono-magmatic processes that occur in subduction zones generally relies on interpretations of the bulk-rock compositions of associated volcanic rocks. These, however, have typically undergone extensive modification in the crust and interpreting the mantle processes that have contributed to their genesis is complex. Direct evidence of the composition of the mantle beneath subduction-related volcanics is rare as mantle xenoliths are seldom brought to the surface. An exception is the Antarctic Peninsula, which consists of a series of suspect arc terranes accreted to the margin of Gondwana. Subduction occurred along a trench, off the west coast, and lasted over 200 Ma. It finally ceased after a series of ridge-trench collisions, which began at ~50 Ma in the south and ended at ca. 4 Ma in the north. This was followed by extensive alkaline volcanism along the length of the Antarctic Peninsula. At several localities these post-subduction volcanics contain abundant, fresh spinel-bearing lherzolites, harzburgites and pyroxenites. The widest variety of xenoliths occurs on Alexander Island and Rothschild Island in the accreted Western Domain, where olivine compositions range from Fo_{77} to Fo_{91}. Xenolith textures and plots of mineral chemistry suggest that the constituent mineral phases are in equilibrium and can be used to determine pressures and temperatures. These PT estimates indicate that the lithosphere has a normal, unperturbed mantle geotherm and a thickness of ~90 km.

Preliminary modelling of incompatible-trace-element ratios of diopsides and augites present in the peridotites suggests that they are not simple residues of mantle melting. They have a wide range of La/Sm ratios and appear to have undergone variable degrees of modal metasomatism, which has also resulted in an increase in bulk-rock concentrations of major elements, such as Fe and Al. Variable Ti enrichment in spinels and very high oxygen fugacities suggest that an extreme range of melt compositions may have interacted with the mantle beneath the Antarctic Peninsula and produced the diverse lithologies that we have observed in the mantle xenolith suite. These include boninites (Mg-rich, hydrous melts) and small fraction melts such as lamprophyres.

Mixing of mantle melts recorded in Icelandic phenocrysts: The significance of clinopyroxene stability in depleted compositions

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Mixing of chemically heterogeneous mantle melts in the lower oceanic crust has been invoked to explain the large ranges of incompatible trace element ratios observed in olivine hosted melt inclusions in primitive Icelandic basalts, and the decrease in this variability with degree of crystal fractionation. We show that before mixing is completed, these melts, sourced from different regions of the melting column, can influence the crystallisation history and chemistry of phenocryst phases hosted in the erupted basalt.

Ion microprobe and LA-ICPMS trace element analyses were performed on high Mg# (85-92) clinopyroxene and high An content (80-90) plagioclase from the primitive Borgarhraun flow in northern Iceland. Major and trace element compositions were used to search for clinopyroxene-melt pairs close to equilibrium and thus suitable for thermobarometry. Thermobarometry results indicate that clinopyroxene crystallised at ~9(±2) kbar, close to the Moho. The forsterite content of olivine in Mg-Fe equilibrium with the clinopyroxene and the trace element content of the equilibrium melt were estimated using crystal-crystal and crystal-melt partition coefficients. This conversion allows the compositions of clinopyroxene point analyses to be compared with those of melt inclusions and their host crystals. Both converted clinopyroxene compositions and olivine-hosted melt inclusion data show a wide range in incompatible trace element ratios close to Mg# ~90, requiring mixing of mantle melts during crystal fractionation. However, the trace element enriched part of the range observed in the olivine-hosted melt inclusions is absent from clinopyroxene compositions. While the range in La/Yb of 92 olivine-hosted melt inclusions is 0.09-3.23, that for 167 converted clinopyroxene compositions is 0.11-1.29. Phase relations can explain this observation: deep-sourced, enriched melts have a long olivine-only crystallisation path and so cannot form high Mg# clinopyroxene prior to mixing with more depleted melts. Modeling crystallisation of primitive Icelandic basalt compositions using MELTS supports this explanation.

Bulk crystal Sr isotopic ratios complement the trace element data. The clinopyroxenes have lower $^{87}Sr/^{86}Sr$ (0.703054±7) than the later-crystallising plagioclase (0.703106±11). The latter value is close to the highest published whole-rock ratio for this flow (0.703099±8). This is consistent with initial clinopyroxene crystallisation from depleted, low $^{87}Sr/^{86}Sr$ melts, with most plagioclase formed later, after mixing-in of enriched melts.

The results have implications for the provenance of crystals hosted in basalts. Non-equilibrium textures, major and trace element compositions, or isotopic ratios differing from whole-rock values may not always be used to infer a simple xenocrystic origin. Instead, these features may be vestiges of the chemically and isotopically diverse mantle melts from which phases crystallised before melt mixing and eruption.

Channelised melt transport and the extraction of mantle properties from basalt compositions

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The products of basaltic volcanism preserve abundant evidence for high amplitude, short wavelength compositional variation within the mantle entering the melting region under basaltic volcanoes at spreading ridges and ocean islands. In particular, recent study of isotopic variation in closely spaced eruptions from individual volcanic segments of spreading ridges or in olivine-hosted melt inclusions from single hand-specimens has highlighted the requirement for small-scale mantle source heterogeneity. The mantle heterogeneities responsible for the isotopic variation in primary melts are also likely to correspond to variations in major element contents, mineralogy and melting behaviour. As each heterogeneity rises in the melting region it undergoes progressive near-fractional melting. Such melting can generate incremental melts with a wide range of trace element compositions from each heterogeneity. Therefore, near-fractional melting of a heterogeneous mantle can generate melts that occupy a large volume of trace element and isotopic space. However, the compositional variations found in melt inclusions from individual eruptions lie close to binary mixing lines in plots of isotopic compositions against incompatible trace element contents. Sets of closely-spaced samples from individual volcanic systems also appear to display binary mixing trends, quite different to the predictions of models of fractional melting of heterogeneous mantle. The results of simple physical models indicate that channelised melt flow can have a significant influence on the distribution of melt compositions supplied from a melting region. The wide range of incremental fractional melt compositions are filtered by the channels to supply a bimodal distribution of compositions from the melting region to the overlying magma chambers. Mixing within this bimodal distribution can then generate the apparent binary mixing arrays. Melt mixing during transport therefore controls the end-members of binary mixing arrays. These end-members need not directly correspond to the composition of physical entities in the solid mantle source that enters the melting region. Simple models of mixing in channels will be used to match observations from Iceland, and to extract physical information about the nature of the channels. This information will be compared with geological observations of relict channels in the mantle section of ophiolites.

Magma sources and melt evolution during the 1875 volcanotectonic episode at Askja, north Iceland

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The 28th-29th March 1875 silicic explosive eruption at the Askja central volcano, north Iceland, was preceded and superseded by basaltic volcanism on the Askja volcanic system. These basaltic eruptions are: Holuhraun, a fissure eruption ~20 km south of Askja, that occurred some time in the period 1867-75; several basaltic eruptions, including two tuff cones within the Askja caldera, in the period 1860-75, and Nyjahraun, a fissure eruption ~60 km north of Askja constructed in at least six eruptive episodes between February and November 1875.

Current debate on Icelandic volcanotectonic episodes that simultaneously activate the central volcano and the associated fissure swarm centres around two contrasting ideas. The lateral flow hypothesis suggests that magma replenishment, pressurisation of a shallow crustal chamber and subsequent lateral injection of shallow crustal dykes into the fissure swarm as the driving mechanism of rifting on the volcanic system. The magma reservoir hypothesis postulates that volcanotectonic episodes are driven by magma pressurisation in large and elongate reservoirs at the base of the crust (>20 km depth) and subsequent injection of subvertical dykes into the upper crust.

Previous studies of the 1875 activity on the Askja volcanic system, e.g. [1], noted a strong major and trace element compositional similarity between Nyjahraun and Askja 20th century basalts. It was therefore proposed that the Nyjahraun lavas were fed by lateral flow from a shallow crustal holding chamber beneath the Askja central volcano. However, detailed study of new and existing major and trace element data lend support to the magma reservoir hypothesis.

Our XRF and electron microprobe data suggest that Holuhraun, Askja and Nyjahraun were derived from separate magma storage regions and arrived at the surface via separate plumbing systems. The Askja and Nyjahraun sources appear to be chemically similar, but the Askja basalt is expected to have evolved via mixing with partial melts in the crust while the Nyjahraun magma evolved without such interactions. By contrast, Holuhraun is thought to have a different source composition to the Askja and Nyjahraun magmas and an entirely separate plumbing system.

We intend to analyse REE and oxygen isotopes in melt inclusions from the Holuhraun, Askja and Nyjahraun products to further investigate source characteristics and possible heterogeneities beneath the Askja volcanic system on very short timescales, and to determine the ranges in degree of melting and differences in magma evolution in the region during the 1875 episode.

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Investigating magma plumbing beneath Anak Krakatau volcano, Indonesia: evidence for multiple magma storage regions

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Improving our understanding of magma plumbing and storage remains one of the major challenges for petrologists and volcanologists today. This is especially true for explosive volcanoes, where constraints on magma plumbing are essential for predicting dynamic changes in future activity and thus for hazard mitigation. This study aims to investigate the magma plumbing system at Anak Krakatau; the post-collapse cone situated on the rim of the 1883 Krakatau caldera. Since 1927, Anak Krakatau has been highly active, growing at a rate of ~8 cm/week. The methods employed are a.) clinopyroxene-melt thermo-barometry [1,2] b.) plagioclase-melt thermo-barometry [3] c.) clinopyroxene composition barometry [2,4] and d.) olivine-melt thermometry [5]. The minerals analysed are from basaltic-andesites erupted between 1990-2002, with an average modal composition of 70% groundmass, 25% plagioclase, 4% clinopyroxene and <1% olivine. Clinopyroxenes are homogenous and display no obvious zoning. Plagioclases are considerably more heterogenous, exhibiting complex zoning and An content between An_{45-80}. In addition, mineral compositions of older clinopyroxenes, erupted between 1883-1981, are used for comparison [6,7]. Previously, both seismic [8] and petrological studies [6,7,9] have addressed the magma plumbing beneath Anak Krakatau. Interestingly, petrological studies indicate shallow magma storage in the region of 2-8 km, while the seismic evidence points towards a mid-crustal and a deep storage, at 9 and 22 km respectively.

Our results imply that clinopyroxene presently crystallizes in a mid-crustal storage region (8-12 km), a previously identified depth level for magma storage, using seismic methods [8]. Plagioclases, in turn, form at shallower depths (4-6 km), in concert with previous petrological studies [6,7,9]. Pre-1981 clinopyroxenes record deeper levels of storage (8-22 km), indicating that there may have been an overall shallowing of the plumbing system over the last ~40 years. The magma storage regions detected coincide with major lithological boundaries in the crust [7,8,9], implying that magma ascent at Anak Krakatau is probably controlled by crustal discontinuities. Our study therefore shows that petrology has the sensitivity to detect magma bodies in the crust where seismic surveys fail due to limited resolution. Combined geophysical and petrological surveys offer an increased potential for the thorough characterization of magma plumbing at active volcanic complexes.

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Compositional variance in products of the 1998 and 2004 eruptions at the Grímsvötn central volcano, Iceland

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Geochemical investigation of the 1998 and 2004 tephra deposits from Grímsvötn central volcano reveal significant and systematic variations in major and trace element compositions with stratigraphic height. The range in incompatible element concentrations in the 1998 and 2004 products indicate that this compositional variation can be explained by 10-20% fractional crystallisation during residence in the shallow (1-3 km depth) magma storage zone beneath the Grímsvötn volcano. As expected the 1998 and 2004 products have similar Zr/Nb values (1998, 10.1; 2004, 9.7), indicating common source. However, they define two distinct trends on FeO vs TiO_2 plot, both intercepting the origin, suggesting independendent evolution within the shallow (low-pressure) magma storage zone via fractional crystallization of plagioclase. This result is somewhat surprising considering the small volumes (<0.05 km^3) of magma erupted and short repose interval between these two events. Previous studies of historic Grímsvötn products (e.g. 1983, 1934) give the impression uniform magma compositions [1, 2]. The largest known eruption from the Grímsvötn volcanic system is the 1783-84 AD Laki eruption (15 km^3), which is characterized by exceptionally uniform magma composition [3].

Our new results have implications for how we view the magma plumbing system and storage zones beneath Grímsvötn. Firstly, our results imply that the 1998 and 2004 eruptions were fed by physically separate magma pockets residing in the shallow magma storage zone beneath the Grímsvötn volcano. Secondly, the observed compositional patterns of Grímsvötn products – variable in small volume eruptions at the central volcano and uniform in large eruptions out on the fissure swarm – argues against a common magma storage zone for events on these two parts of the Grímsvötn volcanic system and, by deduction, discards the idea that the Laki eruption was fed by lateral flow of magma from a shallow chamber beneath the Grímsvötn volcano.

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The emplacement and geochemical evolution of the Pilanesberg Complex, South Africa

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The 25 km-diameter Pilanesberg Complex, South Africa, consists of felsic volcanics into which were intruded a number of syenitic and foyaitic facies. No mafic or intermediate compositions are present. It is currently considered to have formed as a series of ring dykes and cone sheets, sequentially emplaced from the centre outward, although very poor outcrop precludes identification of contact relations and dips between the different intrusive rock types [1]. Based on a number of observations and theoretical considerations of emplacement mechanisms, I reinterpret the intrusions as having been emplaced sub-horizontally, followed by subsequent centripetal subsidence. This structural reinterpretation was inspired by the revised geometry of the Ardnamurchan Complex [2], long considered the type locality for ring dykes. This overall shape for the Pilanesberg was originally proposed by Shand [3], but rejected by subsequent authors [1].

The originally described Inner and Outer Syenite are re-interpreted to be the cogenetic upper and lower marginal syenite. It was intruded by a small Red Foyaite, followed by the Inner and Outer White Foyaite, which are now considered to be the upper and lower facies of a single, inward crystallizing body. Emplacement of a number of relatively small foyaitic facies terminated the intrusive episode. A number of geochemical similarities between the two Syenite rings and the two White Foyaite rings suggest that each pair is consanguineous. However, as the White Foyaite sheet crystallized inward it liberated a fluid that caused extensive alteration of all overlying rocks, mainly the Red Foyaite, the upper White Foyaite and the volcanic rocks. Primarily, the alteration caused replacement of Na by K, a decrease in Zr, Y, Nb, Ce and La, and an increase in Ba and Rb. REE patterns in the unaltered rocks, specifically, the lack of an Eu* anomaly, and variably high Sr contents suggest that feldspars were not a significant component of the fractionating assemblage that produced these compositions. Extremely high concentrations of incompatible trace elements, the absence of any composition with more than 2% MgO and the enormous size of this intrusive complex create problems for the modeling of the genesis of the Pilanesberg Complex.

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Large- and small-scale igneous layering in the Ben Buie Intrusion, Mull

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The Ben Buie intrusion [1, 2] is a large (12km^2+) gabbro body associated with Centre 1 of the Palaeogene Mull central igneous complex. Unlike most of the other large basic intrusions of western Scotland, there are no detailed published maps of internal lithological variation.

We present preliminary field and petrographic data from the Loch Fuaran area demonstrating the presence of a wide range of spectacular layering and cumulate structures on variety of scales. These include layers on a 10-50m+ scale which can be traced over km scales,, and a wide range of small scale structures including a range of modal layering types in olivine gabbros and trocolites, deformational structures such as loads and flames, peridotite layers, finger structures, coarse skeletal olivine rocks, igneous breccias, and some very unusual “spotty” layers rich in very large olivine oikocrysts.

Compared with most other Scottish Palaeogene basic and ultrabasic intrusions, small-scale layering in Ben Buie is often highly disrupted and discontinuous, probably indicating a very dynamic tectonic regime during crystallization. However, outcrops around Loch Fuaran support the suggestion [3] that these small scale-deformational structures may not have completely disrupted a simple vertical (and potentially mappable) stratigraphy.

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Physical behaviour of steeply dipping crystal mush

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The Marginal Border Series of the Skaergaard Intrusion, East Greenland, crystallised on the steeply dipping side-walls of the magma chamber. The rocks represent a series of mafic cumulates which crystallised inwards during fractional crystallisation of a single pulse of basaltic magma. They show the same progression of mineral assemblage and the same cryptic mineral compositional variation as that of the better known Layered Series, which crystallised on the chamber floor, demonstrating the “onion-skin” style of solidification of this box-shaped magma chamber. The original study of Wager & Deer (1939) divided the Marginal Border Series into the outer Tranquil Zone and an inner Banded Zone, although this field-based division bears no relationship with the progressive fractionation of the gabbros.

A key feature of the Tranquil Zone is the “Wavy Pyroxene Rock”, which comprises geometrically aligned, lensoid segregations of very coarse-grained plagioclase and poikilitic augite set within otherwise uniform, unbanded and homogeneous gabbro. These segregations consistently strike parallel to the chamber wall and dip towards the contact. The shape, size, grain-size and mineralogy of the segregations change systematically away from the intrusion wall. They become bigger, chemically more evolved and more irregular in shape with increasing distance from the intrusion’s margins, and thus with stratigraphic position. We suggest that the Wavy Pyroxene Rock represents tearing of the poorly-consolidated crystal mush, during localised sagging of the vertical mush zone. Small, regularly spaced and shaped, tears formed in the thinner, more rapidly chilled, outer parts of the MBS, while larger irregular tears occurred in the inner, highly porous and poorly consolidated regions. Once the tears had formed, interstitial liquid moved into the space, crystallising as relatively evolved coarse-grained segregations. We use mineral chemistry to estimate the porosity when tearing occurred, and hence information about the physical condition of the crystal mush.

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Sulphide saturation and degassing in Reunion magmas

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Recent investigations into the partitioning of trace metals between fluids and melts and into the release of trace metals from volcanoes during degassing, have highlighted the ability of these elements to behave in a volatile fashion. Many of these trace metals are also chalcophile and have high sulphide-melt partition coefficients which means they are removed from a silicate melt on formation of a sulphide or sulphate melt within the magmatic system.

Insight into the interplay between sulphides, silicate melts and vapour and its effects on trace metal concentrations have been sought at Reunion Island. Here samples of cumulate nodules rapidly erupted, quenched and deposited in the Bellecombe ash member, Piton de la Fournaise have been acquired [1]. These cumulate nodules contain quenched interstitial glass with small round bodies of quenched immiscible sulphide melts. They provide evidence for sulphide melt formation during fractional crystallisation and removal of the sulphide melt, as they fractionate out with dense crystals. These samples provide a rare opportunity to investigate the importance of sulphide melt formation during crystallisation and degassing. Measured partition coefficients are applied to simple crystallisation models and results are compared to a compilation of published whole rock and melt inclusion data from Reunion Island, which have been extracted from the GEOROC database. These models are used to estimate the proportion of sulphide melt, which is able to sequester Cu. Subsequently this result has been applied to the large April 2007 eruption of Reunion Island, where melt inclusion and matrix glass data have been used to estimate the amount of S and Cu released by degassing during the eruption.

