Radiometric constraints on timescales of degassing and crystallization for lavas from arcs, ridges, rifts, and ocean islands

Mark K Reagan

University of Iowa, Iowa CIty, IA 52242, USA

E-mail: mark-reagan@uiowa.edu

The relative activities of short-lived radionuclides (e.g. 210Pb T1/2 =22.6 y and 210Po T1/2 = 138 d) in lavas are revealing contrasts in late-stage magmatic processes for different tectonic settings. Most basalts erupted from ocean islands and continental rifts have (210Pb/226Ra) < 1. Although 210Pb deficits in some of these lavas have been attributed to magma genesis or differentiation, most are caused by degassing of 222Rn in a CO2-dominated vapor phase as magmas decompress over periods of years to decades (e.g. Turner et al., 2012, G-cubed). Some small volume trachytes and phonolites can have (210Pb/226Ra) >1 as a result of removal of 226Ra during rapid fractionation of amphibole and K-feldspar (e.g. Reagan et al., 2008, GCA). Lavas ejected from a large and growing phonolite magma body at Erebus have 210Pb-226Ra equilibrium (Sims et al., 2013, J.Pet). Although arc lavas can have significant excesses or deficits of 210Pb, they more commonly have (210Pb/226Ra) within 10 percent of equilibrium. These near equilibrium values illustrate that water-rich arc magmas tend to degas for short periods of time, causing crystallization, higher viscosities, and magma stagnation. Excesses of 210Pb in arc magmas are commonly associated with magma intersection, and likely result from 222Rn transfer in a vapor phase from larger volumes of intruding magmas into smaller volumes of previously stagnated magmas, a process that can lead to their defrosting. Deficits of 210Pb in some arc magmas show that these magmas did not stagnate either due to latent heat inhibiting crystallization or to a more CO2-enriched volatile content. The lavas erupted in 2004-2008 from Mount St. Helens had progressively greater 210Pb deficits with time, illustrating that the entire magma body lost what little gas it had for the entire eruption. Mid-ocean ridge basalts have 210Pb deficits and excesses like arc lavas. Small 210Pb deficits have been attributed to melting and rapid melt migration to the surface (Rubin et al. 2005, Nature). However, the 210Pb excesses found in some MORB illustrate that gas loss and accumulation also play a role in their genesis (Waters et al., submitted, EPSL). Most subaerially erupted lavas from all settings degas more than 90 percent of their 210Po before eruption, providing a way to detect juvenile versus older ejecta. Exceptions to this rule include rare lavas erupted from Mount St. Helens between 2004 and 2008 that ceased open-system degassing weeks to months before eruption due to their extreme viscosity and low overall volatile contents.

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Are high magma supply mid-ocean ridge magma chambers open or closed-system?

Ken H Rubin[1], Chris J Russo[1], Mike R Perfit[2], John M Sinton[1]

[1]Dept. of Geology and Geophysics, Univ. of Hawaii, Honolulu, HI 96822, USA, [2]Department of Geological Sciences, Univ. of Florida, Gainesville Fl 32611, USA

E-mail: krubin@hawaii.edu

Mid ocean ridge (MOR) volcanism at high magma supply is often thought of as a near steady-state process, with frequent magma supply from below and relatively frequent eruptions. Repeat eruptions at several MOR sites over the past several decades allow one to probe this assumption using radioactive disequilibrium between 210Pb and 226Ra, which is governed by a 22 year half-life. There are multiple possible causes of 210Pb-226Ra radioactive disequilibria in magmas, but in magnesian (>7 wt o/o MgO) tholeiites, this is thought to be produced primarily by mantle melting, followed by decay during melt transport and pre-eruptive storage. Petrological, geochemical and U-series data on four mapped eruption sequences at two sites on the East Pacific Rise (at 9.8 deg N in 1991-92 and 2005-06, and at 17.5 deg S in ca 1990 and ca 1980) demonstrate that successive eruptions separated by 10-20 yrs were fed by the same mantle-derived magma batches that had resided in the crust and lost 210Pb-226Ra radioactive disequilibria by decay, under nominally closed-system conditions. All of the erupted magmas were >7 wt o/o MgO and only sparsely plagioclase phyric. At both sites, crustal magma residence timescales must be very short for the component of the melt that caries live Pb-Ra disequilibrium to be preserved in erupted magmas. On the N-EPR, the two eruptions produced lava flows with only small amounts of compositional variability, but the magmas of the later eruptions were more differentiated (by ca 1wt o/o MgO). On the S-EPR, two eruptions of chemically heterogeneous magmas have variable but indistinguishable ranges of 210Pb-226Ra, MgO, Pb isotopic characteristics, and other geochemical tracers, indicating that they both probably represent mixes of the same two distinct magma batches in the crust. Several things are learned from this study: (a) Erupted magmas resided in the crust for no more than several decades, but longer than the 1-2 decade repose interval at both sites; (b) Erupted magmas are mixtures of melts that act as closed-systems during the repose period, only one of which needs to carry Pb-Ra disequilibrium (the other could be in secular equilibrium); (c) not every MOR eruption at high magma supply ridges requires new magma input from the mantle; (d) mush zone interactions did not induce 210Pb excesses, and (e) crustal melts can differentiate along a range of P-T paths over these short time intervals. Magma chamber thermal modeling indicates that to continually supply heat to observed high temperature hydrothermal systems, magma chambers need to be replenished on decadal timescales if hydrothermal systems are driven by heat from only the small shallow melt lenses detected seismically at ridges. Resupply of magma to these lenses from deeper melt segregations or a crystal mush zone during the repose interval can supply the heat and still allow for the apparent U-series closed-system behavior if the same mantle-derived magma batches are involved.

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Li-Pb and U-Th-Ra isotope systematics in metasomatised harzburgite xenoliths from Batan Island, Philippines

Simon Turner[1], Janne Blitchert-Toft[2], Raul Brens[1], Xiaoming Liu[3], Roberta Rudnick[3], Tracy Rushmer[1]

[1]Macquarie University, Australia, [2]Ecole Normale Superieure de Lyon, France, [3]University of Maryland, USA

E-mail: simon.turner@mq.edu.au

Subduction delivers sediment and hydrated oceanic lithosphere into the convecting mantle. Some of these materials are involved in magma generation and returned to the surface as arc volcanism. The remainder continues into the deeper mantle contributing to long-term heterogeneity that may be later sampled by mantle plumes. In order to understand the global cycling of volatiles in subduction zones it is essential to understand the physical and chemical processes of fluid release and melting. Significant debate remains on the role of aqueous fluids versus wet melts and the release of fluids and melting are both strongly dependent on slab temperatures. Metasomatised xenoliths from Batan Island, Philippines, represent unique samples of the sub-arc mantle. They have incompatible trace element and radiogenic isotope characteristics typical of their host lavas and arc lavas in general. Li concentrations in the xenoliths and host lavas range from 1.2 to 8.2 ppm whilst Li isotopes show a significant range from -1.3 to 2.2 and correlate positively with Sr isotopes. Pb isotopes range from 18.37 to 18.50, from 15.60 to 15.72 and from 38.48 to 38.75. These data cannot be explained by addition of a single subduction component to the mantle wedge but arguably require both fluid and sediment addition. The xenoliths also, remarkably, preserve extreme U-Th-Ra disequilibria. These disequilibria do not result from either infiltration by the host magma, steady-state diffusion in the mantle or subsequent crustal level processes. Rather, the xenoliths provide the first direct evidence that such signatures originate in the mantle and that contributions from both wet sediment melts and aqueous fluids were separately delivered from the slab. The data also require that metasomatism was ongoing at the time of their incorporation in the host magmas.

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On the timescales of magma accumulation and evolution at Tambora (Sumbawa, Indonesia) prior to the 1815 eruption

Ralf Gertisser[1], Stephen Self[2], Heather Handley[3], Louise Thomas[2], Peter van Calsteren[2], John Wolff[4]

[1]School of Physical and Geographical Sciences, Keele University, Keele, ST5 5BG, UK, [2]Department of Earth and Environmental Sciences, The Open University, Milton Keynes, MK7 6AA, UK, [3]GEMOC, Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW 2109, Australia, [4]School of Earth and Environmental Sciences, Washington State University, Pullman, WA 99164-2812, USA

E-mail: r.gertisser@keele.ac.uk

The great Tambora eruption in 1815 has been one of the largest explosive eruptions in historic time. It produced extensive pyroclastic fall and density current deposits from the evacuation of a 30-33 km^3 trachyandesite to tephriphonolite magma body [1, 2]. Geochemical modelling suggests that the parental trachybasalt of the evolved 1815 magma may be produced by 2% partial melting of a garnet-free, I-MORB-like mantle source contaminated with 3% fluids from altered oceanic crust and < 1% subducted sediment, preserving the small ^{238}U excesses observed in the 1815 Tambora rocks. Magmatic differentiation from primary trachybasalt to trachyandesite and tephriphonolite occurred during two-stage, polybaric differentiation at depth(s) around the Moho and in a shallow-level crustal magma reservoir emplaced at a maximum depth of 7.5 km, but with a degassed cap possibly extending to depths as shallow as 2.3 km below the summit. This crustal reservoir grew by influx of basaltic trachyandesite magma, which is interpreted to have formed predominantly by partial crystallisation of primary trachybasalt in the inferred deep reservoir or hot zone [3]. Subsequent magmatic differentiation dominated by fractional crystallisation, magma recharge/mixing and convection over timescales of 4000-4500 years led to the trachyandesitic (and ultimately tephriphonolitic to phonolitic) melts that erupted in 1815. Highly calcic, in some cases corroded, plagioclase and other mineral phases in ^{226}Ra-^{230}Th equilibrium (> 8000 years old) provide physical evidence for incorporation of antecrystic material into the 1815 magma. Magma accumulation and differentiation at shallow depth prior to the eruption were accompanied by continuous degassing of sulphur and other volatile species, which appear not to have accumulated within or towards the top of the magma reservoir to contribute to the volatile budget of the eruption, but to have escaped to the surface passively through permeable wall rocks.

References: [1] Self et al. (2004). Geophys. Res. Lett., 31, doi:10.1029/2004GL020925; [2] Gertisser et al. (2012). J. Petrol., 53, 271-297; [3] Annen et al. (2006). J. Petrol., 47, 505-539.

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Evolution of magma plumbing system of the Iwate Volcano, Northeast Japan, constrained by chronological relationship of the bulk chemical and isotopic composition

Jun'ichi ITOH, Isoji MIYAGI, Nguyen HOANG

Geological Survey of Japan, AIST, Japan

E-mail: itoh-j@aist.go.jp

Iwate Volcano is one of the active volcanoes in the NE Japan Arc Quaternary volcanic front. The volcanic activity started about 300 ka, however, most active only since the last 120 ka. Topographically, the volcano is divided into two bodies: Higashi-Iwate (HI) forming a stratocone and Nishi-Iwate (NI) having a 2.5 by 1.5 km caldera. Eruption activities of the Iwate Volcano are divided into 4 stages for NI and 3 stages for HI. The chronological relationship of these stages is interfingered. Eruptive rocks of Iwate volcano are composed mainly of low-K tholeiitic basalt to andesite. Calc-alkaline andesite to dacite are rare component.

Low-K tholeiite from the two volcanic bodies (NI and HI) are interpreted to be derived from different sources and/or different magma chambers based on the major and trace element compositions. In the case of NI, interaction of primitive magma with heterogeneous crustal assimilant (assimilation and fractional crystallization: AFC) in crustal magma chambers would explain the chemical and Sr-Nd-O isotopic compositions. Whereas, chemical variations of the HI volcanic rocks are controlled mainly by fractional crystallization (FC).

AFC process gradually progressed in the NI magma chamber, and the injection of the newly arrived primitive magma renewed the chamber. Drastic change of chemical and isotopic compositions are observed before and after the caldera forming stage. The fact that the most geochemically enriched volcanic rocks erupted only before the caldera forming, while the volcanics produced after the depression were isotopically depleted. We suggest the caldera formation may relate to activities of shallower crustal magma chamber where crustal material may be more enriched than those deeper, formed after the collapse.

Bulk chemical compositions of HI eruptive rocks show two chemical trends; High-Si and Low-Si type. High-Si type shows significantly increase in SiO2 (51 to 55) with the increase in FeO/MgO ratios (1 to 2). SiO2 contents of the Low-Si range between 51 and 53. Comparison of the bulk chemical trend between the two chemical types and MELTS (Ghiorso and Sack, 1995) model variation trend suggest that the High-Si type is formed at lower pressures (ca. 0.5-1 kb) than the Low-Si type (ca. 3-7 kb). The temporal chemical variation of the Low-Si type rocks shows MgO decrease with eruptive sequence. This compositional cycle lasted about 3-4 thousand years. Whereas the High-Si type volcanics occurred in the later stages of the composition cycle. We proposed that the magma plumbing system in the HI main magma chamber was stored at 3-7kb condition and FC process controlled the change of eruptive products. The injection of more primitive magma into main magma chamber renewed the chemical cycle of HI volcanics. In contrast, the High-Si magma was operated by FC process in shallow magma pocket where magma being stored at lower pressures (0.5-1 kb).

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The post-Minoan plumbing system behaviour at Santorini Volcanic field: implications for the current unrest phase

Chiara Maria Petrone[1], Lorella Francalanci[2], Georges E. Vougioukalakis[3]

[1]Natural History Museum, Department of Earth Sciences, Cromwell Road, SW7 5BD London, United Kingdom, [2]Dipartimento Scienze Terra, Università di Firenze, Via La Pira 4, 50121 Firenze, Italy, [3]I.G.M.E., 3rd Entrance Olympic Village, Athens, Greece

E-mail: C.Petrone@nhm.ac.uk

Explosive volcanic eruptions are often triggered by replenishment of the magma chamber by new magma. In the case of the historical eruptions at Santorini extremely short residence time has been recently estimated for the intrusion of basaltic andesitic magma in the dacitic reservoir. Understanding the occurrence of replenishment and the dynamics of magma mixing is thus crucial to a correct evaluation of the risk of explosive volcanoes.

The post-caldera islets of Palea- and Nea-Kameni formed as result of nine eruptive events from A.D. 46-47 till 1950 in the center of the Santorini Minoan caldera. These nine eruptive events lead to the emplacement of dacitic lava flows and domes also characterised by the presence of basalts to andesites mafic magmatic enclaves.

