IAVCEI (Volcanology, Geochemistry)

VS01a - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-0455

Temporal variation of seismicity pattern related to the eruptions of volcano Nyamulagira in 1991 and 2006

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The seismic activities prior to the eruptions of Nyamulagira volcano on September 20th, 1991 observed at Bulengo station and on November 27, 2006 observed at Rusayo station have been analyzed. The two eruptions were preceded by seismic swarm of volcanic events with mixed frequency (hybrid events). We classified these events as B-type volcanic earthquakes. The prediction method for volcanic eruption introduced by Vought (1988, 1991) was used in this analysis. On the basis of the comparison between the magnitude vs time (M – T) plot and the inverse of strain release rate plot vs time related to the swarm for the period of 12th to 18th of September 1991, we have found that the time of the occurrence of events with maximum magnitude corresponds to the time of failure (tf). It was observed a delay between the time of eruption (Te) and that of failure (Tf) for the September 20th, 1991 eruption, then we induced (Te - Tf) = 5 days. This means that the volcanic process to the eruption was completed about 5 days before the venting of the eruption products. However in 2006, the seismic swarm associated to the eruption was short and lasted only 25 hours. We found that the (Te - Tf) = 13 hours.The main pattern observed on the (M – T) plot for the eruption of Nyamulagira in 1991 is similar to that observed at Uzen volcano (Japan) in December, 1993, and April, 1994, although the two volcanoes are of different nature.

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IUGG-1156

Monitoring the Campi Flegrei caldera through passive image intereferometry

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The Campi Flegrei caldera, Italy, is one of the most potentially destructive volcanic field, due to its eruptive history and that it encloses a densely populated area. It periodically experiences bradiseismic crises which are typically characterized by uplift and low energetic seismic swarm occurrences. Almost no seismic activity has been recorded out of these crises. Therefore a seismic monitoring of the caldera is possible only by analyzing the ambient seismic noise. We apply a Passive Image Interferometry technique to the cross-correlations computed between 3 years of continuous recordings at 11 stations of the Campi Flegrei seismic network, in order to obtain the relative velocity variations throughout the whole time period. The analyzed period of time spans from January, 2011 to August, 2013, during which only a small uplift episode occurred at the end of the summer, 2012. The resulting time series has been compared to the temporal behavior of all other geophysical and geochemical parameters, which are sampled at Campi Flegrei, showing interesting connections. This study is particularly relevant for understanding the background value of relative velocity changes at Campi Flegrei, and more generally for setting-up a seismic monitoring tool at dormant calderas.

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IUGG-1170

Tomography studies of active volcanoes of Kamchatka

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Kamchatka Peninsula is located above the northern edge of the Pacific subduction zone, which determines very intensive seismic and volcanic activity of the region. Seismic tomography is used to study 3D seismic structures beneath volcanoes that helps in understanding the feeding paths of the magmatic systems. Until recently, only one site of Kamchatka, Kluchevskoy volcano group, had sufficient data coverage for performing tomography inversion. In the presentation, we will show a time-dependent tomography model for this group that reveals the evolution of the magma system related to the eruption phases of volcanoes. In the last years, several temporal networks installed on some active volcanoes of Kamchatka provided data for high-quality tomography studies. Combined ambient noise and active source tomography performed for the Avacha volcano have shown that the presently active stratovolcanoes are located at the edge of a large caldera formed due to a catastrophic eruption in recent geologic time. A tomography study of the Gorely volcano is based on using travel times from local earthquakes recorded by a temporary network of 21 stations. The resulting model has shown extremely low average VP/Vs ratio equal to 1.53. This result indicates the presence of high content of gases almost without presence of liquid phases. This shows that Gorely is a kind of a large high-pressure steam boiler with one safety valve, a fumarole in the crater ejecting ~11,000 tons gases per day. In the talk, there will be also some information on the forthcoming experiments.

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IUGG-3997

Geodynamic constraints of volcanic unrest in the Canary Islands

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Seismic and geodetic data acquired during the last decades allowed studying of the dynamic evolution of the North Atlantic Azores-Gibraltar region, including the NW African margin, and its relation to the volcanic activity in the Canary Islands. A unified seismic catalog was compiled and digital long series of data of those seismic and GPS stations installed in the region were processed, enabling the analysis of the stress and strain field variations with time. The key role of the decompression of the lithosphere associated with the occurrence of energetic earthquakes and the changes in the deformation field were also addressed. This joint analysis allowed to identify possible precursory signs of earlier stages of unrest during the last eruptive process at El Hierro in 2011-2012.

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IUGG-4090

Dynamics of Santorini volcano (Greece) during the 2011-2012 unrest

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At Santorini caldera, all known significant volcanic activity following the Minoan eruption about 3,500 years ago, have been confined to the nearly-linear tectono-volcanic zone of Kameni Line (KL). KL has remained seismically quiescent for decades, although there has been geodetic evidence of a small-scale inflation at the northern part of the caldera in the 1990's, probably associated with intrusions along another major tectono-volcanic zone (Columbo Line, CL). Hence, swarms of microseismicity, occurred along KL in 2011 and 2012, were regarded as evidence of a possible reactivation of the volcano. Analytic modeling of available GPS data by several studies permitted the identification of a single source several kilometers north of the KL. This possible source explains most deformation data, but it cannot explain observed seismicity. For these reasons we explored new analytic models that allow for multiple distinct spherical inflationary sources. The new models evaluated deformation across four distinct intervals, corresponding to different levels of seismicity and deformation rates, using the internally developed TOPological INVersion method. This analysis showed that ground deformation reflects the possible interplay of two different magma sources. The first source is located in the northern part of the caldera at about 4 km depth, however the second source is about 8 km deep and below most of the microseismicity along the KL. The deeper sources appear short-lived, probably reflecting rapid pulses of magma injections from depth. Because of their location, they increase the Coulomb failure stresses along the KL, but are insufficiently long to generate easily discernable geodetic signals from intermittent observational methods including InSAR and campaign GPS.

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IUGG-5291

Statistical analysis of large volcano seismology data sets: Rapid cross-correlation and machine learning techniques.

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One of the many challenges faced by volcano observatories is dealing with large seismic data catalogues. For example, during an on-going seismic crisis at Chiles-Cerro Negro volcanoes in Colombia, rates of up to 4000 events per day have been recorded, and over 200,000 earthquakes were recorded over a two-month period in 2014. Furthermore, consistent and efficient re-analysis of data catalogues from key eruptions is important for characterising seismicity surrounding eruptive behaviour, but often these data catalogues can be large and such analysis can be computationally expensive. Statistical analysis of seismic events (e.g. spectral analysis and identification of waveform families) can be useful for characterising seismicity patterns and can be powerful tools for analysing temporal changes in behaviour. However, large-scale analysis of this type has been hindered by computational limitations associated with cross-correlation of large datasets. Waveform classification and the onset of certain types of seismic events can be crucial for volcano monitoring and for understanding subsurface volcanic processes. Waveform classification is often done by an analyst, but analysts can change over the course of long-term data acquisition and inconsistencies can occur. Additionally, during seismic crises, real-time classification may not be possible due to the high rate of seismic events. Automated event classification allows consistent re-classification of data catalogues and can allow rapid classification during seismic crises. We use a fast-approximation method, peakmatch, to easily cross-correlate large data catalogues and facilitate the systematic analysis of large data catalogues and by using machine-learning techniques we are able to automatically classify seismic waveforms.

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IUGG-2163

Seismicity and ground deformation signals at Campi Flegrei (Italy) from dilatometer and long-baseline tiltmeter data.

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Since early 2004 we have operated several subsurface strain and tilt sensors to monitor long period crustal deformation in the Neapolitan region with a view to improve the monitoring of volcanic processes. Six borehole strainmeters were installed in the period 2004-2005 around Campi Flegrei and Vesuvius, and two arrays of long-baseline water tube tiltmeters were installed in underground tunnels close to Pozzuoli in 2008. Renewed activity at Campi Flegrei started in 2005; it was characterized by an initial low uplift rate amounting to a few cm/year. Interrupting this slow deformation we record transient periods of accelerated strain that precede microseismicity. In mid 2006 a multi-hour aseismic strain episode was accompanied by an increase of CO_2 emission, and simultaneous ground displacements were measured also by short-baseline tiltmeters and GPS. This strain episode preceded the seismic activity by a few months, similar to ground deformation during the 1982-1984 major Campi Flegrei unrest. Other aseismic strain episodes have been recorded: in 2009 accompanied by renewed gas emission at Solfatara, in 2010 coinciding with a small seismic swarm, and in September 2012, a few days before the most significant seismic swarm following the 1982-1984 unrest. The duration of these strain episodes range from tens of minutes to a few hours. These strain and tilt signals have been analyzed aiming to shed light on the cause of both seismicity and ground deformation at Campi Flegrei and their possible link. Small but rapid magma-deflation events detected by the strain and tiltmeters, for example, result in transient stresses that permit minor faults to slip tens of minutes after deflation is initiated.

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IUGG-2459

Complex rupture processes at the Bár*arbunga caldera, Iceland

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The 2014-15 unrest of the volcanic system was accompanied by an exceptional increase in seismicity on Iceland. Our aim here is to explain the sustained seismicity below the rim of Bárðarbunga caldera, where more than 60 events of magnitude Ml > 5.0 occurred in the first three months of activity. Using regional broadband recordings, we invert for source parameters and model the source processes for these events. Full moment tensor inversion and moment tensor clustering analyses reveal that most events comprise two types that can be well modelled by superposition of a near-vertical compensated linear vector dipole (CLVD) component and a normal faulting component. The latter differs in orientation for the two event types. Our analysis is extended to smaller earthquake magnitudes by using waveform correlation; this confirms similar rupture processes for weaker events. An apparent discrepancy between seismological observations at local and regional distances, in terms of origin times and radiation patterns, suggests a complex rupture process, composed of different phases. Whereas local data track the nucleation phase, which is characterised by shear failure, regional data reveal the mechanism responsible for the most energetic signal, where the non-DC component becomes more relevant. The combined analysis of local and regional data reveals that, at least during the earliest activity, the event type is related to the location of rupture nucleation. When rupture initiates below the northern rim, the normal faulting component of the moment tensor strikes almost North-South. Conversely, if rupture starts below the southern rim, the normal faulting component strikes East-West. Our analysis is used to simulate, test and discuss different proposed complex collapse models.

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IUGG-4324

Segmented lateral dyke growth in a rifting event at Bárdarbunga volcanic system, Iceland

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Activity in the Bardarbunga volcanic system in Iceland 2014-2015 includes major lava eruption (>1 km3) and gradual caldera collapse (>60 m), connected by a 50-km-long dyke that formed mostly over 2-4 weeks The dyke evolution was revealed by propagating seismicity, ground deformation mapped by Global Positioning System (GPS), interferometric analysis of satellite radar images (InSAR), and graben formation. Joint interpretation of crustal deformation data and relative relocation of earthquakes forms the basis for a model of the dyke intrusion. In 14 days, the dyke grew laterally for over 45 km at a variable rate, with an influence of topography on the direction of propagation. Barriers at the ends of each segment were overcome by the build-up of pressure in the dyke end; then a new segment formed and dyke lengthening temporarily peaked. The strike of the dyke segments varies from an initially radial direction away from the Bárðarbunga caldera, towards alignment with that expected from regional stress at the distal end. A model minimizing the combined strain and gravitational potential energy explains the propagation path. Dyke opening and seismicity focused at the most distal segment at any given time, and were simultaneous with a magma source deflation and slow collapse at the Bárðarbunga caldera, accompanied by a series of M>5 earthquakes. The dyke growth was slowed down by the effusive fissure eruption near the end of the dyke. Lateral dyke growth with segment barrier breaking by pressure build-up in the distal portion of the dyke explains well how magma is redistributed over long distances in shallow crust.

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IUGG-4457

Duration-amplitude relationships of volcanic tremor and earthquake swarms before and during the 2009 eruption of Redoubt Volcano, Alaska

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Duration-amplitude relationships were studied for tremor episodes and earthquake swarms occurring during the 2009 eruption of Redoubt Volcano, Alaska. Duration-amplitude distribution plots were generated daily from January 1 to May 31 and fit with both an exponential law and power law. Comparing r^2 values of the fit for both laws showed that the exponential law fit better for days in which volcanic tremor and earthquake swarms occurred, while the power law fit better for other days. Fitting segments of seismic data with both an exponential and a power law leads to a metric that has potential for volcano monitoring: r^2_{exp} / $r^2_{pow,}$ the ratio of the r^2 fits using the exponential law and the power law. The ratio r^2_{exp} / r^2_{pow} tended to be greater than 1 when volcanic activity or precursory seismic activity was occurring, and less than 1 when no volcano-seismic activity was occurring. Duration-amplitude plots were generated for episodes of volcanic tremor that were identified by the $r^2_{exp} / r^2_{pow} \geq 1$ method and compared in an attempt to identify changes that may have occurred during the eruption. Stronger episodes of volcanic tremor showed higher characteristic amplitudes. Maximum heights of the plumes generated by the explosions showed a positive correlation with the characteristic amplitude of the concurrent tremor.

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IUGG-5660

Magma migration at the onset of the 2012-13 tolbachik eruption revealed by seismic amplitude ratio analyses.

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In contrast to the 1975-76 Tolbachik eruption, the 2012-2013 Tolbachik eruption was not preceded by any striking change in seismic activity. By processing the Klyuchevskoy volcano group seismic data with the Seismic Amplitude Ratio Analysis method, we gain insights into the dynamics of magma movement prior to this important eruption. A clear seismic migration within the seismic swarm, started 15 hours before the reported eruption onset (05:00 UTC, 26 November 2012). This migration proceeded in different phases and ended when eruptive tremor was recorded (at ~11:00 UTC, 27 November 2012). In order to get a first order approximation of the location of the magma, we compare the calculated seismic intensity ratios with the theoretical ones. As expected, the observations suggest that the seismicity migrated toward the eruption location. However, we explain the pre-eruptive observed ratios by a deep-vertical migration under the northern slope of Plosky Tolbachik volcano that would interact at shallower depth with an intermediate storage region and initiate the horizontal migration toward the eruptive vents. A later migration is also captured and coincides with a seismic swarm that started south of Plosky Tolbachik at 20:31 UTC on November 28. This seismic swarm can be considered as a possible aborted eruption. In such remote areas, this type of information is very important. The significant variation, i.e. a fast migration in the shallow parts of the edifice, occurs when the seismic waveform becomes very noisy. From a real-time monitoring perspective, locating each volcano seismic events would be extremely fastidious. Hence, this method would be very helpful in volcano observatories by allowing quick answer to the critical “Migration or No migration?” question.

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IUGG-5722

High-precision resolution of the Bárdarbunga 2014 dyke intrusion and caldera subsidence

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Bárdarbunga volcano in Iceland has been showing signs of increasing unrest over the last 10 years, with seismicity confined north of the caldera rim and extending along the associated northern fissure swarm. However, in the final days leading up to the present eruption at Holuhraun, the unrest suddenly escalated into a propagating dyke intrusion. This evolution started with seismicity quickly moving out of the central volcano into a parallel fissure swarm east of Bárdarbunga, signifying a horizontal dyke propagation extending 48 km northeast to the location of the eruption site. During the dyke propagation, the seismicity spread from a few hundred m/hr to over a km/hr, and at times the advance stalled for days.

High-precision locations of microearthquakes in the dyke have revealed 8 main vertical segments of varying length and strike, but more details in the temporal and spatial distribution of seismicity can be resolved. The tight event distribution in the plane of the dyke suggests that the dyke is rupturing unbroken crust, so focal mechanisms of the individual events should reflect the stress field along the length of the dyke. The time evolution and details in spatial distribution of seismicity on the dyke will be presented and jointly interpreted with earthquake mechanisms on each dyke segment.

A few days after the dyke exited the caldera, seismicity on the caldera rim gradually increased to tens of microearthquakes every day and a few events of M>5 every week. Accompanying this activity the caldera subsided tens of meters. Several approaches to high precision location of the seismicity have been attempted, but the event distribution is more diffuse than along the dyke. The results and joint interpretation with mechanisms will be presented.

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IUGG-0590

High temperature tensional fracturing at Volcán de Colima, Mexico

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During dome-forming eruptions, the rapid transition from effusive to explosive activity is a direct consequence of strain localisation in magma. A deformation mechanism map of magma subjected to strain localisation will help develop accurate numerical models, which, coupled to an understanding of the mechanics driving monitored geophysical signals prior to failure, will enhance eruption forecasts. Here we present our work where seismic data from Volcán de Colima, Mexico, is combined with experimental work to give insights into high temperature tensional fracturing in magma.

The seismic data is derived from several periods during the dome-forming eruption at Volcán de Colima; an eruption that has been ongoing since 1997. For the analysis we implemented various methods to study temporal variations in seismicity, including: automatic event detection, waveform correlation, singular value decomposition, and waveform inversion. Preliminary results suggest variations in precursors to spine extrusions, as well as clusters during them. In our experiments, samples were placed under tensional, high temperature conditions and emitted acoustic emissions were recorded. The acoustic emissions are compared to the field data so that constraints may be placed on the conditions of the natural seismogenic source.

Using a combination of field and experimental data promises a greater understanding of the processes affecting the rise of magma during an eruption. This will help with the challenge of forecasting and hazard mitigation during dome-forming eruptions worldwide.

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IUGG-2240

Volcanic source models for very-long-period seismic signals

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Good broadband seismic sensors are capable to record seismic transients with dominant wavelengths of several tens or even hundreds of seconds. This allows us to generate a multi-component record of seismic volcanic events that are located in between the conventional high to low-frequency seismic spectrum and deformation signals. With a much higher temporal resolution and accuracy than e.g. GPS records, these signals fill the gap between seismicity and deformation studies. In this contribution we will review the non-trivial processing steps necessary to retrieve ground deformation from the original velocity seismogram and explore which role the resulting displacement signals have in the analysis of volcanic events. We will present a variety of VLP signals from Soufriere Hills volcano, Montserrat, West Indies, and White Island, and discuss potential source models that could guide the interpretation of these signals.

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IUGG-2274

New measures of tremor signals associated with eruptions and lahars

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Tremor signals are observed at volcanoes during heightened eruption activities and debris flows or lahars. Quantifying these signals is important in understanding dynamic processes associated with eruptions and lahars as well as monitoring these activities. The reduced displacement (RD) has been traditionally used as a measure of tremor. However, there are two main problems in the reduced displacement to quantify the size of tremor: (1) the frequency is not defined in estimating RD, and (2) the duration of tremor is not considered. In this study, we propose new measures of tremor signals using high-frequency amplitudes. We use the amplitude source location (ASL) method utilizing high-frequency amplitudes under the assumption of isotropic S-wave radiation for tremor signals. We first estimate the source amplitude (SA) using vertical envelope amplitudes band-passed between 5 and 10 Hz and averaged over a 10-s window that includes maximum amplitudes. We then multiply the correction factor for the geometrical spreading and medium attenuation to the observed vertical waveform, and integrate in time its envelope amplitude with a passband of 5-10 Hz. We estimate the offset value of the integrated envelope amplitude during tremor, which we call the total source amplitude (TSA). SA and TSA may be related to the maximum mass flow rate and total mass volume involved during tremor, respectively. We estimated SA and TSA for tremor signals observed at Tungurahua and Cotopaxi volcanoes, Ecuador. We found that TSA linearly increases with increasing SA for lahar tremor signals, whereas TSA exponentially increases with increasing SA for eruption tremor signals. SA and TSA may be used as universal quantitative measures of tremor signals observed at different volcanoes.