Both sulphide formation and vapour exsolution can be said to cause loss of Cu at Reunion Island, however the exact timing and driving force behind sulphide formation is unknown. At Piton des Neiges, the elder volcano on Reunion, high SiO_2 concentrations also correspond to a loss of TiO_2 and FeO, which is related to titanomagnetite crystallisation. The decrease in TiO_2 and FeO is also associated with a sharp drop in Cu to low concentrations, but no loss of other incompatible elements. We propose that a drop in Fe alters the sulphur concentration at sulphide saturation (SCSS), causing S to exsolve as a sulphide melt which then extracts Cu from the silicate melt.

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Reflections on half a century of accessory mineral U-Th-Pb geochronology

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U-Th-Pb dating has been the mainstream method for keeping track of the earth's geological rhythm for more than 50 years and has been pivotal to dating the earliest events of our solar system, absolute calibration of the geological time scale, as well as providing insights into secular evolution of continental crust, rates of magmatic and volcanic processes, and much more. Initially methods were complex and involved very tedious chemical and mass spectrometry procedures therefore the production of dates was limited by comparison with the modern techniques. Methodological advances, particularly the development of 'in-situ' dating methods (SIMS and LA-ICP-MS), and increased precision and accuracy (ID-TIMS) have been very significant and have made access to dating much easier – without the need to be a 'specialist' – leading to a huge growth in data but also accompanied by a lack of appreciation of the subtleties of measurement, uncertainty propagation and understanding, U-Pb systematics, and in part a 'cookbook' approach to dating by users. These technical developments have allowed geologists to answer fundamental questions about the rates and timing of geologic processes that were previously beyond resolve. This talk will reflect on pivotal contributions over the past 50 years, discuss strengths, weaknesses, and caveats of methods and approaches, and it will discuss the exciting research directions that lies ahead in the next 10 years.

On the cause of the Paleocene-Eocene hyperthermals (PETM and ETM2): new evidence for a tectonic-magmatic driver

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The climate record covering the past 70 million years shows that global temperatures peaked during the Early Eocene around ~54 to 52 Ma; the Early Eocene Climatic Optimum (EECO) [1]. Preceding and during the EECO were three transient global warming events, each is marked by an abrupt decrease in the $\delta^{13}C$ of sedimentary carbon (consistent with the rapid addition of massive amounts of CO_2 and/or CH_4, into the hydrosphere/atmosphere) with approximately half the magnitude of its predecessor: the Paleocene Eocene Thermal Maximum (PETM), the Eocene Thermal Maximum 2 (ETM2) and the Eocene Thermal Maximum 3 (ETM3). Two ideas for possible sources of CO_2/CH_4 and potential trigger mechanisms are (i) breakdown of marine methane hydrate [2], possibly related to orbital cycles forcing and/or (ii) for the PETM, thermogenic release of methane by massive sill intrusion into C-rich sedimentary basins, with the gas being released via a complex of thousands of hydrothermal vents [3]. These two potential carbon sources have quite different isotopic ratios, which in mass balance calculations determine the amount of carbon required to account for the carbon isotope excursions.

The PETM has been shown to be synchronous with the onset of peak, continental-breakup related, magmatic activity during the formation of the East Greenland and the Faeroes flood basalt province [4], supporting the sill intrusion model for the source of the methane/CO_2 [3]. Here we develop this model further through combined relative astronomical ages for the PETM, ETM2 and Danish Ash-17 [5] with a new, more precise, $^{40}Ar/^{39}Ar$ age for Ash-17 and ^{238}U-^{206}Pb zircon and $^{40}Ar/^{39}Ar$ ages for a massive sill complex exposed in the Trail Ø/Jameson Land sedimentary basin on the East Greenland margin. This igneous-sedimentary complex is conjugate to the sill-bearing Røst basin on the Norwegian margin, north of the Vøring basin. The combined age data demonstrate synchronicity between ETM2 and intrusion of the sill complex, implicating an identical mechanism as the one proposed for the PETM [3]. The PETM and ETM2 can be understood in the context of 2-stage separation of Greenland and Europe, first with the opening of the NE Atlantic, followed 1.8 myr later by the opening of the Norwegian-Greenland Sea, north of the Jan Meyen Fracture Zone, with each rifting event being accompanied by sill intrusion into C-rich sedimentary basins, triggering the release of massive amounts of methane.

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Vulcano, Italy: the geochemistry of effusive and explosive activity in space and time

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The eruptive history of Vulcano helps define classic “Vulcanian” eruption styles - short periods of explosive vent-clearing activity followed by longer periods of quiescence. Recent research has shown that the magma plumbing system below Vulcano (consisting of La Fossa and Vulcanello eruptive centres) comprises two magma systems: a shallow, evolved, felsic magma and a deep, less evolved mafic magma [1, 2]. The main objective of this project is to understand the geochemistry of the last 6000 years of eruptive activity at Vulcano in both space and time. To define temporal changes in explosive/effusive activity, stratigraphic sections comprising lava flows, pyroclastic fall & flow units have been sampled for "juvenile" components on La Fossa and Vulcanello. In addition targeted ^{14}C dating is being undertaken where data are lacking. Geochemical analyses (ICP-AES & ICP-MS) are used (a) to compare and contrast the amount of fractionation in effusive and explosive deposits (b) to define the periodicity of any switches from explosive to effusive activity and (c) to demonstrate any interaction between co-existing magma systems. Temporal variations in the geochemistry of products from the different eruptive cycles of La Fossa and Vulcanello will be presented and discussed.

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Dating Holocene basaltic lavas using cosmogenic isotopes

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The accurate determination of the timing of Quaternary basaltic volcanism is crucial for understanding of the eruption history and structural evolution of volcanoes, volcano-climate interactions and dating human evolution. The most widely used radiometric dating tools (^{14}C and K/Ar-^{40}Ar/^{39}Ar) have long and distinguished records but are not routinely applicable and reliable alternative techniques are required. Cosmogenic isotopes are produced by the interaction of high-energy cosmic ray-secondary neutrons in minerals at the Earth's surface. Natural accumulation rates of cosmogenic isotopes are primarily dependant on site altitude, but even for modest altitudes sub-10 ka basalts can be routinely dated by ^{3}He and ^{36}Cl using existing technology. I will review the practicalities of exposure dating, demonstrate it's applicability with examples from Stromboli and Ascension island, and take a look into the future.

Geomorphic evolution of composite complexes in a volcanic arc setting since 1 Ma: examples of the Axial Chain and the Grande Decouverte-Soufriere massifs (Guadeloupe, FWI), volume and extrusion rate estimations

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The volcanic story of the island of Basse-Terre within the Lesser Antilles arc (Guadeloupe archipelago, FWI) has been explored through the use of unspiked K-Ar. Four main volcanic massifs contributed to shape the island from 2.8 Ma to present, from north to south, following a migration rate of 18 km/Myr [1]. In this work we focus our attention on the story of the two youngest volcanic complexes located in southern Basse-Terre: the Axial Chain (AC) 1023 ± 25 – 435 ± 8 ka and the Grande Decouverte Volcanic Complex (GDVC) 205 ± 28 ka – present. Whereas the Axial Chain is composed of a succession of imbricate volcanoes, the GDVC is composed of the single composite edifice Grande Decouverte-Soufriere (GDS) and of the peripheral complex of Trois-Rivieres-Madeleine Field (TRMF) [2]. Aiming at estimating maximal effusive volumes emitted through time, we modelled 3D surfaces of both massifs at different stages of their evolution, including pre and post-flank collapse episodes. The volume of the Axial Chain before it was affected by two huge flank collapses [1] reached 180 km^3, which corresponds to an extrusion rate (ER) of $4.7x10^{-4}$ km^3/yr. Post-collapse volcanism such as the Icaques Volcano reaches 8 km^3 hence an ER of $2.7x10^{-4}$ km^3/yr. The GDS overall volume of 16 km^3 corresponds to an ER of $6.4x10^{-5}$ km^3/yr and is of $2.4x10^{-5}$ km^3/yr for the TRMF between 100 ka and present. The five main stages of evolution of the whole GDVC correspond to ERs of $7.2x10^{-5}$ km^3/yr for the phase 250-70 ka, $6.7x10^{-5}$ km^3/yr for 70-48 ka, $3.7x10^{-5}$ km^3/yr for 42-15 ka and $1.3x10^{-4}$ km^3/yr for the last stage that started 15 kyr ago.

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Eruptive history of western and central Aeolian Islands volcanoes (South Tyrrhenian sea): insights from K/Ar dating

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The Aeolian island arc is located on the continental margin of Calabro-Peloritano basement. It contains the whole range of geochemical compositions typical of convergence settings, from calc-alkaline (CA) to potassic series through high-K CA and shoshonitic series. The Aeolian archipelago is divided into three sectors defined by geography, structural setting and geochemistry [1]. The uncommon feature of this archipelago is the huge variety of products emitted in a short time span (less than 500 ka). This makes the Aeolian islands a complex volcanic setting, whose origin is still debated.

In this study, we report on new geochronological data, based on the K/Ar Cassignol-Gillot technique that is well suited for dating Pleistocene to historical volcanic materials [2]. These new ages are used together with new geochemical data to establish a new volcanic evolution model. The studied area includes the western sector of the Aeolian arc (Alicudi, Filicudi, Salina islands), which contains the most primitive products and is not well studied, and the central island of Lipari which is located on the major Tindari-Letojani Fault separating the western and eastern sectors. The major activity of Filicudi is confined around 300-200 ka with emission of CA basalt and basaltic andesites. Then, the volcano shows irregular activity until around 25 ka by emitting high-K basalt, andesite and dacite. The Capo Faro edifice and the oldest part of M. Rivi in northern Salina are constructed before 200 ka, by eruption of CA basaltic andesites. Then, M. Rivi, M. Fossa delle Felci and M. Porri succeed in time with coeval activity around 150 ka and 60 ka, respectively, and produced magma of intermediate composition from CA basaltic andesite to high-K dacite. The last Pollara explosive eruption of High-K rhyolitic products occurred around 10 ka. On the island of Lipari, only two lava samples testify to the activity before 200 ka. The largest volume of volcanic products was CA basaltic andesite to high-K andesite and was emitted before 100 ka. After a period of dormancy, activity started again around 50 ka with the emission of high-K CA and shoshonitic rhyolite and with a gap in dacitic products. Alicudi is the youngest volcano but its activity ended around 20 ka as in Filicudi island, with the less evolved magmatic products of the studied area.

The common feature of these volcanoes is that they show a global evolution from primitive products at the beginning of their activity to differentiated products at the end. However, when studied at a smaller time-scale, the evolution of each island is more complex reflecting a whole variety of specific magmatic processes. Finally, our new set of K/Ar ages allows us to revise the chronology of these volcanoes and to propose a new model for the spatio-temporal evolution of the volcanism.

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High-precision multi-collector $^{40}Ar/^{39}Ar$ dating of volcanic rocks

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Quantification of geological time is essential for decoding the 4.5 billion-year-history of our planet and solar system. As we strive to constrain the timing and frequency of events such as volcanic eruptions, the questions we ask are when did it happen and how fast did it occur? Answering these questions is easy if we only require a rough approximation (to within a few million years). However, if we are to establish links between volcanic eruptions and mass extinction and climate change, or assess the hazard potential of a volcano, we require timeframes for sequences of events at the highest precision.

The ARGUS multi-collector noble gas mass spectrometer [1] housed at the NERC Ar Isotope Facility, S.U.E.R.C., allows collection of more isotope data within 300 seconds than a single-collector noble gas mass spectrometer (e.g. MAP 215-50) does within 1500 seconds. In addition, the multi-collector improves the precision of isotope ratio determinations as small fluctuations in ion production and environmental factors (e.g. temperature) affect all ion current simultaneously. Consequently ARGUS can achieve higher-levels of analytical precision than previously possible, which translates into $^{40}Ar/^{39}Ar$ ages with smaller uncertainties.

This contribution will show examples of $^{40}Ar/^{39}Ar$ ages determined from a wide variety of volcanic and magmatic systems from around the World. It will also explore developments in $^{40}Ar/^{39}Ar$ geochronology that in addition to improving technique accuracy, will allow $^{40}Ar/^{39}Ar$ to routinely date very young (< 0.1 Ma) volcanic rocks.

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Cone sheet emplacement in sub-volcanic systems: a case study from Ardnamurchan, NW Scotland

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Inclined concentric sheet intrusions (ring dykes and cone sheets) are key elements of the intrusive framework of sub-volcanic systems (central complexes). The nucleus of volcanic centres are often identified by the focus of inward dipping cone sheets based on a fundamental assumption about how the general geometry and disposition of the sheets relates to a (central) source. We aim to test the implications for magmatic plumbing (magma flow and linkage) that is generated by this model and thereby examine this fundamental assumption of sub-volcanic systems. Here we present preliminary evidence for magma flow and emplacement dynamics from the cone sheets of Ardnamurchan, NW Scotland, using anisotropy of magnetic susceptibility (AMS) measurements and structural field observations.

AMS data from over 100 oriented block samples from the Ardnamurchan cone sheets reveals magnetic lineations that are consistent with visible magma flow indicators, such as step and broken bridge axes. Flow directions vary from strike parallel to dip parallel and cannot be traced back in a simple way to a source. Field observations show host rock behaviour during cone sheet emplacement can be linked to lithology; magma fingers (ductile) occur in Palaeogene volcanic and volcaniclastic rocks, broken bridges (brittle-ductile) occur in Mesozoic sediments, and angular xenoliths (brittle) occur in Proterozoic psammites. In well exposed coastal sections, cone sheets intruding Mesozoic sediments are observed parallel to bedding, transgressing up the sedimentary sequence and may be described as transgressive sills. At Mingary Pier (NM 493 626) the transgression appears to be controlled by host rock fractures.

Given that there is little compositional variation between different cone sheets, the host rock lithology and structure needs to be considered before grouping them into separate geometric suites related to volcanic centres. Flow direction data does not support a centralised source model and in fact reveals a general NW-SE trend suggesting an alternative source.

Neogene plume-related magmatism of the Al Haruj volcanic field, central Libya

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Major and trace element, Sr-Nd-Pb isotope and mineral chemistry are used to characterise the volcanic rocks of the Al Haruj volcanic field, Libya. The Al Haruj volcanic field lies in the central part of Libya, in an area marked by topographic upift, a positive free air gravity anomaly and a negative perturbation in surface wave velocity between depths of 75-150 km. The volcanic field covers an area of 45,000 km^2, roughly the size of Iceland. It is composed exclusively of basaltic material in the form of lava flows, shield volcanoes, and monogenetic scoria cones. While very little is understood about the petrology of the volcanic field, Klitsch, 1968 made a preliminary study and separated the lava flows into 6 age divisions. The youngest flow is considered to be of Holocene age. Samples were collected from all 6 lava flow divisions as well as scoria cones from within each flow field.

Magmas range from hypersthene normative tholeiitic basalts, through alkali basalts to basanites and span a range of 4.9 - 11.84 wt % MgO. They are enriched in highly incompatible elements relative to primitive mantle, showing compositions similar to Ocean Island Basalts. La/Yb range from 6.71 - 21.29. Major and trace element data suggest magma evolution by fractional crystallisation, dominated initially by olivine and subsequently by clinopyroxene (scoria cones) or plagioclase (tholeiitic flows). Liquid crystal dis-equilibria indicated crystal accumulation ranging from 0-14%. Liquid compositions were corrected for crystal accumulation and olivine (Fo_{70-85}) - liquid and clinopyroxene – liquid equilibra suggest a crystallisation temperature of 1200±50 ºC at pressures of 8.9-13.1 kbar. The most primitive (>7wt % MgO) basalts have been used to model mantle melting processes and indicate 1-5% melting of a primitive mantle source at depths of 120-60 km across the garnet-spinel transition zone (80-100 km). The youngest flows, 5 and 6, are dominantly tholeiitic and less enriched in composition than the older flows, suggesting an increase in melt fraction to 6% over the same depth range towards the end of eruption. This is consistent with the depth range of the negative velocity perturbation observed in surface wave models. Mantle potential temperatures from thermobarometry and geochemical modelling give a range of 1325±75 ºC. Sr-Nd-Pb isotopes will be used to constrain the mantle source composition.

The new analyses are compared with the North African basalts of the Hoggar and Tibesti swells. These volcanic provinces are believed to originate from upper mantle asthenospheric upwellings or plumes. Major element compositions of mafic rocks are similar although the Hoggar and Tibesti have a stronger alkaline component and any tholeiitic basalts are associated with the initiation of volcanism. The Al Haruj basalts are generally less enriched in incompatible elements than both Hoggar and Tibesti basalts. Modelling the melting of the Tibesti basalts from a primitive mantle source predicts a smaller melt fraction (1-3%) over a depth range of 120-70 km. The depth range of the melt regime beneath the Al Haruj is 10km shallower than Tibesti, suggesting the differences in melting are not dominated by changes in lithospheric thickness. The variance between the 2 provinces is more likely to originate from differences in thermal structure of the upper mantle beneath the two swells. The Al Haruj volcanism appears to originate from a small upper mantle upwelling, produced by a positive deviation in mantle potential temperature and is independent of the Tibesti swell.

Volatiles in gases and melt Inclusions erupted during the 2008-9 Halema`uma`u eruption of Kīlauea volcano, Hawai`i

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The volatile content of parental magmas ascending beneath Kīlauea Volcano strongly influences magma buoyancy, mixing and fragmentation. However the role of volatiles during the onset of summit eruptions at Kīlauea remains relatively poorly understood. The 2008-9 Halema`uma`u eruption provides a unique opportunity to study summit eruption degassing with a multi-disciplined approach; using new miniature gas sensors to measure the young and concentrated plume, alongside analyses of volatiles in melt inclusions from summit eruption tephra. The eruption also offers a chance to test long-established models of volatile fractionation and degassing at Kīlauea which were originally proposed almost 25 years ago, and in doing so extend our understanding of magma and degassing pathways at this long-lived and well-studied volcano.

In April 2009, the composition of volcanic gases was measured by non-dispersive infra-red spectrometers, electrochemical sensors and FTIR spectroscopy on the Halema`uma`u crater rim. CO_2 concentration was measured using two 21 cm-pathlength miniature NDIR spectrometers, deployed side by side. SO_2, H_2S and CO concentrations were measured simultaneously by an array of electrochemical sensors adjacent to the CO_2 sensors. Sampling rates of ~1 Hz were achieved on all sensors. The signals were cross-correlated with one another and gas ratios derived for the summit gas plume. Open-path active source FTIR measurements carried out close to the sensors yielded independent ratios between the major volatile species.