Dacitic rocks have low porphyritic index that increases with time. Plagioclase is the prevalent mineral phase, followed by clinopyroxene, orthopyroxene and opaque minerals. Few resorbed xenocrysts of olivine with coronae of pyroxene are also present. Basalts to andesites mafic enclaves have variable texture spanning from cumulate to aphyric. Porphyritic enclaves with olivine in groundmass are also found. Mafic enclaves have ellipsoidal or cuspate shape, with some chilled margins clearly suggesting their molten state at time of incorporation in the host magmas. Host lavas show a general decrease of the evolution degree with time, at the same time enstatite contents of pyroxenes and anorthite contents of plagioclase decrease from mafic enclaves to host lavas. Sr isotopes systematically increase with time and thus toward the less evolved compositions of lavas and mafic enclaves. The latter, along with mineral separates, generally show slightly more enriched radiogenic compositions in respect with host lavas, with the exception of 46-47 A.D. eruptive events.

All data point to mixing/mingling between mafic and dacitic magmas and enclave crumbling processes. The increases in Sr isotope ratios with time and toward more mafic magmas suggest crustal contamination of mafic magmas. Our data suggest the existence of a shallow layered reservoir with dacitic magmas overlaying lower mafic magmas. Cumulitic processes, crystal fractionation eventually accompanied by variable degree of assimilation of crustal country rocks, also characterised the lower part of the plumbing system allowing further layering and evolutionary processes of the mafic magmas which, in turn, generate the complex and variable textures shown by mafic enclaves. Type, composition and distribution of mafic enclaves change in different eruptions suggesting that different part of the layered reservoir where frequently and variably sampled during time. This clearly points to periodic arrival of more mafic magmas during the post-Minoan activity of Santorini suggesting a still very active magma source in agreement with data available for the current unrest phase at Santorini Volcanic field.

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Processes leading up to the 22 ka silicic caldera-forming eruption of Santorini (Greece): Constraints from crystal trace-element fingerprinting and diffusion chronometry

Gareth N Fabbro[1], Timothy H Druitt[1], Fidel Costa[2]

[1]Clermont Université, Université Blaise Pascal, Laboratoire Magmas et Volcans, BP 10448, France,
[2]Earth Observatory of Singapore, Nanyang Technological University, Singapore

E-mail: g.fabbro@opgc.univ-bpclermont.fr

Caldera-forming eruptions are amongst the most destructive phenomena on this planet. Constraining the processes that occur before these eruptions, as well as the timescales of those processes, is vital for forecasting the behaviour of the volcanoes responsible for them. The 21.7±0.2 ka caldera-forming Cape Riva eruption of Santorini Volcano discharged at least ~10 km^3 of dacitic magma (along with a minor basalt-dacite hybrid andesitic component), and caused caldera-collapse. The eruption was preceded by a ~13 ky period of dacitic effusive and minor explosive volcanism. This effusive activity constructed the 1-2 km^3, <200-m-thick Therasia dome complex, centred on the site of the subsequent Cape Riva caldera. The major element geochemistry of the Therasia dacite is very similar to that of the Cape Riva dacite, but its lower incompatible element concentrations (e.g. K, Zr, Rb, La, Ce and Nb) demonstrate that it is a different magma batch. This difference is also apparent in the concentrations of La and Ce in plagioclase crystals from the two magmas. La and Ce diffuse very slowly through plagioclase (<100 μm in 10^7 y at 900℃), and therefore reflect the concentration of those elements in the parent magma on the timescale of our system (<10^5 y). The contrasting trace element compositions of the whole rocks and crystals seem to rule out a simple interpretation that the Therasia dacites were leaks from the growing Cape Riva magma chamber. Modelling of diffusion gradients of relatively fast-diffusing elements such as Mg and Sr in plagioclase crystals provides estimates of the residence times of those crystals at magmatic temperatures. Preliminary results also show that plagioclase crystals in the Therasia dacites have maximum residence times of the order of 10^2-10^3 years. This is short compared to the total 13 ky duration of effusive volcanism, suggesting that the Therasia lavas may represent the repeated ascent, partial crystallisation and eruption of multiple, small parcels of dacitic magma over a long period of time. Field and $^{40}Ar/^{39}Ar$ constraints tie down the arrival of the Cape Riva dacite batch in the shallow plumbing system less than 4000 y prior to the Cape Riva eruption. Preliminary diffusion chronometry results for Cape Riva crystals suggest residence times for some plagioclase crystals as short as 10-10^2 years. This supports the idea that major influx of new, silicic magma occurred shortly before the eruption, and possibly provides more a precise constraint on the timing of this influx.

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Exsolution lamellae in volcanic pyroxenes as an indicator of cooling times and sizes of magma reservoirs

Fidel Costa[1], Jason S Herrin[2]

[1]Earth Observatory of Singapore, Nanyang Technological University, Singapore, [2]Facility for Analysis, Characterisation, Testing, and Simulation, Nanyang Technological University, Singapore

E-mail: fcosta@ntu.edu.sg

Magma residence times below active volcanoes are crucial for understanding the processes of magma evolution and for proper assessment of volcano related hazards. Major progress has been made in the last decades by a combined approach of modeling zoning patterns of crystals, bulk-rock and single mineral analyses of U-Th disequilibria isotope series, and in-situ determination of crystallization ages of zircon. Here we explore another approach that can potentially lead to new insights into the, sizes, residence times and internal processes of magma bodies that is based on the existence of solvus relations in several mineral groups. Clino- and orthopyroxenes for example may start crystallizing at high magmatic temperature, and new compositions will grow with decreasing the temperature. But once the system intercepts the solvus, early-formed pyroxenes will tend reequilibrate through formation of exsolution lamellae. The size, spacing, and composition of the lamellae depend on the initial temperature, cooling rate, and bulk composition. This means that the characteristics of exsolution lamellae are potentially a record of the cooling history which can be related to the size, growth styles (single batch vs. pulses), and cooling rates of the magma. This type of information has been exploited in several studies of plutonic bodies. However, exsolution lamellae have been rarely documented in volcanic pyroxenes (except for plutonic xenocrysts), probably because of faster cooling rates and shorter magma residence times. Using a new Field Emission Gun Electron Microprobe (EM), and electron backscattered diffraction we have found micro to submicron exsolution lamellae subparallel to the [001] plane (e.g., high-T exsolution) on clinopyroxene from dacites and andesites from volcanoes in Chile and Indonesia. The size of the lamellae is too small to fully characterize with the EM so we have used the Focused Ion Beam technique to extract cross-sectional slices of lamellae in clinopyroxenes perpendicular to the 001 plane. We obtained element maps and traverses using energy dispersive spectrometry and electron energy loss spectroscopy with an Analytical Transmission Electron Microscope. We found that the width of the lamellae vary from about 50 nm to a few hundred nm, and thus near the resolution of backscattered electron maps produced by the EM. Using experimentally calibrated growth rates of exsolution lamellae in clinopyroxene, and simplified cooling models of magma reservoirs of various sizes, we find that the observed lamellae require time scales of formation of a few thousand years from a reservoir of a few to tens of km^3. Given the small sizes of the lamellae that we observed, it seems likely that they have been overlooked in other volcanic systems, but the information they could provide is difficult to obtain by other approaches and should lead to better understanding of the growth rates and sizes of subvolcanic magma reservoirs.

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How do quartz watches compare?: glass inclusion faceting versus Ti diffusion profiles

Ayla S Pamukcu[1], Guilherme AR Gualda[1], Florence Begue[2], Darren M Gravley[2]

[1]Department of Earth and Environmental Sciences, Vanderbilt University, United States, [2]Geological Sciences, University of Canterbury, New Zealand

E-mail: ayla.s.pamukcu@vanderbilt.edu

Constraining the timescales over which magma bodies accumulate and erupt is critical to developing methods to effectively monitor and prepare for future eruptions. There are many methods used to assess timescales (radiometric dating, geospeedometry, textural analysis), but results often conflict, and our ability to directly compare timescales obtained from different methods is debated. Here we assess the use of glass inclusion faceting as a geospeedometer. Glass inclusions change from rounded to increasingly faceted over time at magmatic temperatures through dissolution and re–precipitation. Thus, the degree of faceting is a possible measure of residence time. Our prior work on faceting revealed residence times that compare well with those suggested by other methods; however, the results depend on crude estimates of critical parameters such as size, shape, and position of inclusions using optical microscopy. We have started using propagation phase contrast x–ray tomography, which enhances object edges, to image glass inclusions within quartz crystals. We use image processing techniques to find a 3D hull that envelopes the inclusion, and we fit an equal volume ellipsoid to the hull. We compute the volume diffused during faceting as the volume of the ellipsoid that protrudes from the inclusion hull. We also assess size and position of the inclusion within the crystal. This improved characterization allows a more critical evaluation of the applicability of glass inclusion faceting as a measure of residence time. We compare results from glass inclusion faceting with those from diffusional relaxation of Ti in quartz. Variations in cathodoluminescence (CL) intensity correlate well with variations in Ti contents in quartz, so we use CL profiles as a proxy for Ti zoning. We employ a 1D diffusion model along selected CL profiles to find the best fit relaxation length scale, from which we can calculate residence times–taking advantage of experimentally determined diffusion coefficients for Ti in quartz. We are documenting textures of multiple glass inclusions located in distinct zones within quartz crystals to directly compare timescales from faceting and diffusional relaxation. We obtain tomograms of quartz crystals containing inclusions at GSECARS (Advanced Photon Source). We then select grains with multiple inclusions, particularly those with inclusions near the center (along the c axis) of the crystal, which we polish and image with SEM-based panchromatic CL. We have so far imaged crystals from 5 pumice clasts of different compositions of the 240 ka Ohakuri–Mamaku ignimbrites (Taupo Volcanic Zone, New Zealand). Results from the two methods are comparable, lending support to faceting as a geospeedometer. Both methods suggest these magma bodies were short lived, crystallizing over 10s–100s of years prior to eruption, consistent with recent results obtained for crystallization timescales of other giant magma bodies (e.g. Bishop Tuff).

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Tracking pre-eruptive degassing at Laki, Iceland, through diffusion modelling

Margaret E Hartley[1], Dan J Morgan[2], David A Neave[1], John Maclennan[1], Marie Edmonds[1], Thor Thordarson[3]

[1]University of Cambridge, UK, [2]University of Leeds, UK, [3]University of Iceland, Iceland

E-mail: meh43@cam.ac.uk

Information on the timescales of magma ascent, mixing and degassing in volcanic plumbing systems provides important constraints on the interpretation of seismic, geodetic and gas monitoring data prior to and during large fissure eruptions. The AD 1783 Laki eruption, southeast Iceland, produced over 15 km3 of basaltic lava and tephra, and led to three years of extreme climatic variability in Europe and North America. We quantify the timescales of degassing in the Laki magma system, and determine the potential flux of CO2 to the surface in the premonitory phases of the Laki eruption.

Olivine-hosted melt inclusions from Laki range from volatile-rich (5000 ppm CO2) to almost completely degassed (<50 ppm CO2). Volatile saturation models suggest that these melt inclusions were trapped at pressures from <0.1 to >7 kbar, and the melt inclusions preserve a record of concurrent degassing and crystallisation. The total CO2 mass release from the Laki magma is on the order of 370 Mt. Diffusion modelling techniques applied to compositional profiles across olivine and plagioclase phenocrysts enable the timescales of magmatic processes in the run up to the Laki eruption to be constrained.

Olivine crystals from rapidly-cooled tephra samples display up to three distinct compositional zones linked by diffusion profiles, indicative of crystallisation and storage in different magmatic environments. Preliminary modelling suggests that the diffusion profiles reflect timescales on the order of 100 days. These residence times apply to magma storage in a shallow reservoir immediately prior to eruption, thus providing a minimum bound on the timescale of melt inclusion entrapment.

Plagioclase macrocrysts from Laki often have high-anorthite (An84-89) cores surrounded by oscillatory-zoned (An74-80) mantles. The high-anorthite core compositions cannot be reproduced by fractional crystallisation modelling of the Laki carrier melt, and may have grown from depleted melts of the shallow mantle that were mixed into the Laki carrier liquid during the earliest stages of magmatic evolution. The growth of the zoned plagioclase mantles thus represents one of the earliest magmatic processes in the history of the Laki magma. Crystallisation of plagioclase mantles occurred concurrently with the crystallisation of the melt inclusion-bearing olivine macrocrysts. Diffusion of Mg and Sr between plagioclase cores and mantles is expected to provide information on the timescales of processes occurring early in Laki's magmatic history, including the deep degassing of CO2. Suitably-zoned plagioclase macrocrysts are used to obtain direct estimates for the timescales between crystal growth, melt inclusion entrapment and eruption. The timescale estimates are linked to the evolution of the Laki magma body by integrating the diffusion modelling results with the record of cooling and crystallisation preserved in the melt inclusion compositions.

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Short time scales of pre-eruptive magma mixing processes: petrographic evidence from the 2011 eruptions of Shinmoedake volcano, Kirishima volcanic group, southern Kyushu, Japan

Akihiko Tomiya, Isoji Miyagi, Genji Saito, Nobuo Geshi

Institute of Geology and Geoinformation, AIST, Japan

E-mail: a.tomiya@aist.go.jp

We estimated the time scales of magma mixing processes prior to the 2011 sub-Plinian eruptions of Shinmoedake volcano, Kirishima volcanic group, southern Kyushu, Japan, to constrain the triggering process of the eruptions, on the basis of zoning profiles of magnetite phenocrysts and diffusion calculations.

The eruptive products are comprised mainly of phenocryst-rich (28 vol%) gray pumice (SiO_2 = 57 wt%) with minor amount of white pumice (SiO_2 = 62 wt%) (Geshi *et al.*, 2011). We found that the gray pumice was formed by mixing between high-temperature nearly aphyric magma (basalt or basaltic andesite) and low-temperature mushy magma (andesite) (e.g., Saito *et al.*, 2011). The depth of the magma chamber, at which the magma mixing occurred, was about 6 to 8 km, deduced from MELTS calculation (Miyagi *et al.*, 2011).

Most of the magnetite phenocrysts (type-A_1) were originated from the low-temperature magma and their zoning profiles showed considerable increase in Mg and Al contents toward the rims of the phenocrysts, due to mixing with the high-temperature mafic magma. We calculated the time for diffusion to form these zoning profiles (i.e., the time from the magma mixing to the eruption) to be only about 1-2 days. The short time scale suggests that the mixing of high-temperature magma triggered the sub-Plinian eruptions.