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IUGG-2526

Anatomy of a hidden phreatic explosion

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Kawah Ijen volcano (East Java, Indonesia) is well-known for hosting the world largest acidic lake on Earth. During the last years, several hydrothermal unrest were recorded providing a wealth of seismic data, the most energetic being the March 2013.

After several months of quiet activity, on March 20th, the miners who extract the sulphur from the crater heard several explosions and reported a sudden lake level increase (~1 meter).

By looking at the displacement signal at two broadband seismometers (Trillium 120P), we highlight an intriguing, but interesting seismic sequence combining 3 distinct pulses, a seiche and periods of high frequency bursts. First, a Very Long Period (VLP) seismic event triggered a seiche in the lake basin which is followed a few minutes later by a high frequency long-lasting signal (~10 min). We note that this event was not captured by nearby short period seismic sensors. Two more VLP pulses were recorded, each time followed by a seiche-like signal, during the following hours together with high frequency bursts of lower amplitude which do not seem to be correlated, nor (re)activated by the VLP anymore.

We dissect this unique series of events using different signal processing techniques. We first analyze the VLP pulses which need to be treated as deformation signals. By using the Seismic Amplitude Ratio Analysis (SARA, in the 5-15 Hz frequency band), we highlight a migration of the microseismicity associated with the high frequency signals. Finally, the analyses derived from the ambient seismic noise reveal a dramatic change in the Cross Correlation Functions for the two weeks following this event. We better constrain the origin of this crisis by using the lake temperature acquired every hour by a sensor immersed in lake waters.

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IUGG-3917

Heterogeneous seismic anisotropy masquerading as temporal changes: Shear wave splitting at Tungurahua Volcano, Ecuador.

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The measurement of seismic anisotropy using the method of shear wave splitting has potential as a stress monitoring tool and is increasingly being used by researchers. Even though anisotropy, caused preferentially aligned microcracks, can be a valid proxy for determining the stress regime in the subsurface, there are many other reasons that shear wave splitting may be observed. Anisotropy in the crust may be due to aligned macroscopic fractures, layering, or aligned minerals. Apparent SWS may also be observed due to site effects and phase conversions near the surface. Temporal changes in SWS may be an artefact of migrating sources passing through a heterogeneous anisotropic field.

At Tungurahua Volcano in Ecuador, we have analysed shear wave splitting from local VT earthquakes from 2008 to 2012, spanning the onset of major eruptive activity in 2010. We explore both lateral and vertical variation in anisotropy, before targeting temporal variations associated with volcanic activity. Comparison with local geology and ground deformation allows us to identify regions where seismic anisotropy is controlled by local stress and is likely to change due to volcanic activity. Results show that the majority of seismic anisotropy at Tungurahua is caused by static structures that are unlikely to change on timescales relevant for monitoring. Therefore, apparent temporal changes in shear wave splitting measurements are due to sampling regions controlled by different mechanisms of structural anisotropy. These results demonstrate how important it is to identify the cause of anisotropy before seeking temporal variations caused by changing stress.

IAVCEI (Volcanology, Geochemistry)

VS01c - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-4053

String theories: Recent volcano-tectonic seismicity at Soufriere Hills Volcano, Montserrat.

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Soufriere Hills Volcano (SHV) is an andesitic, dome-building volcano on the island of Montserrat. Beginning in 1995, the current eruption has consisted of alternating extrusive and repose phases. The last extrusive phase lasted 4 months, culminating in a partial dome collapse in February 2010. Since then seismicity has been low, although SO2 output has remained steady, and slow inflation, inferred from geodetic data, has continued.

VT earthquakes, in particular sporadic bursts termed VT "strings", have formed the majority of seismicity at SHV since 2010, alongside declining rockfalls as the lava dome has stabilised. These strings are brief swarms of VT activity, with 62 identified since November 2007. They show no obvious differences in hypocentres or waveform characteristics compared to other VT activity, and typically consist of tens of events in tens of minutes. Several strings have been associated with surface activity, preceding ash venting or increased degassing, often correlating with the SO2 flux on short (hours) and long (days) timescales.

Two large VT string events occurred in March 2012 and March 2014, both associated with high SO2 flux (up to 4600T/day) and accompanied by VLP seismic and significant strain signals, indicating pressure changes within the system.

This study presents multidisciplinary evidence from SO2 flux data and borehole strainmeters alongside seismic data to speculate on causative models of this seismicity, including hydrothermal or magmatic fluid processes. Such concepts have been used as evidence of magma-gas decoupling in a recent model proposed for the origin of volatiles at SHV, arising from a depth-extensive crustal magmatic mush system.

Implications for the diagnostic and forecasting potential of VT strings are discussed.

IAVCEI (Volcanology, Geochemistry)

VS01d - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-0858

Back-projecting geyser eruption signals to sources

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El Tatio Geyser Field in the northern Chilean Andes is the third largest geyser field in the world, boasting over 100 accessible hydrothermal features. The Upper Geyser Basin is largest in both area (~5x5km) and number of erupting hydrothermal features of 3 basins that comprise the field. One such feature is El Jefe Geyser (EJG), a columnar geyser with a consistently periodic eruption cycle of ~129s. 51 geophones (1-10m spacing) and 6 broadband seismometers (3-20m spacing) were deployed in a 50x50m grid surrounding EJG and recorded continuously at 1000 and 500Hz respectively for ~2 weeks in October 2012. The dense array served as the seismic framework for a collaborative study of complex hydrothermal system dynamics (downhole temperature/pressure, discharge rate, water chemistry and downhole/thermal video were also collected).

During the recording period ~2500 cultural-noise-free eruptions were recorded. We use this data to study changes in seismic source locations through an eruption and over multiple eruptions cycles using 1) ambient noise tomography to develop a 3D velocity model, and 2) back-projection processing to improve source imaging for repeating harmonic, diffuse seismic sources. We obtain Vp and Vs from ambient noise tomography, then correlate and back-project seismic signals from all available receiver-pairs to potential subsurface source locations assuming linear raypaths. Polarization filtering isolates P and S phases during different stages in the eruption cycle and allows us to generate 4D time-lapsed images of the source field around EJG. We compare the consistency of specific seismic signal observations (i.e. high or low frequency bands) over multiple eruption cycles, and relate changes in source locations for different signals to tomography results.

IAVCEI (Volcanology, Geochemistry)

VS01d - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-1467

Insights into volcanic tremor from bubble burst micro-eruptions at White Island volcano, New Zealand

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White Island volcano, New Zealand produced at least 2 episodes (January and July 2013) of micro eruption though a viscous mud/sulphur rich pool. The micro-eruptions consisted of episodic and at times continuous gas and ash bursts and jets < 80m in height. The first episode was recorded on a single permanent co-located seismic and infrasound sensor and has associated video recording of short periods of video record. The second episode was recorded on two separate seismic-infrasound stations but had no video record. The infrasound records reveal strong spectral signatures and overtones that are often interpreted as either a harmonic resonance due to a stable cavity open to the surface or alternatively to a 'comb' effect caused by a highly repetitious clockwork pattern having very small inter-event variation. The video and infrasound records however show that the micro-eruptions have only a weak clockwork pattern, and instead many events are dominated by a burst and jet pattern. The video records reveal an initial bubble burst followed by a post burst up channel jet. We show through a simple synthetic test that 'harmonic' or 'comb-like' spectral patterns can be alternatively created by repeated excitation of a double pulse event in a non-clockwork pattern. The observed double pulse events could represent both a single gas slug propagating and bursting through an open vent system, or may represent a harmonic resonator having only two observed impulses. A clockwork comb effect is unlikely in this particular case.

IAVCEI (Volcanology, Geochemistry)

VS01d - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-2678

Multiparametric study of the May 2012-April 2013 paroxysmal phase of Mt. Etna New South-East crater

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Between January 2011 and April 2013, Mt. Etna's eruptive activity has consisted of episodic intra-crater strombolian activity and paroxysms from Bocca Nuova and Voragine, and the New South-East (NSEC) summit craters, respectively. Eruptions from NSEC were characterised by initial increasing strombolian activity and lava flow output, passing to short-lasting lava fountaining. In this study we focus on seismic, infrasound, radiometric, plume SO_2, HCl fluxes and GPS data simultaneously collected by the INGV monitoring instrumentation between May 2012 and April 2013. The multiparametric approach allowed us characterising the NSEC eruptive activity at both daily and monthly time scale. In particular, whilst the seismic, infrasound and radiometric signals illuminated on the energy and features of the 13 paroxysmal events fed by NSEC, the SO_2, the halogen fluxes and the GPS data shed light on the likely mechanisms triggering the eruptive phenomena observed at the surface. In detail, we propose that the paroxysms' sequence represented the climax of a waxing-waning phase of degassing that had started since May-September 2012,as suggested by GPS and SO_2 data. In this view, the February-April 2013 eruptive activity reflects the phase of release of a volatile-rich batch of magma that had stored in the volcano shallow plumbing system.

IAVCEI (Volcanology, Geochemistry)

VS01d - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-3272

Automatic discrimination among volcano-tectonic earthquakes, meteo-marine and anthropogenic noise at Campi Flegrei by high order statistics methods

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A fundamental task in volcano-seismology is the characterization of the source of volcano-tectonic (VT) earthquakes; this passes through the discrimination of seismic events from the ambient background noise. Recently, a robust automatic procedure has been implemented for extracting the prominent seismic waveforms from continuously recorded signals. The intuitive notion of maximum non-gaussianity is achieved adopting techniques which involve higher-order statistics in frequency domain., i.e, the Convolutive Independent Component Analysis (CICA). This technique is successful in the case of the blind source separation of convolutive mixtures. A recent application regards the recognition of seismic Long-Period (LP) events at Campi Flegrei (Italy).

Here, we focus on the VT activity at Campi Flegrei Caldera during the 2006 ground uplift. This phase was characterized by the occurrence of approximately 300 low-magnitude VT earthquakes (Md < 2). Most of them were concentrated in distinct seismic sequences with hypocenters mainly clustered beneath the Solfatara–Accademia area, at depths ranging between 1 and 4 km b.s.l.. Besides VT earthquakes, LP signals were recorded during seven days, starting on October 23, 2006, and with the maximum rate on days 26 and 27. The events are located at depths of about 500 m b.s.l. beneath the southern rim of the Solfatara crater.

We show that CICA technique is able to separate different spectral components in the seismic signals which correspond to the meteo-marine, anthropogenic and VT activity contributions. In particular, the VT earthquakes can be discriminated on the basis of their corner frequency. This is particularly relevant in observatory practice where a fast discrimination can be crucial in the hazard evaluation.**IAVCEI**

(Volcanology, Geochemistry)

VS01d - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-3516

On the use of remote infrasound and seismic stations to constrain eruptive sequence and intensity during the 2014 Kelud eruption

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The February 2014 eruption of Kelud volcano destroyed most of the instruments deployed in the near-field. Our analyses using remote seismic and infrasound sensors unravel the eruptive chronology, which shares similarities with large historical eruptions. The first explosion was a relatively small event compared to the second, which occurred ~15 minutes later and was recorded 7,000 km away from the volcano by seismometers. In the time lapse from the first to the second explosion (i.e., 12 minutes after the first explosion and 8 minutes before the second eruption), a sustained acoustic signal was recorded as far as Alaska (USA) at a range of 11,000 km. Owing to an efficient coupling, and the attenuation of the acoustic wave, the acoustic signal was also seismically recorded (dominant period of 195 and 300 s).

These results suggest a bottom-up trigger for the first minor explosion followed by a top-down trigger for the second and most significant event. Based on the unloading of Kelud dome and the magmatic reservoir depth, we estimate the fragmentation speed to 20 m/s, which is consistent with experimental results.The infrasonic wave duration coupled with the total emitted mass of lava indicates an intensity around (10.9-11.1, I = log10 mass eruption rate + 3 (Pyle, 2000)), slightly above the Mount St Helens 1980 eruption. We demonstrate how remote infrasound and seismic sensors are critical for the early detection of volcanic explosions, and how they can help to constrain and understand eruptive sequences.

IAVCEI (Volcanology, Geochemistry)

VS01d - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

IUGG-5535

Real-time infrasonic monitoring of the eruption at a remote island volcano, Nishino-Shima, Japan

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On November 20, 2013, a submarine eruption started close to Nishino-Shima island, which is about 1000 km south of Tokyo. A new island emerged in November 2013, and it merged to Nishino-Shima in January 2014. The island is still growing (February 2015) by lava flows and a central cone is building up by Strombolian activity. The real-time monitoring of the eruption is crucial for understanding formation processes of a new volcano island, and the related disaster prevention. The in-situ monitoring, however, is difficult practically, because the closest inhabited island (Chichi-Jima) is 130 km away from Nishino-Shima. This study presents the signal processing for infrasonic observation at Chichi-Jima that enables real-time monitoring of the activity at Nishino-shima.
For the monitoring, we use records at two online stations. One is an east-west component of a velocity meter at a permanent seismic station operated by the Japan meteorological agency (JMA). They were corrected for atmospheric pressure using an empirical ground response to infrasound. The other one is a micro barometer installed at the meteorological observatory of JMA in October 2014. To suppress outliers, each record was normalized by the envelope. We, then, calculated their cross-correlation functions. They show clear successive arrivals of infrasound from Nishino-Shima. The typical peak amplitude is on the order of 1 Pa, and the typical duration is on the order of one week. Semblance analysis of an offline tripartite-array observation (from May 2013) also supports these results. The observed temporal variations were primarily controlled by the effective sound velocity structure. With a more quantitative estimation of the meteorological effect, we could infer activities of the eruption in real time.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-052

Seismic unrest and paroxism at Irazu volcano, Costa Rica, but no eruption

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At the end of 2011 we started recording low frequency seismicity (LF) at Irazú volcano, Costa Rica. In average there was an event recorded every 30 hours. In September 2012 a large (Mw 7.6) subduction zone earthquake perturbed the rate of events recorded, increasing both LF seismicity and dispersion of inter-event times. Rates of seismicity recover after December 2012 stabilizing in one event every 24 to 30 hours, with a larger scatter in inter-event times. By mid 2014 the number of events started to increase slowly, following a power-law, similar to material failure phenomena. At the end of an accelerated rate of seismicity, LF events happened so close in time that it became a continuous tremor, with the same frequency band as the LF events. Following this tremor, a paroxysm in the form of a stronger tremor, with broader spectra, followed for half an hour. This strong tremor was recorded on seismic stations as far as 50 km away from Irazú volcano, with a signal above the background noise. No LF seismicity was recorded after the paroxysm; instead, a few tectonic events were recorded an hour later, less than 3 km below the top of the volcano. As no thermal anomalies, active fumaroles or magmatic degassing has been observed, neither particular activity during or after the paroxysm, the LF seismicity must be related to a deep source below the hydrothermal system. This sequence can be explained as fluids in a deeper reservoir, in contact with a source of heat, been heated and mobilized to a bigger and shallower reservoir through a narrow conduit. LF events are very similar and hence, non-destructive. The paroxysm must have modified the geometry of the conduit for it to cease to produce LF events, and increased the stress locally, which was later released by tectonic events.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-064

Wide-band monitoring of Aso Volcano with seismometer, tiltmeter and continuous GPS from 2010 to 2014

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Aso Volcano is one of the most active volcanoes in the world and previous efforts have revealed magma plumbing system through discoveries of volcanic tremors (VTs) (e.g. Takagi et al., 2009), long-period events (LPs) (e.g. Chouet, 1996) and very-long- period events (VLPs) (e.g. Kawakatsu and Yamamoto, 2007). Recent deployment of continuous V-Net across Japan includes collocated multi-sensors such as seismometers, tiltmeters as well as acoustic sensor near the caldera region offer an unique opportunity to systematically examine how dynamic waves from seismic sources interact with the volcanic system. To design a monitoring scheme useful to detect and interpret various seismic signals from the volcanic system, we first analyze V-Net as well as nearby continuous GPS data to examine seismic/geodetic signatures associated with activities near Aso Volcano. We conduct spectrogram analysis in the wavelet domain across the multi-band, multi-sensor observatory and construct templates associated with previously identified VTs, LPs and VLPs. However, in order to focus on the volcanic processes, it is desirable to exclude seismic signatures associated with non- volcanic tremors/slow-slip located the down-dip end of the subduction zone interface. In this presentation, we will document preliminary result of 4-year (2010-2014) continuous monitoring near Aso. It is essential for volcano seismology to build a comprehensive representation of volcanic behaviour.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-086

Forecasting volcano seismicity evolution: Tools developed during the El Hierro (Canary Islands) volcanic process

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Significant deformations, followed by increased seismicity were detected since July 2011 at El Hierro, Canary Islands. A submarine eruption was first noticed on 10 October 2011, ceasing on 5 March 2012. However, the seismic activity did not end with the eruption, as other seismic crises followed, with several earthquakes with magnitudes greater than 4 (M5.4, 2013/12/27). The seismic episodes presented a characteristic pattern: over a few days the number and magnitude of seismic event increased persistently, culminating in seismic events severe enough to be felt all over the island. In all cases the seismic unrest was preceded by significant deformations that continued during the whole episode. A model combining the geometry of the magma injection process and the variations in cumulative seismic energy has allowed successful forecasting of major earthquake sequences. We use the Yokoyama empirical relationship for a threshold of cumulative seismic energy released before magmatic eruptions in closed volcanic systems. The analysis is focused on the time and space evolution of the magma-induced pressure sources, and not on the precise determination of their pressures, locations and dimensions. A major advantage of these simple forecast models is that they only require data of the temporal and spatial evolution of seismicity and deformation as it becomes available, offering an almost real-time capability to provide decision-makers with realistic scenarios and forecasts 24 to 48 hours in advance.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-087

Finite-source waveform inversion of Long Period (LP) volcanic events on Etna volcano (Italy): synthetic test.

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Long period (0.1-2 Hz) events are frequently observed on active volcanoes and are often related to fluid and gas movements inside the edifice. Nowadays full moment tensor (F-MT) inversions are usually carried out under the assumption of a point source. However source dimension of LP events may involve finiteness. We first carry out full moment tensor inversion to constrain a possible crack plane. Then, many sources along the identified plane are supposed to act simultaneously. Probability functions based on the pseudo-algorithm proposed by Zhang et al. (JGR, 2014) are given to each source to minimize the misfit between observed and retrieved signals. Subsequent iterations are conducted until the best matching solution is obtained. Sources with the low scaling factors are removed and we finally obtain a set of preferable sources which could act simultaneously (or time-shifted). We test this methodology on synthetic signals computed in a 3D realistic velocity model of Etna volcano (Italy) with topography and a grid spacing of 40 meters. Both a point source and a finite source (250m length, moving at 40 m/s) representing a horizontal crack are prepared with a Ricker source time function of characteristic frequency of 0.7 Hz. The seismograms are filtered between 0.1 and 1.2 Hz. Our synthetic tests show a higher misfit value for the point source case (0.75) than the finite source case (0.35). In the former case, the possible solutions are not converged in a localized (real single) point, but probability spreads widely in the given model space. On the other hand, significant probability is obtained only for the real extension of the finite source in the latter case. This difference allows guessing the finite dimension of the source.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-088

"Volume source representations: a unified explanation based on the representation theorem"

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There have been proposed two different volume changes from the seismic moment, the stress-free volume change dV_T and the confined volume change dV_C. The former is used in the moment tensor representation, while the latter is the actual volume change. These two volumes have been mentioned from the Eshelby's virtual operation approach. However, why dV_T should appear in the moment tensor and why it is linked to Eshelby's operation are not obvious. This study shows a unified explanation for their relation to the moment tensor following the representation theorem. The representation theorem gives the displacement field in terms of two surface integrals over the source surface: one is for the surface displacement and the other is for the surface traction. Only the first term has been considered for a seismic fault, because the second term vanishes due to the balance of the traction across the two adjacent fault surfaces. We here point out both terms are necessary in the representation for a volumetric source. Because the moment tensor uses only the first term, the second term contribution has to be involved as an additional surface displacement, which causes an imaginary volumetric change. Based on this idea, we derive an explicit representation of this imaginary volumetric change and relate dV_T to dV_C. Alternatively, we derive an equivalent volume source representation just by using the second term, taking the first term contribution into account as 'imaginary stresses'. Our imaginary volume/stress approach will clarify the classic volume source theory.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-089

Exploring the broad-band nature of volcanic long-period events: Example from Turrialba volcano

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The spectral content of seismic events on volcanoes ranges from ultra long period events with periods of more than 100 s to volcano-tectonic events with frequencies above 10 Hz and the events are usually classified by their dominant frequency content. For long-period (LP) events this band lies between about 0.3 and 2 Hz, with frequencies varying between different volcanoes and time periods. They are mostly found in the uppermost several hundred metres of the volcano and thought to be related to processes in the magmatic and/or hydrothermal system.