Tephra erupted from the new Halema`uma`u vent in September 2008 was sampled and olivine-hosted melt inclusions were isolated and exposed for analysis by electron microprobe and LA-ICP-MS for major and trace elements; SIMS was performed for analysis of volatile species. We present S, Cl, F, H_2O and CO_2 concentrations in melt inclusions and matrix glasses, as well as major and trace element data in order to establish degassing and melt evolution trends. We compare the data to those collected previously for East Rift eruptions and for other historical summit eruptions of Kīlauea Volcano to assess whether the volatile budget can elucidate pre-eruptive magma dynamics and whether the volatile content of parental magmas has an influence on eruptive style for this volcano. Preliminary results indicate that the summit eruption tephras have a relatively low pre-eruptive H_2O concentration compared to tephra produced during other summit eruptions, which might indicate magma chamber convection, a difference in parental magma composition, or magma mixing.

Continental-marine tephra correlations: linking the distal tephras of the Marsili Basin (southern Tyrrhenian Sea) to the proximal source deposits of the Aeolian Islands, Southern Italy

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The near synchronous and instantaneous deposition of volcanic ash over wide geographical regions provides useful isochronous layers within a variety of sedimentary archives. These layers provide a powerful tool enabling the correlation of archives. Furthermore, where the source of the tephra layer is known and the age is established, the tephra layer offers chronological constraints. Here we attempt to test a continental-marine tephra correlation, linking the distal tephras of the Marsili basin to their proximal source deposits in the Aeolian Islands. Proximal deposits of sub-plinian eruptions on the islands of Lipari, Stromboli and Salina during the last ~30ka have been analysed, along with four visible distal tephra layers from the Marsili Basin core (~80 km from the islands).

Grain-specific methods of tephra analysis are adopted in the acquisition of major (EPMA) and trace (LA-ICP-MS) elements, a largely unused approach for the latter. Major element data alone is considered insufficient in establishing unique geochemical 'fingerprints' for individual eruptions. Many evolved magmas from the same source compositionally overlap through time and as the full compositional range may not be recorded distally, this becomes a problem for distal-proximal correlations. Trace element concentrations respond to more subtle variations in magma genesis responding to fractionation, mixing and assimilation. Consequently it is believed this variation will enable the generation of distinct geochemical 'fingerprints'.

Preliminary geochemical data is presented demonstrating the geochemical variability between the proximal deposits of Lipari, Stromboli and Salina. The acquisition of trace element data for the recent activity at Lipari (cycles IX and X) has demonstrated that there is little magmatic evolution over a period of ~11ka. Trace element patterns are indicative of similar degrees of K-feldspar fractionation, with anomalies in Ba, Sr and Eu. Additionally, presented here is preliminary geochemical data from the four distal tephra layers extracted from the Marsili basin core and possible correlations to their proximal deposits.

Application of trace element chemistry to Holocene tephrochronology in the North Atlantic region

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Explosive volcanic eruptions are considered to be geologically instantaneous events, and as a result the tephra layers they produce can be used for precise dating and correlating of Quaternary events. Icelandic tephra layers have been identified in Greenland ice cores as well as in soil, lacustrine and marine sediment archives across the North Atlantic. These provide a valuable dating tool for palynological, archaeological, palaeoclimatic and sedimentological studies in this region. Tephrochronology is used in conjunction with radio-carbon dating and soil accumulation rate studies to provide a robust and comprehensive dating method. While basaltic cryptotephras are identified, distal tephra deposits are dominated by silicic tephras (SiO2 > 63 wt. %). This dominance may be the result of low basaltic shard concentrations, post-depositional dissolution (known to affect basaltic glass in particular), or may simply be due to the typically explosive nature of silicic eruptions, which extend higher into the stratosphere, enabling transportation of ash particles by stratospheric winds to distal locations.

Previous workers have focused on identifying tephra layers using major element oxide data from the vitreous phase analysed by electron microprobe. Major element data has proved very effective in identifying the source volcanoes of tephra deposits as each system has a distinct geochemical fingerprint resulting from its location within Iceland's rift and flank zones. Electron microprobe analyses are favoured as the method is relatively inexpensive and provides rapid results. However, loss of mobile elements (i.e. Na_2O) during tephra analyses impact the overall wt. % values of the other elements analysed resulting in mis-identification and mis-correlation between tephra deposits. Application of major element analyses in the identification of tephras from within the same source volcano has, however, not been as successful. Distinguishing between these units is dependent on identifying subtle variations in chemistry representative of minor changes in magma evolution within the volcano through time. These variations are highlighted when using incompatible trace and rare earth elements. Researchers at the University of Edinburgh are currently developing a robust database of major and trace element chemistry for proximal tephras from reference locations within Iceland for use within the tephrochronology community. Major element data is being analysed using an electron microprobe and trace element data is being analysed via ion probe and laser ablation ICP-MS. Preliminary data for five large silicic Holocene eruptions of the Hekla volcanic system have confirmed the potential of this geochemical fingerprinting approach, allowing for distinction between three tephras previously considered to be geochemically identical.

Steep sided cones and their rapid collapse on the Mid-Atlantic Ridge, 45ºN

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The study of slow-spreading mid-ocean ridge volcanism provides important insights into the mechanisms of oceanic crustal accretion. This study uses a combination of side-scan sonar and recently developed methods of high resolution bathymetry and video data collection to describe the volcanic features on the Mid-Atlantic Ridge axis at 45ºN in more detail than has previously been possible.

Within most axial valleys lie Axial Volcanic Ridges (AVRs), linear volcanic features thought to be the focus of volcanism at slow spreading ridges[1-4]. AVR volcanic morphologies have been described independently in a number of studies, through combinations of remote sensing (predominantly through the use of side-scan sonar) and deep towed cameras or submersibles. These different methods have led to classification of volcanic features on two very different scales. While the resolution of the side-scan sonar studies allows only for the identification and classification of features tens to hundreds of metres in size, the photographic and submersible studies describe features from centimetre to metre scale. Until now it has been difficult to reliably link these observations together as no intermediate sensing method has been available. This study uses 1m resolution ROV multibeam bathymetry to address this problem and link features identified at different scales together.

We identify a prominent 22km long axial volcanic ridge within a 1000m deep axial valley, which ranges from 6 to 14km across. We find that "hummocks" described in previous side-scan sonar studies are actually steep-sided volcanic cones. These cones range from 2 to 200m in height and 40 to 400m in diameter and we identify over 8000 of them on the surface AVR. We calculate the average volume of a cone to be 224,300m^3 and estimate the AVR is built of approximately 72,000 such cones. We estimate these edifices form on time scales ranging from less than one hour to several months, as the products of single eruptions. Cones of all heights, but particularly those over 70m, are prone to collapse soon after forming, probably as a result of being built on unstable material on sloping seafloor. We estimate the minimum magmatic flux to the surface for this segment to be at least 64,000m^3 yr^{-1}, which is equivalent to producing one average volume cone every 3.5 years.

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Widespread transport of pyroclastic density currents from a Skye volcano: correlation of ignimbrite lithofacies and the evolution of the Palaeogene Skye Central Complex, NW Scotland

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A re-investigation of the volcanic rocks of the Skye Central Complex (SCC), NW Scotland, provides evidence for the widespread transport (up to 20 km) of pyroclastic density currents (PDCs) across the Palaeogene landscape. Detailed mapping and logging of volcaniclastic rocks (previously interpreted as agglomerates, felsites and lavas [1]) within the SCC, has allowed us to identify several distinct silicic ignimbrite lithofacies: (1) lithic-rich massive lapilli tuff, locally with normal and reverse grading, and/or diffuse stratification; (2) poorly sorted massive lithic breccia; (3) fines-rich massive lapilli tuff containing abundant accretionary lapilli; (4) rheomorphic lapilli tuff; and (5) rare massive crystal tuffs. These lithofacies provide evidence for extensive silicic pyroclastic activity within the SCC, and can be correlated to recognise two distinct eruption phases in its evolution, which had not previously been constrained.

At Fionn Choire on the NW margin of the Cuillin Hills on Skye, massive lapilli tuffs (unwelded, incipiently welded and intensely welded/rheomorphic), crystal tuffs and breccias crop out. These ignimbrites (and scattered exposures at Sgurr Thuilm, NNE of Glen Brittle) are cut by the Cuillin Centre gabbros and represent the first phase of silicic pyroclastic activity in the SCC. The massive crystal tuff, previously interpreted as porphyritic andesite lava [1], comprises ~50-60% plagioclase crystals, typically 1-2 cm and rarely up to 5 cm across, and shows tractional stratification and inverse crystal grading. This massive crystal tuff also contains distinctive rounded lapilli of mechanically fractured granite. The same unit has been identified at Ben Suardal, some 20km to the SE of Fionn Choire, indicating widespread transport of this unusually crystal-rich PDC. The intensely welded lapilli tuff, previously interpreted as flow banded rhyolite [1], displays a eutaxitic/parataxitic fabric and is commonly rheomorphic.

A second phase of silicic pyroclastic activity, post-dating the Cuillin and Western Red Hills intrusions is recognised, particularly in the Kilchrist area where a variety of ignimbrite lithofacies (types 1-4), forming a 200 m thick sequence, have been identified and correlated. A distinctive incipiently welded massive lapilli tuff can also be correlated with a sequence at Moll, some 10 km to the NNW, where it fills a palaeo-valley within the Northern Porphyritic Felsite (part of the Western Red Hills Centre).

Our detailed new stratigraphy records a complex eruptive history. The low-grade ignimbrites were typically deposited from unsteady currents with variable vent mass flux, and the accretionary lapilli were probably produced within co-ignimbrite ash clouds. These eruptions were also interspersed with low eruption column boil-over events where heat was maintained sufficiently for intensely welded/rheomorphic high-grade ignimbrites to develop.

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Can changes in caldera structure affect eruptive behaviour? An investigation in central México

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Silicic explosive caldera volcanoes generate some of the most catastrophic events at the Earth's surface, yet we know relatively little about their internal structures and whether this may affect how the magma chamber evolves and erupts over time. Some well-dissected ancient calderas (e.g. Snowdon, Scafell, Glencoe) reveal complex-faulted ('piecemeal') internal structures, but few modern examples of this are known largely because at young volcanoes most internal faults and associated conduits are hidden [1].

Los Humeros caldera, in Central Mexico is a possible modern example of a piecemeal caldera. It shows an overall trend from early, large-volume explosive rhyolitic eruptions towards more frequent, but smaller eruptions of less evolved (basaltic) magma with time. The eruption-units became progressively more zoned with increasing proportions of less-evolved magma. It has been proposed that Los Humeros volcano became more fractured with time due to successive caldera collapse events, and that this led to shorter magma residence times beneath the volcano, an increase in eruption frequency, and a reduction in eruption magnitude with time [2].

We aim to test this hypothesis by determining how the structure of the caldera changed with time by (1) attempting to map fault development by locating former eruption vents using fallout isopleths and isopachs, lava flow vents and scoria cones; (2) detailed structural mapping of representative sectors of the caldera floor where scarps and tilted sections may mark re-activated caldera faults; (3) analysis of subsurface data from geothermal drilling. We are documenting the pyroclastic stratigraphy together with geochemistry and petrology. This will involve field determination of the number of eruptions, hiatuses recorded by unconformities and palaeosols (which record extended repose periods) and $^{40}Ar/^{39}Ar$ radiometric analysis of key horizons (at S.U.E.R.C. Argon Isotope Facility). In this way we shall constrain temporal trends in eruption frequency and geochemistry.

Establishing a link between structural development and the scale and frequency of explosive eruptions would have significant implications for hazard prediction at other active caldera volcanoes worldwide.

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Granular segregation, levee formation and mobility of pyroclastic currents: new insights from sums, experiments and ignimbrites

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Particle size segregation can have a pronounced feedback on bulk flow properties and hence on the rate of advance and runout distance of a wide range of geophysical flows, including pyroclastic density currents. This occurs largely via the spontaneous formation of coarse-grained lateral levees and lobate terminations where resistance to flow is relatively high. This presentation reports new and preliminary results of large-scale experiments at the USGS debris-flow flume (in Oregon), as well as insights gained from small-scale granular avalanche experiments and from numerical modelling. At the flume we have captured both surface flow patterns, with high-speed photography, and contemporaneous internal segregation of coarse-grained material using tracer particles. Deposit granulometric architecture is captured by detailed transect sampling and systematic excavation. Results for wet 50:50 sand and gravel mixes show that levees can form very rapidly and that material at the front is partly re-circulated in the flow head; along the flow axis tracer pebbles segregate vertically at ~10-20 cm s^{-1} in a flow with a mean velocity of ~4 m s^{-1}. Small-scale laboratory experiments using initial sheet flows of fine ballotini and coarse carborundum produce fingering instabilities with characteristic wavelengths that define the width of subsequently formed leveed channels. Coarse-grained levees rapidly form, with a lining of fine material on their inner walls and across the channel floor. The deposition within the leveed channel acts to reduce friction and promote over-passing of coarse material to the flow front. Mathematical models utilising depth-averaged attributes reproduce the form and circulation within coarse-grained flow-head regions in three dimensions and indicate that fully coupled simulations that include segregation-mobility feedback effects are now within reach. Reconnaissance fieldwork on the 'Pumice Plain' at Mount St Helens during 2009 has found superb canyon-wall dissection of the pumice-rich, lobate ignimbrites of the July, August and October phases of the 1980 eruption. Preliminary observations reveal internal ignimbrite architectures of channels and levees akin to the deposits of our experiments. Complex particulate grading patterns, lateral and vertical, inverse and normal, reveal channelization and channel lining that can account for the considerable and protracted fluid behaviour of the channelized currents and their fresh deposits. In 2010 we will undertake a detailed study in collaboration with USGS-CVO to sample the 1980 deposits in detail and relate these to the excellent observational records and to our experimental data.

Ignimbrite reworking: experimental and field observations of remobilisation, shear instabilities and recumbent flames

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Sectioning of deposits from laboratory flume experiments provides detailed insight into the complex nature of interaction between consecutive pulses of granular flow, analogous to successive pyroclastic density currents (PDCs) (or pulses within single unsteady PDCs). Sequential charges generate complex shear-derived reworking and interaction between the active flow and underlying deposit. Recumbent flame structures are observed alongside larger scale Kelvin-Helmholtz (K-H) instabilities, and mathematical modelling indicates that similar instabilities should also form in natural PDCs. Complex, well developed reworking structures involve significant mixing at the boundaries between successive flow deposits. This has implications for the interpretation of temperature proxy data gleaned from charcoals [1], and chronostratigraphy (i.e., phenocrysts $^{40}Ar/^{39}Ar$, charcoal ^{14}C) from flow deposits and any underlying fall deposits. Furthermore, these shear instabilities provide a syn-depositional mechanism for recumbent flame structure formation in laminar shearing systems.

Observations from Bandas del Sur Formation ignimbrites (Tenerife, Spain) demonstrate entrainment of material from underlying substrate into the over-riding flow. Assuming that laminar shear is prevalent in the depositional region of dense PDCs, the lack of clear K-H instabilities in field deposits may be explained by 1) masking due to the “uniformity” in colour, constituents and composition of successive PDC deposits, and 2) rapid vertical migration of the shear zone during deposition precluding full K-H growth and preservation. The ability of thin dense granular currents to remobilise significant volumes from underlying loose material suggests an important role for reworking in the stratigraphies of density-stratified pulse and flow sequences, not least in inferences drawn from their interpretation (e.g. eruption volume & rate, flow volume, flow thickness).

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Modelling lahars at Galeras volcano, Colombia: a method for risk assessment

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Lahar hazard assessment typically involves trying to match results from model simulations with field observations. Here we attempt a similar assessment for an area within the Azufral Valley, Galeras Volcano, Colombia, where there is a very limited amount of field data. Risk to the bridge is assessed by combining observations of flow deposits from the field with computer simulations of flows. Recent flows within the valley have formed by one of two processes: remobilisation of pyroclastic deposits by heavy rain or failure of hydrothermally altered rocks near the active crater. This research aims to establish the risk to the Alfonso Lopez Pumarejo Bridge from such lahars. The bridge connects the small town of Consacá, to the West of Galeras, with Pasto city to the south and provides a vital transport link.

Fieldwork identified deposits from a range of flows, from debris flows to water floods, producing levees of more than a few metres in height. Historical deposits more than three metres high can be found downstream of the bridge. The bridge itself displays some erosion to the supports, especially those to the southern side of the river that appear to be built on flow deposits. These observations were used to assess the types of flows that have traversed the valley in recent times; however, there is little known about the scale of these flows.

The Titan2D geophysical mass flow model [1] was used to simulate flows of different volumes and basal frictions to determine the size of flow needed to 1) undercut the bridge, 2) undermine the bridge supports, 3) bury the bridge. The simulations show that as the volume of the flow is increased, the flow depth and velocity increases. When the basal friction of the flow is increased, the velocity of the flow decreases. This research also highlights the difficulty in using computer models to simulate complex processes such as lahars and gives an evaluation of Titan2D with this respect.

The results from both field and modelling efforts are brought together to establish the risk to the bridge and identify key information needed to produce a risk assessment for the area in question.

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Infrasound generated by Strombolian eruptions: insights from laboratory experiments

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In recent years infrasonic monitoring at volcanoes has become an increasingly common tool. Much of the current work on volcano infrasound has concentrated on Strombolian eruptions [1, 2, 3]. The various suggested mechanisms for the production of infrasound at these volcanoes include an "explosive point source" at depth within a fluid filled conduit [4], the oscillation prior to bursting of a large gas slug at the surface of a fluid filled conduit [2], or the actual bursting of this gas slug [1]. The precise mechanisms at the vent need to be understood if infrasound recorded in the field is to be used to infer conditions in the volcanic system.

In this work, laboratory experiments using audio recordings and high speed video footage have been conducted to gain a deeper understanding of these oscillations. A simple model is used as an analogy for a Strombolian eruption: a bubble rises through a viscous Newtonian fluid (Golden syrup) and bursts at the surface. Although the experimental set-up is simple and idealized, it allows control of physical properties and measurement of the processes observed far more accurately than would be possible in the field. Various physical parameters which may control the form of the acoustic wave produced, such as viscosity, bubble volume, and rupture speed, have been investigated.

Initial results show that the onset of the main part of the acoustic waveform occurs concurrently with the onset of bubble rupture. Viscosity is seen to influence both the amplitude and the frequency of the waveform, and perhaps plays a part in controlling the speed of rupture. It seems plausible that the rupture speed and pressure difference control the rate of mass outflow from the pressurised bubble, which in turn controls both the amplitude and frequency of the waveform. Results are to be compared to a simple numerical model linking the flow of mass from a pressurised bubble through a growing aperture, and the pressure fluctuations this causes in the atmosphere.