This mixing process was not accompanied by a significant change in the volume of the magma chamber because no significant crustal deformation was observed several days before the eruptions (Japan Meteorological Agency, 2011). We propose magmatic overturn or melt accumulation within the magma chamber as a possible process.

Some magnetite phenocrysts (type-A_0) showed almost no increase in Mg and Al, indicating that they were not affected by the magma mixing and were incorporated in the magma during the ascent. The time for diffusion of type-A_0 magnetite was less than 0.4 days. This time scale corresponds to the duration of magma ascent from the magma chamber to the surface. This means that the average ascent velocity was more than 15 to 20 km/day.

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On the longevity of large upper crustal silicic magma reservoirs

Sarah E Gelman[1], Francisco J Gutierrez[2], Olivier Bachmann[3]

[1]University of Washington, USA, [2]Universidad de Chile, Chile, [3]ETH Zurich, Switzerland

E-mail: baolivie@ethz.ch

Understanding the timescales and processes involved in the formation and maturation of upper crustal magma reservoirs, ultimately sourcing the largest volcanic eruptions on Earth, is one of the most fundamental goals of volcanology. While such reservoirs are known to assemble incrementally over extended periods of time, debate persists regarding the timescales of melt preservation in the cold upper crust. If rapid cooling individually freezes incoming replenishing intrusions, accumulations of eruptible magma are impossible, precluding caldera-forming eruptions for all but the highest magma emplacement rates. Recent numerical thermal models have been used to assess the viability of upper crustal silicic magma survival, and have suggested that supervolcanic reservoirs must form in geologically short timescales with anomalously high injection rates, and subsist only ephemerally, making them less predictable. Motivated by geological observations suggesting the contrary, we have improved upon these models by incorporating two fundamental features of natural systems not previously considered: (1) a non-linear crystallization-temperature relationship adapted for upper crustal silicic magmas and (2) a temperature-dependent thermal conductivity. We demonstrate that the incorporation of both of these properties can allow an upper crustal reservoir to remain above its solidus for hundreds of thousands of years, on par with estimates from zircon crystallization histories, when fed by magma fluxes typical of large magmatic provinces. While the crystallization-temperature path plays the most significant role in maintaining a large pool of eruptible magma, the incorporation of temperature-dependent thermal properties, together with a deeper emplacement level, significantly extends the lifetime of such reservoirs. These results provide strong support for long-lived upper crustal mushes as a staging ground for accumulation of highly eruptible, crystal-poor silicic magmas, and further assert the evolutionary link between volcanic and plutonic systems

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Petrogenetic process controlling explosivity at an intraplate volcano: a case study from Ulleung Island, Republic of Korea

Marco Brenna[1], Shane J Cronin[1], Ian E M Smith[2], Richard C Price[3], Young Kwan Sohn[4]

[1]Massey University, New Zealand, [2]University of Auckland, New Zealand, [3]University of Waikato, New Zealand, [4]Gyeongsang National University, Republic of Korea

E-mail: m.brenna@massey.ac.nz

Ulleung Island represents the top of a 3000 m (from sea floor) intraplate alkali volcanic edifice in the East Sea/Sea of Japan. The emergent section of the volcano consists of a basaltic lava and agglomerate succession intruded and tilted by a younger trachytic core. Younger eruptions at c. 20 ka and 8-5 ka generated thick tephra sequences of phonolitic composition and carried to the surface intrusive syenitic accidental clasts. In major element space, there is a continuous spectrum of compositions from trachyte to phonolite but offset trace element trends exclude a direct relationship between these two end member compositions. Within the phonolitic tephras two subgroups can also be distinguished. The early erupted tephras are considerably enriched in incompatible elements and chondrite normalised rare earth element (REE) patterns display negative Eu anomalies. Later tephras have compositions intermediate between the early tephras and the trachyte/syenite samples and their REE patterns do not have significant Eu anomalies. Petrographic evidence and mineral chemistry suggest a genetic relationship between the syenitic xenoliths and their host phonolitic pumices. The c. 20 ka eruption was fed by a phonolite magma enriched in incompatible elements, possibly by fluids from the crystallizing portion of the hosting shallow magma reservoir; these fluids caused alteration, which gives the lower tephras an orange colour. The subsequent c. 8-5 ka eruption was fed by a new magma batch, which evolved through crystal fractionation but also assimilated parts of the previous reservoir. The phonolite erupted explosively as opposed to the trachytes, which erupted effusively or formed cryptodomes. The differences in eruption style are mainly due to different degrees of fractionation and enrichment in a shallow magma reservoir.

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Shallow crustal magma residence times and storage conditions revealed through in situ zircon chemistry at the Pastos Grandes Caldera Complex in SW Bolivia

Jason F Kaiser[1], Shanaka de Silva[1], Axel K Schmitt[2], Mayel Sunagua[3]

[1]Oregon State University, USA, [2]University of California Los Angeles, USA, [3]Formerly Servicio Nacional De Geologia Y Tecnico De Minas Sergeotecmin, Bolivia

E-mail: geojason.kaiser@gmail.com

The Pastos Grandes Caldera Complex in the Central Andes of southwest Bolivia provides the unique opportunity to study a young volcanic terrain along with its associated plutonic record. Studying both records together can expound the relationship between volcanic activity and pluton emplacement and evolution. The multicyclic caldera has erupted over 2500 km ^{3} of high K dacite and rhyolite ignimbrite from at least two caldera-forming supereruptions depositing the 5.45 +/- 0.02 Ma Chuhuilla, and the 2.89 +/- 0.01 Ma Pastos Grandes Ignimbrites (PGI). The much younger Chascon dome (85-94 ka) formed inside the margins of the Pastos Grandes Caldera and contains granodiorite plutonic xenoliths. Similar xenoliths have also recently been discovered in the intracaldera facies of the PGI. Together, the ignimbrites, post-collapse lava domes, and xenoliths provide a complete view of the magmatic cycles associated with a silicic, caldera-forming, eruption.

U-Pb zircon crystallization ages of the ignimbrites, collected via SIMS, reveal the pre-eruption magmatic histories. Weighted average U-Pb zircon ages from the Chuhuilla and PGI are 6.04 +/- 0.06 Ma (MSWD = 2.53; n = 45) and 3.36 +/- 0.037 Ma (MSWD = 5.79; n = 64), respectively. From a comparison of the zircon crystallization and eruption ages, minimum residence times of magmas associated with the ignimbrites are 0.59 Ma and 0.47 Ma for the Chuhuilla and PGI, respectively.

The plutonic xenoliths of the Chascon dome have a weighted average zircon crystallization age of 2.64 +/- 0.906 Ma (MSWD = 4.54; n = 54). Preliminary trace element concentrations, collected from the same spots as the U-Pb data, provide a chronologic view of magma chemistry and conditions in the ignimbrites and xenoliths. REE patterns are nearly identical in both the PGI and the xenoliths representing the remnant pluton. Many other elements such as Th, Hf, and Ti also remain constant with time. The uniform Ti concentrations indicate that temperature and composition remained uniform (650-700 C) throughout the span of zircon crystallization during the Pastos Grandes magma cycle. Collectively, these data connote that the xenoliths represent remnant magma after the PGI and record a total magmatic cycle time (minimum) of 1.60 Ma.

Post-collapse lava domes yield zircon crystallization ages in agreement with both the PGI and the plutonic xenoliths, suggesting that they represent effusive "leaks" from the solidifying post-climactic pluton.

Granodiorite xenoliths present in the intracaldera facies of the PGI likely represent the remnant magma after eruption of the Chuhuilla Ignimbrite. These xenoliths are currently under investigation, and can provide an integrated view into the magmatic evolution of a multi-cycle caldera system.

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Volcanic and compositional evolution of Nemrut stratovolcano over ca. 550,000 years as reflected on land and in tephra layers drilled into adjacent huge Lake Van (Eastern Anatolia)

Mari Sumita[1], Hans-Ulrich Schmincke[1], PaleoVan scientific team

[1]GEOMAR Helmholtz-centre for ocean research Kiel, Germany

E-mail: msumita@geomar.de

We have analyzed the evolution of explosive volcanism (stratigraphy, volcanology, composition) of a large, previously poorly studied stratovolcano by studying both land deposits and several hundred tephra layers drilled at Lake Van, the largest saline lake in the world (130 km WSW-ENE extent, max. depth 450 m). One of our aims is to reconstruct the evolution of one or more theoretical stratovolcano based entirely on the tephra layers drilled in 2010 in the ICDP PaleoVan project - pretending the source to be unknown. This model is then compared with the tephra studies of two real volcanoes: Historically active alkalic Nemrut (2,948 m asl), famous for its caldera, rises west and neighboring calcalkalic larger Suphan (4,058 m asl) north/northeast of Lake Van. This approach should aid in reconstructing volcano evolution based entirely on drill data. Another goal is to understand the interaction of climate - paleoclimate being the rationale of the Paleovan project - volcanism and tectonism, the Van basin being located in the collision zone between the Arabian and Eurasian plates.

We have recognized ca. 40 variably peralkaline trachytic and rhyolitic fallout tephra units on land, some of large magnitude (up to ca. 30 km^3 DRE), and ca. 12 slightly welded and slightly more mafic ignimbrites. Rhyolitic activity increased strongly during the past 200 ka, major eruptions occurring in intervals of 20-40,000 years. Axes of major fallout fans are oriented dominantly west-southwest, the main reason for the dominance of Nemrut-sourced tephras in the cored section. Basaltic tephras are next to absent.

Results from drilled tephra deposits: (1) Explosive eruptions began ca. 550,000 years ago dominantly from nearby sources. (2) Calcalkalic dacite-rhyolite tephras are more common among older tephras while the upper ca 100 m of the 220 m cored section are almost exclusively peralkaline trachyte and rhyolite. (3) Basaltic tephra is common in the lower ca. 80 m (older than ca. 400 ka), common videromelane shards indicating subaqueous eruption. Basaltic eruptions dominantly occurred at low altitudes possibly also in the early lake stage. (4) Fallout tephras dominate but ca. 10-12 thicker (up to 6 m) and poorly sorted tephras are interpreted as syn-ignimbrite turbites suggesting several caldera stages. (5) The overall volcanic evolution began with a dominantly basaltic stage accompanied by 2 or more explosive volcanoes, beginning with the calcalkalic one. (6) Compositions changed significantly, the calkalkalic center prevailing early, the alkalic later. (7) At least 2 different centers are involved because of lack of overlap in mineralogy and bulk chemistry (fayalite, hedenbergite, sporadic aenigmatite, anorthoclase in the alkalic volcano and plagioclase, hypersthene, clinopyroxene and olivine all in partial disequilibrium in the calcalkalic center). (8) The alkalic volcano was either much larger (more active), younger or located more upwind than the calcalkalic one.

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Understanding regular variability in magma composition and eruption frequency through high-precision, long tephra records

Shane J. Cronin[1], Ian E.M. Smith[2], Mark S. Bebbington[1], Michael B. Turner[3], Gert Lube[1]

[1]Volcanic Risk Solutions, Massey University, New Zealand, [2]School of Environment, Auckland University, New Zealand, [3]Department of Geology, Macquarie University, Australia

E-mail: s.j.cronin@massey.ac.nz

It has long been recognized that reawakening stratovolcanoes have a semi-regular pattern of activity, with return periods of large, destructive eruptions at many volcanoes around the world on the order of 200-500 years. This may be driven by magma-production rates, heat flow or mantle fertility of various volcanic settings, or simply represent the time taken for the filtering and processing of magma as it makes its way through the crust to eruption. Plaguing the quest for a deeper understanding of the processes leading to regular large eruptions at stratovolcanoes is the need for a complete record of volcanic output over time. We attempt to fill this gap by building the highest possible resolution records of volcanic activity for the longest possible periods at individual volcanoes. We present here our results from two tephra records containing more than 160 eruption events, one from Mt. Taranaki, New Zealand that extends for 32 ka and the other from Gunung Merapi, Java, Indonesia that spans 10 ka. Both records show regular variations in dome-building vs. explosive eruptions, the former represented by fall and surge layers dominated by dense juvenile lithics and the latter by lapilli-dominated pumice fall and pyroclastic flow deposits. Both records also show regular cycles in variations of eruption frequency. Glass and titanomagnetite chemistry (via Electron microprobe) shows regular variations in erupted composition that match with eruption frequency cycles. Titanomagnetite Ti, Al and Mg contents show strong correlation with eruption style and frequency. Mg and Al contents of titanomagnetite and glasses of each record indicate cycling between the eruption of mafic and evolved andesitic magmas. Variability in Ti concentrations primarily reflects late-stage solid-state exolution in magmas stored in shallow conduits and domes. By contrast, homogenous Ti, Al and Mg contents of titanomagnetites reflect the initial partial melting, fractional crystallization, assembly and mixing of multiple magma sub-batches at mid to lower crustal depths before sudden eruption via sub-plinian processes. Contrasting in these two records, however, is the overall frequency of eruptions and the nature of long-term geochemical changes. The Taranaki system shows an increasing average Ti content in titanomagnetites, corresponding with higher alkali (especially K) contents in glasses and whole-lapilli compositions. By contrast, the Merapi system appears relatively more stable over time. Comparing and contrasting these two long records, along with the assembling of similar detailed eruption sequences at other stratovolcanoes, can provide improvements to the hazard assessment at such volcanoes through the more robust informed application of probabilistic methods. This research direction can also provide new insights into the magmatic and eruptive dynamics of stratovolcanoes, and especially transitions between various eruption mechanisms and magnitudes.