In order to deal with relatively low S/N-ratios, LP events are typically analysed in a relatively narrow frequency band of their highest energy. While this ensures stable source inversions, the results are limited to this frequency band and the actual source process may not be well reflected by the resulting model.

In many cases, source-time functions obtained by moment tensor (MT) inversions show pulsing or resonating waveforms, and the source is subsequently interpreted to be purely dynamic. If the actual source exhibits an additional static deformation or other low-energy, long-period motion though, this would not be reflected in filtered inversion results.

Observations from a high-quality experiment near the summit of Turrialba volcano suggest that ramp-like displacements are present for some LP events. This near-field effect can only be observed on the closest stations and is completely masked by traditional filters. However, an extension of MT inversions towards lower frequencies is not trivial as noise and tilt signals can cause problems. Here we present an analysis of these LP events with methods constrained by lab experiments and numerical simulations, and show that there is more to their source than just pure resonance.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-090

S wave attenuation and high-frequency seismic wavefield at Taal volcano, Philippines, inferred from high-frequency seismic waveform simulations

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The existence of a region of strong S wave attenuation (a low-Q region) near the ground surface, which may represent degassing magma, was estimated at Taal volcano, Philippines, from source location analysis using the amplitude source location (ASL) method. The ASL method uses high-frequency amplitudes under the assumption of isotropic S wave radiation caused by the scattering of seismic waves. To investigate the validity of the estimated Q structure based on a stochastic approach of the ASL method and to understand the nature of seismic wavefield, we used a deterministic approach based on numerical simulations of high-frequency seismic waveforms. We synthesized waveforms of volcano-tectonic events at Taal using a 3-D finite-difference method. We used focal mechanisms derived from first-motion polarities, and examined various sizes of Q anomalies, in which P and S wave velocities and density were assumed to be constant. To evaluate the fits between the observed and synthesized waveforms, we calculated the normalized residual using mean amplitudes in five frequency bands (0.5-2, 1-6, 3-8, 5-10, and 7-12 Hz). Our simulations provided the minimum residual when using the low-Q region estimated by the ASL method. We also found that the residuals depended on assumed focal mechanisms. If the radiation pattern of the observed waveforms is isotropic, it is expected that the residuals do not depend on focal mechanisms. The coincidence of the low-Q region estimated from the stochastic and deterministic approaches and the residual dependence on focal mechanisms indicate that the radiation pattern of observed waveforms in a high-frequency band is not completely isotropic and is also affected by a focal mechanism.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-091

Seismic signatures considering fluid-rock dynamic interaction

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Seismic signatures are often the only available quantitative information of the complex processes that take place within volcanic conduits and before eruptions. Examples of such phenomena are pressure drops, magma movement, explosions, gas burst, and the like. Numerical techniques are powerful tools for understanding the seismic wave field and the associated fluid-rock dynamic interaction of such complex systems.
We describe a model of fluid-rock dynamic interaction that simulate the distinctive physical processes which are triggered by the same internal sources and occur at its own time scale. The model is conformed by coupling two numerical approaches: one calculates, under an averaging scheme, the stress-strain of the cyclic dynamic interaction between the fluid and the rock wall, assuming an incompressible and viscous fluid that flows while the elastic solid responds oscillating. The other approach based on Trefftz's method considers the pressure wave propagation in and outside the conduit. These methods are complementary; in both the fluid is within a conduit limited by an elastic solid with axisymmetric geometry; and both allow for fluid-solid elastic coupling accounting for the radiated P- and S-wavefields into the solid. The signals emitted and propagated reveal fluid-solid interaction.
The model may serve to understand field and laboratory data and contribute to the solution of the inverse problem, giving clues on the source mechanism and the system´s nature. In principle these aspects can be inferred from recorded seismograms.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-092

Try to draw the volcanic eruptions and earthquake activity in the same figure in and around Japan

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The relation between the volcanic eruption and the occurrence of large earthquakes were well known. It was the famous eruption of Mt. Fuji in 1707 in Japan. It was followed 49 days after the occurrence of M9 Hoei earthquake. But, 2011 off Tohoku, Japan M9 earthquake did not follow eruptions, yet. The seismicity was commonly analyzed in time and space, using several database, for example ISC catalog. But the data of volcanic eruptions were not popular and needed to analyze the relation.
The data of eruptions in and around Japan was inputted in order to search the relation between eruptions of volcanoes and occurrence of large earthquakes. The database of the Global Volcanism Program by Smithsonian Institute was adopted. The histories of volcanoes in Japan were checked and only 'Confirmed' eruptions were adopted.

The format of eruption data is same as the hypocenters’. The location of the volcano, not craters, is the epicenter. The height of volcano is minus depth of hypocenter, and the volcanic explosivity index is used as the magnitude of the earthquake. The origin time is the date of the eruption and is assumed on 00:00:00 time. The eruption was assumed every day from the start of the eruption to the end. If the start date and the stop date were only known in year, Jan. 1 was assumed for the start day and Dec. 31 for the stop date. Totally more than 153,000 eruptions were inputted from AD 20 to 2014.

Mixing this data and earthquake catalog, we can get some relations between eruptions and earthquake occurrences. One is that the 1922 M7.6 earthquake in Okinawa followed VEI 4 eruption near Miyako island in 1924. The other is some large earthquakes occurred before and after the large eruptions in NE Japan in 17 century.

IAVCEI (Volcanology, Geochemistry)

VS01p - VS01 New Advances in Volcano Seismology and Related Geophysical Methods

VS01p-093

A multi-parameter investigation into the recent and ongoing volcano-seismic unrest on Nisyros volcano, Greece.

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Nisyros is a Quaternary strato-volcano located in SE Aegean Volcanic Arc (Greece). It hosts an active hydrothermal system and has generated historic phreatic eruptions. Significant seismic activity began in the area of Nisyros volcano in July 2014, together with increased intensity of fumarolic activity and new structural features on Nisyros itself. Local seismicity has since remained elevated above background levels, with current unrest representing the highest peak in activity since the 1995-1998 volcano-seismic crisis, which was attributed to local magmatic inflation and degassing. In response to renewed activity, a local seismic and GPS network was deployed on Nisyros and surrounding islands (August 2014) and repeat measurements of hydrothermal features were made, to better constrain the source and implications of unrest. Here we present our initial findings. We recorded frequent local micro-seismic events, many of which have signals typical of hydraulic fracturing and are indicative of shallow boiling/degassing activity and subsurface fluid propagation. Ground deformation recorded by GPS corresponds with radial spreading patterns expected to occur with magmatic inflation beneath Nisyros and active extension on newly observed structural features. Fumarolic outlet temperatures increased from July – September 2014 and measured fluids were pH 1. Field evidence suggests a large fracture system which has developed in the caldera since 2001 may be related to active magmatic degassing. Recognising the signals and source of unrest at volcanic-hydrothermal systems is vital in identifying anomalous behaviour and potential precursor activity of magmatic and phreatic eruptions, which often occur without significant warning. Our investigation into the Nisyros unrest is ongoing.

IAVCEI (Volcanology, Geochemistry)

VS02a - VS02 Lava Flows

IUGG-0967

Nornahraun lava morphology and mode of emplacement

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The ongoing Nornahraun eruption is the largest effusive eruption in Iceland in ~260 years, with an estimated lava volume of ~1.15 km^3 covering an area of ~83.9 km^2 (as of 15 JAN 2015). The flow field provides an unprecedented opportunity to study a continuum of morphologies from pahoehoe to ‘a‘a, which have been monitored in the field and from remote sensing platforms. At the onset of the eruption 31 AUG, lava flows advanced rapidly (400–800 m/hr) from the 1.5 km long fissure as large slabby pahoehoe sheet lobes. By 1 SEPT, a central open channel developed, feeding a 1–2 km wide active ‘a‘a frontal lobe that advanced 1–2 km/day towards the NE. In addition to its own caterpillar motion, the frontal lobe advanced in a series of breakouts, predominantly slabby and rubbly pahoehoe. The flow front came to halt on 12 SEPT 18 km from the source vent. Subsequently, a new lobe broke out S of the first lobe and migrated eastward until it also came to arrest at a slightly shorter distance from the fissure. This mode of gradual clockwise propagation of new frontal lobes continued from mid-SEPT to end-NOV. At this time the main lava channel partly crusted over and a series of insulated flows overrode the previous emplaced flows, changing transport system to include closed/insulated (and inflating) pathways in addition to open channels. Resultantly, the area now covered by the flow field has undergone several topographic inversions due to stacking of lava lobes.

IAVCEI (Volcanology, Geochemistry)

VS02a - VS02 Lava Flows

IUGG-2396

Evolution of lava extrusion through the geological history of a volcano: Insights into the magma system properties

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The extrusion of lava from a vent depends on factors such as magma rheology, conduit dimensions and magma chamber depth and size. Additional factors that influence the dynamics of a lava flow include topography and cooling effects. Thus the morphology and dimensions of a lava flow unit should reflect the influence of these parameters. The magma system information we can infer from eruption parameters during lava effusion or the final lava morphology is usually limited as there are many unknown variables and few available equations to solve them. In this study we present a methodology which incorporates the variations of erupted volume and effusion rates of past eruptions through the geological history of a volcano in conjunction with eruptive parameters of recent eruptions to estimate the depth and size of magma chamber feeding a volcano.

We applied the method on Lonquimay volcano, located in the Southern Andes of Chile. Individual lavas from older units are more voluminous (~0.1 km3) and reached longer distances (~15 km) than lavas from younger units (0.01 km3 and 3 km respectively). We attributed these variations to the load imposed on the magma system by the growth of the volcano edifice. Using these data together with the eruptive parameters from the 1988-90 eruption (effusion rate evolution and total erupted volume) we estimated the depth and volume of the magma chamber feeding the eruptions at the volcano. Our results indicate that the top of the magma chamber is located at 6 km below the surface and the volume is ~20 km3. These results are in good agreement with thermobarometric calculation and previous geophysical studies. We acknowledge FONDECYT project N°11121298.

IAVCEI (Volcanology, Geochemistry)

VS02a - VS02 Lava Flows

IUGG-2816

The surprising terminus of the turbulently emplaced Athabasca Valles Flood Lava

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The Athabasca Valles Flood Lava is the youngest and most pristine flood lava on Mars. It extends ~1500 km from the Cerberus Fossae fissures, has a volume of ~5000 km^3, and was turbulently emplaced with a peak effusion rate of ~10^7 m^3/s. Previous work has focused on the features in the proximal section (the 300-km-long Athabasca Valles) and medial section that filled the Cerberus Palus basin. These earlier studies have detailed a wide variety of unusual volcanic landforms including multi-ringed phreatovolcanic constructs, multi-kilometer-scale rafted plates, giant lava coils, and suggestions of decameter-scale mechanical erosion by the flood of lava. Here we describe some puzzling features that can be found toward the terminus of this flow. The margin of the flow >1000 km from the vent is characterized by masses of pahoehoe lobes transitioning into inflated sheets. The surface of these sheets preserves evidence of an initial phase where the flow advanced as a platy-ridged flow (rubbly pahoehoe) that was subsequently extended, embayed and partially buried by pahoehoe breakouts from within the sheet. In many areas the flow exhibits a distinctive banded appearance, possibly related to pulses of lava during the initial emplacement. It is surprising that the signs of rapid turbulent emplacement are so muted by the flow terminus. The most enigmatic features are where the lava interacted with surficial deposits, especially those that filled kilometer-scale craters. In at least one case the crater fill was uplifted, most likely by invasive lava. An alternative hypothesis is that the uplift was caused by the formation of a ~100 m thick ice lense as ground ice melted by the lava accumulated and froze within the crater.

IAVCEI (Volcanology, Geochemistry)

VS02a - VS02 Lava Flows

IUGG-3519

The thermospectral infrared properties of active basaltic flows: Constraining petrology, lava cooling and flow propagation models

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Basaltic volcanism is ubiquitous on the terrestrial planets and is the most common form of extrusive activity on Earth, with over half of the volcanoes consisting largely of basalt. Recently, new eruptions (or new phases of ongoing eruptions) have occurred at Tolbachik in Russia (2012-2013); Bardarbunga in Iceland (2014); Etna in Italy (2014); and Kilauea in Hawaii (2014) emphasizing the hazard potential of basaltic activity. Therefore, this style of effusive volcanism and especially its surface manifestation (lava flows) warrants continued study both from a fundamental science and hazard mitigation point of view. Monitoring flow propagation direction and velocity is critical in these situations and a number of models have evolved over time focused on heat loss and down-flow topography to predict flow advance. In addition to topography, the dominant (internal) factors controlling flow propagation are the discharge rate combined with cooling and increases in viscosity, but all these models rely on measuring the temperature of the cooling glassy surface commonly using infrared (IR) instruments. New laboratory and field-based studies are attempting to characterize the cooling, formation, and dynamics of basaltic surfaces using IR data. Preliminary results are focused on resolving flow compositional, textural, and silicate structural changes. These parameters control the surface-leaving heat flux and therefore improved accuracy in their retrievals increases our ability to constrain and model flow surface and interior temperatures. The impact of this improved accuracy is now being assessed using FLOWGO model simulations of the Tolbachik flows and has immediate implications for an improved understanding of basaltic lava flow emplacement.

IAVCEI (Volcanology, Geochemistry)

VS02a - VS02 Lava Flows

IUGG-3686

"Fill and spill" lava emplacement and its effects on local lava discharge rates and flow morphologies

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Reconstructing magma effusion rates from lava flow dimensions and morphologies requires an understanding of how lava transport processes can affect local discharge rates and mask signatures of primary vent conditions. This study focuses on the December 1974 flow in the SW Rift Zone of Kilauea Volcano, Hawaii, USA, using observations of flow characteristics, airborne and tripod LiDAR, Differential GPS, and Multi-View Stereo Photogrammetry. The study area shows evidence of basin infilling with a prominent “bathtub ring” of lava standing 0.6–1.7 m above the current surface of the pond. The total area of the pond is 0.11 km^2, implying 6.6–18.7 × 10^4 m^3 of lava drainage. The pond has pahoehoe margins, and its interior is covered by meter- to tens of meters-wide plates, separated by spiny lava. The plates have pahoehoe-like surfaces that exhibit polygonal swales like those on the Kilauea Iki lava lake. We infer that lava from the source vent filled a basin between older flows and a prominent scarp in the Koae fault system. As the lava level rose, it embayed the surroundings and constructed a perched lava pond. Within a few hours (based on the cooling-limited thickness of the disrupted pahoehoe slabs), the pond breached its confinement and drained. This movement caused the pond's crust to separate into large plates, with spiny lava upwelling in the cracks. The surge of lava toward the SW also caused slabs of pahoehoe to pile up against the surrounding tumuli. In the channels, elevated discharge rates caused shear-induced disruption of the flow into aa clinker. The process of basin infilling and drainage, which we term “fill and spill” emplacement, was repeated several times along the length of the December 1974 flow, producing a series of ponds connected by spillway channels.

IAVCEI (Volcanology, Geochemistry)

VS02a - VS02 Lava Flows

IUGG-5482

Lava flow morphology and dynamics during the 2014/2015 Fogo eruption, studied using Terrestrial Laser Scanner data

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Fogo Volcano is the only historically active volcano of the Cabo Verde Islands. Pico do Fogo stratocone (2829 m), the most prominent feature within "Chá das Caldeiras" (Chá), started a flank eruption on the 23rd of November 2014. In only one day the lava flows travelled a distance of ~ 4 km, reaching the first houses of the agricultural settlement of Portela. Over a period of two weeks, about 200 buildings and a significant portion of the agricultural land within the Chá were destroyed. The villages of Portela, Bangaeira and Ilheu de Losna are no longer existent.

During a field campaign in January 2015, Terrestrial Laser Scanner (TLS) data were collected, using a RIEGL VZ-6000 instrument, targeting the new lava flows as well as the active crater of Little Pico.