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The evolution of volcanic eruption columns

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The classical steady state model for Plinian eruption columns, due to Woods [1], is extended to allow the source conditions at the volcanic vent to change in time. It will be shown that when the source conditions change rapidly, over time scales typically less than approximately 3—4 min, this new time-dependent volcano model [2] becomes appropriate.

The differing effects on the eruption column between changing in source velocity and source temperature are considered. Qualitatively similar structures are formed when either the source velocity or source temperature is reduced. A transient region is formed, characterized by a narrowing of the ‘top hat’ eruption column radius. Within the developed model it is also possible to allow for the source size (i.e. vent size) to change in time too.

A first attempt to a model a Plinian eruption column, from its dynamic initiation in a volcanic eruption, is made. It is shown that the velocity at the front of the eruption column is significantly slower than the velocity at the same height in an established eruption column. Therefore, current best estimates of developing eruption column heights, based on quasi-steady models, are a significant over-prediction.

It is hoped that this new time-dependent volcano model will be a useful tool for practitioners investigating eruption dynamics of volcanos, or the more time periodic vulcanian eruptions.

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Understanding the cessation of lava flows using remote time-lapse camera data

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The early stages of effusive volcanic eruptions, during which lava flows are lengthening, are often monitored closely for hazard management purposes, and so the processes involved are relatively well understood. However, the later stages of relatively long-lived eruptions can comprise many months of small and transient flow activity at ephemeral vents which, due both to their scale and to problems of access, are more difficult to observe and hence are less well understood. Nevertheless, if we hope to comprehensively model lava flows in the future, the controls on the initiation and cessation of such vents and flows need to be understood. Here we present data from a remote camera deployment which captured flow processes during the development of a portion of the most recent flow field emplaced on Mount Etna, one month before the eruption ended.

The eruption, which lasted from May 13th 2008 to July 5th 2009, emplaced flows from a fissure at 2700 m a.s.l on the headwall of the Valle del Bove. These reached 6 km in length during the first 2 months of activity, before gradually contracting due to diminishing effusion rates. Activity after August 2008 caused substantial modification of the headwall, producing a megatumulus, the active portion of which gradually reduced through 2009. During fieldwork in mid-June 2009, the upper part of the flow field was tubed, and lava was emerging from a number of tumuli at ~2600 m a.s.l., feeding several flows that reached a few hundred metres in length. A remote time-lapse camera was installed on the flow field to record the activity of an ephemeral vent that fed several small flows over a ~24 hour period. Images were collected at 3 minute intervals, and recorded apparent changes in effusion rate on timescales of minutes to hours, the inflation and deflation of tumuli, the formation of breakouts and channel switching. The data provide unique insights into processes that lead to the cessation of activity of small flows, and the initiation of new flow units.

Graben-related volcanism and associated sedimentation, landscape evolution and palaeo-ecology during the early development of the Palaeogene Mull Lava Field, NW Scotland

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The name Staffa Formation is proposed for the early sequence of volcanic and associated sedimentary rocks of the Palaeogene Mull Lava Field, which crops out in the Inner Hebrides, off western Scotland. The Formation is defined as the sequence between the sub-Palaeogene unconformity and the base of the so-called Plateau (Formation) lavas. Field observations across the outcrop reveal that the Formation is a complex, laterally-variable sequence of lava facies, hyaloclastites and other breccias, and various interflow sedimentary rocks. The sedimentary rocks and associated palaeo-surfaces, in as much as they represent significant periods of hiatus in the volcanism, have enabled us to subdivide the Formation into anumber of allostratigraphical units termed genetic sequences. Each sequence is essentially a couplet comprising a basal sedimentary unit and an upper volcanic unit. In detail, some sequences may comprise more than one, laterally restricted, sub-couplet. There are systematic patterns in both the distribution and thickness of the sedimentary and volcanic lithofacies that make up these major units. The individual sequences appear to show a strong structural control of thickness, distribution and lithofacies, which we link to palaeo-topographic effects, especially their position within pre-existing Palaeogene fault-controlled valley systems or active, syn-volcanic graben development. The presence and significant roleplayed by the contemporaneous drainage system and topography during the evolution of the Staffa Formation is demonstrated by the number and variety of intercalated sedimentary units and the nature and facies of the volcanic products. The clearest example of the latter is the close association of hyaloclastite breccias and the emplacement of thick, impounded lava flows exhibiting classical two-tiered columnar joints. Palaeontological data, most especially palynological analysis, allows further detailed ecological characterisation of the sedimentary units and palaeo-surfaces and the development of a model for the early landscape evolution of the lava field. The taxa of the sedimentary sequence at the top of the Formation are typical of the early Eocene and contain elements characteristic of post-Late Palaeocene Thermal Maximum sites throughout the NE Atlantic region.

A Palaeogene, Pre-Flood basalts Supervolcano in Co. Antrim? evidence from the 'Clay with flints'

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Usually sandwiched between the Cretaceous Chalk (Ulster White Limestone Formation) and the Palaeogene Antrim Lava Group flood basalts, the Clay-with-Flints (1) deposit was believed to have formed as a palaeosol, combining the weathering products of chalk and flint, an aeolian component and illuvium from the overlying basalt lavas (2). However, its mineralogy includes altered olivine, broken quartz crystals and euhedral crystals of zircon and chrome spinel (preliminary U-Pb zircon age 60.9 ± 0.5 Ma), which clearly indicate that complex, contemporaneous volcanism contributed much of the clay fraction (3).

New geochemical and isotopic data lead us to suggest the following multi-stage model (as opposed to an early, single, explosive 'acid-basic' event):

1) Pre-basalt explosive (pyroclastic flow) eruption of 'andesitic' or more evolved magma, during which flints were entrained from the early Palaeogene land surface, the resulting deposit covering a substantial area of NE Ireland.

2) In places a later, airfall pyroclastic component (lapilli tuff) was added, this relating to the earliest flood basalt eruption which encountered a wet terrain.

3) Redistribution of these earlier pyroclastic materials by mudflows, perhaps related to plume uplift and subsidence.

We thus propose there may have been an early Palaeogene pre-flood basalts central volcano in NE Ireland, probably the first, or one of the first, magmatic manifestations of the Icelandic Mantle Plume on the Irish lithosphere. In its magma chamber there was early crystal fractionation of basaltic magma (AFC?), generating the more siliceous liquid responsible for the first explosive event, but most of this volcano's remnants are now hidden beneath the later flood basalts (possibly aided by pre-basalt caldera collapse?). On this model there are exciting possibilities for economic mineralisation (Ni, etc) beneath the Antrim Plateau.

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Magma intrusion, degassing and hydrothermal setting of the Yellowstone Caldera

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The Yellowstone Caldera continues to exhibit considerable unrest, displayed by frequent earthquakes, considerable ground deformation and persistent hydrothermal activity [1]. Yellowstone ranks among Earth's most prolific heat sources and a potent producer of natural emissions of carbon dioxide. Recent work indicates that magma intrusion rates remain high beneath Yellowstone, and the region is underlain by both rhyolitic and basaltic magma. In this presentation, I will discuss recent activity and unrest at Yellowstone, evidence for continued intrusion beneath the region, and our efforts to use gas and fluid geochemistry to gain insight into ongoing magmatism and related hydrothermal activity [2]. Our gas sampling reveals marked geographic variability as one traverses the caldera, yet impressive consistency within a given area. Isotopes of helium, carbon, oxygen and hydrogen, as well as trace gas ratios provide insight into shallow crustal and magma degassing [3]. Gas variations and flux are interpreted to demonstrate that gas is derived not through mere boiling of a liquid-dominated hydrothermal system, but instead indicate open-system passage of gas through the hydrothermal system from magma combined with decarbonation/degassing of crustal rocks.

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Abstracts

Poster Presentations

Alphabetical order

Imaging active lavas with a very-long-range terrestrial laser scanner and thermal camera

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Our understanding of lava flow processes has improved greatly over the past few decades, and the initial stages of flow emplacement can now be reproduced relatively well by numerical flow models. However, long-lived eruptions commonly produce complex flow fields consisting of multiple channels and lava tube systems, and the roles played by processes such as channel switching, flow inflation, ephemeral vent formation and drainage cannot currently be modelled. In order to increase our understanding of these processes, the activity and topographic development of flow fields needs to be monitored frequently and in detail during eruptions.

Data of sufficient accuracy, spatial resolution and repeat frequency can now be acquired using laser scanning techniques. The use of airborne surveys allows measurements over hazardous terrain, but over-flight costs prevent the frequently repeated data acquisition required to assess the development of lava flow fields. Until recently, the use of ground-based terrestrial laser scanners (TLSs) in volcanological applications has been hampered by relatively short maximum measurement ranges (often hundreds of metres). Here we present data acquired using a new Riegl LPM-321 TLS, which has a quoted maximum range of 6000 m. During the recent eruption of Mt. Etna, Sicily, we successfully used the instrument to image both lavas and ash slopes at distances of up to 3500 m. Despite very low effusion rates at the time of surveying, topographic changes associated with the emplacement of new flows and the inflation of existing flows were detected. Active flows captured within the datasets can be visualised by fusing the topographic data with thermal images, allowing ongoing activity to be represented in orthorectified datasets.

Volcanology and petrology of arc magmatism in South Mayo

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The Ordovician Lough Nafooey Group of South Mayo is believed to mark the onset of subduction within the Iapetus Ocean. In order to place this group in a volcanological and tectonic context the two lowermost formations, the Bencorragh and Finny Formations, are being investigated.

Detailed field investigations and systematic sampling across the two formations have revealed a complex stratigraphy. Both formations have similar volcanological features; they are composed of pillow and massive lavas, with interbedded breccia units. As a result they have been defined based upon the first appearance of andesitic magmas. The stratigraphically lower Bencorragh Formation is defined by spillites while the overlying Finny Formation is slightly more evolved and is defined by keratophyres. Geochemical analysis has shown that both formations have differing source characteristics. Major element data shows that the Bencorragh Formation has both a tholeiitic and calc-alkaline signature. This implies the transition from ocean floor magmatism to arc magmatism occurred within the Bencorragh Formation, instead of at the boundary between the two formations, and subduction was ongoing during part of the Bencorragh.

A 3-D visual model is being produced for this area which incorporates the geology, stratigraphy, structure and geochemical analysis and presents it within a user-friendly interface. The results of investigations and analys which have been carried out will be presented within this format.

Hazards on Tendaho dam and irrigation scheme due to active propagation of the Red Sea rifting structures towards to the Tendaho Graben; Afar Depression, NE Ethiopia

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The proposed Tendaho Reservoir and Irrigation site is located at the center of the Afar Depression where the Main Ethiopian Rift (MER), the Red Sea Rift and the Gulf of Aden Rift join at the extensional triple junction. The entire irrigation scheme and the reservoir area lie within the Tendaho Graben and at the west horst of the Graben (Tendaho Goba'ad Discontinuity (TGD)), respectively. The rifting hazards were estimated from the datasets of published tectonic model of the area, seismological records, field mapping of historical evidences and the recent formation of the Dabbahu, 2005 and Karbahri, 2007 rifting episodes. Three assumptions were considered for the prediction of potential occurrence of the active rifting hazards in the Tendaho Graben. The 50 - 60km wide Tendaho Graben was opened by the Manda Hararo and Tendaho rifting (1) with a constant spreading rate; (2) with a number of violent rifting episodes and magma injection; (3) with both events alternatively. Based on the above assumptions, the average potential occurrence of the active rifting hazards during the lifetime of the schemes were estimated as 0.6 and 1.8% from the Manda Hararo and Tendaho rifts, respectively. If the rifting is supplied with sufficient magmatic injection, the horizontal and vertical ground deformation along the rifting axis may reach up to 15 – 20km buffer zone. Such deformation affects nearly 75% of the project schemes (the irrigation structures, embankment dam and reservoir).

Forecasting large explosions using thermal satellite data at Bezymianny volcano, Kamchatka

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Volcanic ash injected into aircraft routes poses a severe risk to both life and cargo, with an estimated economic risk in the US alone of $70 million annually. Here we present a new method of forecasting explosive eruptions based on the spectral radiance received by orbiting Advanced Very High Resolution Radiometers (AVHRR). Volcanic dome building episodes commonly show increases in extrusion rate prior to erupting explosively, which will result in an increase in the radiated thermal flux that can be detected by satellites and therefore used in forecasting.

From mid-1993 to mid-2008 Bezymianny exhibited 20 large (ash plumes>6 km a.s.l.) explosions, and three phases of dome growth without reported accompanying explosions. AVHRR data are available surrounding 19 of the explosions. Three types of precursory activity are observed before explosions: (I) in two cases precursory thermal anomalies clustered around the mode of the dataset (8.5℃), (II) three explosi ons were preceded by major thermal activity causing sensor saturation and (III) fourteen explosions were preceded by minor precursory thermal activity in which an upward trend in thermal anomaly values was detected 1-5 days before an explosion.

A pattern recognition algorithm based on the trends observed prior to known explosions uses contextual, temporal and fixed threshold approaches to analyze slope and intercept values of straight lines fitted through 30-day moving windows of AVHRR thermal data. Using type II and III precursory patterns, the algorithm triggered at least one alert in the 30 days preceding all of the 17 explosions that show precursory increases in pixel-integrated radiant temperature. The alerts issued by the algorithm are colour coded: yellow, orange and red alerts indicate probabilities of an explosion within the next 30 days of 43, 64 and 83% respectively.

This study highlights that it is possible to develop a computationally simple but successful algorithm to forecast explosive behaviour in near real-time based on thermal changes. This algorithm will provide alerts of changes in the time series that would not be obvious to analysts looking at a single image and it can serve as a trigger to evaluate other available geophysical datasets (e.g. seismic data) alongside the thermal data. Precursory thermal data from future explosions can be used to update and adjust the algorithm as required, potentially resulting in even greater forecasting accuracy. It will be beneficial to try this technique at other dome-forming volcanoes around the world.

Anatomy and emplacement of a caldera-bounding ring-dyke: an example from Loch Ba, Isle of Mull, northwest Scotland

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The Igwisi Hills Volcanoes, Tanzania: superbly preserved rare examples of young kimberlite volcanism

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The Igwisi Hills volcanoes in Tabora Province, Tanzania, are the youngest kimberlite volcanoes on Earth. They occur isolated from other young, rift-related volcanoes on the western side of the Tanzania Craton. Recent fieldwork on the volcanoes has allowed the creation of a new geological map and has uncovered deposits types not recognised before and not recorded in any other kimberlites worldwide. They comprise three well-preserved small volcanoes aligned SW-NE. The NE volcano comprises a flat-bottomed crater 400 m in diameter. Crater walls comprise fine-grained, granite-rich vent-clearing pyroclastic rocks overlain by scoria fall deposits. An olivine-rich vesicular lava has breached the NE side of the crater, flowing ~ 500 m from the volcano. A series of lava terraces suggest that the crater was periodically filled with a lava lake. The central volcano comprises a 70 m-high elliptical mound of gently dipping scoria and coarse ash, open to the north, and within which a 50-m high, horseshoe-shaped lava coulee has grown. This lava coulee, which is the first ever to be documented from a kimberlite eruption, flowed several hundred metres to the SW. The SW volcano is a 40-m high low aspect-ratio cone of scoria and ash with a broad, flat crater floor. A stubby vesicular lava flow was emitted from the SE side of the volcano. The presence of coulees and viscous-looking lavas was unexpected given the low-silica contents of kimberlite magmas and their inferred very low viscosities—significant groundmass crystallisation must have occurred during ascent. There is no reliable absolute age for the volcanoes yet, but a sweepstake by the authors, prompted by a prize of a good bottle of wine, produced guestimates over two orders of magnitude, from 7-700 ka.

The interactions between tephra and advancing lava during basaltic fissure eruptions: examples from the Roza Member, Columbia River Basalt Province

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Synchronous effusive and explosive activity can occur during basaltic fissure eruptions. Lava pooling at the base of fountains can advance through tephra falling from either its parent fountain or from the fountain of a neighbouring fissure segment. There are a number of ways in which the lava and the tephra can interact and these have implications for our ability to reconstruct events during fissure eruptions and for how we estimate the partitioning of erupted magma into effusive and explosive products. In the Roza Member of the CRBP, pahoehoe lobes and sheetflows are seen intercalated with tephra deposits. At some locations, tephra which fell onto the tops of hummocky inflating flows became disrupted by tumuli into a series of mounds and hummocks. During the inflation of the tumuli, tephra percolated into the clefts and around the rubble, in some cases coming into contact with lava hot enough to thermally alter it. Tephra beneath some sheet lobes has become welded to a depth of > 1 m, and forms a glass in contact with the lava. The basal and upper surfaces of a flow field are diachronous and thus where the advance of lava and the fallout tephra are synchronous, the lava will cut diachronously up through the accumulating tephra deposit with distance from source. These interactions pose problems when trying to correlate pyroclastic layers around fissures and attempting to construct isopach maps: without marker horizons within the tephra deposits it becomes extremely difficult to correlate pyroclastic units around a fissure. Dense welding of thin (< a few decimetres) tephra layers by lava flows means they might be extremely hard to recognise away from a fissure (i.e, in distal areas).

Extracting palaeo-volcanological reconstructions of explosive eruptions from limited outcrops

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Many of the worlds volcanoes are found in areas where limited outcrops of previous volcanic events are preserved (e.g. tropical rainforests and deserts). Hazard assessments in these areas require a new and different methodology compared to eruptions where there is a substantial record. The aim of this study is to determine optimum field measurement and sampling strategies in order to calibrate tephra dispersal models when there are few outcrops that can be used for this purpose.

Computer simulations of tephra dispersal are a primary method of hazard assessment. A major problem with these simulations is that they are often dependent on field data, such as deposit thickness, grain size distribution and maximum particle size, from a large number of sites. Data from a field study on the Minoan Fall deposit on Santorini has been modelled in TEPHRA2 in an attempt to reconstruct the plume dynamics from a single outcrop. Simulations were based on a large amount of information on grain size distribution and maximum lithic particle size collected from one location in the deposit. Two outcrops were modelled in this way one on the main dispersal axis and one off axis.

Uncertainty in the data collected in the field can lead to discrepancies in the reconstructed plume dynamics, e.g. column height and maximum discharge rate. The uncertainties in the field practices used in this study have been evaluated in an attempt to constrain the most representative way of collecting data from a single outcrop. Maximum particle size has been determined by measuring the 5 largest particles in different sized areas to determine the effect of area sampled on the largest particle measurement. The methodology for measuring maximum particle size was also tested by calculating the estimated sphere diameter (ESD) of each particle from two and then three orthogonal axes. Grain size distribution of the fall deposit was determined from different volumes of the sample to identify the optimum size of sample required.