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Effect of volatiles, crystallization, and lava dome effusion rate on pyroclastic surge dispersal at Merapi volcano, Java, Indonesia

Kimberly Genareau[1], Shane J. Cronin[2], Gert Lube[2]

[1]Lehigh University, U.S.A., [2]Massey University, New Zealand

E-mail: kig210@lehigh.edu

The behavior of volatile elements in an erupting magma will have direct effects on the rheology of effused lavas and the dynamic properties of pyroclastic density currents resulting from dome collapse and explosive activity. Pyroclastic density current deposits from the October/November 2010 surge-producing events at Merapi volcano, Java, Indonesia were examined using a combination of scanning electron microscopy (SEM), stereo-scanning electron microscopy (SSEM), secondary ion mass spectrometry (SIMS), and electron microprobe (EMP) analyses. Samples from the two climactic and lethal surge events on 26 October and 5 November were examined, in addition to several intermediate surges, taken from a series of transects between 3 and 8 km from source. Microtextural and geochemical properties of the tephras reveal variations in volatile behavior that influenced the physical properties of the resulting pyroclastic surges. The number density of plagioclase feldspar microlites is ten times higher in the 5 November event, while the number of pyroxene/Fe-oxide microlites is fifteen times higher compared to the 26 October event. SSEM analyses of the intermediate surges reveal variations in vesicle morphology during the transition between the two main surge-producing events. EMP analyses indicate synchronous growth of feldspar microlites and phenocryst rims in both phases of dome effusion. Degassing of the 26 October dome at relatively greater depths in the plumbing system lead to a significant shift of the feldspar liquidus, resulting in alkali-rich compositions compared to the dominantly plagioclase compositions found in the 5 November lava crystals. Despite efficient degassing of the earlier dome, enough volatiles remained in the interstitial melt to cause sudden, significant vesiculation of the residual melt following decompression. In addition, CO_2 contents of groundmass glasses in the 26 October dome material is significantly higher (2-3 times) than that of the 5 November lavas. Textures within lapilli of the 5 November surge deposits revealed the development of permeable vesicle pathways, enabling efficient degassing and decompression-induced crystallization of phenocryst rims and microlite phases in the shallow conduit in a few days prior to collapse. Trends in volatile elements during the final stage of feldspar phenocryst growth will be presented. Variations in lava textural and chemical characteristics are a function of lava effusion rate and decompression path between the different effusive stages. The behavior of volatile elements, mainly H_2O, CO_2, and Li, between the main surge-producing events of 26 October and 5 November, 2010, affected magma rheology over several days during an increased rate of lava dome effusion, altering the composition of the products, the generation of fine ash, and the transport properties (total volume, run-out distance) of resulting pyroclastic density currents.

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Understanding the volcanic activity at Popocatepetl Volcano, Mexico from 1997 to 2010

Julie Roberge[1], Severine Moune[2], Angel Briseno-Arellano[3]

[1]ESIA-Ticoman, Instituto Politecnico Nacional (IPN), Mexico, [2]Laboratoire Magmas et Volcans, Universite Blaise Pascal, Clermont Ferrand, France, [3]Facultad de Ingeniera, UNAM, Mexico

E-mail: robergejulie@gmail.com

Popocatepetl volcano located southeast of Mexico City has been the site of open vent degassing since late 1994. The products of these eruptions show evidence of a mixture of siliceous and mafic magmas shortly before eruption. We present a qualitative analysis of the activity of Popocatepetl from 1997 to 2010 based on the daily reports from CENAPRED (National Center for Disaster Prevention). The daily reports are a compilation of the number of gas/gas and ash emissions and number and intensities of tremors and volcanotectonic earthquakes events. Gas and ash emissions, tremors and volcanotectonic earthquakes were plotted in number of events against time for each month, year and the total of the years studied. In addition, the earthquakes were further characterized according to their intensity and location around the volcano. All the combined data display trends showing that the volcanic activity increases at the end of each year and gradually decreases in March, with even lower activity during the summer. In January 2010, videos of the degassing activity were taken while measuring SO_2 fluxes with a DOAS (Differential Optical Absorption Spectroscopy). The video clearly shows two types of degassing: 1) diffuse degassing from the central vent of the volcano where the lava dome is emplaced, and 2) jet-like degassing from fumaroles at the Eastern side of the crater. These fumaroles form a degassing site with very rare lava emission. It was observed that when the degassing activity intensifies at one site, it decreases at the other. However, preliminary data indicate similar SO_2 fluxes which imply that the source of gas is the same for both types of degassing activities and only the emission site changes.

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Relationships between mafic replenishment and eruption triggering at silicic systems: Insights from time scales of magma interactions

Caroline Bouvet de Maisonneuve[1], Fidel Costa[1], Christian Huber[2]

[1]Earth Observatory of Singapore, Nanyang Technological University, Singapore, [2]School of Earth and Atmospheric Sciences, Georgia Tech., USA

E-mail: carolinebouvet@ntu.edu.sg

In silicic systems (dacites to rhyolites), evidences of mixing/mingling with a mafic component (basalts to basaltic-andesites) are frequently observed. The time scales for mixing prior to eruption have been inferred using the presence of disequilibrium mineral assemblages and applying reaction and diffusion-based models. Interestingly, these time scales are often on the order of a few hours to months, and the usual interpretation is that the intrusion of mafic magma triggered the silicic eruption. However, given the complexity of fluid dynamic interactions between magmas of contrasting physical properties it is unclear whether these time scales accurately record the arrival of mafic magma in the system, or if there is a delay between replenishment and mixing that is not registered by the crystals and their reactions.

The efficiency with which two magmas interact and mix depends on several factors, including the mafic injection rate, the Ra number (i.e. the ability to convect), and the viscosities of both magmas. In the case of large injection rates, low magma viscosities, and the presence of a large reservoir (i.e. large Ra), silicic and mafic magmas will mix rapidly. Therefore the time scales recorded by reaction and zoning of mafic minerals will accurately report the time between mafic injection and eruption. On the other hand, if the injection rates are low and the viscosity of the ambient silicic magma is high (i.e. low Ra), the mafic magma can pond at the base of the reservoir rather than mix. In this case, the zoned mafic minerals record a time scale that can be significantly shorter than that of injection, and thus lead to erroneous interpretation of eruption triggers.

We investigate the likelihood and implications of each scenario by combining theoretical arguments and thermal modelling with petrological investigations. We consider the case of the Rabaul caldera where above background seismic and deformation signals started in 1971, and peaked between 1983 and 1985, but the onset of eruptive activity only occurred in 1994. Evidence for basaltic injection into a dacitic reservoir is preserved in the 1994-to-present eruptive products. A textural maturation from fine, acicular to large, blocky mafic crystal clots implies different relative ages of formation. Modelling the trace element zoning in plagioclase yields two contrasting time scales of mixing. One event occurred a couple of decades prior to the 2006 eruption and coincides with the peak of unrest. The other occurred a few days to weeks prior to the 2006 eruption, which could imply that mafic injections were the trigger for this eruption. We explore the range of mechanical parameters pertinent to the Rabaul system to address whether (i) all the basaltic replenishment occurred in 1983-85 and mixing occurred subsequently as a number of discrete events, or (ii) multiple replenishment events are required to produce the observed sample textures and characteristics.

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Late stage assembly of a voluminous ignimbrite from multiple magma batches as revelaed by in-situ Sr isotopic measurements

Ben S Ellis[1], Darin M Schwartz[2], William M Phillips[3], Dawid Szymanowski[1], Olivier Bachmann[1]

[1]Institute for Geochemistry and Petrology, ETH Zurich, Switzerland, [2]Geological Sciences, University of Idaho, USA, [3]Idaho Geological Survey, USA

E-mail: ben.ellis@erdw.ethz.ch

The Heise caldera complex of the Yellowstone hotspot track represents a multi-cyclic caldera which was active between about 6.6 and 4.5 Ma. The youngest explosive eruption of the centre produced the 1,800 km^3, rhyolitic Kilgore Tuff which is exposed to the north and south of the Snake River Plain. As part of a new mapping initiative and building on previous work in the region we are characterising the mineral componentry of the Kilgore Tuff. Previous work has shown that Kilgore Tuff represents the largest low-^{18}O rhyolite known with O isotopes homogeneous in quartz and feldspars yet heterogeneous in zircon. Here we investigate multiple mineral phases to decipher the magmatic processes occurring prior to this catastrophic event. In feldspars we analysed major and trace elements and $^{87}Sr/^{86}Sr$ ratios via in-situ LA-ICPMS, our results show that multiple populations of plagioclase exist within the Kilgore Tuff. The main plagioclase population is between 0.7116 and 0.7118, which is more radiogenic than the reported bulk values of 0.7103-0.7107. The variability observed in plagioclase in the Kilgore Tuff is in contrast both with the hotter rhyolites of the central Snake River Plain further west, and with the older explosive deposits from the Heise centre. Such compositional variety is surprising given the oxygen isotope evidence for magma homogeneity prior to eruption and the relatively high magmatic temperatures (estimated between 800-900 °C) which should act to homogenise isotopic variability. Under such conditions, Sr isotopic homogeneity in plagioclase is likely achieved in 5 mm grains within <10 kyr. The observed Sr isotope heterogeneity in Kilgore Tuff plagioclase may result from isolation of magma batches until shortly before eruption. Such rapid priming of the magma reservoir is increasingly being observed and may be a common occurrence in large-volume volcanic systems.

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Deformation of Cordon Caulle Volcano (Chile) measured by InSAR from 2007 to 2011

Jennifer A Jay[1], Matthew E Pritchard[1], Fidel Costa[2], Luis E Lara[3]

[1]Cornell University, USA, [2]Earth Observatory of Singapore, Singapore, [3]SERNAGEOMIN, Chile

E-mail: jaj88@cornell.edu

We combine petrological and ground deformation data to constrain the subsurface magmatic and hydrothermal processes related to the 2011-2012 rhyodacite eruption of Cordon Caulle volcano in southern Chile. The geochemical data indicate that the phenocryst-poor rhyodacite erupted in 2011-2012 is very similar to that of the 1960 and 1921-1922 eruptions. The calculated pre-eruptive conditions for the 3 erupted magmas are also indistinguishable: 900 +/- 20 deg C, 4 +/- 0.5 wt percent H2O, and 150 +/- 20 MPa. This implies that either (1) there has been no significant intrusion of magma in about 100 years while still erupting about 2 km3 (DRE) in the 3 eruptive periods, or (2) that all new additions are rhyodacitic melt that are indistinguishable from that in the shallow reservoir and is probably generated much deeper, in the lower crust. Using InSAR, we have found a complex history of ground deformation preceding the eruption at Cordon Caulle, and the nature of the several distinct inflation events are informed by this petrological data. This is one of the few large rhyodacite eruptions with detailed images of ground deformation in the years before the eruption.

InSAR studies show that Cordon Caulle has undergone episodes of deformation since at least 1996 and has varied between subsidence and uplift in different locations of the volcanic complex. Between 2007 and 2009 we observe two distinct uplift episodes, both with a maximum uplift signal of 18.5 cm at the center of deformation. We also find an episode of deformation occurring sometime between Feb-Mar 2010 located in the Cordillera Nevada caldera with 10 cm uplift within the caldera and 10 cm subsidence on the eastern rim of the caldera. This deformation episode is likely related to the nearby Trahuilco hot springs, which is fed by a shallow steam-heated aquifer and is the main outflow of the Cordon Caulle geothermal system. We do not observe any deformation from late 2010 to early 2011, when the ALOS satellite ceased operation. Petrological studies of the clinopyroxene exsolution lamellae in the 2011 eruptive products indicate the existence of a large (10 km3) long-lived (5 ka) shallow magma reservoir. We hypothesize that the 2007-2009 uplift episodes could have resulted from an injection of magma into the base of a pre-existing rhyodacite magma reservoir with minimal interaction between the 2 magma sources. Initial modeling of the 2008-2009 deformation pattern using one inflating point source puts the deformation source at about 7 km depth with a volume change of 0.03 km3. Assuming an appropriate value for magma compressibility, the combined modeled reservoir volume change from 2007-2009 could account for the volume of the 2011-2012 DRE erupted material of 0.8 km3. However, this simple model does not provide an accurate fit to all available ascending and descending interferograms, suggesting that a more complicated source may be involved, such as a prolate spheroid or faulting.

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Magmatic control on volcanic activity at Volcan de Colima, Mexico

Reubi Olivier[1], Blundy Jon[2], Pickles Joe[2], Varley Nicholas[3]

[1]Institut des sciences de la Terre, Universite de Lausanne, Switzerland, [2]School of Earth Sciences, University of Bristol, UK, [3]Facultad de Ciencias, Universidad de Colima, Colima, Mexico

E-mail: olivier.reubi@unil.ch

Volcan de Colima historical activity is characterized by periods of intermittent effusive and Vulcanian eruptions punctuated by major sub-Plinian to Plinian eruptions, the most recent of which occurred in 1913. The effusive-Vulcanian phases are dominated by andesitic lavas with 61 wt% SiO_2, when the Plinian eruptions involve more mafic andesites with 58 wt% SiO_2. The systematic shifts in compositions associated with the Plinan eruptions indicate a link between the eruptive cycles and the magmatic dynamics.

Detailed petrological and geochemical investigations of the magmas erupted during the effusive and Vulcanian activity between 1998 and 2010 enable us to constrain the storage conditions and pre-eruptive evolution of these magmas. The melt inclusions exhibit compositional trends consistent with up to 40% crystallization under vapour-statured conditions at pressures <1.5 kbar. Decompression induced dehydration is driving crystallisation in the sub-volcanic magmatic systems. Compositional zoning of phenocrysts indicates that, in addition to magma mingling in the ascending dacite melt of mafic crystals, magma mixing was important in the 1998-2010 magmatic system but involved predominantly dacitic magmas with limited compositional variability. The range of ($^{210}Pb/^{226}Ra$) activity ratios and the width of amphibole reaction rims indicate that the feeding magmatic system comprised several magma batches with residence and degassing times in the vapour-saturated section of the system ranging from several days to 7 years. No significant differences in petrology, volatile contents, degassing paths and time scales are observed between the Vulcanian and effusive eruptions, implying that these shifts in eruption style are principally related to conduit dynamics. The most vigorous effusive phases may, nonetheless, be related to influx of undegassed dacitic magmas.

The last major Plinian eruption, in 1913, erupted magmas clearly distinct from those of 1998-2010 in terms of storage conditions and pre-eruptive magmatic evolution. The most distinctive features of the 1913 magmas are the higher H_2O contents (and storage pressures) of the melt inclusions, the textural and chemical evidences for magma mixing with mafic melts shown by some phenocrysts, and the more mafic compositions of the groundmass glasses compared to the melt inclusions. Taken together this indicates that the Vulcanian-effusive activity characteristic of the 1998-2010 period and the 1913 Plinian eruption represent clearly distinct pre-eruptive scenarios rather than a continuum. Influx and mixing of mafic magmas in the dacitic subvolcanic reservoir was important prior to the 1913 eruption and most likely caused the shift in eruptive style. The rates and periodicity of replenishment of the subvolcanic system by, respectively, dacitic and mafic magmas appear to be key parameters controlling the eruptive cycles at Volcan de Colima.