Here we compare a high-resolution DEM derived from TLS data to a pre-existing, pre-eruptive airborne Lidar DEM, featuring a resolution of 5 m, in order to estimate the erupted lava volume. On the base of the pre-eruptive DEM, the erupted lava volume, and the TLS DEM we then forecast the paths of the lava flows retrospectively and estimate potential paths of future flows. We also compare multi-temporal TLS data of parts of the current, but inactive, flow field to monitor flow dynamics (mainly cooling after emplacement) over a period of 10 days as well as flow morphology. The active crater was also covered by multi-temporal scans and from different look angles. The vent shows topographic changes (growth) due to its increased strombolian activity during the time of TLS observations. Our study shows the great potential of high-resolution TLS data to monitor lava flow morphology and dynamics, which has implications for hazard mitigation.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-442

Emplacement of thick lava flows: The case of El Metate, Michoacán-Guanajuato Volcanic Field (MGVF), Central Mexico

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The MGVF has a total area of ca. 40,000 km^2 and contains a high number of eruptive vents with over 1000 small monogenetic cones (average vol. of 0.021 km^3) and ca. 400 medium-sized volcanoes (average vol. of 3.3 km^3). Most of these medium-sized volcanoes may be characterized as shields due their low slope angle (10º in average) which indicates dominant effusive activity as opposed to the small cones formed explosively. This study focuses on a succession of lava flows forming El Metate volcano which is probably the youngest shield of the MGVF (<3,775±50 years B.P.). Unlike a typical shield volcano composed of a succession of thin fluid basaltic flows, El Metate consists of well-preserved >60 m thick andesite flows distributed radially around a summit dome. Detailed mapping and sampling allowed us to reconstruct its eruptive history and determined the time sequence of lava flow emplacement. We have identified 13 to 14 individual lava flows covering 103 km^2 and representing a total volume of 11 to 15 km^3. The longest of them is 15 km long, 77 m thick in average and up to 2.5 km wide, representing a volume of up to 3.4 km^3. Rheological parameters, emplacement duration as well as effusion rate were obtained from geometrical dimension of the flows. The velocity of flow emplacement is found to be quite low due to the high viscosity of the lava, but the impact on the local environment of such voluminous deposit is significant. Although the shield volcanoes are more sparsely distributed in time and space and less abundant than the small monogenetic cones, the risks associated with renewal of this type of activity in MGVF should not be neglected. The young age and large volume of this eruption bear important implications, especially for evaluating future hazards in the region.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-443

Testing models of lava-water interaction with field data

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The interaction between hot lava and ground water/ice produces landforms that can provide important insight into the nature and extent of water, especially on Mars. A remarkable outcrop of a Miocene Columbia River Basalt sill that intruded into lake sediments in western Idaho provides a rare opportunity to test models of lava-water interaction. Of order one meter of lake sediments are exposed above and below the ~0.5 m thick sill. The sediments are related to the Clarkia fossil beds that exquisitely preserve leaves, pollen, and other organic material. This pristine organic material allows the application of geothermometry techniques used in the petroleum industry. Initially translucent pollen grains, upon heating, turn to yellow and progressively darker shades of brown, eventually blackening near 300°C. The measured temperature profile is essentially constant at 250-300 °C, both above and below the sill. This challenges current conduction-based models because conductive temperature profiles traverse 200-300 °C over a short depth interval. No plausible set of input parameters for any model that relies primarily on conduction will provide a good fit to the field observations. The problem is that steam neither stays stationary nor simply exits the system. Instead, it seems that the steam travels a modest distance before recondensing. A “heat pipe” circulation system is then set up, producing a very constant temperature profile across the 2-phase region. However, steam at 250-300 °C requires a pressure ~7 MPa. This corresponds to hydrostatic pressure at a depth of hundreds of meters under a mix of sediments and water but the sill was probably much shallower. This suggests that the steam was raised to a pressure significantly above hydrostatic.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-444

Evidence for inflated lava flows near Hrad Vallis, Mars

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Flat-topped lava flows are common on Mars, and may be analogous to lava-rise plateaus on the Earth. The leading hypothesis for their mode of formation is as inflated lava flows, and here we identify an excellent candidate for an inflated lava flow north of Hrad Vallis, Mars (34°N, 218°E). Hrad Vallis is inferred to have formed in association with the intrusion of a shallow sill that melted part of the martian cryosphere to produce an enormous lahar-like mud flow. However, a reexamination of the region using Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) images (6 m/pixel) reveals a complex history involving the emplacement of flows from Galaxias Fossae (38°N, 218°E) to the north. The inflated flow is ~45-m-thick and extends ~110 km from the Fossae. This flow illustrates inverted topography where it encountered an older exposed dike, radial to the Elysium Mons Volcano. Where exposed on both sides of the flow, the dike has positive relief (~20-m-high), and we suggest that the flow was emplaced as a pahoehoe-like lava flow that was confined by topographic obstacles and inflated to thicknesses of ~45 m. These obstacles include the exposed dike and, possibly, former mud flow deposits from Hrad Vallis, which have been subsequently eroded. If so, this implies an erosional history for the surrounding landscape, and places important constraints on the origin of numerous enigmatic craters and other landforms in this region.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-445

Q-LavHA: A Quantum GIS plugin to simulate lava flows

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Q-LavHA is a user-friendly Quantum GIS plugin which simulates lava flow propagation from one or multiple regularly distributed eruptive vents on a Digital Elevation Model (DEM). It combines existing probabilistic and 1D thermo-rheological deterministic (FLOWGO) models and proposes improvements in order to refine the probability of lava flow spatial spread and terminal length. The spatial spread is constrained by the steepest slope following the probabilistic approach of Felpeto et al. (2001). The corrective height factor which is included allows the lava flow simulation to overcome small topographical obstacles. The terminal length of the lava flow can be determined based on a fixed length value, a Gaussian probability density function, or based on the thermo-rheological properties of a cooling open-channel lava flow following the approach of the FLOWGO model (Harris and Rowland, 2001).

In this contribution, we present a sensitivity analysis of the Q-LavHA parameters on the quality of the simulations for specific flows at Etna (Italy), Karthala (Comoros) and Nyamuragira (Democratic Republic of the Congo) volcanoes. Additionally, we investigate the influence of the underlying slope and the DEM resolutions on the selection of optimal input parameters.

Q-LavHA is designed for scientists and stakeholders confronted with imminent or long term lava flow hazard from basaltic volcanoes. Q-LavHA can improve their understanding of the spatial distribution of lava flow hazard, influence their land use decisions and support evacuation planning. Q-LavHA has been developed in Python in order to allow users to adapt the code to their needs. Its availability as a Quantum GIS plugin with a user friendly interface facilitates its distribution and use.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-446

Rubbly-pahoehoe lavas from southern Paraná-Etendeka Continetal Basaltic Province

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Recently rubbly-pahoehoe lavas were identified in the southern portion of Paraná-Etendeka LIP. These lavas represent an important component of the volcanic stratigraphy in the southern portion of Brazil. They occur as thick (40-45 m) tabular lavas that spread for several kilometers and cover pahoehoe flow fields. The rubbly lavas are characterized by a tabular classic architecture marked by the vertical stacking of several lava flows, which together can reach a maximum thickness of 500 m in the main valley of Torres Syncline. The internal structure of single rubbly-pahoehoe lava can be divided in four parts. The basal portion is characterized by aphanitic and vesicular basalt, and the basal surface is commonly glassy and oxidized. The core is mainly aphanitic and aphyric basalt and in some cases with irregular columnar joints, and the upper portion of the core is coarsely vesicular or amygdaloidal basalt. The cavities range from 1 to 6 cm in diameter in a sub spherical shape and a random distribution and are filled mainly by zeolite. The flow surface is brecciated, and forms a rubble layer with an irregular geometry and have an average thickness of 5-7 m. It is formed of vesicular basalt fragments with random distribution. The diameter of the fragments varies from 5 cm to 25 cm with an average of 10 cm. The occurrence of rubbly-pahoehoe lavas imply in a change of the dynamic of the volcanism and may represent an increase in volcanic activity. The absence of multiple lobes or associated pahoehoe lobes indicates that rubbly-pahoehoe lavas emplaced as simple flow, probably formed during sustain eruptions. The disruption of flow surfaces may indicate oscillations in effusion rates during the emplacement.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-447

"Numerical simulations of lava flows. A calibration from thermal images of lava emplacement at El Reventador volcano"

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El Reventador volcano, located in the Ecuadorian Subandean Zone, is one of the most active volcanoes in this country. In continuous activity since 2002, El Reventador is responsible for the strongest eruption in the last 125 years in Ecuador (VEI 4). After its reactivation, seismic, infrasound, lahar, visual and infrared monitoring instrumentation have been deployed on the volcano by the Instituto Geofísico of the Escuela Politécnica Nacional (IG-EPN). Based on visual and thermal data collected between 2002 and 2014, at least 35 lava flows of different lengths were identified. At the end of 2013 the IG-EPN installed a fixed infrared camera in the southeast flank of the volcano whose images are transmitted in near real time to the IG Data Center in Quito. Thermal images allowed us to identify 7 small lava flows in the southern flank during 2014 and three of them were georeferenced using a 1m-resolution DEM acquired in 2013 by photogrammetry. From these georeferenced images, we have determined the lengths, the areas, the volumes and the velocities of these lava flows and their evolution in time. Then, we have used an isothermal model based on a Bingham rheology and the numerical code VolcFlow to determine the best values of the yield strength and the viscosity that reproduce the field data. The simulated flows show a good fit with the natural flows, demonstrating that, to the first order, an isothermal model could be used for hazard assessment related to lava flows at El Reventador volcano. In conclusion, an isothermal rheology is able to reproduce the emplacement of this more viscous lava flow and this was checked for the first time in the lava flow emplaced on 4th-5th December, 2010 in Tungurahua volcano.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-448

Eruptive dynamics of Quaternary effusive volcanism from Laguna del Maule Volcanic Field

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In this study we analyzed Quaternary lava flows from Laguna del Maule Volcanic Field, in the Chilean Andes, in order to estimate eruptive parameters such as effusion rates and erupted volumes to get insights into the magma system properties like magma chamber depth, size and architecture. The analyzed lavas have a rhyolitic - andesitic composition being most of them acidic, with volumes of a few cubic kilometers, thicknesses up to 140 m and maximum lengths of 10 km. Modeling of the advance of these flows gives velocities in the order of 10^{-4}-10^{-3} ms^{-1} and effusion rates of 10-10^{2} $m^{3}s^{-1}$. Petrologic studies which includes quantitative textural analyses and mineral and glass compositions, reveal similar temperatures, pressures, H_2O content and oxygen fugacity by similar composition. Our main results indicate that the eruptions that generated the emplacement of the lava flows were triggered by the injection of magma batches into a magma chamber that is divided into many sub-compartments which could explain the broad distribution of the vents. On the other hand, the analysis of the lava morphologies suggests a crustal yield strength control over the internal viscosity of the flow.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-449

Satellite observations of the variability of lava effusion rates during terrestrial eruptions over the past 15 years

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There are several reasons why it is important to know how lava effusion rates vary during effusive eruptions. Lava effusion rate is, after chemistry, the most important factor which determines how far a lava flow can advance (Walker, 1973). Temporal variations in effusion rate are also related to magma chamber properties (Wadge, 1981), and integrating effusion rate over time yields estimates of total lava flow volume. Satellite remote sensing offers a means to estimate lava effusion rate at all of Earth's volcanoes at almost daily time scales. The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, flown onboard NASA's Terra and Aqua spacecraft, has acquired data during almost every mafic lava flow forming eruption that has occurred on Earth since 2000. In this presentation we will compare and contrast how effusion rates have varied during 66 eruptions at 23 different volcanoes, between 2000 and 2014. As well as documenting differences in intensity and magnitude (effusion rate and total erupted volume) our results also highlight differences in the "shape" of the effusion rate vs. time curves that relate to differences in magma supply conditions.

IAVCEI (Volcanology, Geochemistry)

VS02p - VS02 Lava Flows

VS02p-450

Growth of the Holuhraun lava flow by sequential lobe emplacement, as quantified by time-lapse terrestrial lidar measurements

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The ongoing eruption at Bárðarbunga, Iceland, has emplaced a ~17-km-long basaltic lava flow field in the Holuhraun region, covering >80 km^2 and with a volume of >1 km^3. Following initial lengthening, the flow expanded laterally through periods of lobate advance from regions of the flow field margin. Between 20 and 26 September, 2014, vehicle-based GPS mapping and MODIS data indicated that new lobes were emplaced over a ~5 km length of the north-eastern flow margin.

Here, we present data collected on 21 September using a Riegl LPM-321 terrestrial laser scanner (TLS) to measure flow advance in this north east active region, approximately 4 km from the effusive vent. The flat local topography of Holuhraun, which lacks any elevated viewpoints within a few kilometres of the active flow portions, prevented surveying of the full active area. Consequently, the data acquired covered ~250 m of advancing flow front, and up to ~400 m behind the flow margin.

Repeated scans were carried out at ~12 minute intervals, over a period of ~3 hrs, to produce a time-lapse sequence of 16 DEMs. The data illustrate lava emplacement by sequential breakout of lobes[HT1] , typically 20-50 m wide and 3-5 m thick. Lava thickness at >300 m behind the flow fronts was ~10-14 m, but inflation at that distance was not observed. Individual lobes could initially advance rapidly (e.g. 180 m hr^{-1}), with the overall advance rate being ~20 m hr^{-1}. Volumetric advance rate for the surveyed region was relatively steady at 10 m^{3}s^{-1} during the period, equating to 0.04 m^{3}s^{-1} per metre of measured flow front. Extrapolating this over the ~5 km length of the active flow margin, implies an overall growth rate for the entire lateral region of 200 m^{3}s^{-1}, [HT2] in line with estimated eruption effusion rates at the time.

IAVCEI (Volcanology, Geochemistry)

VS03a - VS03 LIPs: vents and volatiles

IUGG-3848

Bimodal stratigraphy of the Lake Owyhee volcanic field, Oregon: Implication for storage and eruption sites of Columbia River Basalt magmas

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The greater Lake Owyhee volcanic field of southeastern Oregon is composed of thick mafic lava packages, previously correlated with the main members of the Columbia River Basalt group (CRBG), and numerous rhyolitic ignimbrites and lava flows. Rhyolitic volcanism of this field constitutes the north-central part of a ~350 km diameter-wide mid-Miocene rhyolite flare up related to the flood basalt magmatism of the CRBG and is surrounded by the well-known dike systems of the Steens, Monument, and Chief Josh dike swarms. Rhyolitic units are distributed over ~15000 km^2 and select prominent silicic units include the newly redefined Dinner Creek Tuff and associated fallout deposits (together ~500 km^3), the ~100 km^3 lava flows of the Littlefield Rhyolite, and tuffs and lavas of Mahogany and Three Fingers calderas. New age dates on rhyolites range from 16.5 to 15 Ma indicating contemporaneity with Grande Ronde Basalt magmas (16.5 to 16 Ma, Jarboe et al., 2010; 16 to 15.6 Ma, Barry et al., 2013) that account for ~72% of all CRBG magmas. Local Grande Ronde venting sites within the perimeter of rhyolite exposures exist in form of pyroclastic near-vent deposits. The first direct evidence for crustal reservoirs of Grande Ronde magmas in the area comes from cognate mafic inclusions in Dinner Creek Tuff that have Grand Ronde-like compositions or lie on mixing trends with Grand Ronde compositions. Our study suggests that Grand Ronde Basalt crustal reservoirs existed in the greater area of the Lake Owyhee volcanic field and that widespread 16–15 Ma rhyolites may have had a 'buffering' effect as rheological or density barriers allowing Grande Ronde magmas stored underneath to erupt after rhyolites or in peripheral areas after traveling in dikes for many kilometers (cf.,Wolff et al., 2008).

IAVCEI (Volcanology, Geochemistry)

VS03a - VS03 LIPs: vents and volatiles

IUGG-4226

Geochemical stratigraphy of Tarim flood basalts, NW China: magma types, spatial distribution, and implications for eruption sources

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We present flow-by-flow compositional data on the ~400-m-thick and ~110-km-long sequence of mafic lavas from the Kupukuziman and Kaipaizileike Fm in Keping, Permian Tarim flood basalts, NW China. The KP and KZ Fm contain 2 and 12 lava flows, respectively, separated by an 800 m thick sedimentary interlayers. Major and trace element data for 43 samples (KP=8, KZ=35) show a range of compositions from 41.6 to 49.4 wt % in SiO_2. Six distinct composition groups are recognized and traced laterally, 2 in KP and 4 in KZ. The two KP lavas have different TiO_2 (3.2% vs 3.9%) and incompatible elements (e.g. Nb: 25 vs 30 ppm, Ta: 1.5 vs 1.8 ppm). The 12 lavas in KZ can be divided into 4 groups based on Mg# (30 to 43), Lu/Hf ratio (0.079 to 0.086), and incompatible elements (e.g. Zr: 450 to 250 ppm, Nb: 42 to 25 ppm, Sm/Yb: 2.8 to 2.3). The 4 KZ groups from lowermost to uppermost contain 2, 1, 4 and 5 lava flows, respectively. KP basalts are distinguished from KZ by higher Nb/Zr and Th/La ratios. A megacrystic plagioclase lava in the KZ section has been used as a correlation marker, but compositional data suggests it may not be traced. Comparing our comprehensive Keping dataset to other areas of the Tarim province, Northern Tarim basalts have lower TiO_2, P_2O_5, FeO(t), Zr and Y, and significantly higher Nb/Zr (avg. 0.16 vs 0.09) and La/Yb (avg. 17.3 vs 9.8). Qimugan and Damusi basalts (SW Tarim), despite being close to each other (~70 km), have distinct Th/La and Ti/Zr ratios. We divide all the Tarim basaltic lavas into four distinct geochemical units, which are aerially restricted and may indicate corresponding magmatic centers: Keping, Northern Tarim, Qimugan, and Damusi. Previous chemostratigraphic correlations were based on less well-defined stratigraphy and require reevaluation.

IAVCEI (Volcanology, Geochemistry)

VS03a - VS03 LIPs: vents and volatiles

IUGG-4917

Devolatilization of sedimentary rocks during LIP formation and the implications for past environmental crisis

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The emplacement Large igneous province is regarded as the main processes behind past environmental crises such as the end-Permian and the end-Triassic. The details of these links are however still under investigation. Among the suggestions are lava degassing of mantle- and crustal-derived gases, explosive lava and phreatomagmatic eruptions, and gas release from contact metamorphism related to sub-volcanic sill complex. Whereas the lava piles of LIPs are relatively well studied and investigated, the sub-volcanic sills, dikes, and contact aureoles are poorly studied and documented. We present borehole and field data of sills and contact aureoles from the Siberian Traps, the Karoo LIP, and the NE Atlantic LIP. The data has been compiled during field campaigns and borehole studies the past decade. Sill geometries and thicknesses vary considerably from kilometer-scale intrusive complexes to individual thin sills of a few tens of meters. We show that thick and shallow sills are emplaced within coal horizons in the Siberian Traps, but are unusual in the Karoo and the NE Atlantic. Moreover, very thick sills (100-300 meters) are emplaced within the vast Cambrian salt formations below the Siberian Traps lavas. We show that depending on the specific composition of the sedimentary rocks undergoing metamorphism, the potential for degassing of both greenhouse gases (CH_4, CO_2), aerosols (SO_2), and ozone destructive gases (CH_3Cl, CH_3Br) is substantial. Devolatilization and degassing to the atmosphere can explain many of the climatic and environmental responses available from proxy data studies and from the fossil record.

IAVCEI (Volcanology, Geochemistry)

VS03a - VS03 LIPs: vents and volatiles

IUGG-5174

Estimating the impact of the cryptic degassing of Large Igneous Provinces: A mid-Miocene case-study

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Large Igneous Provinces (LIPs) have been emplaced throughout Earth's history and have been linked to major environmental disruptions. The largest LIP eruptions are widely considered to have had an impact on global climate through basalt CO_2 degassing but the impact of the more numerous smaller LIPs is debated. Here we test the hypothesis that LIPs had a greater impact on Earth's climate history than previously estimated because of the 'cryptic degassing' of intruded and crust-contaminated magma, injecting extra CO_2 over and above that coming from sub-aerial basalts. We use biogeochemical models to investigate the potential impact of the Columbia River Basalts (CRB) during the mid-Miocene where multiple palaeorecords for this geologically relatively recent event enable rigorous data-model comparison. We find that the effect on the long-term carbon cycle of basalt degassing from the CRB alone is negligible, but that a total CRB emission of 4090-5670 Pg of carbon with 3000-4000 Pg of this carbon emitted during the Grande Ronde Basalt eruptions, a flux within the acceptable estimated range when cryptic degassing is included, does well in reproducing the record of benthic $\delta^{13}C$ and atmospheric CO_2 change during the core of the Miocene Climatic Optimum. However, other processes are required to drive observed warmth before 16.3 Ma and to match observed calcite compensation depth behaviour after ~15.4 Ma. Our findings therefore rule out the possibility that CRB emplacement alone can fully explain the mid-Miocene palaeorecords but they demonstrate the enhanced climate impact possible when substantial cryptic degassing accompanies LIP emplacement.

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IAVCEI (Volcanology, Geochemistry)

VS03b - VS03 LIPs: vents and volatiles

IUGG-0484

Environmental effects of sulfur emitted by large-scale flood basalt eruptions

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Continental flood basalt (CFB) volcanism has been temporally, and therefore causally, linked to periods of environmental crisis in the past 260 Ma. The majority of the proposed causal relationships are, however, qualitative, in particular the potential climatic and environmental effects of large amounts of sulfur dioxide (SO_2) emitted to the atmosphere. CFB provinces are typically formed by numerous individual eruptions, each lasting years to decades, with highly uncertain periods of quiescence lasting hundreds to thousands of years.