Mantle micas within xenoliths from Oldoinyo Lengai, Tanzania

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Oldoinyo Lengai is one of the most active volcanic producers of carbon dioxide gas (~7,200 tons/day), and combined with its extrusive carbonatite lava activity, contributes an important carbon footprint in the East African rift valley, which is a high CO_2 region. Oldoinyo Lengai appears to operate on two scales, with (a) long term nearly continuous passive carbonatite lava effusion, interrupted by (b) more explosive activity (1966-7, 2007-8) dispersing ash-rich products. The onset of this latest explosive activity began with a voluminous lava flow down the western flank of the volcano consisting of mixed silicate and carbonatitic material [1]. Further investigation of this lava revealed the presence of melanophlogite [2] not previously seen within the lavas at Oldoinyo Lengai, posing the question whether changes have occurred in the volcano dynamics since its activity in 2006 -7 that allows the crystallisation of this interesting mineral.

Since its violent eruption in 2007, Oldoinyo Lengai has been relatively unstudied due to its unstable upper flanks and inaccessible excavated pit crater. However in 2009 a suite of 12 xenoliths from both the upper flanks surrounding the active northern crater and within the inactive southern crater were recovered along with a mica book up to 4cm across and 0.5cm thick, previously unseen at Oldoinyo Lengai but present at other volcanic centres in the vicinity [3]. The xenoliths represent both igneous and fenitised material revealing the intricate nature of the volcanic complex beneath the edifice of Oldoinyo Lengai. Microprobe analysis of the minerals within the xenoliths reveal a number of interesting features; in particular that of a large (up to 1mm across) phlogopite crystal, hosted in an ijolitic xenoliths, showing kink band deformation and compositions akin to mantle (Mg # 84 - 86) and kimberlitic material. Olivine megacrysts are also present within this ijolite block and show high Mg# 82 – 84. Although similar to those previously described [4], the Mg number of more recent xenoliths are higher and the deformation of mica minerals is unreported.

The aim of this study is therefore to determine whether these megacrysts were derived from the mantle or whether they represent early crystallisation or metasomatic minerals. The outcome of this would provide an insight into the dynamics of the magmatic system beneath Oldoinyo Lengai.

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Diagenetic effects of igneous bodies in sedimentary basins

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Until recently, volcanic dominated sequences have been disregarded as being significant in terms of their potential to act as oil or gas reservoirs. However, recent exploration has identified new play models comprising of siliciclastic sedimentary rocks, intrusions, lavas, and volcaniclastics. But just how problematic are igneous bodies in sedimentary basins? Recent work has started to direct attention to the sediment-lava interface at the base of flood basalt units and at the relationships between intrusions and the host sedimentary basins.

This investigation aims to produce a conceptual model for diagenesis within such basins. Firstly the diagenesis of sediments with no volcanic input will be considered, including factors such as compaction, cementation, and dissolution, amongst others. Secondly the diagenesis around volcanic intrusions will be considered. The effects of intrusions on surrounding sedimentary rocks is very different to that of normal burial diagentic processes, although over large distances the maximum temperatures attained in the host rock may not be much more than the temperatures of advanced burial diagenesis, clearly localised areas will be greatly affected. The direct diagenetic effects of the hot contacts between the intrusion and the host rock will be examined, as well as more indirect effects such as the ability of the intrusion to compartmentalise the reservoir or to act as a conduit and/or driver for fluids. The effects of lavas will act as the third component to the model. Similar to intrusions, lavas have a hot contact at their base. However weathered material can also be incorporated into sediments forming volcaniclastics. The burial diagenesis of volcanic fragments is different to that of siliciclastic material and therefore adds another level of complexity to the diagentic model.

During the Palaeogene, intense volcanic activity strongly influenced the development of the western portion of the Faroe Shetland basin. Recent discoveries within the interbasalt sediments in the offshore basin, outlines the importance of understanding the diagenetic effects of igneous bodies. The best sediment-igneous relationships in onshore examples will be integrated to address issues raised from the offshore examples and ultimately provide a better understanding of the North Atlantic Igneous Province.

$^{40}Ar/^{39}Ar$ ages and volatile contents from subglacial and subaerial rhyolite glass

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Dating of volcanic glass by $^{40}Ar/^{39}Ar$ offers a valuable means of accurately dating geologically recent eruptions, yet is typically avoided due to the associated analytical challenges (e.g., alteration, recoil, alkali loss). Characterization of major volatile contents (e.g., H_2O CO_2) in glass can lend a better understanding of the eruption, devolatilization, and degassing history of the magma. This can allow for a better assessment of determined $^{40}Ar/^{39}Ar$ ages and perhaps illuminate trends between eruption environment, degassing behavior and the occurrence of poor/incorrect ages.

In this study, young subaerially (post-glacial) and subglacially erupted obsidians from Torfajökull, Iceland, were dated by $^{40}Ar/^{39}Ar$ to constrain the time of eruption and compare the Ar-isotope signature in obsidian from different eruptive environments and with different degassing histories. To investigate the role and extent of degassing, major volatile contents (H_2O CO_2, F, Cl and S) were measured by Cameca NanoSIMS 50L [1].

Ages from subglacial glasses range from 89 ± 19 to 114 ± 22 ka at Bláhnúkur, and from 193 ± 22 to 207 ± 5 ka at Háskerðingur. High ^{36}Ar concentrations are present, consistent with previous Ar-Ar studies of Icelandic rocks [2]. This suggests atmospheric contamination to varying degrees present in both subaerial and subglacial glasses, contributing to large corrections for atmospheric argon and resulting in larger errors on the determined ages. No plateau ages were determined on the post-glacial subaerial glasses. Low volatile contents indicate that all of the glasses are largely degassed, with typical H_2O contents of 0.1 wt % and degassed entirely of CO_2 indicative of equilibrium at atmospheric pressure.

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Evidence of late-stage metasomatism preserved in chromitite seams of the Shetland Ophiolite (Scotland)

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The lower (mantle) portion of the Shetland Ophiolite Complex (~492 Ma) contains numerous podiform Cr-spinel-rich seams. In reflected light, thin sections of many of these chromitite seams (>60% Cr-spinel) contain Cr-spinel crystals that are either relatively fresh, have a well-developed sieve texture, or a combination of both of these textural types. The chromitite seams appear to be texturally equilibrated and there is evidence for sintering of Cr-spinel crystals. In the case of the sieve texture, Cr-spinel crystals display many internal cracks and ragged poorly defined edges. Reflected light petrography reveals that the sieve-textured areas are associated with areas of brighter reflectance, particularly around crystal edges and along cracks within crystals. Typically, there are also many small (<0.1 μm) very high reflectance grains, some of which represent Platinum-group minerals (PGM) [1].

Unaltered Cr-spinels have compositions ranging between stoichiometric picrochromite ($MgCr_2O_4$) and chromite ($FeCr_2O_4$). These data plot in the 'ophiolite field' of standard discrimination diagrams [2] (e.g., Cr# vs. Mg# and Al^{3+} vs. Cr^{3+}) and are interpreted to represent primary Cr-spinel compositions. The sieve-textured zones correspond to Cr-spinel compositions that are markedly depleted in Al^{3+}. Corresponding enrichments in Fe^{3+} and Cr^{3+} are observed, indicating that the sieve-textured Cr-spinel is ferritchromit. Combined, the textural and mineral chemical evidence suggests that the ferritchromit is the result of late stage alteration of the Cr-spinel. Given that serpentinisation is typically associated with highly reducing fluids, it is suggested that the Shetland Ophiolite chromitites also record a later-stage low temperature oxidation event that caused Fe^{3+} enrichment after pervasive serpentinisation [1].

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Using thermochronology to identify "hidden" magmatic events in the geological record: evidence for mid-Eocene magmatism in the Scottish onshore NAIP

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Our understanding of any volcanic system is dominated by information that can be gathered from rocks sampled at the surface. In many cases these can tell us something about the processes that occurred, or are still occurring at depth; however, we can rarely build up a comprehensive three dimensional model of the system without relying on cross sectional exposures and our existing knowledge. Post-magmatic denudation exposes the plutonic roots of volcanic systems, but it may also remove all evidence of small volume, high level, or late stage intrusive and extrusive events, that are important if our understanding of the entire system is to be accurate. For this reason the later stages of the magmatic evolution of many Large Igneous Provinces are poorly constrained and there are therefore significant uncertainties in estimations of total volumes, and the impact of these large magmatic events.

The widening thermal sensitivity of low termpreature thermochronology, achieved through the combination of the fission track and (U-Th)/He systems (apatite and zircon), now provides a powerfull tool for identifying these "missing" late stage or small volume intrusive events that are unexposed at the present outcrop, and for constraining the former extent and volume of eroded sections. We present a case study from the Hebridean Igneous Province where the combination of zircon (U-Th)/He, apatite fission track and apatite (U-Th)/He has revealed important information about the immediately post-magmatic Palaeogene denudation, but also revealed strong evidence for a previously unidentified mid-Eocene magmatic event in this region.

Across all four central complexes of the Hebridean Igneous Province zircon (U-Th)/He cooling ages (61.4 ± 2.3 Ma on Skye; 58.0 ± 1.7 Ma on Mull; 55.9 ± 3.2 Ma on Ardnamurchan; 55.6 ± 5.4 Ma on Rum) are indistinguishable from the apatite fission track cooling ages (61.2-57.2 Ma) and overlap crystallization ages, implying that all plutons cooled rapidly to near surface temperatures immediately after emplacement. Denduation of the major Hebridean lava fields and volcanic superstructures was therefore very rapid, and occurred immediately after the cessation of eruption. However, some apatite fission track ages, the fission track lengths, and apatite (U-Th)/He ages identify a significant mid-Eocene (45-47 Ma) cooling that locally affected parts of the Skye and Rum central complexes. The data implies the structurally-controlled advection of heat driven by shallow level intrusion at ~47 Ma. This is the first identification of magmatic activity in the Hebridean Igneous Province in the mid Eocene, and demonstrates the ability of low temperature thermochronology to identify "hidden" magmatic events.

We also present new U-Pb data and low temperature thermochronology that constrain both Palaeogene emplacement and mid Eocene cooling of the St Kilda Central Complex. Together, these data elucidate the regional post-rift evolution of the European Atlantic Margin.

Petrology and geochemistry of intra-caldera ignimbrite sequences from the Central Ring Complex, Isle of Arran

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The current exposure of the British & Irish Palaeogene Igneous Province is dominated by significant thicknesses of fissure fed basaltic lava fields, and large, granitic and gabbroic plutonic complexes that represent the root zones of the Palaeogene volcanic superstructures that deveopled immediately after fissure fed activity. The unroofing of these plutonic central complexes has removed the majority of the late stage volcanic products and obscured the …..

We present prilinary field data, petrology and geochemical analyses from a intra-caldera sequence of ignimbrites, the

The Central Ring Complex on the Isle of Arran is the only reported exposure of caldera

Observations of the Central American Volcanic Arc from InSAR

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We present selected results from an InSAR survey of volcanoes in Central America. The Central American Volcanic Arc is made up of over 75 Holocene volcanoes, of which about 25 are historically active. The majority of these volcanoes aren't monitored and a significant number are isolated and inaccessible. Satellite data is therefore a unique source of information for assessment of the level of volcanic activity.

Interferometric Synthetic Apeture Radar (InSAR) is a satellite technique that uses the phase difference between radar images to find small ground motions. In the past few years, new satellites using longer wavelength radar have opened up much of the tropics for InSAR studies, since older, shorter wavelength radar instruments are unable to penetrate dense vegetation.

Just over 50% of all volcanoes surveyed showed no deformation, including several volcanoes that were actively erupting during the period of the survey. The lack of deformation observed at erupting volcanoes may be indicative of a lack of shallow magma storage and rapid transport of magma during eruptions. The remaining volcanoes were dominated by atmospheric signals that we analyse in terms of their relationship to seasonal variations in water vapour. Interesting results so far include atmospheric signals at Momotombo, Nicaragua and subsidence associated with edifice instability at Arenal, Costa Rica.

Emplacement temperatures of pyroclastic and volcaniclastic deposits in kimberlite pipes in Southern Africa

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It continues to be debated whether kimberlite pipes are formed by the explosive degassing of magma or by the interaction of rising magma with ground water (phreatomagmatism). A crucial piece of knowledge that has been lacking is the emplacement temperatures of kimberlite deposits, and this information would provide important constraints on kimberlite eruption mechanisms. Progressive thermal demagnetization studies are a powerful tool for determining the emplacement temperatures of ancient volcanic deposits and we present the first application of such techniques to kimberlite deposits.

Lithic clasts were sampled from a variety of lithofacies, from three pipes for which the internal geology is well constrained (A/K1 pipe, Orapa Mine, Botswana and the K1 and K2 pipes, Venetia Mine, South Africa). The sampled deposits included massive and layered vent-filling breccias with varying abundances of lithic inclusions and layered crater-filling pyroclastic deposits, talus breccias and volcaniclastic breccias. Lithic clasts sampled from layered and massive vent-filling pyroclastic deposits in A/K1 were emplaced at >590℃. Results from K1 and K2 provide a maximum emplacement temperature limit for vent-filling breccias of 420-460℃; and constrain equilibrium deposit temperatures at 300-340℃. Crater-filling volcaniclastic kimberlite breccias and talus deposits from A/K1 were emplaced at ambient temperatures, consistent with infilling of the pipe by post-eruption epiclastic processes. Identified within the epiclastic crater-fill succession is a laterally extensive 15-20 metre thick kimberlite pyroclastic flow deposit emplaced at temperatures of 220-440℃. It overlies the post-eruption epiclastic units and is considered an extraneous pyroclastic kimberlite deposit erupted from another kimberlite vent.

The results provide important constraints on kimberlite emplacement mechanisms and eruption dynamics. Emplacement temperatures of >590℃ for pipe-filling pyroclastic deposits are consistent with volatile-driven eruptions, and suggest phreatomagmatism did not play a major role in the generation of the deposits. The discovery of an extraneous pyroclastic flow deposit within the Orapa A/K1 epiclastic crater, which was erupted from another vent, suggests kimberlite eruptions are capable of producing sustained eruption columns and thick pyroclastic deposits involving significant transport away from source.

Geochemical and textural insights into degassing of obsidian from Lipari Island, Italy

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Obsidian is dense volcanic glass which occurs in both effusive and explosive silicic volcanic deposits and is thought to form in the volcanic conduit or lava dome through degassing, melt-vapour separation and densification. Effusive and pyroclastic obsidian often show distinct geochemical and textural characteristics that might shed light on degassing processes and eruption mechanisms. The aim of this study was to understand how pyroclastic obsidian formed at the Monte Pilato volcano, Lipari, Italy. Samples of both pyroclastic obsidian, collected from thick sequences of tephra fall erupted 4810 ±10 yr BP (before present) to 729AD [1] and effusive obsidian from the Rocche Rosse lava flow (erupted 729AD) were collected. Fourier transform infrared (FTIR) spectroscopy was used to measure the water contents of the obsidian and scanning electron microscope (SEM) images were used to identify and characterise textures relating to degassing and gas loss. There are two mechanisms for forming pyroclastic obsidian at Monte Pilato, based on volatile contents and texture. The pyroclastic obsidian is mostly formed by shearing and brecciation of magma at the conduit walls during eruption. A fraction of the pyroclastic obsidian appears to be derived from a slowly cooled body, shown by the presence of spherulites which take some days to form in hot glass, which was excavated by subsequent eruptions.

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Volcano-tectonic evolution of Martinique Island (Lesser Antilles Island arc): new geochronological, geomorphological and geochemical constraints

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The Lesser Antilles Island arc, which is double in its northern part, was built in response to the subduction of the Atlantic plate under the Caribbean plate. The northeastern branch, called the Limestone Caribbees is extinct since the Oligocene, whereas the western branch, the Volcanic Caribbees, is active since 5 Myr [1]. Due to its central position where the two northern arcs merge, Martinique is the island where the most complete history of the arc can be found. We present here geochronological, geochemical and geomorphological studies investigated in Martinique Island to constrain the evolution of its volcanic activity, with a special emphasize on the timing of its initiation in the Oligocene, and its westward migration since the Miocene.

We have obtained 60 new unspiked K-Ar ages on selected lava flows and domes. In agreement with biostratigraphic data, We show that the Older Arc has been active from 24.8 ± 0.4 to 20.8 ± 0.4 Ma, and, based on biostratigraphic data, we propose an age of 24.5 ± 0.3 Ma for the Oligocene-Miocene boundary as recorded in Martinique. Then, the Intermediate arc, mainly composed of hyaloclastites, was emplaced in a submarine to a subaerial context between 16 and 7 Ma. Within the whole arc, it is though to be the only outcropping products emitted during the Early Miocene. During the Pliocene, volcanic activity jumped 25 km northward, where Morne Jacob volcano was built from 5.5 to 1.5 Ma, and experienced a creeping of its northern flank at about 2.2 Ma. It induced geochemical changes in shallow reservoirs, as evidence by the eruption of more basic lavas within the depression. Then, monogenetic volcanoes with various dynamisms erupted to the southwest to form the Trois Ilets peninsula (2.4 to 0.345 Ma). Simultaneously, the Carbet Complex (1 Ma – 322 ka), Mont Conil (550 – 125 ka), and finally the Mount Pelée were active along the western part of the island. Flank collapses have been recurrent processes on the western flank of these three andesitic volcanoes at 337 [2], 120, 25 and 9 ka [3]. Using GIS software, we modeled paleotopography of the Pliocene volcanoes in order to propose minimum volumes and construction rates, and to complete the knowledge about the Lesser Antilles volcanism. To conclude, our dataset of 60 new K-Ar ages ranging from 26 Ma to 30 ka allow us to better constrain the different building stages of Martinique Island, and to identify high magmatic production rates and geochemical changes linked to regional geodynamic changes or flank collapse events.

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Preservation of inherited argon in plagioclase and implication for residence time after reservoir remobilization: a case study of Central Lesser Antilles Islands

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In the last 20 years, on-land observations coupled with marine geophysical surveys have demonstrated that at least 47 flank collapse events occurred on the back-arc side of the Volcanic Caribbees, and resulted in debris avalanches [1]. These events were rapidly followed by voluminous eruptions, as evidenced by the presence of lava spines and domes inside the horseshoe-shaped structures. Other studies have also suggested the occurrence of magma mixing within the Plio-Pleistocene volcanoes of the Volcanic Caribbees, resulting in explosive eruptions. The chronology of these different events is still a matter of debate, although important for future volcanic hazard assessments.