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The 1707 AD eruption of Fuji Volcano, Japan: Magmatic Processes and Timescales

Elisabeth Widom, David C Kuentz

Dept. of Geology and Environmental Earth Science, Miami University (Ohio), USA

E-mail: widome@MiamiOH.edu

Fuji Volcano, one of the most hazardous volcanoes in Japan, has erupted primarily basaltic magmas throughout its history. However, the most recent eruption in 1707 AD produced a chemically zoned deposit with compositions ranging from basalt to dacite. This eruption was one of the largest (0.7 km^3 d.r.e.) and most explosive eruptions in Fuji's history, and related tephra deposits a few centimeters in thickness reached as far as Tokyo, approximately 100 km from the vent [1-3]. Prior studies have proposed a variety of processes to explain the chemical variations in this deposit, including liquid immiscibility [4], magma mixing involving magmas from discrete magma chambers [2], and fractional crystallization with minor crustal assimilation and basaltic magma injection [5]. In order to further constrain the timescales of magma evolution leading to the 1707 eruption, we have evaluated a suite of samples from throughout the 1707 AD deposit for 238U-230Th-226Ra and Ba systematics. Major and trace element variations, as well as constant Sr, Nd and Pb isotopes throughout the Fuji 1707 AD deposit are consistent with fractional crystallization of plagioclase, pyroxene, olivine and magnetite, and minor apatite as the dominant process leading to chemical variations. U-series disequilibria data show that all samples are U-enriched, consistent with derivation from a mantle wedge that has been fluxed by hydrous slab fluids [6; this study]. Essentially constant 230Th/232Th, but decreasing 238U/232Th with increasing SiO2 and 230Th/238U close to radioactive equilibrium in the most evolved samples could be explained by assimilation of old, low U/Th crust with a 230Th/232Th ratio similar to the Fuji basalts. However, Os isotope variations indicate that the most evolved samples have been affected by less than 0.2 percent crustal assimilation, which should have an insignificant effect on the U-Th disequilibria. Fractionation of apatite during magma differentiation can alternatively explain the variations in 238U/232Th. The constant 230Th/232Th requires this fractionation to take place over a timescale of less than 10 ka. However, activity ratios of 226Ra/230Th greater than 1 in all samples [6; this study] indicate that magma fractionation timescales may be substantially shorter. Decreasing 226Ra/230Th with increasing SiO2 can be explained by instantaneous or continuous fractionation models, and indicate timescales of magma fractionation from parental basalts to dacite on the order of 10^3 years. References: [1] Miyaji (1984), Bull. Volcanol. Soc. Japan 29, 17-30. [2] Yoshimoto et al. (2004), Proc. Japan Acad., Ser. B 80, 103-106. [3] Miyaji et al. (2011), JVGR 207, 113-129. [4] Kawamoto (1992), Int. Geological Congress Abs. 29, 558. [5] Watanabe et al. (2006), JVGR 206, 1-19. [6] Kurihara et al. (2008), Radioisotopes 57, 471-483.

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Uranium-series timescale constraints on recent changes in the eruptive behaviour of Merapi Volcano, Java, Indonesia

Heather Handley[1], Ralf Gertisser[2], Mark Reagan[3], Katie Preece[4], Kim Berlo[5], Jenni Barclay[4], Richard Herd[4]

[1]Department of Earth and Planetary Sciences, Macquarie University, Sydney, NSW 2109, Australia, [2]School of Physical and Geographical Sciences, Keele University, Keele, ST5 5BG, UK, [3]Department of Geoscience, The University of Iowa, Iowa City, IA 52242, USA, [4]School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK, [5]Department of Earth Sciences, University of Oxford, Oxford, OX1 3AN, UK

E-mail: heather.handley@mq.edu.au

The 2010 eruption Merapi volcano (Central Java, Indonesia) was the volcano's largest eruption in 140 years and was much more violent than expected. Prior to 2010, for example in 2006, volcanic activity at Merapi was characterised by several months of slow dome growth punctuated by gravitational dome failures, generating small-volume pyroclastic density currents. We present new uranium-series (U-Th-Ra-Pb) isotope data for the volcanic products of both the 2006 and 2010 eruptions at Merapi to investigate the driving forces behind the recent unusual explosive behaviour and their timescales. The 2006 and 2010 volcanic rocks display ^{238}U excess and suggest variable enrichment by a U-rich fluid or melt (e.g., subducted slab or crustal assimilant) within the last 380 kyr. The 2010 deposits display a slightly wider range in (^{238}U/^{232}Th) (0.671 to 0.723) compared to those of 2006 (0.702 to 0.720). A negative correlation is observed between (^{226}Ra/^{230}Th) and Th (as index of differentiation). Assuming that the degree of disequilibria in the sample with the highest (^{226}Ra/^{230}Th) (3.28) represents that at the onset of differentiation, ^{226}Ra excesses implicate short timescales for magmatic differentiation at Merapi of $<$ 750 years for the 2006 and $<$ 300 years for the 2010 volcanic rocks, noting that apart from one 2006 sample, the volcanic rocks of both eruptions have similar (^{226}Ra/^{230}Th) activity ratios. However, it is unlikely that the U-series data at Merapi can be interpreted within the context of simple closed-system evolution due to the previous recognition of open-system processes, such as magma recharge, magma mixing and mingling processes and assimilation of crustal carbonates. The 2006 and 2010 volcanic rocks have initial (^{210}Pb) values of 2.66 to 3.04 dpm/g and 2.22 to 3.08 dpm/g and (^{210}Pb/^{226}Ra)$_0$ ratios of 0.81 to 0.95 and 0.72 to 0.96, respectively and may suggest persistent and complete ^{222}Rn degassing over a few years to a decade prior to eruption possibly related to the time for magma ascent from a deeper crustal reservoir. The 2010 volcanic rocks show the largest ^{210}Pb deficits suggesting longer timescales of degassing prior to eruption compared to the 2006 eruption. However, volcanic rocks of both eruptions display relatively similar range in (^{210}Pb/^{226}Ra)$_0$ ratios.

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Magma-mixing and -mingling as key magmatic processes controlling the development of the volcanic events in the Gutâi Neogene Volcanic Zone, Eastern Carpathians, Romania

Marinel Kovacs[1], Alexandrina Fülöp[2], Zoltan Pécskay[3], Maria Jurje[4]

[1]Tech.Univ.Cluj-Napoca, North Univ.Center Baia Mare, Baia Mare, Romania, [2]DeBeers Canada Inc., Toronto, Ontario, Canada, [3]Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen, Hungary, [4]Mineralogy Museum of Baia Mare, Baia Mare, Romania

E-mail: marinelkovacs@yahoo.com

The Gutâi Volcanic Zone (GVZ) belongs to the Neogene-Quaternary volcanic chain of the Carpathians developed on the north-western part of the Romanian territory. A calc-alkaline intermediate volcanism represented by a series of rocks ranging from basalts to rhyolites (andesites are the prevalent ones) took place during Miocene (13.4-7.0 Ma). The mineralogical, textural and geochemical features of many of the igneous rocks from GVZ suggest that magma-mixing and -mingling processes were involved during their genesis (e.g. the large-sized embayed sanidine crystals coexisting with high Mg# (85-90) chromian-diopside and high amount of gabbroic-type MME in the same biotite dacite and the large-sized sieve-textured or strong reverse zoned plagioclases together with large-sized embayed quartz crystals in the same andesite rock). Most of the rock types are dacites and subordinately andesites mainly related to extrusive domes (13.2-8.0 Ma). In some cases, two different but co-genetic rock types appear spatially and temporally associated as a result of magma-mixing and -mingling (e.g. biotite dacite and biotite andesite). Sometimes, one of the rocks is a hybrid rock such as a MME-hosting dacite and the other one is compositionally close to the potential basic end-member such as a basaltic andesite with 51.5-54.3 SiO_2. Some of the magma-mixing and -mingling products show compositions matching with the acidic end-members (e.g. the biotite dacites/rhyolites with glassy, perlitic groundmass texture). The mineralogical and geochemical similarities between the MME of the dacite rocks and some of the basaltic rocks from GVZ suggest the involvement of such basaltic magmas as basic end-members. These features enable the reconstruction of the magmatic processes developed in the crustal magma chambers or in the volcanic conduit, processes which controlled the emplacement of these rocks. Many volcanic events controlled by repeated magma-mixing and -mingling processes took place during the volcanic activity of GVZ and conducted to the emplacement of important volcanic structures by triggering the eruption events timewise in different locations of the area. The different PT parameters of the mineral phases contained in the hybrid rocks, suggest different conditions of evolution of the magma-mixing and -mingling processes involving different magmatic sources. The small-volume acidic MME-hosting volcanic rocks (e.g. the Dănesti dacite/rhyolite -11.6 Ma, Valea Morii dacite -10.1 Ma and Laleaua Albă dacite -8.0 Ma) resulted from magma-mixing and -mingling processes developed in small-sized, shallow level evolved/silicic reservoirs. Opposite to these, some hybrid rocks which represent one of the dominant volcanic phases in GVZ (e.g. the large-spread quartz andesite complexes – 11.3-10.5 Ma) resulted from magma-mixing and -mingling processes developed in large-sized differentiated magma chambers with near-continuous replenishment by new basaltic magmas.

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Evolution of magma plumbing system of Miyakejima volcano

Masashi Ushioda[1], Eiichi Takahashi[1], Toshihiro Suzuki[2], Morihisa Hamada[1]

[1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, Japan, [2]IFREE, JAMSTEC, Japan

E-mail: ushioda.m.ab@m.titech.ac.jp

Miyakejima is an active tholeiitic volcanic island located at about 200 km south of Tokyo in Izu-Mariana arc. Miyakejima is a typical volcano in immature arc crust. Tsukui et al. (2001) divided the volcanic activity of the last 10,000 years into four stages: 10-7ka (Ofunato Stage), 4-2.5ka (Tsubota Stage), 2.5ka to AD1154 (Oyama Stage) since AD1469 (Shinmio Stage). According to Niihori et al.(2003), products of the Ofunato Stage were basalts and they were relatively primitive basalts. On the other hand, products in Tsubota Stage were andesites and those in the latter two stages were mixed products of basalt and andesite. Precise knowledge of depth, temperature, water content and fO2 of magma chamber are essentially important in discussing evolution of magma plumbing system. The purpose of this study is to investigate the evolution of the magma plumbing system in Miyakejima in the last 10ka based on high-pressure experiments and petrology. We show that a simple system in the Ofunato Stage developed into a complex one and this accounts for the change in chemical and petrological features in the subsequent stages of Miyakejima volcano.

To understand the evolution of the magma plumbing system, first we studied the magma chamber in Ofunato Stage by high-pressure experiments. Experiments were performed at 1.0-2.5kbar with various H2O content using IHPVs at the Magma Factory, Tokyo Tech. Based on the experimental results and petrology of products in Ofunato Stage, magma chamber in Ofunato Stage was reconstructed. The magma chamber was located at 5-6km depth (about 1.5kbar) and water-rich (about 3wt.%) basalt magma crystallized olivine and calcic plagioclase (which is the typical phenocryst assemblage throughout Ofunato Stage). Volatile content (H2O, CO2, S and Cl) of melt inclusions were analyzed by FTIR and EPMA. Maximum H2O and CO2 content of a melt inclusion in olivine are 3.3wt.% and 160wt.ppm, respectively. The gas saturation pressure of magma indicates that the pressure of magma chamber in Ofunato Stage should be at least 1.5kbar.

Whole rock compositions in Ofunato and Tsubota stage was analysed by XRF. A series of crystallization trends were calculated using MELTS program (Ghiorso and Sack, 1995), and it is found that andesites erupted in Tsubota Stage can be formed by fractional crystallization of OFS basalt at pressure less than 1.5kbar which corresponds with that of shallow level chamber in the two-layered magma chamber after Sinmio stage (e.g. Amma-Miyasaka and Nakagawa, 2003). Postulated water content in magma (about 0.6 wt.%; water-saturated pressure of basalt for this water content is less than 1.0kbar), however, is much lower than in Ofunato Stage (about 3 wt.

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Magma mixing indicated by heterogeneous structure in the Mikurasawa lava, the Taisetsu volcano, in central Hokkaido, Japan

BABA HIKARU[1], WADA KEIJI[1], SATO EIICHI[2]

[1]Hokkaido University of Education at Asahikawa, Japan, [2]Kobe University, Japan

E-mail: hikaru.baba@gmail.com

The eruption products of the Taisetsu volcano in central Hokkaido show the heterogeneous structures such as mafic inclusions and banded lavas, caused by magma mixing. The Mikurasawa lava erupted from a vent of outside the Ohachidaira caldera (about 30 Ka) at a younger stage (<10-20 Ka) of the Taisetsu volcano. This andesitic host lava has various types of mafic inclusions, and both dacitic and mafic elongated parts make up the banded structure. These heterogeneous structures in the Mikurasawa lava are the most case of characterizing the Taisetsu volcano particularly. The key to elucidating magma mixing processes with petrological technique is to understand the factors of forming heterogeneous structures in the Mikurasawa lava.

The host lava is characterized by coexisting phenocrysts which crystallized from different end-member magmas. The plagioclase phenocryst is classified into three types by An content of the core. Type-A plagioclase phenocryst (An>82) indicates no zoning in the core, but indicates strong normal zoning in the rim. Type-B plagioclase phenocryst (58<An<82) indicates heterogeneous zoning in the core; the compositional range is from An=47 to An=82. The core composition partially overlaps with that of type-C plagioclase phenocryst. Type-C plagioclase phenocryst (An<58) indicates continuous zoning overall phenocryst; this characters are good agreement with those of the dacitic part. Type-C phenocryst in the host lava indicates reverse zoning in the rim. The augite and orthopyroxene phenocrysts are classified into two types based on Mg# versus Ti and Al content respectively. Using two pyroxene thermometer (Wells, 1977), temperatures of felsic and mafic end-member magmas were estimated 900℃ and 1000℃.

Mafic inclusions in the host lava are classified into two types by the color of the interstitial glass; clear glass and brown glass. Each type of mafic inclusions is classified into two sub-types by granularity of groundmass minerals; fine-type and coarse-type.