I will present results obtained from a global aerosol-climate model set-up to simulate the sulfur-induced climatic and environmental effects of individual decade to century-long CFB eruptions. For sulfur dioxide emissions representative of a single decade-long eruption in the 65 Ma Deccan Trap Volcanic Province, the model predicts a substantial reduction in global surface temperature of 4.5 K, which is in good agreement with multi-proxy palaeo-temperature records. However, the calculated cooling is short-lived and temperatures recover within less than 50 years once volcanic activity ceases. In contrast to previous studies, I show that acid rain from decade-long eruptions cannot cause widespread vegetation stress or loss due to the buffering capacities of soils. The direct exposure of vegetation to acid mists and fogs, however, could cause damage where the exposure is high and sustained, such as at high elevations. Finally, I will use these modeling results to place constraints on the likely environmental effects and habitability by simulating different eruption frequencies and durations as well as hiatus periods and by comparing to the proxy records.

IAVCEI (Volcanology, Geochemistry)

VS03b - VS03 LIPs: vents and volatiles

IUGG-0983

Quantifying sulfur emissions from Large Igneous Provinces: a new method based on clinopyroxene/melt sulfur partition coefficient

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Synchronicity between most Phanerozoic Large Igneous Provinces (LIPs) and major mass extinctions suggests a causal link between these events, due to the environmental impact of massive outpours of volcanic gases such as SO_2 and CO_2. Estimates of gas contents of the basalts are still scarce, but they are crucial to assess LIPs climatic impact. Classically, the amount of sulfur in basaltic melts is assessed through melt inclusions analyses, while here we present a new approach for S quantification, in 3 steps. 1) Determination of clinopyroxene/melt S partition coefficient (K_D) by micro-XRF (Diamond synchrotron, UK) and ion microprobe (WHOI, USA) on experimentally obtained augites and basaltic glasses; 2) Measure of S in natural augite crystals by in-situ micro-XRF; 3) Calculation of the S concentration in the equilibrium melts through the experimentally determined K_D. Applying this method to different LIPs, we recently showed that the amount of S in the basalts correlates positively with the severity of environmental damage, suggesting that outgassed volcanic S (along with other volatiles) potentially affects global climate. Previous measurements were made under the conditions appropriate for LIPs, but to allow applicability to a broader spectrum of igneous compositions we performed further piston cylinder experiments (at 800-1000 MPa and 1000°-1350°C), to constrain K_D variations as a function of the composition, oxidation state and water content of the melt. Using andesite and dacite glass powders doped with pyrrhotite, and a Mid Ocean Ridge Basalt, anhydrous and hydrous (ca. 5 wt.% H_2O) experiments were performed at different oxygen fugacities – low enough that all S was present in the melt as sulfide and high enough that all S in the melt was present as sulfate.

IAVCEI (Volcanology, Geochemistry)

VS03b - VS03 LIPs: vents and volatiles

IUGG-4723

High precision 40Ar/39Ar dating of the deccan traps and implications for volatile release at the cretaceous-paleogene boundary

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Climate-modifying volatiles from LIPs have long been implicated in major ecological crises such as mass extinctions at the Cretaceous-Paleogene boundary (KPB). Critical to this discussion, among other considerations, is the tempo of eruptions. Unfortunately, in no case as yet has a detailed chronology with true age resolution better than ±50 ka been established for any LIP. The $^{40}Ar/^{39}Ar$ method applied to plagioclase is the most straightforward, widely applicable and assumption-free means of dating basaltic LIP lava eruptions, but achieving age precision at the permil level is not routine.

We report here the results of a detailed $^{40}Ar/^{39}Ar$ geochronologic study of the Deccan Traps LIP, based on sampling of multiple stratigraphic sections spanning the 3000+ m thick lava pile exposed in the Western Ghats escarpment. Rigorous attention to sample preparation, neutron fluence monitoring and other technical aspects, combined with numerous replicate analyses, provide the most precise $^{40}Ar/^{39}Ar$ results yet obtained, and arguably the most accurate dating of any kind, for these lavas. Results from the Jawhar through Ambenali formations within the Deccan group indicate that the majority (80-90% by volume) of Deccan volcanism in the Western Ghats spanned less than 600 ka, consistent with eruption during magnetochron 29r.

Results to be presented will clarify the exact stratigraphic level of the KPB, the maximum duration of hiatuses represented by oxidized inter-lava layers (red boles), and the overall tempo of eruptions through the main volcanic episode. Specifically, these results will test the hypothesis that inception of the voluminous Wai Subgroup coincided with the Chicxulub impact event.

IAVCEI (Volcanology, Geochemistry)

VS03b - VS03 LIPs: vents and volatiles

IUGG-5110

The effects of large igneous provinces on the global carbon and sulphur cycles: understanding the sources and the sinks.

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The correlation between Large Igneous Province (LIPs) and extinction events suggests that volcanism can have a detrimental impact on Earth surface conditions. Changes in atmospheric and ocean chemistry, particularly the climate-sensitive carbon and sulphur cycles, are the most probable method of inducing global ecosystem stresses. However, the interactions and feedbacks between volcanism and these cycles are numerous and complex, making analyses and characterising the response to a LIP problematic. Here we summarise the sources and sinks of carbon and sulphur from large volcanic eruptions using information from modern and ancient systems. For the sources, we summarise the current understanding of volcanic emissions, and explore the relative contributions and importance of magma-derived degassing versus secondary degassing from sediments affected by magmatic intrusions and lava. In addition, we will explore the various ways in which LIPs can reduce atmospheric concentrations of these same elements. The relative contributions of each source and sink are in part determined by the mode of LIP emplacement and eruption style, along with the subsequent timescales of such effects. Therefore, we explore a few key examples with recent data to demonstrate how the environmental impact can vary considerably with differing modes of emplacement, LIP duration and eruption styles.

IAVCEI (Volcanology, Geochemistry)

VS03p - VS03 LIPs: vents and volatiles

VS03p-380

The source and impact of geochemical heterogeneities within lava flow-fields on the potential atmospheric sulphur burden of flood basalt eruptions.

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Gas release by flood basalt (FB) eruptions is considered to induce atmospheric perturbations that produce significant environmental and climatic impacts. The earliest erupted lava in both the Deccan and Columbia River FB provinces have been driven to volatile saturation, indicated by the presence of immiscible sulphide, unlike their later counterparts. The volatile saturation of these initial magmas influences the nature of the eruption itself, and consequently its potential atmospheric H_2SO_4 aerosol yield of the eruption. The magnitude, coverage, and impact of the resulting aerosol cloud is dictated by the eruptions' ability to loft the gaseous plumes into the upper levels of atmosphere. Recent studies have indicated that these earliest part of these lava flows display the greatest degree of crustal contamination, which may explain the sulphur saturation of their magmas. These geochemical heterogeneities at such a confined scale within FB provinces have been attributed to temporal changes in melt chemistry during eruption.

Established petrological methods along with novel geochemical proxies are used here to identify and quantify the magma evolution processes responsible for the sulphur saturation. In particular, we use the exceptional sensitivity of the radiogenic ^{187}Re-^{187}Os system, as well as the highly siderophile stable isotopes S, Cu and Zn to detect the presence of radiogenic crustal material. These techniques will identify the compositional signature of the magma sources in question as well as to determine the sulphur species present and extent of degassing.

New data on the Nornahraun eruption N. Iceland and the 1783-4 Laki eruption will be presented, both providing excellent modern analogues for FB eruptions, providing the platform to ground truth these methods.

IAVCEI (Volcanology, Geochemistry)

VS03p - VS03 LIPs: vents and volatiles

VS03p-381

'Apparent' space-time mismatches over the Indian subcontinent since the Mesozoic and phenomenon of lateral channeling

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The Indian lithosphere has undergone significantly large number of high intensity geodynamical events over past 150 Ma e.g. continental breakups and collision, mantle plume induced LIPs, and high plate velocity. This has raised a few ‘apparent’ space-time (or cause & effect) mismatches. For example, (i) development of Rajamahendri traps, and Salma dyke of early Tertiary ages is attributed to the distantly located Reunion mantle plume near the west coast, and (ii) mid-Cretaceous volcanism along the eastern margin of the Madagascar- before its breakup from the central Gondwanaland (or Greater India) along the present western margin of India and is attributed to the Marion plume. But between 100-150 Ma the paleo-position of the Marion plume is supposed to be near the northern part of the eastern margin of India, and close to Antarctica. This study suggests that such ‘apparent’ space-time mismatches could be resolved by invoking channeling of thermo-magmatic fluxes from the mantle plumes. Because when an upwelling plume-head reaches base of the continental lithosphere, then its hot material tends to flow laterally also, through certain facilitating corridors generally the mobile belts (Paleo sutures/rifts) because the lithosphere, under them, is relatively thin, in comparison to that beneath the older/cratonic parts. This fact and composition of mobile belts allow long distance flow (or channeling) of mantle plume material and heat, as has been evidenced elsewhere also. This process seems to resolve the ‘apparent’ space-time mismatches and the phenomenon may be utilized in understanding older formations also.

IAVCEI (Volcanology, Geochemistry)

VS03p - VS03 LIPs: vents and volatiles

VS03p-382

Volcanic stratigraphy and near-vent deposits of the Tarim flood basalts, NW China.

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The early Permian Tarim flood volcanics (NW China) are composed of a bimodal suite of effusive and explosive mafic and silicic eruptive units, plus associated dikes, sills and intrusions of ultramafic to granitic composition, ranging in age from ~358 to 205 Ma. While the bulk of the province (>99 %) underlies the Takelamakan Desert, the main outcrop in Keping exposes ~100 km of laterally continuous mafic lavas and volcaniclastic deposits, with intercalated silicic pyroclastic units. The exposed stratigraphy is defined by mafic lavas that form two distinct packages – the lower Kupukuziman Fm (KP) has 2 basalts, mafic volcaniclastic deposits, and silicic airfall tuffs and ignimbrite. The upper Kaipaizileike Fm (KZ) is laterally variable, with up to 12 mafic lavas separated by 15-30 m thick qtz- and fsp-rich sandstones. Between the KP and KZ Fms is an 800 m thick sequence of siltstone and sandstone informally referred to as the FP Fm. Depositional textures and localized coal beds suggest sediments are deltaic to fluvial. Lavas are ropy to rubbly inflated pahoehoe flows from 3 to 70 m thick, and form localized peperite deposits along basal layers emplaced onto sand. Mafic volcaniclastic deposits are abundant in the KP. They consist of bedded, sorted fine-grained ash in the east, transition to massive, fine-grained, and bomb-bearing (bombs 5-15 cm), and massive accretionary lapilli bearing tuffs with bombs (bombs 20-40 cm) intercalated with thin and fine-grained, finely laminated tephra in the west. Deposit morphology and facies suggest concentrated and dilute pyroclastic density currents and ballistic fallout originated from vent sites near the western-most Tarim outcrops; we postulate this was a vent area for the lower KP Fm. Upper KZ lavas appear to originate distally.

IAVCEI (Volcanology, Geochemistry)

VS03p - VS03 LIPs: vents and volatiles

VS03p-383

The enigma of continental flood basalt (CFB) vents

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Although more CFB provinces are being explored, the number of vent complexes discovered is not growing. Only one complete complex has been described in detail, through the Roza vents of the Miocene Wanapum Basalt Formation of the Columbia River Basalts (CRB). Vents of the main-phase Grande Ronde Basalts are also being recognized; some contain evidence of phreatomagmatic activity, as described from vents in basal parts of the Jurassic Karroo-Ferrar CFB, Antarctica.

The Roza vent complex is narrow (1-2 km), and almost 200 km long. It is a fissure and due to the presence of other CRB dykes, it has been assumed that all CRB vents will also be fissure-like. But is that the case? While the whole fissure is very long, every indication suggests that the vents were focused and thus segmented throughout its whole extent. Some vents are capped by small shields, but deposits around the northern vents provide evidence for vigorous fire fountaining. There is reason, therefore, to believe that some Roza fissure-segments supported high fire fountains and high columns, as interpreted for the only historic analog, Laki 1783. However, it is not known what percentage of erupted Roza magma underwent this vigorous style of degassing.

The Deccan LIP typifies enigmas of CFB vents. Several feeder dyke systems have been recognized, and many kilometers of lava logged in the Western Ghats, but no evidence for vents or near-vent deposits have been found. Despite this increased knowledge of the lava stratigraphy, the style of venting remains elusive.

IAVCEI (Volcanology, Geochemistry)

VS04a - VS04 Collapse Calderas

IUGG-1543

Graben calderas: Examples from Mexico, Central America, and the Andes.

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A graben caldera is a volcano-tectonic depression formed during collapse of intra-graben blocks affecting a shallow magma chamber that was emplaced beneath the graben, producing massive eruptions of pyroclastic density currents generally forming large-volume ignimbrites. Pull-apart grabens are included in this caldera type in transtensional settings. The standard sequence observed in graben calderas include, from oldest to youngest, alluvial fan deposits and/or lacustrine deposits, pyroclastic surge deposits and/or minor volume ignimbrites, a large-volume ignimbrite that could be massive or made of successive layers, and sometimes post-collapse silicic lava domes aligned with the graben trend. Fallout deposits, plinian or non-plinian, are not observed in the sequence. Thus, onset of caldera collapse represented by the major ignimbrite must occur just after deposition of continental sediments within the graben domain; the sediments indicating a pre-existing tectonic subsidence stage. A similar volcano-tectonic development is observed in pull-apart grabens. Therefore, extensional or transtensional tectonics, before and during caldera collapse, and the emplacement of a sub-graben shallow silicic magma chamber are the necessary conditions for the development of graben calderas. The Sierra Madre Occidental (SMO) volcanic province of Mexico includes several graben calderas associated to voluminous silicic ignimbrites. The voluminous ignimbrites of the SMO were erupted from fissures associated to grabens or half-grabens of Basin and Range tectonics (Geology 2003, 31, 773-776; Caldera Volcanism 2008, Elsevier book). Examples are found in SMO, Catalan Pyrenees, Central America and the Andes. Supported by PAPIIT IN-104615, CONACYT CB-240447.

IAVCEI (Volcanology, Geochemistry)

VS04a - VS04 Collapse Calderas

IUGG-1677

Vent opening process of the Osumi pumice fall as the precursor for caldera collapse of Aira Caldera, Japan

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Decompression of magma chamber during precursory eruption is a key to understand the mechanism of caldera collapse with large silicic ignimbrite, as the rapid decompression of magma chamber by withdrawal of magma during the precursory eruption controls the timing of the collapse and eruption of catastrophic ignimbrite. The eruption of Ito ignimbrite deposit more than 300 cubic km from the Aira caldera around 29 ka followed a precursory Plinian eruption which produced Osumi pumice fall deposit with ~40 cubic km in magmatic volume. The Osumi pumice fall shows upward-increasing of grain size, suggesting the increase of the eruption rate throughout the eruption. Osumi pumice deposit contains ~5 volume percent of xenolith grains, which consists both of the volcanic rock from the surface and the Tertiary sedimentary rocks, low grade metamorphic rock and granitic rock from the basement. Presence of these xenoliths from the basement throughout the deposit indicates the enlargement of the conduit during the precursory eruption. The vertical change of the components of xenolith grains may indicates the horizontal propagation of the conduit wall. Enlargement of the conduit increases the eruption rate throughout the precursory eruption to withdraw enough volume of magma to induce the caldera collapse. Contrary, smaller Plinian eruptions from Aira caldera provide no clear evidence for the enlargement of conduit. Efficient enlargement of the conduit during the precursory eruption can be a key process to trigger the caldera collapse and eruption of catastrophic ignimbrite.

IAVCEI (Volcanology, Geochemistry)

VS04a - VS04 Collapse Calderas

IUGG-3032

Flow mechanism and discharge rate of the parent Peach Spring Tuff pyroclastic density currents during the Silver Creek caldera eruption

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The ~18.8 Ma Silver Creek caldera eruption generated a dense rock equivalent volume of ~1200 km^3 of pyroclastic material, about half of which was trapped in the subsiding caldera while the other half was dispersed by pyroclastic density currents that formed the Peach Spring Tuff. The most distal deposit is 240 km west of the caldera (~175 km when post-tuff faulting is accounted for). We report field data that show the currents entrained blocks of size up to ~70-90 cm from the substrates along the flow paths. The blocks were at reconstructed distances of ~30-160 km to the west and east of the caldera and were dense volcanic, plutonic, and metamorphic rocks present on alluvial fans and highlands at the time of eruption. Detailed field mapping showed transport distance of the blocks by the currents was tens to a several hundreds of meters. Complementary laboratory experiments showed how large particles can be captured from a granular substrate by dense gas-particle flows and then deposited downstream. They revealed the critical flow velocity required to entrain particles of a given size and density. Application to the Peach Spring Tuff suggested that the basal part of the parent pyroclastic density currents had high particle concentration and that entrainment of the largest substrate blocks required a relatively uniform and modest speed of ~5-20 m/s, which corresponded to a discharge rate of ~10^7-10^8 m^3/s for a minimum of 2-8 hours. These results suggest that sustained high eruption discharge rate and long-lived high pore pressure in dense granular dispersion, rather than large initial velocity and/or turbulent transport with dilute suspension as proposed by earlier works, can explain extremely long runout distances of pyroclastic density currents during caldera eruption.

IAVCEI (Volcanology, Geochemistry)

VS04a - VS04 Collapse Calderas

IUGG-4557

"Collapse calderas and their geothermal potential"

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It is not uncommon to observe that collapse calderas host productive geothermal fields or have been associated to important post-caldera hydrothermal anomalies. What makes collapse calderas suitable sites for hosting geothermal reservoirs is related to the characteristic internal structure of such volcanic depressions and to presence of a long lived thermal anomaly, which in many cases is related to post-caldera volcanism rather than to the effect of the pre-caldera magma system. In this presentation I will show a conceptual model on the development of geothermal reservoirs inside collapse calderas based on different case studies.

IAVCEI (Volcanology, Geochemistry)

VS04a - VS04 Collapse Calderas

IUGG-5067

A sill intrusion model applied to volcanic calderas

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Volcanic calderas often show long-term unrest with remarkable ground deformation, seismicity, and geochemical changes, that do not culminate in an eruption, whereas sometimes an unrest accompanied by minor geophysical changes is followed, in few months, by an eruption. Typical examples are Rabaul Caldera in 1994 and Sierra Negra in 2005. A process of sill intrusion can explain these common features which has also been supported by many observations carried out on different calderas. Here, we present a dynamic model of sill intrusion in order to explain the episodes of uplift and subsidence observed in volcanic calderas. In our model, the sill, fed by a deeper magma reservoir, intrudes below a horizontal elastic plate, representing the overlying rocks, and expands with axisymmetric geometry. The model is based on the numerical solution of the equation for the elastic plate, coupled with a Navier-Stokes equation for simulating the dynamics of the sill intrusion. We performed a number of simulations, with the objective of showing the main features of the model. The Experiments have indicated that, when the feeding process stops, the vertical movement reverses its trend and the area of maximum uplift undergoes subsidence. Under certain conditions the subsidence can occur even during the intrusion of the sill. The stress field produced by the intrusion is mainly concentrated in a circular zone that follows the sill intrusion front. Results are consistent with the characteristics of calderas, described above.