We compare here K-Ar ages obtained both on groundmass separates and on plagioclases from the same sample on different lava dome from central Lesser Antilles islands: Scotts Head (Dominica), Pitons du Carbet (Martinique) and Gros Piton (Saint Lucia). Lava emplacement ages obtained on carefully separated groundmass, the last liquid phase to crystallize in contact with the atmosphere, are accurate and in agreement with the geological evolution of the complex. In contrast, plagioclase systematically gives apparent ages 2 to 3 times older than the groundmass due to a partial retention of inherited argon, a characteristic of xenocryst components. The fraction of inherited argon retained in xenocrysts depends on the type of mineral and on its thermal history, which for a given mineral can be directly linked to its residence time in a magma chamber at a given temperature. Taking advantage of the argon excess, we modelled the residence time of plagioclase phenocrysts using available data on the magma chamber temperature conditions prevailing in the Lesser Antilles (850 – 600℃, [2]), and potential inherited crystal initial ages (26 Ma - 15 ka). Considering cylindrical plagioclase crystals with radius of 3 mm, Arrhenius diffusion coefficient (D_0) of $8.714.10^{-9}$ cm²/s, and activation energy (E) of 26440 cal/mol [3], we modelled an argon diffusion of $D_{Ar} = 5.97.10^{-14}$ cm²/s. With such diffusion coefficients, the age differences measured between groundmass and plagioclase require plagioclase residence times of less than a hundred years before groundmass emplacement. Our results suggest that the lava dome emplacements studied here have been triggered by reservoir remobilization less than a hundred years before being erupted, consistent with the observations made by Harford [2] for the current eruption of Soufriere Hills (Montserrat). Such an approach should help us to better constrain the timing between magmatic intrusion, flank collapse, magma mixing and associated eruptions.

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Diagenetic effects of Etendeka volcanism on aeolian sediments: inferences from isotopic evidence

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Aeolian sands of the Cretaceous Etjo Formation in the Huab Basin, Namibia have been drowned by lavas of the Etendeka Flood Basalt province, preserving complex field relationships between the sedimentary and igneous environments and direct diagenetic effects of igneous activity on the sandstones, and potentially indirect diagenetic effects where dykes and sills compartmentalise the basin. Burial of this desert system by pahoehoe lava has preserved duneforms by passive drowning, first by ponding in interdune areas, subsequently enveloping and starving of sediment in the entire system such that the youngest dunes are isolated barchanoids forming on pahoehoe surfaces, themselves drowned in lava flows. Where dunes have been flooded, the direct diagenetic effects of the hot lava are apparent, most of all where the lava flows are thickest in the interdune ponds. Sediments at hot contacts with lava flows and associated dykes are indurated or baked. A reduction in sediment porosity is found in close proximity to hot contacts due to increased carbonate pore filling cement, porosity increases away from hot contacts and cement fraction decreases. The normalised $\delta^{18}O$ isotope ratio relationship is less clear, the general trend is that the value decreases with distance (15.6‰ (± 0.2) near to the contact to 14.4‰ (± 0.2) at 4 m). Importantly at both hot ponded lava contacts a distinct decrease of 0.2‰ to 0.3‰ is seen between 0 cm and 30 cm from the lava. The general trend suggests that the high temperature of the enveloping lava directly influenced the cement forming diagenesis. The source of the cement is currently under investigation using δC^{13} isotopic analysis, $\delta^{13}C$ is between -2.34‰ and -7.95‰ where hot contact diagenesis has occurred. Compartmentalisation of the system is directly attributable to the igneous activity, isolated dunes are covered by lava and erg fields are segmented by related dykes and sills effectively forming permeability barriers. Where compartmentalisation is seen, diagenetic differences are apparent across permeability barriers which are similar to the directly affected hot contacts. The effect of igneous sheets as fluid flow barriers may indicate that indirect diagenetic effects are controlled by the geometry and distribution of the igneous rocks within the aeolian system. The question is raised as to whether the diagenetic fluids are directly attributable to the igneous activity or formed later during burial, $\delta^{18}O$ isotopic analysis may provide cement formation temperatures which can be reconciled with burial history. There does not appear to be a clear relationship between $\delta^{18}O$ and distance from permeability barrier, although there is variation within the data of up to 2.5‰ which may be significant. $\delta^{13}C$ isotope values are within the range seen at hot contacts which suggests similar source cements at both hot contacts and compartment related diagenesis rocks.

Evaluating inter-eruption hiatus in Tenerife: combining $^{40}Ar/^{39}Ar$ and sediment chemistry

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In volcanic regions the inter-eruption sediments and paleosol units represent the periods of hiatus between volcanic eruptions. This study shows results of investigation into inter-eruption sequences from 3 locations in Tenerife, Canary Islands. Chemical profiles through the interbed sequences show differences in the chemical weathering of the parent materials and shown differences between those profiles representing paleosol profiles and those formed by the insitu weathering of pumice parent material. Some of the most useful indictors are the Al:Base ratios and Chemical alteration indices as well as various element ratios which are used to show changes through the profiles and differences between at the same location. The %change in elements between the soil profile and the parent material composition show the element losses and additions to the profiles and are used to suggest durations of volcanic hiatus and the processes occurring, with a range of interbed durations from short, 4-8 Ka durations to other units with much longer durations of over 20 Ka.

$^{40}Ar/^{39}Ar$ dating of the volcanic units bounding the paleosol profiles provides another method for estimating the duration of the hiatus between the volcanic events. Although of low precision, the data presented allow comparison with the durations suggested from the sediment chemistry. The data set shows different processes occurring in different locations and show that the investigated profiles are not all paleosol sequences, with the chemistry showing the influence of a range of factors including additions to the system and effects of leaching and differences due to different parent material chemistry.

Textural analysis of Bushveld oikocrysts: a window into primary cumulate textures

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Layered anorthosites from Impala Platinum Mine in the Upper Critical Zone of the Bushveld Complex display a mottled texture. These 'mottles' are pyroxene oikocrysts (up to 2 cm across) hosting chadocrysts of plagioclase. They are surrounded by a pure plagioclase host (also up to 2 cm wide). Quantitative data obtained from these samples is used to carry out a detailed textural analysis. The CSD (crystal size distribution) is measured, to study processes which operated within the magma chamber during the time of solidification [1, 2]. There are a range of processes thought to be operating within magma chambers during solidification which affect the textural evolution of igneous rocks, particularly in 'cumulates'. The final texture of the rock can be unravelled to identify the most important processes during solidification, and address the changes between primary accumulation and post cumulus processes.

The plagioclase chadocrysts appear to have been 'frozen in' the large pyroxene grains which grew around them at a faster rate. There is strong evidence to suggest that oikocrysts preserve an earlier stage of textural development by surrounding and isolating these grains [3, 4], and therefore these chadocrysts may be indicative of the original shape, size and distribution of the cumulate plagioclase grains. As the pyroxene crystal grows the magma becomes displaced around the plagioclase preventing chemical transport via the liquid, and thus slowing down grain boundary movement of the chadocrysts, thus inhibiting textural changes. In different samples oikocrysts differ in terms of size and also the proportion of plagioclase to pyroxene. The CSDs of the chadocrysts will be plotted for a range of these different oikocrysts for comparison. They can also be compared to CSDs of the surrounding anorthosites which preserves a later textural stage. The results can also tell us about the post-cumulus processes such as crystal aging and compaction, which affected the textural development of the anorthosites. Other methods of analysing the textural evolution such as the spatial distribution will also be used, which can provide information on crystal growth and accumulation. Geochemical data already exists on the compositions of these individual oikocrysts and the surrounding anorthosites in terms of incompatible trace elements that provide information on the proportion of trapped interstitial magma, with which these results can be integrated.

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Evolution of an emergent explosive peralkaline volcano: caldera-collapse eruptions of Pantelleria, Straits of Sicily.

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A new investigation of Pantelleria volcano, south of Sicily, is being undertaken with the aim of improving our understanding of caldera eruptions at strongly peralkaline volcanic systems. Recent studies at Pantelleria have focused on the post-caldera volcanism (< c. 40,000 ka). Instead, we shall focus on the (older) large caldera-forming explosive eruptions. The last caldera-forming eruption emplaced the c. 45,000 ka Green Ignimbrite (Villari 1971). Our fieldwork suggests that the lowest exposed parts of caldera scarps attributed to this eruption are draped by the ignimbrite, casting new doubt on the configuration of this caldera. Initial work suggests that Pantelleria's caldera is complex and developed during several distinct collapse eruptions, some of which were probably considerable larger than the Green Ignimbrite eruption.

Many of the caldera-forming units on Pantelleria were interpreted as welded fallout deposits in previous studies, primarily because they mantle topography. But, although a few minor fallout deposits do occur, all the major caldera-forming units are re-interpreted as low-aspect ratio ignimbrites, on the basis of: (1) marked lateral facies and thickness variations, (2) very poor sorting with matrix-support; (3) imbricated clast fabrics; (4) localised low-angle diffuse cross-bedding; (5) erosional features; and (6) lateral and vertical changes in chemical composition and lithic populations. A few of them have associated sub-Plinian pumice fallout deposits. Most are intensely welded and have well-developed proximal heterolithic breccias >5 m thick with blocks ≤ 1 m. Although previously interpreted as fluvial gravels, they record the climactic phases of the main eruptions. Their ignimbrite origin is revealed by (1) gradations into ignimbrite (massive lapilli-tuff), (2) local gradations into welded facies, (3) close association with proximal scoria-agglomerates (similar to well-known coarse ignimbrite facies at Santorini, Ta'al and Acatlán); (4) abundant evidence for thermal spalling of block surfaces, and variable elutriation, but no evidence of abrasive polishing; (5) occurrence on caldera rims; and (6) absence of typical fluvial facies.

We are subdividing the volcanic succession into palaeosol-bound eruption-units. The recognition as ignimbrite has enabled correlations between what were formerly considered to be disparate fallout units in different sectors of the island, leading to a reduction in the overall number of units. Rather we distinguish several large caldera-forming events, and we shall characterise their petrology and chemistry, also drawing from the cognate lithic clasts contained in the ignimbrites. Combined with new radiometric dating and volcanological interpretation this should lead to a much improved understanding of magma chamber evolution, collapse, and possible cyclicity at this strongly peralkaline caldera volcano.

The crystallization of anorthoclase phenocrysts in Damavand lavas

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The quaternary stage of young volcanism in North of Iran is marked by the formation of a large stratovolcano named Mount Damavand which is 5678 meters in height and approximately 400 square Kilometers in Size.

The Eruption consists of mainly Trachyandesite and minor Olivine basalts. All the petrological and geochemical evidence suggest that the primary chemical composition of magma in Damavand is potassic and normally phenocrysts of Sanidine should be present in Trachyandesites, in another word potassic magma could not crystallize phenocryst of Anorthoclase (Na-rich Alkali Feldspar). So how can the abundance of phenocrysts of anorthoclase in Trachyandesites be justified?

In this article we discuss about three main reasons which changed the primary potassic nature of magma to the Na-rich composition which resulted in the crystallization of Anorthoclase.

The three reasons are:

1) The Crystallization of Phlogopite

2) The presence of Anothite .

3) Magmatic hybridation.

$^{40}Ar/^{39}Ar$ dating of the Valsequillo volcanic deposits in Central Mexico: Implications for the first human colonization of the New World

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It is currently accepted that the Clovis culture was the first to migrate into the New World at 13.1 ka [1]. However, archeological evidence in the form of stone tools, linguistics, craniometrics and genetics suggest that the first Americans were ethnically diverse and a few sites dated to 15-16 ka BP challenge the 'Clovis First' model.

Perhaps the biggest challenge to the 'Clovis First' model was the reported presence of human footprints within a basaltic ash (Xalnene Ash) dated to 38.04 ± 8.57 ka using optically stimulated luminescence (OSL) [2]. However, Renne et al. [3] challenged the validity of the footprints by dating lapilli from the Xalnene ash using $^{40}Ar/^{39}Ar$ and reported an age of 1.30 ± 0.03 Ma (2σ). They also reported a reversed palaeomagnetic polarity for the ash, consistent with deposition during chron C1r.2r. Such antiquity casts considerable doubt on the interpretation of the impressions as human footprints. Gonzalez et al. [4] questioned the validity of the $^{40}Ar/^{39}Ar$ age and highlighted the heterogeneous nature of the lapilli as a potential problem for $^{40}Ar/^{39}Ar$ geochronology. The lapilli contain abundant phenocrysts and xenocrysts. Olivine phenocrysts can be contaminated with excess Ar (^{40}ArE) [5] and hence the dating of ^{40}ArE-bearing lapilli and xenocrystic material may potentially produce anomalously old $^{40}Ar/^{39}Ar$ ages. Gonzalez et al. [4] also dismissed the significance of the reversed palaeomagnetic polarity as the proposed age of the ash (38.04 ± 8.57 ka) overlapped with the Laschamp Geomagnetic Excursion at 40.4 ± 1.1 ka.

Subsequently there has been support for both sides of the debate. The OSL age presented was questioned [6] and reconfirmed by [7]. The OU $^{40}Ar/^{39}Ar$ laboratory showed the presence of ^{40}ArE in the samples although they were unable to date the ash [2]. Palaeomagnetic data has both supported emplacement of the Xalnene Ash during the LGE [8,9] and at 1.3 Ma [10]. The age of the 'alleged' footprint-bearing Xalnene ash and hence the timing of the first colonization of the Americas remain highly controversial.

Attempting to resolve the controversy surrounding the Xalnene Ash we report new $^{40}Ar/^{39}Ar$ data for the volcanic rocks of the Valsequillo Basin. We sampled basaltic lava flows and alkaline tuffs from the Valsequillo stratigraphic sequence to produce a chronology for the basin fill and processed the basaltic ash and lavas removing phenocrysts and xenocrysts.

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$^{40}Ar/^{39}Ar$ dating of hydrothermal activity, biota and gold mineralization in the Rhynie hot-spring system, Scotland

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The Rhynie cherts are hot spring sinters that contain world-renowned plant and animal remains and anomalously high quantities of heavy metals, including gold. The biota in several beds is preserved undeformed with plants in life positions thus establishing that they and the indurating hydrothermal fluids were coeval. Despite the international importance of the Rhynie cherts their age is poorly constrained for three reasons: (1) the lack of a precise radiometric age, (2) low resolution of spore biostratigraphic schemes for Devonian terrestrial deposits, with only one to a few zones per stage, and (3) poor resolution of the early Devonian timescale. Wellman [1] assigned a Pragian-?earliest Emsian age to the Rhynie cherts on the basis of the spore assemblage. An $^{40}Ar/^{39}Ar$ study of bulk chert yielded an age of 395 ± 12 Ma (1σ) [2]. Although there is slight overlap at the 1σ level, the two ages are not precise.

This study presents a new high-precision $^{40}Ar/^{39}Ar$ age for the Devonian hot-spring system at Rhynie. Othoclase-rich K-feldspar sampled from veins that represent feeder conduits and a hydrothermally altered andesite wall rock, date the hydrothermal activity, the indurated biota, and syn - K-feldspar gold at 403.9 ± 2.1 Ma (2σ). This reproducible $^{40}Ar/^{39}Ar$ age shows that K-feldspar can be used as a reliable geochronometer as long as its microtexture and post-crystallisation thermal history are understood. Oxygen isotope data show that the K-feldspar was precipitated from a dominantly meteoric fluid, which mixed with magmatic fluids from a degassing magma chamber.

The $^{40}Ar/^{39}Ar$ age also provides a robust marker for the *polygonalis-emsiensis* Spore Assemblage Biozone within the Pragian-?earliest Emsian. Furthermore, the age identifies the early Devonian pull-apart volcano-sedimentary basins of the British and Irish Caledonides (and at depth hot jogs in transcurrent fault zones), as specific targets for future gold exploration.

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Geochronology of Mount Morning, Antarctica: two-phase evolution of a long-lived trachyte-basanite-phonolite eruptive center

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Mount Morning is a Cainozoic, alkaline eruptive centre in the south-west Ross Sea, Antarctica. New ages on 17 Mount Morning volcanic rocks (combined with 34 existing ages) allows division of Mount Morning volcanism into two phases, erupted between at least 18.7 Ma and 11.4 Ma, and 6.13 and 0.02 Ma. The position of Mount Morning on the active West Antarctic Rift System within the stationary Antarctic plate is a key factor in the eruptive centre's longevity. The earliest, mildly alkaline, Phase I volcanism comprises predominantly trachytic rocks produced by combined assimilation and fractional crystallization processes over 7.3 m.y. Strongly alkaline Phase II volcanism is dominated by a basanite – phonolite lineage, with the youngest (post last glacial maximum) activity dominated by small volume primitive basanite eruptions. The evolution from mildly to strongly alkaline chemistry between phases reflects magma residence time in the crust, the degree of mantle melting, or the degree of magma – country-rock interaction. Phase I magmatism occurred over a comparable area to the present-day, Phase II shield. The 5.2 m.y. volcanic hiatus separating Phase I and II coincides with a cycle of eruption and glacial erosion at the nearby Minna Bluff eruptive centre. Mount Morning is the likely source of volcanic detritus in Cape Roberts drill-core (about 24.1 to 18.4 Ma) and in ANDRILL drill-hole 1B (about 13.6 Ma), located 170 km north and 105 km north-east respectively, of Mount Morning. Based upon the timing of eruptions and high heat-flow, Mount Morning should be considered a dormant volcano.

The origin of micron-sized silicate spherules emitted during quiescent degassing from the 2008-2009 summit eruption at Kilauea Volcano

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The 2008-2009 Halema'uma'u eruption provided a unique opportunity to investigate processes occurring within a quiescent plume, due to the highly concentrated emissions (up to 600 ppm SO_2) and young plume age (<30 s) at the crater rim.

Aerosols were sampled from the plume using filter packs and analysed using scanning electron microscopy and energy-dispersive X-ray spectroscopy. We found that micron-sized silicate spherules were emitted in great abundance from the Halema'uma'u vent. These spherules have also been detected in the emissions from other volcanoes and are presumed to form by ejection of molten droplets from the magma, followed by rapid “spherulization” and freezing. The spherules in the Halema'uma'u plume show a compositional continuum between that of the melt and nearly-pure SiO_2, with proportional decreases in the weight ratios of Mg/Si, Na/Si, Ca/Si and Al/Si. This compositional variability cannot be explained by the accepted mechanism for basaltic glass leaching, where Mg, Na and Ca are leached more rapidly than Al. We suggest instead that it reflects condensation of vapor phase silicon monoxide (SiO) onto ejected melt droplets shortly after emission, diluting the concentrations of Mg, Na, Ca and Al equally. Additionally, results from sun photometry show for the first time that the emission rate of spherules is temporally variable on timescales of seconds to minutes. This variability is indicative of highly dynamic processes occurring at the top of the volcanic conduit (in response to external forcings, e.g., rock falls, or internal factors, e.g., the dynamics of bubble formation and rupture).