Heterogeneous structures at the outcrop, phenocrysts compositional variety in the host lava, and diversity of mafic inclusions suggest that three mixed (andesitic, dacitic and mafic) magmas were erupted, those from different stage of mixing events in the zoned magma chamber with mush layers injected by two kinds of mafic end-member magmas.

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Evolution of magma plumbing system of Sakurajima volcano in the last 50 years: Frequent vulcanian eruptions controlled by basalt injection

Kaho Ebihara[1], Mitsuhiro Nakagawa[1], Akiko Matsumoto[1], Mizuho Amma-Miyasaka[1], Masato Iguchi[2]

[1]Hokkaido University, Japan, [2]Kyoto University, Japan

E-mail: shrimp@mail.sci.hokudai.ac.jp

Sakurajimna volcano, a post-caldera volcano of Aira caldera in South Kyushu, has repeated plinian eruptions three times since 1471 and effused lava in 1946. Vulcanian eruptions have continued since 1955 until now. Nakagawa et al. (2011) concluded that three end-member magma mixing have occurred in 1914, 1946, 1958 and 1990; basaltic magma (B) inject into mixed magma of silicic (S) and andesitic (A) just before eruption. We develop petrological study of the vulcanian eruptions in the last 50 years to investigate temporal change of magma plumbing system in detail. Whole-rock SiO_2 content of erupted materials in the last 50 years are 58-64% (andesitic). Although these rocks have gradually changed to become more mafic with time since 1914, their compositional trends in SiO_2-variation diagrams are consistent with those of 1914 and 1946. All the ejecta contain plagioclase, orthopyroxene, clinopyroxene and magnetite as phenocrysts, and sometimes accompanying olivine. Plagioclase phenocrysts show compositionally bimodal distributions (An60 and An80), and sometimes there exist compositional peaks of An90. Orthopyroxene phenocrysts show unimodal or bimodal distribution in the range of Mg#65-75, and clinopyroxene phenocrysts similarly in Mg#70-80. Furthermore, normally and reversely zoned phenocrysts of plagioclase and pyroxene usually coexist in a single sample. Olivine phenocrysts are mainly divided into two types, one is Fo70 (surrounded by thick pyroxenes), and another is Fo80 (surrounded by microlites, have no reaction rims). Bimodal distribution of plagioclase phenocrysts, coexistence of normally and reversely zoned phenocrysts and presence of Mg-rich olivines that compositionally disequilibrium with pyroxenes suggested that magma mixing also occurred in the last 50 years. S-magma: plagioclase (An=46-64), orthopyroxene (Mg#=60-68), clinopyroxene (Mg#=66-72) and magnetite, and A-magma: plagioclase (An=64-86), orthopyroxene (Mg#=68-76), clinopyroxene (Mg#=72-79) and magnetite, and B-magma: plagioclase (An=86-94) and olivine (Fo=75-82). The end-member magmas of these vulcanian eruptions are similar to those of Nakagawa et al.(2011). The relationships between ratios of these phenocrysts and whole-rock SiO_2 suggests that whole-rock compositional variations of juvenile materials since 20th century should be formed by injection of B-magma into the mixed magma of S and A (Nakagawa et al., 2011). The level of eruptive activity would correlate to whole-rock chemistry of juvenile materials. During the periods, in 1914 and from the late 1970's to 1980's, which the level of the activity increased, whole-rock SiO2 contents of the juveniles had also decreased. This fact suggests that the scale and/or frequency of the injection of B-magma would control the level of eruptive activity. In other word, we suggest that monitoring of the B-magma might be essential to forecast future eruptive activity in Sakurajima volcano.

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Magma process and systems of the Kyoho eruption of Shinmoe-dake volcano in Kirishima volcanoes, Japan

Tsuyoshi Miyamoto

Center for Northeast Asian Studies, Tohoku University, Japan

E-mail: t-miya@cneas.tohoku.ac.jp

Shinmoe-dake volcano in Kirishima volcanoes at south Japan has erupted in January 2011. This activity has been in about 300 years since the Kyoho eruption (AD1716-17). From the similarities in the magma composition and the eruption sequence between the 2011 eruption and the early stage of the Kyoho eruption, it is important to understand the magma process of the Kyoho eruption. But the 2011 eruption after the first stage has a longer dormancy than the Kyoho eruption. Thus I examined the Kyoho eruption products to understand the difference of magma systems between two episodes.

The Kyoho eruption products are classified into eight units (Sm-KP1 to Sm-KP7, and Sm-MP) (Imura and Kobayashi, 1991; Tsutsui and Kobayashi, 2011). Pumice clasts in all units are dark-gray and rare yellow. Dark-gray pumices have lower bulk-rock SiO2 content (57-58.5 wt.%) than the yellow ones (62 wt.%). Almost pumice show the heterogeneous texture on a scale from millimeters to tens of micrometers. Mineral assemblages of phenocrysts in all pumices are composed of plagioclase, orthopyroxene (Opx), clinopyroxene (Cpx), and Fe-Ti oxides. Olivine phenocrysts are contained only in the dark-gray pumice of Sm-KP4.

In dark-gray pumices, the distribution of the core Mg-value in Opx is bimodal in the range of 64-66 and 73-76. Low-Mg core Opx has thick rim of 72-74 with reverse zoning. The other mineralogical features in the dark-gray pumice also show the mixing of mafic and felsic magmas. But the olivine (Fo77-80) in Sm-KP4 is not in equilibrium with high-Mg core Opx. This indicates that high-Mg pyroxene was derived from mixed magma without mafic magma, whereas the low-Mg pyroxene was from felsic magma.

Mafic magma did not erupt independently in both eruptions. The heterogeneous texture in pumice indicates that two magmas ascended in conduit at the same time. In addition, the absence of isolated olivine and a thick reverse-zoned rim of Opx in mixed magma show that mixed magma was already produced before the magma ascent. The strong chemical zoning and the various zoning profiles of the Usp component in a magnetite phenocryst indicate that mafic injection occurred repeatedly before eruption. The magnetite phenocrysts have significant compositional variation, which is larger than the zoning within each phenocryst. In spite of mingling magmas on the ascent, the bulk chemical compositions lie in a narrow range; these imply that the heterogeneity is derived not from the chemical composition but from physical conditions such as temperature and oxygen fugacity. The 2011 pumice are similar to the Kyoho products. However, whereas the olivine is rare in Kyoho pumice, 2011 eruption products almost contain the olivine without pyroxene reaction rim. This discrepancy would indicate that the mixed magma produced before eruption decreases, and at the next stage the activity might change to the other eruption style for an increase of the ratio of mafic magma.

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Changes in magma composition and formation process of Minamidake stratovolcano, at Sakurajima volcano, Kyushu, Japan; inferred from paleomagnetic age estimate and chemical composition analysis.

Daisuke Miki[1], Kozo Uto[2], Nguyen Hoang[2], Kazuhiro Ishihara[1]

[1]Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University, Japan, [2]National Institute of Advanced Industrial Science and Technology, Japan

E-mail: dmiki@svo.dpri.kyoto-u.ac.jp

Sakurajima volcano is a stratovolcano complex situated in south Kyushu, Japan. Fukuyama (1978) divided lava flows of Minamidake stratovolcano which distributed south part of Sakurajima, into M1-M4 in order from the lower. Paleomagnetic ages of M1 and M2 lava were obtained by Miki (1999) as 4 ka, and, 2 ka or 3 ka, respectively. Samples for paleomagnetic measurements and XRF analysis collected from mainly M3 and M4 lava distributed in south and southeast slope of Minamidake. Paleomagnetic age is estimated by comparison between known geomagnetic secular variation and measured paleomagnetic direction and paleointensity. As a result, paleomagnetic ages of M3 and M4 are estimated as about 2.9 ka and about 1.0 ka, respectively. From results of XRF analysis, M4 lava shows 65 wt% of SiO_2 and relatively high P_2O_5 and TiO_2 contents, where about 62 wt% of SiO_2 and relatively low P and Ti contents are observed from lower lavas (M1-M3). These facts are consistent with that products of recent 2000 years in Sakurajima volcano show higher P and Ti contents, pointed out by Uto *et al.* (2005). It is considarable that the main body of Minamidake stratovolcano, consists of M2 and M3 lavas, was formed during several hundred years around 3000 years ago. And, no lava whose age is between about 3 ka and late 8th century is found. Chemical composition of lavas of high P and Ti group including "histric lavas" seems to change systematically, where that of low P and Ti group is uniform. During recent 1300 years, SiO_2 content increased until Bunmei eruption (late 15c), then decreased until present. This may an important information to consider about evolution process of magma chamber of Sakurajima volcano.

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Dynamics of magma mixing and structure of silicic magma chamber: Evidence from petrogenesis of two types of mafic inclusions of Kurodake volcano, Central Hokkaido, Japan

Eiichi Sato[1], Keiji Wada[2]

[1]Institute for Promotion of Higher Education, Kobe University, Japan, [2]Hokkaido University of Education at Asahikawa, Japan

E-mail: esato@people.kobe-u.ac.jp

Kurodake volcano was formed about 0.2 Ma with andesitic lava flows and dome. The lavas contain a number of mafic inclusions (< 20 vol.%) ranging in size from < 1 cm to about 30 cm in diameter. The mafic inclusions have typically rounded to ellipsoidal shapes, and have sharply defined smooth contacts with the host lavas. The mafic inclusions are classified into two types, referred to as Fine-type and Coarse-type, on the basis of size of groundmass. The groundmass of the Fine-type inclusions is composed of acicular minerals (0.1 to 0.3 mm in size). On the other hand, the groundmass of the Coarse-type inclusions is composed of considerable tabular minerals (> 85 vol.% and 0.2 to 0.5 mm in size). The plagioclase phenocryst, microphenocryst, and groundmass core compositions of the host lavas have a large variation in composition from An_{38} to An_{90}. They can be classified into three groups based on their core compositions: An-rich (An > 80), intermediate (60 < An < 80), and An-poor (An < 60). The plagioclase phenocrysts have various core compositions ranging from An-poor to An-rich. The An-rich and An-poor plagioclase phenocrysts show normal zoning and reverse zoning, respectively. The plagioclase microphenocrysts and groundmass have narrowly core compositions than the phenocrysts. Most of plagioclase microphenocrysts and groundmass are classified into the intermediate. In the Fine-type inclusions, An-rich and An-poor plagioclase phenocrysts coexist, and most of plagioclase microphenocrysts and groundmass are classified into the intermediate. While, in the Coarse-type inclusions, most of plagioclase phenocrysts, microphenocrysts, and groundmass are classified into the An-poor. These features suggest that the Fine-type inclusions are formed from hybrid layer between mafic and silicic magmas, whereas, the Coarse-type inclusions are formed by undercooling around margin of silicic magma chamber. We presume that the margin of the silicic magma chamber is highly crystalline. When the host magma included the Fine-type inclusions uprises, the host magma engulfs the highly crystalline part as the Coarse-type inclusions.

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Sulfur-rich basaltic magma injection into the magma plumbing system of Asama 2004 eruption: Melt inclusion study for magma compositions, the timing of degassing and mixing, and sulfur supply

Yoshiaki Yamaguchi[1], Tamami Yamaguchi[2], Yasushi Ohta[3], Toshisuke Kawasaki[4]

[1]Shinshu university, Japan, [2]Kawasaki Municipal Science Museum, Japan, [3]Pacific Metals Co., Ltd., Japan, [4]Ehime University, Japan

E-mail: yoshia_ygutti@d4.dion.ne.jp

In the evolution of Asama volcano, most of the erupted materials have andesitic compositions, however, melt inclusion studies found no sign of primary andesitic melt and revealed that basaltic liquid formed a part of the ejecta. Melt inclusion study of 2004 scoria (23 September) (SiO_2 61 wt%) revealed that sulfur-rich basaltic magma (SiO_2 52 wt%, S <2600 ppm) injected into the reservoir beneath the volcano and mixed with a long-lived crystal-rich felsic-magma (SiO_2 64 wt%) in the ratio 36 : 64. Diffusion profiles of Fo composition in olivine phenocrysts suggest a short period (<a few months) from the basaltic magma injection to the eruption. There is no trace of new phenocryst growth from the mixed magma.

Olivine phenocrysts include ferric-bearing crystalline phases together with the basaltic melt, suggesting a high oxygen fugacity condition of the basaltic magma. Measured sulfur X-ray peak shifts for the trapped melt indicate that the dominant sulfur-bearing species is SO_4^{2-} (>NNO + 1), corresponding with high sulfur solubility in the magma. This initial high sulfur concentration has, however, mostly been diminished (from 2600 to 1300 ppm or lower) before the melt entrapment, due to magma boiling and sulfide phase precipitation. The melt inclusions commonly show various petrological features of the heterogeneous trapping (melt plus bubbles) of vesiculated magma. There are only a few pre-boiling melt inclusions. Further, common sulfide inclusions in olivine suggest that sulfur precipitations decreased continuously in sulfur concentration of magma during the crystallization. Hence, the most mafic (SiO_2-poor) and pre-boiling melts have the highest sulfur concentration (2600 ppm). These data provide us a valuable source of information about the primary sulfur budget and the sulfur supply systems in arc magmas in central-northeastern Japan.

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Olivine residence times for historical lavas of Chokai volcano, NE Japan: Estimation by Fe-Mg and Ni diffusions in olivine crystals

Takanori Sato[1], Masao Ban[2], Tsukasa Ohba[3], Shintaro Hayashi[4]

[1]Graduate School of Science and Engineering, Yamagata University, Japan, [2]Faculty of Science, Yamagata University, Japan, [3]Faculty of Science, Akita University, Japan, [4]Faculty of Science, Akita University, Japan

E-mail: s12e105m@st.yamagata-u.ac.jp

Chokai volcano is an active strato-volcano situated in the rear arc side of northeast Japan arc. Chokai volcano erupted more than ten times in historic period. The magmatic activity occurred at least three times between AD 871 and 1801. Based on petrologic data of the historical lavas, it has been proposed that the erupted products were formed by magma mixing. However, little is known about time intervals between mixing and eruption. Here we estimate the time intervals based on Fe-Mg and NiO zoning of olivine phenocrysts in the historical lavas.