IAVCEI (Volcanology, Geochemistry)

VS04b - VS04 Collapse Calderas

IUGG-1571

Metallogeny of the *tiavnica Stratovolcano, central Slovakia

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The Štiavnica Stratovolcano is the largest one in the Tertiary volcanic arc of Carpathians and Pannonian basin. It hosts the famous Štiavnica-Hodruša ore district. The stratovolcano evolved in 5 stages (Chernyshev et al., 2013) involving several mineralization types: (1) Growth of the extensive andesite stratovolcano including emplacement of diorite porphyry stocks (15.0 – 13.5 Ma) hosting Au porphyry mineralization occurrences. (2) Denudation of the stratovolcano and contemporaneous emplacement of subvolcanic intrusive complexes in basement rocks (13.5 – 12.9 Ma); the oldest diorite intrusion is parental intrusion of a barren high sulfidation system; granodiorite pluton is parental body for magnetite skarn mineralization and intrusion-related stockwork/disseminated base metal mineralization; granodiorite to quartz-diorite porphyry stocks and dyke clusters host sub-economic porphyry/skarn Cu-Au ± Mo mineralization. (3) Subsidence of the caldera and its filling by differentiated andesites (13.1 – 12.7 Ma); the early caldera subsidence was accompanied by Au-Ag epithermal mineralization of intermediate sulphidation type on subhorizontal veins at the base of pre-caldera andesite complex; caldera filling hosts several contemporaneous barren hot-spring systems and one barren high sulfidation system. (4) Renewed activity of less differentiated andesites (12.7 – 12.2 Ma); no related mineralization. (5) Uplift of the resurgent horst in the central part of the caldera accompanied by rhyolite volcanic/intrusive activity (12.2 – 11.4 Ma); faults of the horst host an extensive system of contemporaneous Ag-Au ± Pb-Zn-Cu intermediate to low sulphidation epithermal veins; their activity continued till 10.7 Ma. The research was supported by grants APVV-0537-10 and VEGA-560-15.

IAVCEI (Volcanology, Geochemistry)

VS04b - VS04 Collapse Calderas

IUGG-1813

Caldera collapse control on eruptive fissure distribution: a model applied to Fernandina (Galapagos)

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Calderas are topographical depressions resulting from the yielding of magma chambers roof after large eruptions or intrusive events. On the outer slope, most calderas display radial fissures and, in limited cases, also circumferential fissures. Despite many hypotheses, the conditions controlling the formation of radial and/or circumferential fissures, and thus the shallow magma transfer within the volcano slopes, are still poorly understood. Here we demonstrate with numerical and analog models that the mass redistribution associated with caldera formation promotes shallow sill-shaped magma chambers and controls the orientation of eruptive fissures. We find that depending on the initial injection depth, dikes will bend or twist about an axis parallel to propagation resulting in circumferential and radial eruptive fissures, respectively. This mechanism is governed by the competition between gravitational unloading pressure and dike overpressure. We apply our results to Fernandina (Galápagos, Ecuador), the best case of caldera with radial and circumferential fissures, showing that the predicted stress field caused by the caldera unloading is consistent with the pattern of eruptive fissures and the dynamics of magma propagation.

IAVCEI (Volcanology, Geochemistry)

VS04b - VS04 Collapse Calderas

IUGG-4642

The eruption, pyroclastic flow behaviour, and caldera infilling processes of the large volume (>1000 km3), Permian Ora (Ignimbrite) Formation (Italy)

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The Permian Ora Fm. (Italy) relates to the Ora caldera 'super-eruption' (> 1000 km3). The stratigraphic architecture of the exceptionally well preserved intra-caldera succession provides evidence for caldera collapse at the onset of the eruption, fissure eruption style, and incremental caldera in-filling by numerous pyroclastic flow pulses. The ignimbrites of the Ora Fm. are crystal-rich (25 – 55%), and ubiquitously welded. The Ora Fm. has been divided into four members (a – d), which define the principal eruption phases: (a) early caldera collapse and vent opening, producing locally distributed, basal co-ignimbrite lithic breccia; (b) vent clearing, which produced the eutaxitic, lithic-rich ignimbrite and minor thin ground and ash-cloud surge deposits; (c) waxing and steady eruption, which produced the dominant eutaxitic, coarse-crystal-rich ignimbrite, with local lithic-rich and fine-crystal-rich ignimbrite and minor surge deposits; (d) waning eruption, recorded by eutaxitic, fine crystal-rich ignimbrite, with local lithic-rich deposits. The incremental filling and late-stage outpouring of pyroclastic material from the caldera is recorded by vertical and lateral lithofacies deposit variation. These findings reveal a structure to the "monotonous", > 1300 m thick, intra-caldera fill and thinner (< 230 m) outflow successions. The absence of a Plinian fallout deposit suggests a lack of a precursor high, buoyant, eruption column. This eruption initiated immediately by a low collapsing column phase, producing the main ignimbrite succession. Simultaneously, catastrophic volcano-tectonic caldera collapse and decompression of the magma chamber occurred. The Ora pyroclastic flow system is suggested as a hot, poorly expanded, high particle concentration, granular density current

IAVCEI (Volcanology, Geochemistry)

VS04b - VS04 Collapse Calderas

IUGG-5089

Another look at the Chalupas Caldera, Ecuador—Identification of structural controls over time

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The Chalupas Caldera is the second largest in the NVZ and its single-event ignimbrite-forming eruption at 200ky produced a bulk volume of ~ 100 km^3. Upon evacuation of the rhyolitic magma, the caldera collapsed along the ring fracture margin of pre-existing andesitic lavas. Subsidence of the 12 km diameter caldera was piston-like with an N-S elongation. Most eruptive products flowed far afield and subsequent resurgences resulted in an andesitic stratocone, domes and lavas emitting from different vents at distinct periods.

Regional stresses in central Ecuador are NE along transpressive faults. The caldera is located in the Quito-Latacunga Microblock, whose southern boundary is the Pisayambo-Cosanga transpressive fault system. In this microblock low internal deformation and seismicity is recognized. The caldera´s eastern boundary is Paleozoic-age accreted felsic metamorphic basement rocks. The western boundary is the 18 km-diameter bimodal Cotopaxi volcano. The southern boundary is comprised of the Pisayambo-Llanganati highlands of Miocene-age lavas. Crustal thickness beneath the caldera is 30-70 km.

Employing a high-resolution 4 meter DEM we created profiles that suggest where tectonic structures around the caldera played a role in its morphology, the collapse, and post-caldera evolution. Additionally, what is the significance of the young rhyolitic centers propagating to the north of Chalupas and that erupt more evolved magmas than those of the Caldera? Do they take advantage of a less restrictive tectonic regime? Lastly, 5000 yrs. ago Chalupas-signature magmas erupted from Cotopaxi´s vent. How did this magma transfer come about, and what were the structural paths taken?

IAVCEI (Volcanology, Geochemistry)

VS04b - VS04 Collapse Calderas

IUGG-5128

Slow collapse of the ice-filled Bárdarbunga caldera, Iceland

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The ongoing slow collapse of the Bárdarbunga caldera in Iceland is the first such event to be monitored in detail. The Bárdarbunga central volcano is dominated by the 65 km^2 caldera that is fully ice covered, located in the north-western part of the Vatnajökull ice cap. The subglacial topographic rims of the caldera have a relief of 500-600 relative to the bedrock floor where the ice thickness is about 800 m. The ongoing unrest in Bádarbunga, associated with the largest effusive eruption in Iceland in over 200 years, has been monitored through regional seismic and GPS networks and InSAR. For the size and extent of the subsidence, airborne radar profiling has been applied as well as satellite mapping. The observed subsidence area exceeds 80 km^2. In the centre the total subsidence was over 60 m in early February. The subsidence bowl mostly coincides with pre-existing caldera but extends beyond it, with about 10 m subsidence observed at the topographic rims. The slow collapse began in late August. The initial rate of subsidence was 0.5-1 m/day but had declined to about 0.1 m/day in February. Geothermal activity has increased considerably in Bárdarbunga since the start of the slow collapse, with formation of ice cauldrons above the spots of geothermal activity. These ice cauldrons have increased in depth by up to 50 m since late September. No signs of water accumulation under the ice within the caldera had been detected by February. Ice flow modelling indicates that in the first months of activity, ice movements other than vertical subsidence played a minor role in modifying the observed subsidence bowl. The slow collapse has been accompanied by a major earthquake swarm, with over 85 earthquakes in the range M5-M5.7, and over 15,000 detected earthquakes.

IAVCEI (Volcanology, Geochemistry)

VS04b - VS04 Collapse Calderas

IUGG-5344

Geophysical modeling of Los Humeros collapse Caldera, Mexico

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Los Humeros caldera is situated at the eastern part of Mexican Volcanic Belt. There are the outer Humeros caldera, formed about 0.5 Ma, and the inner Los Potreros caldera at 0.14 Ma. Los Humeros geothermal field lies inside a Quaternary caldera. The geothermal fluids are contained in andesite overlying a complex basement composed of metamorphic, sedimentary and intrusive rocks. The heat source is the magma chamber that produced two collapses.

Complex geophysical study including 750 gravity points, 25 MT soundings, 25 stations of gamma ray and Radon concentration was carried out in this area. The Digital Elevation Model has been constructed. Aeromagnetic data were provided by Mexican Geological Service.

Complex analysis of geological and geophysical data confirms two main events and several intra-caldera eruptions. Bouguer gravity shows strong negative isometric anomaly with amplitude 15-20 mGals inside caldera; this minimum is coincident with an anomalous conductivity. The near-surface conductor is identified as cap rock confining the geothermal reservoir. The high resistivity part of MT section is interpreted as local basement which may be associated with magmatic chamber. The gravity gradient zones mark the principle faults proposed using morpho-structural analysis. Amplitude of magnetic anomalies reaches 250-300 nT and their distribution is irregular. There are two kinds of faults: deep and relatively near-surface. The deep originated faults are associated with high concentration of Radon up to 3600 Bq/m3. Gravity-magnetic 2.5D modeling supports the existence of several intrusive bodies.

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IAVCEI (Volcanology, Geochemistry)

VS04c - VS04 Collapse Calderas

IUGG-2126

Shallow-depth sill intrusion and time history of the ground displacement pattern: the Campi Flegrei caldera (Italy) case.

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The Campi Flegrei (CF) caldera is located in a densely populated area close to Naples.
It has been recently shown that the 1980-2013 CF ground deformation field can be decomposed into two stationary parts. Large-scale deformation can be explained by a quasi-horizontal source, ~4 km deep, possibly related to the injection of magma and/or magmatic fluids from a deeper magma chamber into a sill, or pressurization of interconnected (micro)cavities. Residual deformation not accounted for by the large-scale-deformation source is confined to the Solfatara fumarolic area and can be ascribed to the poroelastic response of the substratum to pore pressure increases near the injection point of hot magmatic fluids into the hydrothermal system. The geometric parameters of each source are constant over the period 1980-2013 with the exception of volume changes (potencies).
Several papers have ascribed CF deformation to the injection of magmatic fluids at the base of the hydrothermal system. All models predict complex spatial and temporal evolution of the deformation pattern and consequently contrast with observations. Also recently proposed dynamic models of sill intrusion in a shallow volcanic environment do not satisfy the observed stationariness of the CF deformation pattern.
We have developed a numerical dynamic model of intrusion of magma or injection of supercritical fluids in shallow-depth sills, taking account of the sill arrest by ring faults. Fluid propagation is governed by a Navier-Stokes equation for magma intrusion and modelled as creeping flow in porous media (Darcy law) for supercritical fluids injection. In both cases the predicted ground deformation pattern is constant over time, when using numerical values of model parameters which are consistent with findings for CF.

IAVCEI (Volcanology, Geochemistry)

VS04c - VS04 Collapse Calderas

IUGG-2829

The new on-line version of the collapse caldera database (CCDB)

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In 2008 we presented a new general worldwide Collapse Caldera DataBase (CCDB), in order to provide a useful and accessible tool for studying and understanding caldera collapse processes. The main aim of the CCDB is to update the current field based knowledge on calderas, merging together the existing databases and complementing them with new examples found in the bibliography, and leaving it open for the incorporation of new data from future studies. Presently, the database includes over 450 documented calderas worldwide, trying to be representative enough to promote further studies and analyses. We have performed a broad compilation of published field studies of collapse calderas including more than 500 references, and their information has been summarized in a database linked to a Geographical Information System (GIS) application. Thus, it is possible to visualize the selected calderas on a world map and to filter them according to different features recorded in the database (e.g. age, structure). The information recorded in the CCDB can be grouped in seven main information classes: caldera features, properties of the caldera-forming deposits, magmatic system, geodynamic setting, pre-caldera volcanism, caldera-forming eruption sequence and post-caldera activity. During the last seven years, the database has been available on-line at http://www.gvb-csic.es/CCDB.htm previous registration. This year, the CCDB webpage has been updated and improved so the database content can be queried on-line. This research was partially funded by the research fellowship RYC-2012-11024.

IAVCEI (Volcanology, Geochemistry)

VS04c - VS04 Collapse Calderas

IUGG-3213

Campi Flegrei caldera (Italy) unrests: new evidence, monitoring and interpretation issues

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Campi Flegrei caldera, in the Neaples area, has experienced, in the last 2000 years, large up and down ground movements. Unrest episodes involving huge uplift (up to 3.5 m in 15 years) occurred since 1969 to 1984. Following the large unrest culminated in 1984 (uplift rates up to 1m/year), about 20 years of general subsidence started, with some small uplift episodes superimposed (4-11 cm of maximum elevation). Such subsidence period ended at about 2004, when a general trend of slow uplift started. Since 2011, maximum ground uplift measured at Pozzuoli Bay has been 21 cm. The new slow uplift phase has characters different from the 1969-1972 and 1982-1984 large unrests, because uplift rates are much lower (about two orders of magnitude) and seismicity is much weaker. However, geochemical signatures of the on-going unrest are more marked than in previous periods, because a linearly increasing trend of huge deep fluid injection into shallow aquifers is evident from ground emissions. These contrasting characters of the new unrest phase, when compared with the large unrests experienced 30-45 years ago, call for detailed interpretations of these episodes to discriminate magmatic from deep geothermal effects. This work provides a first attempt to discriminate between magma accumulation effects and deep geothermal fluids injection. Such interpretation, based on thermal-fluid-dynamical modelling, relies on accurate in-situ estimation of permeability at depth operated in the framework of the Campi Flegrei Deep Drilling Project, endorsed by ICDP.
2 OV-Group: C. Troise, S. Carlino, R. Somma, A. Troiano, M. G. Di Giuseppe, L. D'auria, G. Scarpato, I. Aquino, G. Berrino, S. Borgstrom, M. Dolce, C. Del Gaudio, F. Obrizzo, M. Orazi, C. Ricco, V. Siniscalchi

IAVCEI (Volcanology, Geochemistry)

VS04c - VS04 Collapse Calderas

IUGG-4435

Intrusion of a magmatic sill beneath Campi Flegrei caldera (Southern Italy) 2012-2013

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Campi Flegrei caldera (Southern Italy) is among the areas with the highest volcanic risk in the world, hosting more than 1 million inhabitants within the caldera borders and their surroundings. In recent years the caldera is experiencing an accelerating uplift rate of the ground deformation. In particular, during the April 2012 - January 2013 time interval the caldera has shown a rapid uplift of about 6 cm with a peak rate of about 3 cm/month in December 2012. This event led the Italian Civil Protection to raise the alert level of the volcano from background to attention. We inverted a ground deformation dataset consisting of both DInSAR (COSMO-SkyMed) and GPS time series using a geodetic imaging technique. Result showed that the ground deformation is compatible with the emplacement of a sill at a depth of about 3 km beneath the caldera centre. Using a numerical model of sill intrusion we have determined the magma viscosity and injection rate. The viscosity is compatible with that of a trachyte and the injection rate shows three distinct episodes with a peak of about 0.2 m^3/s. The total amount of injected magma is about 0.01 km^3, which is of the same order of magnitude of small size (VEI=2-3) eruptions occurred at Campi Flegrei in the last 15ky. Using a FE modelling we also found a causal relationship between the sill emplacement and the occurrence of a seismic swarm on Sep. 2012. This work has been supported by the Italian Department of Civil Protection and by the Italian Space Agency under theSAR4Volcanoes project (agreement n. I/034/11/0) and by MED-SUV project (European Union’s Seventh Programme, grant agreement No 308665).

IAVCEI (Volcanology, Geochemistry)

VS04c - VS04 Collapse Calderas

IUGG-4537

Viscoelastic relaxation effects on ground deformation at calderas, with reference to Campi Flegrei, Italy.

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Continuous ground deformation monitoring (e. g. using continuous GPS) at calderas allows studying the possible evolution of the deformation pattern over time, which in turn may reflect changes in the deformation causative source or be caused by visco-elastic rheologies.
Actually, the rocks close to a magmatic reservoir as well as the deeper part of a caldera are unlikely to behave in an elastic manner, because of their high temperatures and numerous micro-fractures. Viscoelastic relaxation effects have been studied analitically in the past for a point pressure source and a center of dilatation (Mogi sources) embedded in a homogeneous viscoelastic half-space or surrounded by a viscoelastic shell.
Using the Finite Element Method, we model ground deformation from finite ellipsoidal cavities (magma chambers) surrounded by a viscoelastic shell and small ellipsoidal cavities embedded in a viscoelastic region. In both cases, we consider a constant pressure boundary condition (pressurized cavity) and a fixed displacement at the wall of the cavity.
We show that the time evolution of the ground displacement pattern is strongly case-dependent and ranges from being stationary to very complex. As an example, we show what related to the Campi Flegrei caldera, Italy, where the observed ground displacement pattern is stationary, at least on time scales from days to decades.

IAVCEI (Volcanology, Geochemistry)

VS04p - VS04 Collapse Calderas

VS04p-094

Karymshina as the first supervolcano in Kamchatka: boundaries, structure, volcanic stages, volume of pyroclastics

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Data on a caldera discovered in 2006 are provided. The caldera formed in southern Kamchatka during Eopleistocene time (1.2 to 1.8 Ma). The caldera boundaries have been reconstructed and its dimensions are determined (approximately 15×25 km). An uplifted block has been identifed in the northwestern part of the caldera, the block is considered to be the result of viscous rhyolite magmas intrusion (SiO_2 – 70.6-77.6%) at a further time (about 0.5-0.8 Ma), that is, as a resurgent uplift. The structural controls of present-day hydrothermal systems and mineral occurrences situated in the area of study are examined to demonstrate their relations to the caldera and the resurgent uplift. We have reconstructed the boundaries of a large lacustrine basin that formed in the caldera after the resurgent uplift appearance and also the boundaries of thick pyroclastic flow out of the caldera. Three complexes are distinguished according to consecutive stages of the caldera development: precalderian, calderian and postcalderian. It is shown that the caldera-forming eruption was a major one in Kamchatka in regard to its volume of ejected material (approximately 825 km^3 or $2x10^{15}$ kg by its mass), and ranks as a major eruption worldwide. This work was carried out within the projects of the Far East Division, Russian Academy of Sciences: 15-I-2-031, and was supported by the Russian Foundation for Basic Research, project no. 14-05-31319 mol_a.