$^{40}Ar/^{39}Ar$ ages for lava flows and sills within the Antrim Lava Group, NE Ireland

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The Antrim Lava Group (ALG), a major remnant of the British Palaeogene Igneous Province, consists of mainly basaltic rocks that cover much of Antrim and parts of Derry and north Armagh. It is split into three main formations – the Lower Basalt Formation, the Interbasaltic Formation, and the Upper Basalt Formation [1,2]. These are separated by characteristic laterized red bole horizons. The eruption of the Lower Basalt and Upper Basalt Formations of the ALG occurred in two cycles, which are believed to coincide with the two province-wide phases of magmatism recorded at about 59 and 55 Ma respectively [3]. In addition, a large number of mafic intrusions are found throughout the province, including >30 volcanic plugs, a NNW-SSW trending dyke swarm and a number of large sills.

New $^{40}Ar/^{39}Ar$ ages for lava flows from the ALG, obtained by incremental heating analyses of plagioclase separates using a CO_2 laser, give statistically meaningful age plateaus for lava flows from each of the three main formations. The ages record a northwards time progression across the ALG. In southeast Antrim, plateaus of 61.9 ± 0.4 and 59.0 ± 0.4 were obtained for the Lower and Upper Basalt lava flows respectively. In North Antrim, Interbasaltic Formation lava flows yield a younger age of 57.5 ± 0.7 Ma. Plateau ages for the Portrush sill (54.9 ± 0.6 Ma) and Fairhead sill (60.2 ± 0.3 Ma) are also reported, indicating discrete time windows for these geochemically distinctive magmas.

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Constraints on the petrogenesis of Palaeogene flood basalt volcanism in NE Ireland

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A major part of the Palaeogene North Atlantic Igneous Province (NAIP), the British Palaeogene Igneous Province (BPIP) has been extensively studied in the past, with work on the Hebridean islands (e.g. Skye, Mull etc.) making major contributions to research that underpinned much of modern igneous petrology through the 20th century. The Antrim Lava Group (ALG) in NE Ireland is one of the lesser studied parts of the BPIP, yet covers an area in excess of 4000 km^2, with thicknesses >700m reported in some drillholes.

The ALG consists of mainly basaltic rocks, flows of which cover a large portion of NE Ireland. It is split into two main groups – the Lower Basalts and the Upper Basalts, the eruption of which occurred in two cycles. These cycles are believed to coincide with two province-wide phases of magmatism, separated by distinctive laterized red bole horizons and intermediate to felsic lava flows of the Interbasaltic Formation. A large number of dolerite plugs, sills and dykes are also found within the ALG.

Here we present new XRF and ICP-MS data for the ALG and associated intrusions. The Antrim lavas are mostly olivine tholeiites with only a few rocks showing quartz or nepheline in their normative assemblage [1]. The Upper and Lower Basalts are magnesian (>9% MgO), however the Causeway Tholeiite Member of the Interbasaltic Formation is more evolved and forms a low-MgO group. Trace element data indicate that most of the basalts were derived from partial melting of LREE-depleted mantle. All of the Lower Basalts and some of the Upper Basalts have convex-up REE patterns, with light REE showing low ratios (e.g. $(La/Sm)_{CN}$ ~ 0.83), and fractionated heavy REE showing high ratios (e.g. $(Ga/Yb)_{CN}$ ~ 1.6). In contrast, the Interbasaltic formation basalts are consistently depleted in REE ($(La/Sm)_{CN}$ ~1.71, $(Ga/Yb)_{CN}$ ~1.21), suggesting source heterogeneity for the ALG. In addition, geographic trends indicate that pre-existing Caledonian faults in the area (e.g. the Highland Boundary fault) were a major control on magma ascent and eruption across the province.

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Sr-isotopic disequilibrium melting during crustal anatexis

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Radiogenic isotopes (e.g. Sr, Nd, Pb) are widely used for petrogenetic studies in order to identify geological reservoirs and processes occurring throughout the earth. It has been suggested [1] that a melt will inherit the isotopic composition of its source and attain isotopic equilibrium. However, a number of experimental studies have challenged this when investigating Sr isotopic evolution during crustal melting. This study aims to investigate Sr-disequilibrium melting through an *in situ* study of quenched crustal melts (now glasses) within lava-hosted crustal xenoliths in order to constrain the mechanisms inherent to crustal anatexis.

Direct evidence for Sr-disequilibrium melting is rarely preserved as crustal melts have ascended to shallower levels relative to their source (e.g. S-type granites, ignimbrites). Partially melted crustal xenoliths erupted from volcanic centres on the Bolivian Altiplano contain intergranular mafic and felsic glasses. These glasses are quenched crustal melts and provide an insight into Sr-disequilibrium melting. *In situ* sampling using a microdrill (followed by TIMS) has demonstrated that they are out of Sr-isotopic equilibrium with their host rock to variable degrees. Relatively high 87Sr/86Sr glasses (melts) are more likely to be controlled by the dehydration melting of higher Rb/Sr phases e.g. biotite. Less radiogenic melts are more likely to be controlled by the melting of low Rb/Sr phases e.g. feldspar. Clearly these isotopic disequilibrium melts are preserved because diffusion rates were slower than those of extraction i.e. eruption of the host lavas.

Further investigation of the isotopic (and trace element) budgets of these glasses and their neighbouring minerals aims to improve understanding of the mechanisms and timescales through which crustal anatexis occurs.

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Temporal constraints on crustal contamination: whole-rock and crystal-scale evidence from the Carlingford Igneous Centre, Ireland

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Magmatism at the Palaeogene Carlingford Igneous Centre is represented by a major gabbro laccolith and a microgranite ring-dyke, both of which are crosscut by a series of aphyric to highly porphyritic basaltic cone-sheets with subordinate rhyolite, basaltic-andesite and trachy-andesite components. These lithologies, plus local crust, were analysed for major and trace elements and whole-rock Sr, Nd and Pb isotopes to assess petrogenetic processes throughout these three magmatic episodes. All samples ($^{87}Sr/^{86}Sr$ = 0.7057-0.7201$_{(60Ma)}$) deviate markedly from mantle values towards local Silurian siltstones ($^{87}Sr/^{86}Sr$ = 0.7144-0.7276$_{(60Ma)}$). The earlier microgranite ring-dyke ($^{87}Sr/^{86}Sr$ = 0.7067-0.7127$_{(60Ma)}$) seems to have incorporated partial melts of the Silurian crust, rather than bulk material. In contrast, the majority of trends for mafic samples can be explained by bulk contamination. The highly evolved cone-sheet rhyolites ($^{87}Sr/^{86}Sr$ = 0.7098-0.7100$_{(60Ma)}$) lie within the range of the basalt/basaltic-andesite, suggesting fractionation after initial contamination of basaltic parental magmas. K-rich trachy-andesites from cone-sheet intrusions ($^{87}Sr/^{86}Sr$ = 0.7198-0.7201$_{(60Ma)}$) appear to be sedimentary derived, representing the (high-K) melt of hornfelsed xenoliths (*S-type basalts!*). The xenoliths represent the restite remaining after partial melt loss from the local Longford-Down meta-siltstone. Plagioclase phenocrysts from the late porphyritic basalt cone-sheets show that An generally decreases with crystal growth (An_{91-24}), with resorption surfaces marking distinct compositional steps. Convection and re-equilibration in a heterogeneous magma chamber may therefore be an important process affecting these phenocrysts. This is consistent with groundmass values, which are also highly variable and range in $^{87}Sr/^{86}Sr$ from 0.7064 to 0.7092, with matrix feldspar values of An_{62-46}. Micro-drilled Sr isotope analyses of individual zones of large plagioclase phenocrysts show strong variation, with high-An cores yielding both high (0.7070-0.7077) and low (0.7063-0.7067) Sr ratios compared with low An rims. These variations are attributed to the presence of inherited xenocrystic cores from the contact aureole, as well as classical replenishment and magma mixing processes.

Despite the involvement of a single major crustal contaminant, our data imply petrogenetic evolution was not straightforward. Rather, we see a succession of variably overprinting processes that form a time sequence of contamination; from initial formation of microgranite by incorporation of crustal partial melts, to bulk contamination of gabbro and basalt as the system heats up, and subsequent melting of the remaining restites during late-stage cone-sheet emplacement to form a melt of trachy-andesite-type composition.

Methods for reconstructing flood basalt provinces in 3D

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We present new methods and ideas on how to reconstruct the internal structure of a continental flood basalt province (CFBP) in three dimensions. CFBPs consist of sequences of basaltic lava flows, associated sediments and hyaloclastites, and can be several kilometres thick. Flood basalts can be characterised in terms of key internal facies that occur at different levels within the sequence, which can vary both spatially and temporally. It is therefore important to understand the facies distribution from a volcanological perspective, as this can provide data on mechanisms of lava flow emplacement. Additionally, potentially prospective sedimentary basins may lie under CFBPs (for example the North Atlantic Igneous Province, NAIP). Lava flow sequences cause major problems with seismic imaging; however improved knowledge of lava flow thicknesses, volumes and structures can help improve the picture.

Two case studies were selected in the NAIP for excellent 3D exposure and a variety of facies types: a quarry in the Faroe Islands, and two sea stacks and a cliff section in Talisker Bay, Skye. In this presentation, we will show 3D geological models which have been constructed from 'virtual outcrops' captured using terrestrial laser scanning equipment. The laser scan data also allows us to quantify the roughness on the lava flow surfaces. In collaboration with the British Geological Survey, we have used the GSI3D software, developed by the BGS and Insight GmbH, to build the models from laser scan data. The user builds cross-sections from map and borehole data, and the block model is calculated from these. This software is extremely adaptable and has proved very good at handling the laser scan data. A summary of the process of constructing the 3D models will be presented, as well as the final geological models and animations.

Probing the depths; insights from the evolution of a large Palaeocene igneous complex on Ardnamurchan, NW Scotland

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The peninsula of Ardnamurchan is the most westerly point of the British mainland. The igneous complex is part of the British-Irish Palaeocene Igneous Province, which formed (~60 Ma) within a zone of crustal stretching and thinning prior to the opening of the North Atlantic. This deeply eroded igneous complex is located on the very northern boundary of the Northern Highlands Terrane and intrudes Proterozoic metasediments ('Moine schists') and a thin overlying cover of Mesozoic sediments. The igneous complex is divided into three different centres, mostly composed of gabbro, dolerite as well as numerous cone sheets, many being composite in nature. A selection of composite intrusions and samples from the central gabbro bodies of the Ardnamurchan igneous complex, as well as local Moine metasedimentary country rocks, were collected and analysed for Sr, Nd and Pb isotopes to define the role of crustal contamination.

The Ardnamurchan igneous complex also comprises a network of intersecting radial and concentric dykes and faults attesting to several stages of magma chamber inflation and deflation. The sampled cone sheets tend to be enriched to strongly enriched in radiogenic $^{87}Sr/^{86}Sr$ (0.7046 - 0.7149) and show a range of $^{143}Nd/^{144}Nd$ isotope values (0.5114 - 0.5129) with a displacement of the samples away from MORB-like values. The Ardnamurchan isotope data show two distinct linear trends in isotope space. Magma mixing would seem to have been an integral part of the igneous activity throughout the evolution of the complex. The occurrence of composite intrusions with basaltic margins and more felsic andesitic to rhyolitic cores highlights the existence of magma reservoirs, of varying composition, underneath Ardnamurchan and evidence for liquid-liquid mixing imply that these were molten at the same time and ascended together. The majority of the cone sheets and a large portion of the Ardnamurchan igneous complex underwent a two step crustal contamination process. Within the composite intrusions sampled the more mafic rocks, which are consistently found at the margins, are dominantly contaminated in the lower crust by gneisses, not currently exposed at the surface. The more felsic magmas, found in the core of the composite intrusions, show varying amounts of Moine metasedimentary incorporation as do the youngest mafic intrusions. There appears to be a very close temporal connection between the felsic and the more mafic rocks.

The igneous rocks sampled provide a probe into the deep crustal structure beneath the Ardnamurchan igneous complex as the active magmatic system migrated upwards through time progressively sampling higher crustal levels. Isotopic data from this Palaeocene igneous complex as well as others located nearby allow for a better understanding of the deep crustal structure of the North Atlantic Margin.

Extra-thick plates: basis of a versatile mode of mantle magmagenesis, also possessing isotopic selectivity relevant to planetary differences

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Simple, geologically supported, plate dynamical arguments (Osmaston 2005, 2006, 2007, 2008a,b, 2009a,b, eg.[1]) show that tectonic plates are very thick, with cratons having tectospheric keels to near 660km, and that Earth has had a 2-layer mantle since ~2.3Ga. These, which I will begin by outlining, have proved remarkably persuasive, even to seismologists. This finding opens a new door to understanding many features of magmagenesis in the mantle and perhaps in other terrestrial planets.

The splitting of plates that are thin has insufficient temperature potential for inducing magmagenesis but with thick plates, inherently possessing super-adiabatic thermal gradient, it does. That successive OIB compositions rather precisely prescribe a sequence of depths of segregation, often 50km or more, presents persistent problems for mantle magmagenesis. How is such segregation achieved and how do such magmas reach surface without being overprinted by reaction with mantle on the way? The low density of melt renders magma chambers in the mantle untenable; How do you establish one? How do you prevent it collapsing as soon as a vent occurs? And sequences of trace elements are seldom consistent with fractionation from a 'pool'.

We will study the evolution of an induced mantle diapir as it ascends a narrow basal split in a thick plate, and extends it to the surface if that is not already the case. We present three simple variants of this model, adapted to each of OIB, CFB and kimberlite. Source compositions are still important but processing is central and (variably) thick plates provide the column-space to do it in, with a varying result. Among the notable features [2] are:-

(a) Pressure-relief melting in the diapir decreases again as wall cooling asserts control. Enlarged by cumulate intergrowths, the solids form a 'log-jam' in the crack (familiar to grouting engineers), and melt is forced through it (primary segregation). So this depth varies with current parameters (wall temperature, splitting rate), the jam providing xenoliths when ruptured. The pressure-differential to do so and ability to extract melt increases with jam depth - column density above it is lower (kimberlite).

(b) Reduced pressure at the foot of the diapir causes incipient melting of mantle accessories, trace element contents being drawn, and gases diffuse, along melt pathways, resulting in light-isotope enhancement (OIB). This effect (eg. He3/4) increases with column height, and likely affected the isotopic evolution of planetary atmospheres, exemplified in Earth-Mars comparisons like H/D and Ar36/40.

(c) Heated by an eruption, the big volume increase (per joule) at the gt-sp peridotite phase change at ~50km in the walls may close the crack, prising it apart elsewhere, extending island chains. It may also control eruptivity and, by alternating thermally, prolong it, as in the lunar maria sequences.

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Use of volatile degassing to reconstruct palaeo-ice thickness at Bláhnúkur, Torfajökull, Iceland

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The solubility of water in silicate melts is a function of the pressure experienced by the magma [1]. In subglacial settings, this pressure is dependent on the thickness of ice or water overburden during an eruption. Assuming that the magma degasses so that the volatiles are in equilibrium with the ambient pressure, this potentially allows one to reconstruct the ice thickness by measuring the volatile content of glasses [2].

A number of glassy samples have been collected from Bláhnúkur, a subglacial, rhyolitic, small volume edifice in South Iceland. It is part of the Torfajökull central volcano complex and is believed to have erupted 95,000 years ago beneath ice >350 m thick [3]. The samples, which were collected from a range of elevations and provide a good lateral coverage of the volcano, were analysed for their water content using Fourier Transfer Infra-red (FTIR) spectroscopy. VolatileCalc [4] was then used to convert these water concentrations into values of pressure, which can then be used to estimate ice thicknesses [2].

The results show that the majority of samples had water contents that decreased with height, consistent with the presence of an ice sheet when these samples were erupted. Furthermore, the values obtained suggest that the ice sheet surface was at about 1,050 m a.s.l. at the time of the eruption (450 m thickness), with a magma temperature of 850℃ and zero magmatic CO_2 content providing the best fit to the data. This means that the ice would have been 100 m thick at the summit of Bláhnúkur when the eruption occurred. However, there are some sampling locations that disagree with this overall trend and there are many potential explanations for why these anomalies may exist, including loading by rock rather than ice and underpressure conditions due to meltwater drainage.

Although there are limitations to the use of degassing to reconstruct palaeo-ice thicknesses, for example the influence of other volatile species on the solubility of water is poorly understood [5], the results to date are promising, and further measurements are being carried out on other subglacial rhyolite edifices in Iceland.

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The applicability of InSAR to measuring deformation rates of Colombian volcanoes

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This study was undertaken to assess the applicability of synthetic aperture radar interferometry (InSAR) to monitoring deformation rates of Colombian volcanoes. Interferograms were generated utilising L-band data spanning a 2 year period, between January 2007 and January 2009. The processing was carried out using JPL's Repeat Orbit Interferometry Package (ROI_PAC).

Analysis of 62 interferograms covering the north Andean volcanic chain revealed that the majority of Colombian volcanoes were not deforming, although a subsidence signal was detected on the northeast flank of Galeras volcano. The maximum observed deformation at Galeras corresponds to approximately -3 cm in the satellite's line of sight. The period during which deformation was observed coincides with the January 2008 eruption and it is proposed that this signal was caused by deflation of the magma chamber during this explosive event. Modelling was undertaken using the University of Miami's GeodMod software, to determine the most likely parameters for the source of deflation. A number of models were tested including a point-source (Mogi 1958) and prolate spheroid (Yang et al. 1988).

Although several volcanoes were active throughout the observation period, no pre-eruptive deformation was confirmed during this study. This is consistent with observations made from previous InSAR studies undertaken in the southern and central Andes. Despite the lack of pre-eruptive deformation, the subsidence signal observed during the January 2008 event does provide insight into the volume of ejecta, depth to source, and potentially the size of the chamber. This information may be useful in characterising the internal structure of the volcano as well as the magnitude of future eruptions.

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Relationship between monogenetic volcanism and stratovolcanoes in western Mexico: the role of low-pressure magmatic processes.

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A large Quaternary monogenetic volcanic field is present in the western part of the Trans Mexican-Volcanic Belt (TMVB). It is constituted by mafic-intermediate scoria cones and silicic domes arranged in two NNW-SSE alignments which mark the north and south borders (Northern Volcanic Chain, NVC, and Southern Volcanic Chain, SVC, respectively) of the San Pedro-Ceboruco graben. The products of this monogenetic field span a large range of compositions (from basalt to rhyolite) and magma affinities (from sub-alkaline to Na-alkaline), defining different magmatic groups. Mafic and silicic monogenetic centres from the north alignment, also coexist with two stratovolcanoes (Ceboruco and Tepetiltic) sometimes punctuating their flanks.