Samples for this study are from the Senjadani lower and upper lavas (AD871), the Kohjingatake lower lavas (some period between AD 871 and 1801). Phenocryst assemblages are similar in all samples, and the phenocrysts are divided into mafic magma derived (An-rich plg and olv) and felsic magma derived ones (An-poor plg, opx, cpx, and hbl). Silica contents of the lavas are 56-58% and in the Senjadani lower lavas, ca. 51% in the upper lavas, 59-60% in the Kohjingatake lower lavas.

Olivine phenocrysts are less than 1.2 mm in size and subhedral in shape. Most olivine crystals have the reaction rim of orthopyroxene but some do not. These olivines have broad homogeneous cores and narrow, normally zoned rims. Fo content of core typically spans 74 to 79, and that of rim decreases to be around 64. In addition, NiO content of core is ca. 0.02 wt% and that of rim decreases to be ca. 0.002 wt%. We calculated residence times for the olivine crystals on the assumption that the zoning was produced by diffusion of the elements after the magma mixing event.

We used diffusion coefficients for Fe-Mg and Ni calculated by the equations of Costa et al. (2008) and Petry et al. (2004). We selected olivine crystals without reaction rim and whose crystal orientations are easily determinable in the thin section. We measured compositional profiles across these zoned olivine crystals by electron microprobe. Using the methods of Costa and Chakraborty (2004), we compared modeled diffusion profiles with the observed ones, and determined the times required to produce the measured profiles. The obtained olivine residence times were one month to one year for the Senjadani lower lavas, one year to one year and a half for the Senjadani upper lavas and two months to eight months for the Kohjingatake lower lavas.

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Depths of two magma chambers of the Fuji 1707 eruption

Toshitsugu Fujii[1], Atsushi Yasuda[2], Akiko Yasuda[2]

[1]Crisis and Environment Management Policy Institute (CeMI), Japan, [2]Earthquake Research Institute, University of Tokyo, Japan

E-mail: fujii@eri.u-tokyo.ac.jp

Fuji volcano dominantly consists of basalt; however, several lines of evidence indicate existence of differentiated SiO_2-rich magma beneath. The olivine-hosted melt inclusions clearly show the existence of andesitic liquid. Phenocrystic plagioclase generally show bimodal distributions in compositional frequency, while most olivine phenocrysts show unimodal distribution with reverse zoning and frequently contain andesitic melt inclusion. These suggest that erupted magmas of Fuji are generated through mixing between basalt and more SiO_2-rich magmas. It has been argued that the SiO_2-rich magmas evolved within a shallow magma chamber is mixed with the newly ascended basalt magma which have differentiated in a deep magma chamber (e.g. Kaneko, et al., 2010).

The depth of the deep magma chamber has been estimated to be deeper than 20 km based on the compositional variation of basalt magmas (Fujii, 2007) and to be 25 km by high pressure melting experiments on the basalt scoria of the 1707 eruption (Ushioda et al., 2012).

The depths of the shallow chambers, however, have not been well constrained because the SiO_2-rich end member magma has been usually dissolved in the mixed basalt magma and is obtained only as a melt inclusion in phenocryst.

Among the eruption history of Fuji volcano, the 1707 eruption was peculiar because the SiO_2-rich end member magma was extremely differentiated to dacite composition and resulted in unmixing with the basalt magma. This is a rare case we can obtain the composition of the SiO_2-rich magma as dacite pumice erupted at the beginning.

Recent finding of hornblende phenocryst in the dacite pumice of the 1707 eruption gives constraint on the depth estimation of the evolved magma chamber. The pressure estimated is below 200 MPa and is almost 100 MPa. The melt inclusions hosted in hypersthene phenocryst in dacite contain around 4 wt% of H_2O, indicating a crystallization pressure around 100-150 MPa. These suggest the shallow magma chamber is around 4-6 km in depth. This estimation is consistent with the volatile concentration of olivine-hosted melt inclusions in basalt scoria of 1707 eruption. The most volatile-rich melt inclusion in olivine shows basaltic composition which indicates unmixing nature and contains 3wt% H_2O and 300 ppm CO_2, suggesting the depth of crystallization of 6km or deeper.

The evidence described above indicates that a shallow and a deep reservoir are involved in the 1707 eruption. The first is shallow as well as 4-6 km, and the deeper is around 25km. As most basalts of Fuji volcano show evidence of mixing between a SiO_2-rich melt such as andesite, and a basalt magma, the magma plumbing system derived from the analysis of the 1707 eruption might be applied to the usual eruptions through the development of Fuji volcano.

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Processes leading up to the 22 ka silicic caldera-forming eruption of Santorini (Greece): Constraints from field, $^{40}Ar/^{39}Ar$ and chemical data

Gareth N Fabbro[1], Timothy H Druitt[1], Stephane Scaillet[2]

[1]Clermont Université, Université Blaise Pascal, Laboratoire Magmas et Volcans, BP 10448, France,
[2]Institut des Sciences de la Terre d'Orléans (ISTO), INSU-CNRS, Université d'Orléans, France

E-mail: g.fabbro@opgc.univ-bpclermont.fr

Large caldera-forming eruptions are commonly preceded by effusive eruptions whose magma chemically and petrologically resembles that of the climatic eruption. Studying these lavas can reveal processes that occur in the build-up to these often-catastrophic eruptions. On Santorini, the 21.7±0.2 ka caldera-forming Cape Riva eruption produced at least 10 km^3 of dacitic magma, along with a minor andesitic component. It was preceded by a period of effusive volcanism that discharged 1-2 km^3 of magma and built up the so-called Therasia dome complex. The Therasia dome complex is dominated by at least 12 different dacitic coulées and domes, which total up to 200 m in thickness. These are intercalated with the dacitic products of sub-plinian explosive activity, and are capped by an andesitic lava flow (the upper Therasia andesite). The Therasia lavas were fed by dykes, with vents located within the area that subsequently collapsed to form the Cape Riva caldera. The majority of the Therasia dome complex was erupted in a period of about 13 ky, starting 36.0±2.8 ka. The youngest lava has an age of 23.2±2.3 ka, less than 4000 y before the Cape Riva eruption. The Therasia dacites contain between 65 and 69 wt% SiO_2, and have 1-17 wt% phenocrysts of plagioclase, orthopyroxene, clinopyroxene and Fe-Ti oxides. This closely resembles the Cape Riva dacite, which has a similar phenocryst assemblage and 64-67 wt% SiO_2. The upper Therasia and Cape Riva andesites are also similar to each other. They are both hybrid andesites (60-62 wt% SiO_2) with crystals of plagioclase, orthopyroxene, olivine and Fe-Ti oxides, and formed by mixing ~60 wt% dacite with ~40 wt% basalt. The occurrence of hybrid andesites at the top of the Therasia sequence suggests that, for the first time since ~36 ka, mafic magma was reaching shallow levels of the plumbing system under Santorini. Despite the similarities in the petrology and major-element chemistry of the Therasia and Cape Riva magmas, however, the Cape Riva dacite is depleted in incompatible elements such as K, Zr, Rb, La, Ce and Nb. This fits with the long-term trend towards more depleted magma compositions on Santorini, and implies that the Cape Riva and Therasia magmas were distinct batches. The two hybrid andesites (Therasia and Cape Riva) also exhibit the same differences in trace element composition. This could be explained by a large influx of silicic magma (and accompanying basaltic magma) into the shallow plumbing system in the short period between the end of the construction of the Therasia dome complex and the onset of the Cape Riva eruption. One implication of this interpretation is that the transition from prolonged effusive to major explosive activity coincided with this upward transfer.

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A combined mineral and melt inclusion study of the Nea Kameni dacites

Ben S Ellis[1], Michael C Rowe[2], Kostas Kyriakopoulos[3]

[1]Institute for Geochemistry and Petrology, ETH Zurich, Switzerland, [2]School of Environment, University of Auckland, New Zealand, [3]Department of Geology and Geoenvironment, National and Kapodistrian University of Athens, Greece

E-mail: ben.ellis@erdw.ethz.ch

Since the voluminous 3.6 ka Minoan eruption, the Santorini volcano has been periodically erupting small volumes of dacitic magma. This study examines mineral and melt inclusions geochemistry of lavas spanning from 1573 to 1950 from Santorini volcano. Unlike the larger explosive events which commonly contain clasts of multiple compositions, the eruptions of Nea Kameni have been compositionally monotonous in bulk terms. The Kameni dacites do however contain two populations of feldspar, one An_{38-65} interpreted as crystallising from the dacitic liquid and a second An_{86-94} interpreted as xenocrystic. The two populations are distinct in terms of $^{87}Sr/^{86}Sr$ as determined via LA-ICPMS with the higher anorthite plagioclase having higher $^{87}Sr/^{86}Sr$. The larger dataset provided by LA-ICPMS (albeit with reduced precision) indicates that plagioclase grains within the Kameni dacites are isotopically more variable than existing data for the preceding explosive volcanism. Further differences are observed in the trace element compositions of the plagioclase grains, with the higher-anorthite population having systematically lower Sr and Ba abundances than the lower-anorthite plagioclase. The mafic and silicic plagioclase compositions appear to have remained approximately constant throughout the last 500 years of volcanism on the Kameni islands. Groundmass glass compositions are rhyolitic (SiO_2 73.5-73.8 wt.%) and melt inclusion compositions hosted within plagioclase exhibit two compositional populations which are related to the host composition. High anorthite plagioclase contains less evolved melt inclusions (SiO_2 51.2-58.1 wt.%) whereas the lower anorthite plagioclase contains melt inclusions more similar to the groundmass glass (SiO_2 63.6-71.4 wt.%). Water contents of the dacitic inclusions as determined via SIMS are slightly less than predicted via plagioclase-melt hygrometry (4-5 wt.%) but consistent with previous estimations.

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Evolution of the Austurhorn Intrusive Complex revealed by zircon elemental and isotopic geochemistry and geochronology

Abraham J Padilla[1], Tamara L Carley[1], Calvin F Miller[1], Joseph L Wooden[2], Rita C Economos[3], Axel K Schmitt[3], Chris M Fisher[4], John M Hanchar[5]

[1]Vanderbilt University, United States, [2]Stanford University-USGS MAC, SHRIMP-RG Lab, United States, [3]University of California-Los Angeles, United States, [4]Washington State University, United States, [5]Memorial University of Newfoundland, Canada

E-mail: a.padilla@vanderbilt.edu

The Austurhorn Intrusive Complex (AIC) is a small silicic intrusion along the SE coast of Iceland comprising large bodies of granophyre, gabbro, and a mafic-felsic composite zone that exemplifies mafic-felsic interactions common in Icelandic silicic systems. Despite being one of Iceland's best-studied intrusions (Blake 1966; Furman et al 1992a,b; Thorarinsson and Tegner 2009), zircon studies are notably lacking for the AIC, as well as for other Iceland plutons. The value of zircon as a tracer of the history and evolution of its parental magma(s) has been widely recognized. Here, we present the first detailed chronologic, elemental, and isotopic study of Icelandic plutonic zircon, likely Iceland's dominant zircon population.

The elemental composition of AIC zircons form a broad but coherent array that partly overlaps with the well-constrained signature of zircons from Icelandic silicic volcanic rocks (Carley et al 2011). The broader range of AIC zircon is likely due to the effect of crystallization down to the solidus in plutonic environments (absent in volcanic environments). With some exceptions (see below), Ti concentrations range from 6-25 ppm (Ti-zirc temperatures 730-870 deg.C), and Hf concentrations are low (below 10,000 ppm), typical of Iceland zircon. Epsilon-Hf values are well-constrained at +13(+/-)1 epsilon units, falling between epsilon-Hf for Iceland basalts from rift and off-rift settings and suggesting a single source for the different units of the AIC. Similarly, d18O values are generally well-constrained at +3 to +4 per mil, consistent with Icelandic magmatic zircon (Bindeman et al 2012) and suggesting contribution from hydrothermally-altered crust to the petrogenesis of the parental silicic magmas.

The notable exceptions to the trends described above are analyses of zircons from a high-silica miarolitic granophyre that display CL-dark zones with convolute and irregular zoning. These fall well outside the AIC elemental and isotopic arrays, and are primarily distinguished by extreme Hf (up to 24,000 ppm) and lower Ti (down to 2 ppm [630 deg.C]), far higher and lower, respectively, than other analyzed Icelandic zircon, as well as generally higher U and Th. Their d18O values range from normal (+4) to extremely low (-6 per mil). We interpret these unusual analyses to reflect hydrothermal recrystallization.

Field relationships provide clear evidence that the AIC was constructed by repeated mafic and felsic intrusions. In-situ (SHRIMP) dating of 5 zircon samples yields a pooled age of 6.43(+/-)0.04 Ma for the entire complex. However, the relatively high MSWD (1.6) suggests real spread in ages, and UNMIX analyses and subtle peaks in probability-density plots are consistent with multiple ages ranging from 6.3 to 6.6 Ma. Assuming this interval is real, it may reflect prolonged lifetime of a periodically rejuvenated mush, or re-melting events that revived earlier-solidified magmatic increments to the AIC.

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Post-supereruption reconstruction of Taupo volcano (New Zealand) through systematic crystallization episodes

Simon J Barker[1], Colin J.N Wilson[1], Bruce L.A Charlier[2], Wooden D Joseph[3]

[1]School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand, [2]CEPSAR, The Open University, Walton Hall, Milton Keynes, UK, [3]SUMAC, Department of Geological and Environmental Sciences, Stanford University, USA

E-mail: smnbarker@gmail.com

Large explosive silicic supereruptions have received much attention because of the challenges in explaining how such large volumes of magma are accumulated and stored, and over what time intervals. The processes that follow supereruptions are less fully documented and, in particular, how and on what time scales the overall magma system moves into a post caldera mode of activity. The 530 km^3Oruanui eruption from Taupo volcano, New Zealand, is the worlds youngest (25.4 ka) supereruption. Following this event and after only 5 kyr of quiescence, Taupo volcano erupted three dacitic pyroclastic units of modest volume (<0.1 km^3), followed by another 5 kyr year time break, and then eruption of the modern sequence of rhyolitic units starting at 12 ka. Here we present U/Th model age dating of zircons extracted from the post Oruanui eruption products to investigate how Taupo's magmatic system was reactivated following a supereruption. Zircon model ages in first erupted rhyolites indicate that there is minimal or no inheritance of crystals from either of the two dominant age modes (35 and 90 ka) in the Oruanui magma source. Post Oruanui age spectra are typically centered close to eruption ages with subordinate pre 300 ka plutonic and pre 100 Ma greywacke grains. In addition, there is consistent inheritance of grains between the temporally spaced but geographically overlapping post Oruanui eruption groups, allowing the identification of systematic dominant age peaks since the Oruanui supereruption. We interpret this consistent and repeated pattern to result from recycling of crystals from post supereruption episodic heating and cooling cycles, reflecting periods of magmatic rejuvenation and eruption, versus cooling and crystallization, acting within a crustal protolith independent of that which was dominant in the Oruanui system.