IAVCEI (Volcanology, Geochemistry)

VS04p - VS04 Collapse Calderas

VS04p-095

Detailed morphology and structure of a caldera lake: Lake Towada (Towada Caldera), NE Japan Arc

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We are surveyed underwater by broadband multibeam echo sounder (SONIC 2024) and sub-bottom profiler (SES-2000) in order to define the geologic history of Lake Towada. The bathymetry and sub-bottom profiles reveal the character of landforms and lead to a chronology for the volcanism within the post-caldera after ca. 15 ka. Lake Towada, has been formed in the Towada Caldera, is a lake of 8.7×8 km diameter, 61 km^2 area, 400 m altitude, and 326.8 m maximum water depth. In the center of the Towada Caldera, the central cone of Goshikiiwa Volcano (basalt to andesite) was formed in 15.5-11.7 cal ka BP. The inner caldera (Nakanoumi, diameter 2.5×3 km), is formed in the center of Goshikiiwa volcano, is a deep (water depth ~325 m) than the surrounding lake water depth (water depth ~70-80 m). The caldera wall of Nakanoumi caldera forms a steep slope and the wall height is 500 m (relative height). However, part of the caldera wall, water depth 0-200 m is gently sloping. Such topographical features suggest that the Nakanoumi caldera formation occurred in two stages. From the results of the new sub-bottom profiles, gush of cold or hot water from the local part of the bottom of Nakanoumi Caldera is suggested. After the formation of the Goshikiiwa volcano, three lava domes has been formed in the caldera floor. Then, at the lake bottom of Lake Towada, the erosion valleys to reaching the Nakanoumi has been formed. Based on topographical features and new sub-bottom profiles, is suggesting that the formation of the valleys was formed by closely related to the formation of Nakanomumi caldera.

IAVCEI (Volcanology, Geochemistry)

VS04p - VS04 Collapse Calderas

VS04p-096

Geothermal activity associated with unrest at subglacial calderas in Iceland, explored with numerical reservoir simulations

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Thermal signals from sub-surface magmatic sources are difficult to quantify, as the measurement of fluxes from the ground to the atmosphere is subject to large uncertainties. Ice cauldrons are shallow depressions which form on the glacier surface due to basal melting, as a manifestation of heat flux from below, and are observed at several of Iceland's volcanically and geothermally active subglacial calderas, e.g. Bárdarbunga, Grímsvötn and Katla. The melting ice acts as a calorimeter, allowing estimations of heat flux magnitude to be made. Monitoring ice cauldrons provides a unique opportunity to quantify surface heat flux to a much improved accuracy.

Accompanying the ongoing caldera subsidence at Bárdarbunga volcano, several ice cauldrons have developed around the caldera wall. These cauldrons currently range in volume from approximately 0.002 km^3 to 0.01 km^3, and have formed over the last six months. We present time series data of the development and evolution of these cauldrons, with estimates of the heat flux magnitudes involved. These data are compared with thermal data from Grímsvötn, one of the most geothermally active calderas in the world. Geothermal activity at Grímsvötn has been observed to create ice cauldrons of 0.03 km^3 in one year, which corresponds to a thermal anomaly of ~200 W m^{-2}.

We investigate the influence of increased permeability and shallow magmatic intrusions on established geothermal systems, using analytical and finite element modelling, looking at the timescales of variations in the surface heat flux, and the spatial extent of associated surface anomalies.

IAVCEI (Volcanology, Geochemistry)

VS06a - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-0960

Constraining the role of topography, slope and confined-vs-unconfined flow on pyroclastic density current transport and depositional processes: Mt. St. Helens

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Our ability to interpret the deposits of pyroclastic density currents (PDCs) is critical for understanding the transport and depositional processes that control PDC dynamics. These interpretations provide hypotheses that can be tested experimentally, and relationships that can be used to partially-validate numerical models. PDC deposits from the May 18, 1980 eruption of Mt St Helens (USA) are found along the steep flanks (10°-30°) and across the pumice plain (~5°) up to 8 km north of the volcano. The pumice plain deposits are primarily thick (3-12 m), massive and poorly-sorted, and represent deposition from a series of concentrated PDCs. In contrast, the steep flank deposits are stratified to cross-stratified, suggesting deposition from dilute PDCs. We (1) compare the flank and pumice plain deposits to constrain overall evolution of the PDCs with regards to density stratification, transport and depositional mechanisms, and the influence of topography, and (2) use flank bedform characteristics to investigate the influence of slope on transport and depositional mechanisms within dilute PDCs. We find that the flank deposits are not typical veneer deposits; instead, confinement of the concentrated currents by topography along the steep flank resulted in high basal shear stress and traction transport in a series of rapidly aggrading, unsteady currents. We also find that bedform amplitude, wavelength and the presence of regressive bedforms increase with increasing slope, suggesting bedform morphology is a function of flow velocity. These are important findings to test experimentally since the controls on bedform morphology in density stratified flows remain poorly constrained.

IAVCEI (Volcanology, Geochemistry)

VS06a - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-3266

Inside Pyroclastic Flows – Large-scale simulations of Pyroclastic Density Currents at PELE volcano, New Zealand.

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PELE (Pyroclastic-flow Eruption Large-scale Experiment) is a large-scale facility for experimental studies of pyroclastic density currents (PDCs) in New Zealand. It can generate hot, high-energy flows of natural volcanic material and air that achieve velocities of 7–30 ms^{-1}, flow thicknesses of 2–4.5 m, and runouts of >35 m. The experimental PDCs are synthesized by a controlled 'eruption column collapse' of ash-lapilli suspensions onto an instrumented channel.

We will present high-speed movies and sensor data of PELE PDC simulations generating short, pulsed and sustained currents over periods of several tens of seconds; dilute surge-like PDCs through to highly concentrated pyroclastic flow-like currents. The dilute variants develop a basal <0.05 m-thick regime of saltating/rolling particles and shifting sands waves, capped by a 2.5-4.5 m-thick, turbulent suspension that grades upwards to lower particle concentrations. High-speed video allows capturing the detailed deposition processes leading to stratified dunes, wavy and planar laminated beds and thin ash cloud fall layers. Concentrated currents segregate into a dense basal underflow of <0.6 m thickness that remains aerated. This is capped by an upper ash cloud surge (1.5-3 m-thick) with 10^0 to 10^{-4} vol% particles. Their deposits include stratified, massive, normally and reversely graded beds, lobate fronts and laterally extensive veneer facies beyond channel margins.

We conclude with a dimensional analysis demonstrating that PELE's flows scale well to natural PDCs and we discuss the opportunities to use large-scale PDC simulations to validate and potentially improve current numerical PDC hazard models.

IAVCEI (Volcanology, Geochemistry)

VS06a - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-3467

A validation framework for pyroclastic density current models

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In recent years, also thanks to the increase of available computer power and the improvement of the numerical codes at disposal of the scientific community, computational models of pyroclastic density currents have become more and more popular. In some cases, numerical predictions have supported decision making during volcanic crises.
However, model predictive capability is currently limited by: 1) incomplete knowledge of the physical processes taking place during eruptions; 2) insufficient numerical model resolution and difficulty of estimating the related numerical error; 3) large epistemic uncertainty associated to initial and boundary conditions. Because of the high impact that simulations can have in hazard assessment studies, models credibility and adequacy need to be assessed by establishing a consensual validation procedure.

By restricting the focus on the use of models for pyroclastic density currents hazard assessment, we here describe a hierarchical procedure analogous to that proposed by Oberkampf and Trucano (2002) [Progr. Aerosp. Sci., 38] for Computational Fluid Dynamics models. In this framework, comparison with experimental benchmark cases and with field observations constitute necessary validation tiers. With this contribution we hope to open a broad, multidisciplinary discussion with goals to:
- consensually evaluate the accuracy of numerical models in representing PDC-related phenomena;
- drive future research (e.g., validation experiments, field measurements, uncertainty analysis);
- provide an interpretation framework for model-derived hazard maps;
- increase awareness of the community about the potential and limits of numerical tools and the actual complementarity of experimental (both laboratory and field based) and numerical studies.

IAVCEI (Volcanology, Geochemistry)

VS06a - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-3779

Dilute experiments for benchmarking pyroclastic density current models

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Experiments provide a means of validating numerical models of pyroclastic density currents (PDCs). There are, however, limitations to experimental parameter space and to the types of observations that can be made. Our experiments are generated by feeding heated talc powder into a large, effectively unconfined tank at controlled rates. We scale experiments such that the Froude, densimetric and thermal Richardson, particle Stokes and Settling numbers, and thermal to kinetic energy densities are similar to those of dilute PDCs. The experiments have lower Reynolds numbers than natural currents, but are fully turbulent, thus the large scale structures should be dynamically similar; note that only if experiments are comparable in thickness and speed to natural systems can they have comparable Reynolds scaling. Laser sheets illuminate current interiors and feature-tracking-velocimetry characterizes 2D velocity planes and 3D current structures. High-frequency thermocouples measure temperature throughout the tank and provide independent means of describing entrainment and current structures. Deposits can be mapped after each experiment, but deposit mass/area on the order of 0.5 mg/cm^2 precludes bedform analysis. Experiments can be fed for durations >600s, allowing study of impulsive, steady, and unsteady currents. Currents show turbulence stratification. As the experiments are conducted in air, they entrain and heat ambient air, reverse buoyancy, and lift off at scaled distances similar to those at which natural currents form plumes; unconfined experiments show that entrainment through lateral current margins dominates when liftoff begins. Topographic barriers (hills, ridges, or valleys) generally enhance entrainment and promote liftoff in unconfined currents.

IAVCEI (Volcanology, Geochemistry)

VS06a - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-3903

Modeling the dynamics and sedimentation of dilute pyroclastic density currents on Earth and Mars

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Dilute pyroclastic density currents (surges) are destructive flows generated by volcanic eruptions. Such flows are often unsteady, density-stratified, turbulent, and produce a range of deposit characteristics, but controls on their dynamics, sediment transport and deposition remain poorly understood. Here we discuss two models aimed at improved understanding of dynamics and sedimentation. Model 1 comprises simulation of axi-symmetric flow and sedimentation from a steady-state, vertically uniform density current. Equations for conservation of mass, momentum, and energy are solved, and effects of atmospheric entrainment, particle sedimentation, basal friction, temperature changes, and variations in current thickness and density are explored. Model 2 is fully 3D and accounts for unsteadiness. Runs were conducted for both Mars and Earth conditions and accounted for predicted finer grain sizes and greater collapse heights on Mars. Model 1 predicts realistic runout distances and bedform wavelengths for several well-documented field cases, although results are heavily dependent on source conditions, grain-size characteristics, and entrainment and friction parameters. For instance, increasing particle settling velocity decreases both runout distance and bedform wavelength. Model 2 shows that Earth surges initially outpace equivalent Mars surges due to faster propagation velocities associated with higher gravitational acceleration, although the Mars cases ultimately outdistance equivalent Earth cases. Model 2 also predicts more inflated flows on Mars at early times, again due to lower gravity and atmospheric pressure. Reduced co-ignimbrite plume development on Mars is predicted by Model 2 due to the difficulty in generating buoyancy in a low-density Martian atmosphere.

IAVCEI (Volcanology, Geochemistry)

VS06a - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-4757

Investigating stratified turbulence and non-equilibrium dynamics of pyroclastic density current by a new fast-Eulerian model

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A new fast Eulerian model of pyroclastic density currents (PDC) was developed to carry out Large Eddy Simulations of a polydisperse gas-particle flow generated by the sudden released of a batch of pyroclastic material. The model formulation is based on the equilibrium-Eulerian approximation (Ferry and Balachandar, Int. J. Multiph. Flow 2001; Cantero et al., J. Geophys. Res., 2008) for a polydisperse flow and is appropriate up to particle Stokes numbers less than 1. The model describes the dynamics of the different particle sizes of the mixture and particularly their interaction with the flow turbulence. Disequilibrium and transient effects between the particles and the gaseous phase of the mixture, such as turbulent entrainment, preferential concentration and particle sedimentation are also described by the model.

The model was used for simulating the dynamics of PDC at the volcanic scale in the context of the model inter-comparsion benchmarking exercise. The effect of several physical (initial

concentration, temperature, volume and grain size distribution) and numerical (the subgrid turbulence models, grid resolution and dimensionality) parameters on the PDC dynamics has been explored.A systematic quantitative analysis of the influence of these parameters on the dynamics of the PDC has been carried out. Investigated variables include the spatial and temporal evolution of the flow runout, flow mixing with the atmosphere, flow stratification, momentum distribution within the current and associated sedimentation patterns. The investigation of the effects of these key physical and numerical parameters represent an important step in the understanding of the complex physics of this phenomenon as well as in the assessment of the associated hazards.

IAVCEI (Volcanology, Geochemistry)

VS06b - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-1142

Field validation of pyroclastic density current (PDC) models: examples from Merapi and Soufriere Hills volcanoes

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Models of pyroclastic density currents (PDCs) are widely used for fundamental research, but their use for hazard assessment is having a growing importance. Prediction of the impacts of PDCs is required for estimating the area that may be affected by the movement of a potential flow and to map hazard intensity parameters (i.e., velocity, temperature, dynamic pressure). Numerical models now exist, capable of approximating the motion of a given volume of pyroclastic material from its source to the deposition area. Because of the high impact that modeling and simulations can have, their credibility needs to be assessed. To assess the adequacy of numerical models for PDCs, a consensual validation procedure should be established. Validation is the process of demonstrating that a model reasonably represents the developer's/user's physical conceptual model for a process. Results produced by one fluid, depth-averaged mass-flow models, like Titan2D and VolcFlow, inherently contain errors and uncertainties that can affect the accuracy of its solutions. Such artifacts arise throughout multiple levels of the modeling process such as in theoretical, experimental, and numerical domains. Here, a suite of test cases with validation metrics are used to highlight uncertainties related to the numerical simulations of well-constrained concentrated PDCs from Merapi (Indonesia) and Soufriere Hills (Montserrat) volcanoes. Each of these test cases has a particular solution to which numerical results are compared. Through a series of such comparisons, it is hoped that a general validation methodology emerges that can be used in the future to maintain a measure of depth-averaged models' accuracy regarding the simulation of various concentrated PDC events and prediction of their related impacts.

IAVCEI (Volcanology, Geochemistry)

VS06b - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-2094

An integrated pTRM–charcoal reflectance approach to reconstruct the emplacement temperature of ignimbrites: the 4.6ka Fogo A sequence, São Miguel, Azores

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The emplacement temperatures of three ignimbrites belonging to the 4.6 ka Fogo A plinian eruption sequence in São Miguel Island (Azores) were determined using pTRM of lithic clasts and reflectance (Ro%) of charcoal fragments embedded within the deposits and collected at the same localities close to each other. The Fogo A sequence is characterised by a thick plinian deposit interbedded with two intraplinian ignimbrites (pink and black intraplinian ignimbrite) and capped by a final ignimbrite (dark brown ignimbrite). A total of 140 oriented lithic clasts from the three ignimbrites were collected from 15 localities. The emplacement temperatures of the pink and black intraplinian ignimbrites inferred from pTRM analysis were respectively ≥400°C and ≥600°C; the temperatures of the dark brown ignimbrite estimated between 300° and 350°C. Thermal estimations of 3 key sites were compared with the results of the analysis of reflectance (Ro%) measured on 8 specimens derived from charcoal fragments collected from the pink intraplinian ignimbrite and the dark brown ignimbrite. Results indicate Ro% values between 1.61 and 1.37 (corresponding to 380-460°C) for the pink intraplinian ignimbrite, whereas fragments collected from the dark brown ignimbrite show Ro% values between 0.85 and 0.50 (corresponding to 330-350°C). No charred wood was found in the black intraplinian ignimbrite. TRM and Ro% results are comparable and validate the use of both methods. Greatest accuracy in the determination of emplacement temperatures of ignimbrites is achieved when both methods can be applied at the same locations.

IAVCEI (Volcanology, Geochemistry)

VS06b - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-2685

Windsnapped and buried: Dynamic processes associated with tree trunk breakage by the 232 AD Taupo Ignimbrite, New Zealand

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Tree blowdown is an increasingly-recognised phenomenon of pyroclastic density currents over forested areas. Damage to trees is comparable to that of strong winds, which can vary from windthrow (uprooting) to windsnap (breakage of the tree trunk). Recent flood erosion of the 232 AD Taupo ignimbrite along the Waipa River, North Island (New Zealand) has exposed 28 ‘windsnapped’ tree trunks preserved in their original upright position. Here the Taupo ignimbrite is about 75 km from its eruption site and forms a lower terrace within a 250 m-deep valley. It is a 17 m-thick, massive, lithic-poor, valley-ponded ignimbrite, with an upper 2 -3 m-thick pumice-rich stratified zone. Trunk diameters range from 40 to 150 cm implying that the trees were large with significant canopies. The height at which tree trunks have broken ranges from 0.6 to 4.5 m above ground. There is a systematic decrease in height downstream within the valley and also across the valley towards its central axis. Individual tree trunk ends are jagged, fractured or tapered implying they were violently snapped and subsequently abraded. Wood charring is minimal and bark layers are either intact or variably stripped off. At the corresponding tree breakage heights the ignimbrite is continuous and fine-grained suggesting that the trees were broken prior to burial, presumably by strong currents ahead of the depositional front. The dominance of windsnapped over windthrown trees is controlled by the mechanical properties of the trees, however, the systematic variation in breakage height may also be related to variations in pyroclastic flow dynamic pressure. Substantial dynamic pressures must have existed above the breakage height (up to 4.5 m) within the pyroclastic flow.

IAVCEI (Volcanology, Geochemistry)

VS06b - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-2792

Titan2D simulations of pyroclastic flows emplaced on January 2001 at Popocatépetl volcano (Mexico).

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On January 22, 2001 the Popocatépetl volcano (Mexico) erupted generating an 8 km ash column and pyroclastic flows that were emplaced on the northern sector of the cone up to 4-6 km from the crater. This episode had an estimated VEI of 3-4 and has been one of the most violent phases since 1994. Based on the direct observation from a camera located at 4.5 km from the crater, the pyroclastic flows were generated during the first minutes of the column ascent. The associated deposits consist of pumice flow units up to 3 m in thickness, massive, clast supported and mostly composed of pumice, scoria and lithics. We used Titan2D code to reproduce the observed maximum runout, flow thickness and flow velocities as estimated by the superelevation method in the field. Simulations were executed considering two different scenarios: 1) a single column collapse event, with a pile height reproducing the altitude from which column could have collapsed and, 2) boiling-over-type activity, with an extrusion flux rate calculated based on the observed eruption duration and the volume estimated from the observed deposit.

IAVCEI (Volcanology, Geochemistry)

VS06b - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-3610

Quaternary ignimbrites of Armenia: Petrology and stratigraphy

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Voluminous Quaternary ignimbrites in Armenia are sourced from Aragats, one of the largest stratovolcanoes in the Eurasia-Arabia collision zone. Based on geological data and petrography, the Armenian ignimbrites can be subdivided into 3 maingroups: 1) the welded ashy-tuffs of Yerevan-Leninakan type, 2) the “flame” tuffs of Shamiram-Byurakan type, and 3) the welded ignimbrites of Artik type. First two types have ash matrix and are distinguished from each other by the degree of welding and fiamme content, and the relative abundances of vitro- and crystal-clasts, among other features. Artik tuffs are characterized by distinct eutaxitic (flow) textures and their low litic clasts content.

The bulk rock major element compositions of Middle Pleistocene ignimbrites correspond to high-K trachydacites and trachyandesites, while their fiamme and glass separates from the matrix arealways silica-rich and correspond to rhyolite and high silica trachydacite magma source.