All data suggest the existence of 4 different types of primitive magmas (Na-alkaline, HTi, LTi/SVC and sub-alkaline) which evolve independently subjected to low-P evolutionary processes characterised by different conditions. Despite the relatively small size and simplicity of monogenetic magmatism trends of major elements variations with silica contents for HTi and SVC series indicate that fractional crystallization controls the liquid line of descend, though each monogenetic centre underwent slightly different conditions and magmatic processes. The positive correlation between Sr isotope ratios and silica contents observed for SVC and HTi groups point to crustal interaction via AFC processes. Source processes + fractional crystallization and AFC processes can act at the same time giving complex geochemical and isotopic characteristics. A strong tectonic control is suggested by geochemical data. AFC processes mainly modify monogenetic magma outpoured between the two stratovolcanoes and on the southern border of the graben, whereas minor crust interaction seem to affect scoriae cones and domes located SE of Ceboruco and N-NE of Tepetiltic. In addition, Na-alkaline magma is outpoured only N-NE of Tepetiltic.

A limited magma interaction between monogenetic and polygenetic magmatism has been recognised at Ceboruco. Nevertheless the mafic magma feeding HTi monogenetic systems might represent one of the possible end-member which triggered the Ceboruco caldera-forming eruption. This can have important implication on other explosive system in which monogenetic magmatism is associated with stratovolcanoes.

Volatile degassing from Kīlauea volcano, Hawai`i: implications for eruption mechanisms and source heterogeneity

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The parental melts of ocean island volcanoes show enrichment in CO_2, H_2O and incompatible elements compared with normal mid-ocean ridge basalts. In Hawai`i, previous studies have revealed that melting taps a heterogeneous source region, giving rise to significant changes in the isotopic and trace element compositions of parental melts supplied to the volcanoes over time-scales of decades to millennia. It is expected that the source region will also be heterogeneous with respect to volatile concentrations, which may lead to some parental magmas being more CO_2-rich than others; influencing magma buoyancy, mixing and eruptive style. As magmas ascend beneath Kīlauea, CO_2 concentrations inherited from mantle melt compositions are likely to be affected by varying degrees of concurrent exsolution, crystallisation and magma mixing. We can attempt to deconvolve these processes, and reconstruct primary melt volatile concentrations through a study of melt inclusions and volcanic gases.

We will examine temporal changes in CO_2 and H_2O concentrations of parental melts from Kilauea to determine: (i) whether the large explosive eruptions, which have punctuated the otherwise effusive eruptive history of Kīlauea, are due to rapid vesiculation of more CO_2-rich parental magmas and (ii) the degree to which magmatic volatiles influence the initiation of summit eruptions, including the 2008-present Halema`uma`u eruption. We will also assess the roles of mantle heterogeneity, degree of partial melting, fractional crystallisation, magma mixing and degassing, in controlling the primary melt volatile concentrations.

A set of more than 40 tephra samples were collected, spanning over 2000 years of eruptive history at Kīlauea. We chose tephra, rather than lava samples to minimise the effects of diffusive loss of H_2O from the melt inclusions. Glasses and olivine-hosted melt inclusions were analysed for major and trace element compositions using EPMA and LA-ICP-MS, preliminary H_2O and CO_2 analyses were carried out using SIMS. We use the incompatible behaviour of H_2O and CO_2, together with non-volatile elements such as Nb and Ce, to estimate volatile concentrations of primary Kīlauea melts. These estimates are then combined with models of mantle melting and volatile solubility to reconstruct magmatic and degassing processes for each eruption.

Propagation characteristics of volcanically generated infrasound at Mount Etna, Sicily

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Low frequency acoustic (infrasonic) signals have recently been shown to exhibit a high degree of utility in the interpretation of key volcanic processes such as degassing, magma motions and plume turbulence and can contribute to significant improvements in understanding the physical mechanics of eruptive activity. Furthermore, infrasonic monitoring systems are relatively inexpensive and simple to install, are not dependent on a clear line of sight to the source region and can provide coherent datasets at distances of tens to hundreds of kilometres from active volcanoes.

Despite these benefits, current models used in the interpretation of volcanic infrasound are relatively simple and little attempt has been made to deconvolve ground and atmospheric propagation effects between source and receiver. Determining the relative contribution of topography, meteorological variability and ground effect on the attenuation of infrasonic waves is a critical step in developing a more robust analytical framework for the characterisation of recorded acoustic pressure traces.

Current work is focussed on utilising a flexible, rapidly deployable, high spatial density wireless infrasonic sensor network coupled with permanently installed monitoring arrays at Mount Etna to enable the development of a multipath model of acoustic signal propagation that supports tomography. Such a model will essentially enable corrective algorithms to be applied to recorded pressure traces facilitating the recovery of infrasonic signals more directly representative of source processes at the active vents whilst also enabling the optimisation of future sensor deployments.

Lithofacies architecture of a proximal ignimbrite: Diego Hernandez wall, Las Cañadas Caldera, Tenerife

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The aim of this work is to understand the processes and conditions near eruptive vents during major ignimbrite and caldera forming explosive eruptions. Precursors, opening stages and waning stages of large explosive eruptions are poorly known, as are relations of proximal to medial and distal components of ignimbrites. Complete records of explosive eruptions must involve interpretation of proximal sequences. This work is to complement the understanding of pyroclastic density current (PDC) spatial and temporal behaviour that has already been derived from medial and distal ignimbrites.

In the proximal Poris ignimbrite five eruptive phases are recorded. A fallout-dominated opening phase is registered as a Plinian fall deposit with evidence of some current reworking, with an ash bed containing accretionary lapilli above. The overlying units are cross laminated and stratified ignimbrites rich in crystals and fine lithics recording a phase of PDC deposition, probably with phreatomagmatic influence. A stratified pumice block tuff above the ignimbrites consists of angular pumice cobbles and boulders supported in a fine matrix and represents a period of interaction of multiple and intergradational proximal processes: fallout, fountaining from the jet, ballistic ejection, and density current formation. Overlying ignimbrite deposits contain numerous scour and bypass surfaces, indicating a main phase of energetic PDC formation. Evidently not all of this phase is recorded as deposits proximally due to material bypass to lower slopes. The uppermost unit that is well exposed is a lithic breccia >5 m thick. Two metres up from its base an influx of mafic banded pumice blocks, up to 1 m in diameter, is recorded. The breccia may be the product of a subterranean collapse that prompted catastrophic fault dilation and enhanced evacuation of the magma chamber. The top of the sequence is poorly preserved and is not yet fully documented; this is fieldwork in progress.

The detailed study of this proximal ignimbrite concludes the first stage of the project. The next stage is to correlate the components of this succession with its medial and distal counterparts using chemistry and mineralogy, so that the full architecture can be evaluated in terms of the entire eruption history.

Using the geochemistry of the post-15 kyr Campi Flegrei eruptions to understand magma generation and eruption within the caldera, and to fingerprint these chronostratigraphic markers

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There have been more than 50 explosive eruptions from Campi Flegrei in the last 15 kyrs, making it one of Europe's most productive volcanoes. Three distinct periods of activity are identified since the large caldera-forming Neopolitan Yellow Tuff eruption at 15 ka, Epoch I (15-9.5 ka BP), II (8.6-8.2 ka BP), and III (4.8-3.8 ka BP). Eruptions are closely spaced within each Epoch, often with repose periods of <50 years, but the Epochs are separated by a long periods of quiescence. Each eruption typically erupts small volumes of alkalic trachytic-phonolitic magma (0.1 km^3 d.r.e.). Here we detail the glass and some mineral chemistry of many of the eruption deposits. These data show interesting spatial and temporal variations, and provide insight into the evolution of the magmatic systems that fed the eruptions.

The ash from these eruptions travels 100's km and is dispersed in a range of distal records, from cave sites to marine cores. Approximately 15 of the post-15 ka tephra are widely dispersed and are found in distal archives (e.g., Lake Monticchio and Aegean Sea). The deposits of the highest-magnitude eruptions, Pomici Principali and Agnano Monte Spina, are distributed over an area >1000 km^2. The detailed glass chemistry of these deposits provides a fingerprint of the eruptions, allowing distal volcanic deposit of these events to be accurately correlated to the precise eruption. These tephra are invaluable as precise chronostraigraphic markers, allowing palaeoenviromental records to be accurately correlated.

Mapping and identification of single eruptive units from remote sensing imagery

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Mapping in the Afar Depression in Ethiopia has identified basaltic fissure vents, constrained the volumes and extents of individual lava flows and recognised geographically disparate felsic volcanic complexes within Afar. We apply an integrated mapping approach involving remote sensing and three-dimensional image analysis of topography and surface rock chemistry based on mineral maps generated from false colour Landsat and ASTER imagery within an immersive visualisation suite. Subsequently these digital images and first pass geological interpretations are transferred to a field data tablet, enabling digital data capture in the field. Fieldwork involves targeted spot mapping, transects and detailed mapping of poor resolution areas. This approach is proving to be particularly successful in producing a subdivision of basaltic lava flows based on surface features, morphology of flow lobes and emplacement styles. The high-resolution record has facilitated investigations of the style and size of fissure eruptions, their source, degassing of fire fountains, the processes affecting synchronous basaltic and felsic volcanic activity, and the style and duration of basaltic lava flow emplacement. With this methodology, further applications such as chemostratigraphy may be utilised in order to elucidate process orientated research of a temporally related series of eruptions. The success of this technique is particularly significant when working in areas which are difficult to access, and may be applied in the future within environmentally or logistically challenging regions.

Understanding hyaloclastites and associated volcaniclastic facies; onshore examples from Iceland

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The understanding into the distribution, porosity and permeability of hyaloclastites and associated volcanic facies is currently limited. In the North Atlantic Margin, for example, it has been demonstrated that lava delta formations comprising volcaniclastic facies such as hyaloclastite are present at many localities and commonly at the base of the main lava flow sequence e.g. onshore in the Faroes Islands and in offshore seismic lines from the Faroe-Shetland Basin.

Hyaloclastite deltas are comprised of several lithofacies types, and although recognised in number of localities, both their physical characteristics, facies associations and what can be deduced from seismic interpretation are not well understood. In this study we aim to look at some key case study areas which represent the spectrum of different hyaloclastite facies and how they are represented in terms of rock properties and facies relationships.

A preliminary field reconnaissance has identified 3 main localities for case study, the 2.8-1.1 Ma Hreppar Formation; in particular the sequence from Stóri-Nupur to Hjalparfoss, the Hjörleifshöfdi peninsula near Vík and the Hvitárvatn hyaloclastite delta succession which could not be reached. Logs and thin section analysis from 2 of these localities (Hjörleifshöfdi and Stóri-Nupur to Hjaparfoss) are presented here. The transition from hyaloclastites to reworked sub aerial volcaniclastics is considered in the Stóri-Nupur to Hjalparfoss case study where a hyaloclastite delta has prograded over a fluvial succession. In this area the transitional environments from 400m thickness of subaerial lava flows of the Veidivotn lava system (Hjaparfoss), intercalated volcaniclastic sediment (Fossness) and submarine hyaloclastite deltas (Melhagi and Stóri-Nupur) have been identified. In our other example at Hjörleifshöfdi the internal facies variations form large successions of hyaloclastites that erupted into the sea are considered. A model for the transition from subaerial to submarine in the Iceland case studies is presented with implications for offshore examples.

Developing models of disequilibrium magma degassing

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Volcanic samples provide a key window into the noble gas composition of the mantle. This composition yields information on the nature, origin and evolution of the sample's source mantle. However, during an eruption, noble gases will partition into the vapour phase and elemental ratios can be fractionated, masking original mantle signatures. If this degassing process is assumed to take place under equilibrium conditions, knowledge of the solubility of the different noble gases will allow the extent of elemental fractionation to be determined and corrected for. However, work by Gonnermann and Mukhopadhyay [1] has drawn attention to the fact that degassing can also take place under disequilibrium conditions. In this case the relative diffusivity of the noble gases must also be considered. Solubility-controlled fractionation increases the ratio of light to heavy noble gases in the melt over the course of the eruption, but diffusivity-controlled fractionation can have the opposite effect. Both factors must be taken into account in a complete model of noble gas fractionation during an eruption.

This study builds on Gonnermann and Mukhopadhyay's [1] existing disequilibrium degassing model. Degassing of the major volatiles (CO_2 and H_2O) controls the evolution of trace volatiles such as the noble gases. A crucial component is determining how to model major volatile concentrations over a number of open-system degassing steps: In the original model, the major volatiles were assumed to degas in equal amounts at each step. In a variation to this model, we have allowed the major volatiles to degas based on the time available at each step; this simulates a more realistic evolution for major volatile concentrations which can make a difference of several orders of magnitude to calculated elemental ratios.

Given the potentially large number of uncertain parameters in an eruption process, investigating the model's sensitivity to changes in its input parameters is an essential component of this study. We find that the model is relatively insensitive to eruption temperature; in contrast, increasing initial CO_2 concentration from 0.07% to 0.82% can decrease final noble gas concentrations by more than an order of magnitude. Uncertainties in relative diffusivity, degree of disequilibrium and eruption pressure can also affect results by an order of magnitude or more. This study takes a step towards understanding the key components of a realistic model of noble gas evolution during an eruption.

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Emplacement of energetic density currents over topographic barriers: constraints from a chemically-zoned, topography-draping, low aspect-ratio ignimbrite on Pantelleria, Italy

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Low aspect-ratio ignimbrites are thought to be emplaced by particularly hazardous, radial, high-velocity pyroclastic density currents from caldera-forming eruptions. Their circular distribution has been inferred to record simultaneous flow in all directions from source, overtopping hills, rather than passively flowing down valleys.

As part of a study into how such currents behave and evolve with time, we have been testing the inference of simultaneous, radial (i.e. rather than sectoral) flow by mapping out the internal chemical-architecture of a zoned, low-aspect ratio ignimbrite sheet on the island of Pantelleria, Italy. This pristine, welded ignimbrite (aspect ratio ≤ 1:5,000) was deposited during a phase of the most recent (~45,000 ka) caldera-forming explosive eruption on the island. One extensive flow-unit is zoned from pantellerite to trachyte, and records that the composition of the erupting magma changed with time. The chemical variations allow us to divide the brief history of the sustained current into successive time-periods. The compositional zones have been mapped internally through the deposit, both (1) regionally (longitudinally from source and laterally around the broadly circular sheet), and (2) around topographic barriers draped by the ignimbrite. The study takes advantage of superlative exposure and topographic control. We have reconstructed how the footprint of the sustained current shifted as the current waxed then waned, and as it encountered and then overtopped barriers. Our data reveal that even this sheet-like low-aspect ratio ignimbrite was not emplaced entirely radially: rather, it flowed into certain sectors before others. Deposition was diachronous, and previously proposed lithofacies correlations within the ignimbrite are demonstrated to be incorrect.

We are now investigating how the current interacted with individual topographic barriers of different sizes and shapes. Both cone-shaped hills and transverse barriers, entirely draped by thin ignimbrite have been mapped in the field, and the chemical variations within the draping ignimbrite have been analysed up and around the topography. Data currently being processed should reveal whether the current's leading edge advanced over topographic barriers initially, as is commonly assumed, or that some barriers temporarily blocked or deflected the current until the mass-flux waxed (or until deposition modified the topography) sufficiently for the current to advance further. The well-constrained case studies will test the validity of concepts such as deflection and flow-stripping developed principally from analogue experiments.

Initial results are changing our understanding of how these unusually devastating pyroclastic density currents behave.

Measurements of halogens, mercury and other trace metals in the Halema'uma'u plume and a preliminary assessment of some possible environmental consequences of the emissions from Kilauea.

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In March 2008 a new gas vent broke through at the Halemaʻumaʻu crater, doubling Kilauea's sulphur dioxide emission rate. In July 2008, a number of measurements were carried out to understand the emissions of mercury and other trace metals from this vent and Pu'u O'o. Halogens, sulphur species and CO_2 were also investigated at the crater edge. A number of vegetation samples were collected, at varying distances from the crater, in addition to rain and fog samples, and their trace metal content studied.

Rain within the plume of Pu'u O'o was highly enriched in trace metals and volcanically influenced fog was also high in metal content. While metal concentrations in the volcanic rain sample were below drinking water guideline levels, the volcanic fog sample was higher than these guidelines in a number of metals. No clear pattern was observed in the trace metal content of vegetation samples collected at various locations in the Hawai`i Volcanoes National Park. The mercury/sulphur mass ratio is estimated as 1.5×10^{-6}, and a mercury flux of at least 1 kg d-1 is estimated from the Halema'uma'u vent of Kilauea. This is predominantly (>78 %) in the form of gaseous elemental mercury at the point of emission. The mean ratios of HCl/SO_2 and HF/SO_2 determined by analysis of samples collected on alkali impregnated filters at the crater rim agree well with previous FTIR measurements at Kilauea. A number of size segregated aerosol samples were also collected at the Halemaʻumaʻu crater edge to investigate their trace metal content. Many metals were largely water soluble, although some metals were largely present as carbonates/oxides or as silicates.

Sequence stratigraphy of sub-marine lava-fed deltas: key concepts and application to the Faroe-Shetland basin

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Lava-fed delta systems represent an important component of sedimentary basin fill proximal to volcanic centres. In the North Atlantic Igneous province, for example, large volumes of volcaniclastic material occurs at the onset of the flood volcanism and the recognition of such deposits in other volcanic rifted margins suggest that their role in these basins has not been fully realised.

Using 2D seismic reflection data that image a late Palaeocene delta system from the Faroe-Shetland basin, North Atlantic margin, four key seismic facies have been identified on the basis of amplitude, continuity and reflector configuration, and how they differ from those of adjacent groups. The facies units are found to record the development of the delta, from terrestrial lava flows to hyaloclastic foresets further into the basin. A series of seismic-stratigraphic units have been identified on the basis of the character of the bounding reflectors and the internal facies components, which help distinguish between individual units. The gross stratal pattern is that of progradation, with aggradation and finally retrogradation towards the end of delta development. Distinct delta front geometries have also been used to indicate how variable the system may have been, both during and after development.

We find that hyaloclastic material resulting from lava flows entering an offshore basin, share many characteristics with clastic sediment, including similar depositional processes and controls on stratigraphic architecture such as eustasy, subsidence and sediment supply. It can therefore be assumed a lava-fed delta system will have features comparable to those used within clastic sequence stratigraphic analysis. Many of the basic key sequence stratigraphic principles such as the use of seismic reflection onlap, downlap and truncation should be applicable as criteria for reconstructing relative sea level and basin fill history. But there are important differences from clastic systems, as the system it is greatly affected by variations in the volume of volcanic material, supply rates of volcanic material, and any volcanically induced subsidence. Therefore, research will focus upon what modifications are required to the classic principles of sequence stratigraphic as applied to carbonate and clastic systems.

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