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Experimental constraints on mixing between basaltic and rhyolitic magmas along the Norris Mammoth Corridor in the Yellowstone National Park (USA)

Daniele Morgavi[1], Diego Perugini[2], Chad J. Pritchard[3], Cristina P. De Campos[1], Peter B. Larson[4], Donald B. Dingwell[1]

[1]Dept. Earth and Environmental Sciences, Ludwig Maximilian University (LMU), Munchen, Germany, [2]Dept. Earth Sciences, University of Perugia, Piazza Universita, 06100 Perugia, Italy, [3]Geology Department, Eastern Washington University, Cheney, Washington 99204, USA, [4]School of Earth and Environmental Sciences Washington State University, Pullman, Washington„ USA

E-mail: morgavi@min.uni-muenchen.de

The magma mixing process in the Norris Mammoth Corridor in Yellowstone National Park (USA) is observed at different scales, including variable structural and textural patterns, as well as morphologies such as filament like structures, enclaves, and mineral phases showing physicochemical disequilibrium. The type and geometry of these structures strongly depends on the mixing dynamics (e.g. Perugini et al., 2012; Morgavi et al., 2013). The quantification of the morphology and the compositional variability of these structures are essential to understand the mixing process and require detailed analytical and experimental studies.

We present the first set of chaotic mixing experiments performed using natural basaltic and rhyolitic melts from the Yellowstone Norris-Mammoth Corridor. The mixing process is triggered by a recently developed apparatus that generates chaotic streamlines in the melts, mimicking the development of magma mixing in nature. The study of the interplay of physical dynamics and chemical exchanges between melts is carried out performing time series mixing experiments under controlled chaotic dynamic conditions. The variation of major and trace elements is studied in detail by electron microprobe (EMPA) and Laser Ablation ICP MS (LA ICP MS).

The mobility of each element during mixing is estimated by calculating the decrease of concentration variance in time. Both major and trace element variances decay exponentially, with the value of the exponent of the exponential function quantifying the element mobility. Our results confirm and quantify how different chemical elements homogenize in the magmas at differing rates. These results constitute a robust basis for determining the timescale of the mixing process at Yellowstone volcano using the differential mobility of chemical elements.

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Magma mixing/mingling and viscous fingering: Analogue experiments and geometry of interfaces

Nodoka Takada[1], Eiichi Sato[2], Kazuhito Yamasaki[1]

[1]Department of Earth and Planetary Sciences, Graduate School of Science, Kobe University, Japan,
[2]Institute for Promotion of Higher Education, Kobe University, Japan

E-mail: esato@people.kobe-u.ac.jp

Magma mixing/mingling is common in the dynamics of volcanic eruptions and igneous activities, and its processes have been investigated by petrological, experimental and theoretical studies. Especially, the morphology of interfaces between the two magmas having different viscosities shows the various complex patterns due to the differences in physical and chemical conditions under the mixing/mingling process (e.g., Wada, 1995; Perugini et. al., 2005; Sato and Sato, 2009). Since the quantity that we can observe easily is the geometrical patterns of the interfaces, it is important to express this physical phenomenon in terms of the geometrical quantities of the interfaces.

The geometry of interfaces enables us to extract the useful information of the mixing/mingling process from the morphological analysis of the interfaces of rocks in nature (Perugini and Poli, 2005; Sato and Yamasaki, 2012). However, few attempts have been made to consider how the dynamic quantities such as the growth rate of the interfaces affect the geometry of the interfaces in the mixing/mingling process.

In this work, to simulate the replenishment of felsic magma chamber by continuous inputs of mafic magmas, we perform the analogue experiment in which we inject air or water into glycerin using the Hele-Shaw cell. In this case, the mixing/mingling process can be described by the DLA model (e.g., Nittmann et al., 1985), and the interfaces show the viscous fingering pattern due to the instability of the interfaces that also occur in the natural cases (e.g., Perugini and Poli, 2005). The following results were obtained.

1. We estimate the three fractal dimensions: the interfaces *Di*, the area of the high viscosity fluids *Dh* and that of the low viscosity fluids *Dl*. We find that the sum of *Dh* and *Di* is the conserved quantity, and the *Di* is proportional to *Dl*. This implies that the fractal dimension of the interfaces (easily observed quantities) enables us to estimate the fractal dimension of the area of the felsic or mafic magma (hardly observed quantities).

2. We find that the radius of curvature of the viscous fingerling depends on the growth rate of the interfaces. This is agreed with the solutions of the development equation of the curvature in the differential geometry (e.g., Nakamura and Wadati, 1993). This implies that we can estimate the growth rate of the interfaces by the radius of curvature of the mafic magmas.

3. In the case of colorless water and black-colored glycerin experiments, the interface of the two fluids shows light to dark gray color. We measure the fractal dimensions of the gray levels classed into several groups to estimate the degree of mixing. We find that the fractal dimensions correlate with the degree of mixing. This implies that we can estimate the degree of mixing from natural mixed rocks.

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The role of bubble ascent in magma mixing

Sebastian Wiesmaier[1], Daniele Morgavi[1], Diego Perugini[2], Cristina De Campos[1], Kai Uwe Hess[1], Yan Lavallee[3], Donald B Dingwell[1]

[1]Ludwig-Maximilians-University Munich, Earth and Environmental Sciences, Germany, [2]University of Perugia, Department of Earth Sciences, Italy, [3]University of Liverpool, School of Environmental Sciences, United Kingdom

E-mail: sebastian.wiesmaier@min.uni-muenchen.de

Understanding the processes that affect the rate of liquid state homogenization provides fundamental clues on the otherwise inaccessible subsurface dynamics of magmatic plumbing systems. Compositional heterogeneities detected in the matrix of magmatic rocks represent the arrested state of a chemical equilibration. Magmatic homogenization is divided into a) the mechanical interaction of magma batches (mingling) and b) the diffusive equilibration of compositional gradients, where diffusive equilibration is exponentially enhanced by progressive mechanical interaction (1). The mechanical interaction between two distinct batches of magma has commonly been attributed to shear and folding movements between two distinct liquids. A mode of mechanical interaction scarcely invoked is the advection of mafic material into a felsic one through bubble motion. Yet, experiments with analogue materials demonstrated that bubble ascent has the potential to enhance the fluid mechanical component of magma mixing (2).

Here, we present preliminary results from bubble-advection experiments. For the first time, experiments of this kind were performed using natural materials at magmatic temperatures. Cylinders of Snake River Plain (SRP) material were prepared for a static layered set-up, with basalt glass placed underneath rhyolite glass. Upon heating, air trapped in the interstices between glass cylinders and the crucible expanded, forming bubbles in the now molten basalt. The bubbles rose, thus entraining a portion of basaltic material into the rhyolite.

The plume-like structure that the advected basalt formed within the rhyolite was characterized by microCT and subsequent high-resolution EMP analyses. The diffusional gradient around the plume tail showed a progressive diffusional equilibration from top to bottom, consistent with increasing time of interaction towards the bottom end of the plume tail. Furthermore, single protruding filaments at the bottom end of the plume tail indicate that the plumous structure is a composite of many smaller plume tails. Possibly, the first bubble rising created a preferential pathway for bubble ascent thereafter. The normalised variance, which serves as a proxy of cation diffusion rate at the interface of rhyolite and basalt, is unsystematic. This is most likely a result of the many small plume tails combined in the hybridised region. In turn, stretching and folding experiments produce very systematic normalised variances. The normalised variance measured in natural magma mixing structures may thus provide characteristic evidence to distinguish between mixing induced by bubble action or scenarios of stretching and folding.

(1) De Campos et al. (2011) Enhancement of magma mixing efficiency by chaotic dynamics: an experimental study, Contrib. Mineral. Petrol., 161(6), 863-881.

(2) Thomas et al. (1993) Mixing of stratified liquids by the motion of gas bubbles: application to magma mixing, Earth Planet. Sci. Lett., 115(1-4), 161-175.

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Amphibole Reaction Rim Development: EBSD insights into crystal nucleation and growth

Sarah Henton De Angelis[1], Yan Lavallee[1], Jessica Larsen[2], Elisabetta Mariani[1]

[1]University of Liverpool, United Kingdom, [2]University of Alaska Fairbanks, United States

E-mail: pelee83@gmail.com

This study employed electron backscatter diffraction (EBSD) to examine the development of anhydrous reaction rims around magmatic amphiboles. Sample materials from the 2006 eruption of Augustine Volcano, Alaska were utilised. EBSD analysis was performed on 3 sample types: 1) naturally produced amphibole reaction rims; 2) reaction rims produced experimentally by heating; 3) reaction rims produced experimentally by decompression. Amphibole, a hydrous mineral, decomposes to form rims of anhydrous minerals when removed from its thermobarometric stability field. The thickness, texture, and mineralogy of these rims are thought to be reflective of the process driving amphibole disequilibrium (e.g. heating, decompression). However, experimental results show that reaction rim formation is also dependent on the magnitude and duration of amphibole disequilibrium. Further, significant overlap in reaction rim thicknesses and reaction rim microlite textures means that distinguishing between heating and decompression is not simple. EBSD data have demonstrated differences in volcanic plagioclase microlite textures as a function of reaction conditions. We collected crystal orientation maps of amphibole reaction rims to investigate how processes of reaction rim microlite crystal nucleation, rim growth and microlite coarsening vary with changing disequilibrium conditions, magnitudes, and durations. This work aims to show that different disequilibrium conditions result in different crystallisation regimes. Consequently, the results provide further insight into the classification of natural reaction rims on the basis of formation processes.

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DIPRA: A new user-friendly program to determine the timescales of magmatic processes from diffusion modelling of multiple elements in olivine

Társilo Girona, Fidel Costa

Earth Observatory of Singapore, Nanyang Technological University, Singapore

E-mail: tarsilo.girona@gmail.com

One recent advance in igneous petrology has been to be able to quantify the timescales and rates of magmatic processes. This provides a lot of valuable information about a wide range of phenomena, such as the residence times of magmas in shallow reservoirs before eruptions. A methodology to determine these timescales is modelling the concentration of different elements in minerals, which is based on chemical diffusion within the crystals. However, despite the good knowledge of diffusion coefficients and the ease of measurements of chemical gradients, the use of this technique is not widespread yet. This could be due in part to the lack of a user-friendly tool that allows modelling the chemical zonings in crystals easily. We have developed an interface-based computer program (DIPRA: Diffusion Process Analysis) that allows modelling intuitively the diffusion of Fe, Mg, Mn, Ni, and Ca in olivine (one of the most widespread minerals in igneous rocks) by performing an automatic and quick fit to the natural chemical profiles. DIPRA accounts for most variables that affect diffusivity, such as temperature, oxygen fugacity, and anisotropy, and initial and boundary conditions can be chosen as complex as the user requires. The program also calculates the uncertainties of the diffusion time based on the uncertainty of the data and temperature. DIPRA is very versatile and, besides being a working tool for petrologists, it could also be useful for teaching kinetics of chemical re-equilibration and timescales of magmatic processes in higher education courses. The program can be downloaded from www.tgirona.com.

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Identifying transitions in activity and precursors to major eruptive events at Mt. Taranaki, New Zealand

Kimberly Genareau[1], Shane J. Cronin[2], Thomas Platz[3]

[1]Lehigh University, U.S.A., [2]Massey University, New Zealand, [3]Freie Universitat Berlin, Germany

E-mail: kig210@lehigh.edu

Mt. Taranaki, located in the western North Island of New Zealand is an andesite stratovolcano which has been in a state of quiescence for the last >200 years. Its record of >100 eruptions over the last 12,000 years and its upwind position with respect to the largest populated areas of the country means that it presents a significant hazard with any re-awakening. Volcanic activity at Taranaki is characterized by periods of hundreds of years dominated by repeated lava dome growth and collapse, interspersed semi-regularly at 300 year intervals with large sub-Plinian explosive events. In addition to widespread tephra falls, Taranaki has produced hazardous pyroclastic density currents in the form of surges, block-and-ash flows, and column collapse pyroclastic flows that reach run-out distances of up to 15 km from the summit. This study focuses on the sequence of pyroclastic deposits that stratigraphically precede the 1655 AD Burrell Lapilli unit, which was the latest sub-Plinian eruption of Taranaki. This eruption culminated a period of repeated lava effusion and dome growth that lasted roughly 1000 years. The pre-Burrell pyroclastic sequence is comprised of several, fall, flow, and surge units and these tephras were analyzed using a combination of scanning electron microscopy, stereo-scanning electron microscopy, secondary ion mass spectrometry (SIMS), and electron microprobe analyses. SIMS analyses of oscillatory-zoned plagioclase phenocrysts from the Burrell Lapilli show increasing Li contents in crystal rims compared to cores. Profiles across phenocrysts show that Li increases substantially even when An contents increase, decrease, or remain relatively constant, indicating that Li variations reflect properties of the ascending magma parcel rather than local chemical gradients at the melt-crystal interface. In addition, thin (10-20 microns), decompression-induced breakdown rims on amphibole crystals and extensive groundmass crystallization of plagioclase microlites in the indicate changes in the volatile content of the magma leading up to the Burrell explosive phase, and thus, Li trends may allow quantification of the timescale during the final stage of magma ascent prior to the Burrell sub-Plinian explosion. Microtextural and geochemical trends in the pre-Burrell sequence will be compared to those of the subsequent Burrell Lapilli unit to highlight the evolution of magma properties during transitions from effusive to explosive activity. Quantifying physical parameters within conduits and understanding how they vary over time to cause dome collapse events and explosive activity will allow researchers to more accurately model (and ideally, with ongoing analysis of samples collected during an eruption crisis, forecast) volcanic behavior. This will lead to improved hazard assessment strategies for >100 andesitic volcanoes worldwide that show regular variations in effusive and explosive activity like those observed at Taranaki.

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