Recently some of the Aragats ignimbrites have been dated by ^{40}Ar/^{39}Ar (AIST, Japan). The results show 0.65±0.038 Ma for Shamiram-Byurakan type and 0.66±0.040 Ma for Yerevan-Leninakan ignimbrites (see also Connor et al., 2010). It is noteworthy, that the new ignimbrite agesare consistent with earlier K-A rage determinations of associated lava flows (Chernishev et al., 2002) and also paleontological data on rodents (Melik-Adamyan, 1994).

IAVCEI (Volcanology, Geochemistry)

VS06b - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

IUGG-5127

Sequential plug formation, desintegration by vulcanian explosions, and the generation of granular pyroclastic density currents

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Tungurahua volcano, Ecuador, has had periodic highly energetic Vulcanian eruptions since 2012, those of 14 July 2013, 18 October 2013, and 1 February 2014 being the most important. These were well-monitored by a 5-station broadband seismic and acoustic array. Small to moderate PDC flows associated with fountain collapses resulted and traveled ≤ 7 km down the steep N, NW, and W flanks of Tungurahua's cone at velocities of 11 - 18 m/s; a small lateral blast and its PDC were clocked at 33 m/s descending the N flank.

Noteworthy, similar repose intervals of 3.5, 7, 3, and 3.5 months between the Vulcanian events (VEI ~2) suggest that the ascending juvenile magma experienced sequential pressurization cycles within the conduit. Because neither crater domes nor their products occur at Tungurahua, the eruptive cycles are apparently due to deeper conduit blockage, apparently the result of the solidification of magma from previous eruption cycles by repeated plug formation. Gases from ascending juvenile magma did not escape easily and gas pressurization ensued. Every 3-4 months plug failure occurred, abrupt decompression followed, and these are associated with the energetic Vulcanian explosions. Kumagai et al. (2010) and Kim et al. (2014) considered explosion depths of 1-2 km based upon seismic and acoustic data. The explosive fragmentation of the plugs (a dense microcrystalline andesite) and the vesiculated glassy andesite of the juvenile magma are the principal rock fragments of the PDC deposits, which typically consist of two adjacent layers; a segregated clast-rich, fines-poor upper layer and a fines-rich lower layer with few large clasts.

IAVCEI (Volcanology, Geochemistry)

VS06p - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

VS06p-384

Field evidence for substrate entrainment by pyroclastic density currents and its effect on downstream dynamics at Mount St Helens (USA)

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Two significant gaps in our understanding of pyroclastic density current (PDC) dynamics include (1) the primary control(s) on substrate erosion and (2) the effect that substrate entrainment has on downstream PDC dynamics. Thirty-five years of erosion into the May 18, 1980 PDC and debris avalanche hummock deposits at Mount St Helens (USA) reveals kilometers of new outcrops, which contain substantial evidence for erosion and entrainment of the substrate. We present evidence for local substrate entrainment from underlying debris avalanche hummocks, as evidenced by an increase in median grain size, an increase in fine ash, a decrease in the pumice to lithic ratio, and an increase in lithologies present in the upstream debris avalanche hummocks. The presence of large, locally entrained lithics (blocks >1 m in diameter in some locations) at various heights within a single flow unit suggests both a continuous entrainment of the substrate from the head and body of PDCs, and a progressive aggradation of the deposits. The debris avalanche deposits were largely buried by the PDCs. The relative amount of entrained substrate material decreases to zero vertically in the stratigraphy, suggesting that surface roughness is important for promoting erosion by PDCs. The conditions that promote erosion and the impact of erosion on downstream PDC dynamics will be explored through a series of fluidized, granular flow experiments. We anticipate that this combination of techniques will yield a more complete understanding of how erosion and entrainment affect PDC dynamics, ultimately enabling more accurate hazard assessments for these dangerous currents.

IAVCEI (Volcanology, Geochemistry)

VS06p - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

VS06p-385

GPR imaging of pyroclastic density current deposits at Mount St. Helens, Washington

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Ground penetrating radar (GPR) is used to image pyroclastic density current (PDC) deposits from the May 18th, 1980 eruption of Mt. St. Helens. The objectives of this work are to (1) test the validity of GPR for mapping subsurface topography (surface roughness), unit contacts, depositional levees, and channel scour and fill features, and (2) identify features for future, more extensive geophysical surveys. Comparison between radargrams and features exposed in outcrops allows us to more confidently interpret subsurface reflectors of interest for GPR transects where outcrops are not available. Outcrop verified features include a scour-and-fill channel and a secondary hydrovolcanic explosion crater. Unverified reflectors are attributed to either depositional levees or debris avalanche hummocks, but cannot be determined due the low resolution of the dataset. This preliminary study validates the GPR method to identify and map the three-dimensional structure of pyroclastic deposits. Future work is proposed to continue field investigation with GPR high density common midpoint stacking methods, tomographic velocity inversion, and seismic methods to improve our ability to distinguish between deposits by material density, sorting, porosity, and radarfacies. This will provide a basis to determine the morphology and extent of three-dimensional flow features and pre-flow topography, enabling a more confident interpretation of the deposits. These results will eventually guide the development of experiments that explore PDC behavior, and improve field constraints for model validation.

IAVCEI (Volcanology, Geochemistry)

VS06p - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

VS06p-386

Validation of a numerical model of fluidised granular flow from laboratory experiments

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Sustained high gas pore pressure is a possible explanation for the origin of pyroclastic flows fluidity and long runout distances. Before testing this hypothesis by confronting field data to numerical models on real topographies, we should ensure that the models are able to reproduce the emplacement of laboratory granular flows with interstitial gas pore pressure. We carried out experiments on dam-break gas-particle flows in a horizontal flume. A static bed of fine particles was fluidised with air at various degrees in a tank, which generated interstitial pore pressure. The bed was released suddenly, which generated a gas-particle flow that defluidised progressively through pressure diffusion. We measured the flow properties, such as the velocity, runout, and surface profile variation with time, as well as the characteristic of the apparatus and of the particles (internal and basal friction angles, pressure diffusion coefficient). Numerical simulations were done with the code VolcFlow, which was modified to take into account gas pressure advection, gas pressure diffusion, and the effect of gas on the basal and the internal friction angles. We show that our new numerical model reproduces accurately the temporal variation of the flow front velocity and of the surface flow profile as well as the final shape of deposit, regardless the initial degree of fluidisation of the granular mixture.

IAVCEI (Volcanology, Geochemistry)

VS06p - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

VS06p-387

The propagation of pyroclastic density currents down slopes

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The spatio-temporal evolution of an unsteady pyroclastic density current has been analyzed extensively in the Boussinesq limit (i.e. for small density contrasts) in the dam-break configuration (i.e. by releasing a fixed volume of fluid from an enclosed lock) over flat, horizontal surfaces. In this conditions, two-dimensional and three-dimensional solutions of a multiphase, non-equilibrium flow model are in good agreement with experimental findings and simplified box model predictions. However, these approximations can be invalid in a volcanological context as volcanoes show angles of incline up to 40 degrees and in pyroclastic flows large density differences exist. Numerical analysis of gravity currents on inclines show some substantial differences against the horizontal case: while the height of the current head in the horizontal case attains a constant values, in the inclined one it drastically grows. This is due to the enhancement of entrainment of the ambient fluid and to the feeding of the front from the fluid layers behind, which move faster than the front. The latter effect is enhanced in concentrated currents as confirmed by lab experiments.
This behavior has important consequences for PDC mobility: in a first stage, the motion on slopes is faster and reaches a larger runout. At later times, a transition to a second regime during which the inclined currents slows down is observed. This behavior can be attributed to the higher resistance acting on the fluid due to the growth of its front. For highly dilute flows the horizontal currents even overtakes the inclined ones.
Despite these significant differences, however, it is still possible to derive a scaling law for turbulent pyroclastic density currents on inclines, which can be useful in hazard assessment studies.

IAVCEI (Volcanology, Geochemistry)

VS06p - VS06 Benchmarking Pyroclastic Density Current Models: Code Inter-Comparison and Field Validation

VS06p-388

Integrating quantitative measures and modeling for disaster risk reduction: The peoples framework

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The assessment of disaster risk reduction and process modeling (e.g. the hazard and risk assessment of pyroclastic density currents (PDCs)) and the use of natural resources (e.g. increase crop yields with soil and water conservation) are currently viewed as independent issues. To better integrate, quantitative measures and modeling for both - resilience and sustainable development – need to be accounted for the complexities across disciplinary and administrative boundaries. The so-called 'PEOPLES Resilience Framework' was developed to create partnerships and communicate pre- and post-disaster recovery of extreme events. As an example, PEOPLES can be combined with environmental, infrastructure, economic or any other quantitative model to assess future scenarios. The Geospatial Project Management Tool (GeoProMT) is a repository for data, algorithms, models and other information to coordinate interdisciplinary collaboration to combine process-based model approaches.

IAVCEI (Volcanology, Geochemistry)

VS08a - VS08 Experimental Studies of Volcanic Systems

IUGG-1767

The role of inertial particles and vent geometries in the rise and collapse of volcanic jets.

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Particle-laden volcanic jets can undergo gravitational collapse to produce ground-hugging pyroclastic density currents or loft material several tens of kilometres. The key to determining which of these two phenomena will occur is the turbulent entrainment of atmospheric air, which adds buoyancy to the jet.

Classical models of eruption columns assume that the entrainment rate is related to the up flow rate of the jet through a coefficient of fixed value, about 10%. In particular, the efficiency of entrainment is assumed to be independent of the vent shape as well as the physical properties of the pyroclastic mixture. However, it has recently been show that the presence of inertial particles in the jet can have a significant effect on entrainment. These changes to entrainment are due to the additional buoyancy of the particles and the particles altering the size, shape and distribution of the entraining eddies. In addition, the presence of a flaring (as opposed to cylindrical) vent has been shown to drastically increase entrainment in the presence of inertial particles as is shapes the initial buoyancy and momentum fluxes.

Natural volcanic vents can be axisymmetric, elongated (fissures) or annular (calderas). Using scaled analogue experiments, we test the effect of these different vent geometries on the entrainment rates into jets laden with inertial particles. We find that the smallest gap size sets the initial entrainment rate and that jets from slotted nozzles may evolve into round jets. These findings make explicit predictions for deposit architectures which can be tested using field data.

IAVCEI (Volcanology, Geochemistry)

VS08a - VS08 Experimental Studies of Volcanic Systems

IUGG-2282

"This is my abstract title":Melting Dynamic of Volcanic Ash under Jet Engine Conditions

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The interaction of volcanic ash with jet turbines during ingestion of ash into engines operating at supra-volcanic temperatures is now widely recognized as a potentially fatal hazard for jet aircraft. Volcanic ash particles have low melting point (approximately 1,100 °C), which is below the operating temperature of modern commercial jet engines (1,100-1,400 °C), so they melt in the hot sections in jet engines (e.g., combustion chamber and turbine). The high temperature behavior of volcanic ash is believed to impact strongly on its deposition in the hot section of jet engines. However, explicit investigation of the melting dynamics of volcanic ash with quantitative descriptions is in its infancy due to the complexity of its melting process. Here we report a quantitative analysis of the melting dynamics of Santiaguito and Eyjafjallajökull volcanic ashes, (selected due to their currently elevated levels of eruptive activity and their hazard potential for aircraft safety), from room temperature to 1550 °C. We have optically monitored four characteristic temperatures defined by the evolution of the geometry of the cross-section of initially cylindrically-shaped compacted volcanic ash (3×3mm) in a heating microscope over a wide range of heating rates (5-1000 K/min).The four characteristic temperatures of these two volcanic ashes become more sensitive to the heating rate as the temperature increases (particularly at temperatures higher than shrinkage temperature). Furthermore, our results suggest that heating rate directly controls the entire melting process, which yields good linear correlations of characteristic temperatures with shrinkage rate, fusion rate and wetting rate in the melting process of volcanic ashes.

IAVCEI (Volcanology, Geochemistry)

VS08a - VS08 Experimental Studies of Volcanic Systems

IUGG-3091

The air-cushioning of pyroclastic flows.

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Pyroclastic flows are the most lethal volcanic threat known to humankind. These ground-hugging mixtures of hot volcanic particles and gas are infamous for travelling enormous distances of up to ~100 km at speeds of 100-200 kilometres per hour. Explaining this fast and far-reaching flow behaviour requires a hitherto unobserved physical process that reduces the apparent friction of pyroclastic flows. Over the past forty years a number of ‘friction-reducing’ mechanisms have been hypothesized, but none of them is accepted and all of them can be challenged.

Here we show that pyroclastic flows can self-generate a thin basal cushion of air along which they slide largely frictionless and partially weightlessly. Our observations and data are based on large scale pyroclastic flow experiments conducted at PELE – an international facility for PDC and mass flow simulations in New Zealand. The experimental pyroclastic flows are generated by column collapse; they accelerate to speeds of 100 kilometres per hour and reach runout distances of more than 35 m. The fully turbulent suspensions segregate into a 0.1-0.5 m thick dense underflow and an up to 4.5 m thick ash cloud. The dense underflows emplace aerated, massive and inversely graded, coarse-topped deposits with numerous degassing pipes and closely resemble natural pyroclastic flow deposits. The geometry of the deposit emplaced by the dense underflows show a reduction in apparent friction of up to 65 percents.

We discuss why this air-cushion mechanism is also likely to occur in natural currents and argue that it offers a strong alternative to the current static gas-fluidization hypothesis for pyroclastic flows.

IAVCEI (Volcanology, Geochemistry)

VS08a - VS08 Experimental Studies of Volcanic Systems

IUGG-3452

Experimental constraints on the energy of steam-driven explosions: a case study on Solfatara crater, Campi Flegrei

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Steam-driven eruptions are very difficult to predict in terms of timing and magnitude bearing significant hazard potential especially in densely populated areas. Here we present the results of a series of rapid decompression experiments at elevated temperatures and pressures aimed to investigate steam explosions. In these experiments fragmentation is triggered by decompression of argon gas assisted by varying amounts of water flashing to steam within the connected pore space of the samples.

The highly active hydrothermal site of Solfatara crater within the Campi Flegrei caldera was chosen as case study; the experimental conditions were used to mimic those of a mixing zone present at the base of this hydrothermal system. Neapolitan Yellow Tuff, considered to be representative for the tuff-sequence expected at depth, is used as sample material. Different degrees of water saturation and tempering of samples allowed to investigate the effect of water-to-steam flashing as well as strength reduction due to zeolite dissolution.

Changes in the fragmentation behavior and ejection dynamics with the mechanical energy released during the explosions reveal significant differences between dry, partially- and fully-saturated conditions. Generally, higher production of fines and higher kinetic energy of ejected clasts is observed with increasing water saturation. These effects are especially enhanced in the case of zeolite-depleted samples reflecting an improved efficiency in the conversion of energy in combination with strength reduction due to zeolite dissolution.

Our results suggest that the gas-liquid ratio within pores plays a key role in the violence of steam-driven explosions. Furthermore the strength of host-rock affects the process of energy release.

IAVCEI (Volcanology, Geochemistry)

VS08a - VS08 Experimental Studies of Volcanic Systems

IUGG-5316

Transport and deposition processes in granular flows and their influence on pyroclastic density current dynamics

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The complex transportation and depositional processes of hazardous volcanic coarse-grained dry granular flows are investigated by means of ad hoc designed flume experiments that allowed both documenting the particulate organisation during transportation along a steep slope and visualising aggradational deposition beyond the break-in-slope. The broad grain-size range used in experiments allowed depicting both the behaviour of coarse clasts and that of fine ash. The kinematic of the granular flow shows that the coarse grained flow moves in an inertial regime for slope angles above the internal friction angle of the material, while the main body moves along the slope with a more complex, not inertial behaviour. The granular material show self-organisation of its internal structure since the early stage of the movement along the slope, with formation of a reversely graded flow that suddenly develop Kelvin-Helmholtz like instabilities at the passage between the fine-grained basal part and the coarse grained upper portion. This flow organisation implies that the frictional work is mainly exerted by the basal, fine-grained part, which is pushed along the slope by gravitational force and by the traction effect exerted by the upper portion of the flow. Deposition occurs in the flat area beyond the break in slope due to the increasing frictional forces and to the decreasing contribution of gravitational force to the granular flow motion. Results can help interpreting the mechanisms of natural volcanic flows forming on steep slopes of stratovolcanoes and provide useful insights on behaviour of natural granular flows.

IAVCEI (Volcanology, Geochemistry)

VS08b - VS08 Experimental Studies of Volcanic Systems

IUGG-2591

Sloshing of a bubbly magma reservoir

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Large earthquakes sometimes activate volcanoes in the near field as well as in the far field. Some volcanoes erupt immediately after the passage of seismic waves, while others take longer. Enhancement of heat flux has also been observed, suggesting an increased gas mobility following the strong shaking. In this work we elaborate on the movement of fluids contained in a solid tank, referred to as sloshing. Severe earthquakes induce sloshing and damage petroleum tanks when it resonates.

We conduct shaking experiments to simulate an earthquake effect on a bubbly fluid. This allows us to investigate how sloshing in a magma reservoir can trigger various volcanic activities. We shake a layered system in which a foam overlies a viscous liquid layer, simulating a seismic wave traveling through a bubbly magma reservoir. We vary the thickness and viscosity of the liquid and foam layers, and the bubble size in the foam. We find that when the bubbles in the foam are sufficiently large (> 5 mm), and the viscosity of the lower layer is low (< 1 Pas), shaking causes ripples on the interface that deforms the bubbles in the foam. The deformed bubbles eventually coalesce and collapse so that the foam volume decreases. A new void space appears at the top of the tank which allows the lower layer to overturn.

If the same phenomena happen in a magma reservoir, the gas released from the collapsed foam may infiltrate in the rock or diffuse through the pores, enhancing heat transfer, or may generate a gas slug to cause a magmatic eruption. The overturn in the magma reservoir provides new nucleation sites which may help to prepare a later eruption. We thus infer that the sloshing can lead to various responses of volcanoes to large earthquakes.

IAVCEI (Volcanology, Geochemistry)

VS08b - VS08 Experimental Studies of Volcanic Systems

IUGG-3038

Gas-driven filter pressing: Insights into melt segregation from crystal mushes

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Gas-driven filter pressing relieves the gas pressure developed through second boiling by expelling melt from a crystal mush. It is thought to play a major role in magma fractionation at depths < 10 km. We present new 4D (3D plus time) time resolved experimental data that constrain conditions under which gas-driven filter pressing can occur. In-situ high-temperature high-speed synchrotron X-ray tomography (500-800 °C, 3 mm/pixel, 1 second per full 3D dataset) were used to collect real time information about the behaviour of hydrous haplogranitic (2.1 wt.% H2O) and dacitic (4.2 wt.% H2O) crystal mushes across a wide range of crystal contents (34-80 vol.%). The data constrain how the crystal content affects the efficiency of gas-driven filter pressing of silicic melt out of the crystal mush framework, and show gas-driven filter pressing operates below the maximum packing fraction of the suspended phases (bubbles + crystals) of ~ 74 vol.%. At lower melt fractions, the crystal mush fractures, implying that for effective gas-driven filter pressing the crystal mush must inflate slowly relative to build-up of pressure and expulsion of melt. These observations suggest a possible explanation for the production of eruptible crystal-poor rhyolites in the Earth’s crust.

IAVCEI (Volcanology, Geochemistry)

VS08b - VS08 Experimental Studies of Volcanic Systems

IUGG-3633

Role of slope angle and substrate roughness on pore pressure generation in ash rich pyroclastic flows: Experimental insights

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Long runout distance of fines-rich pyroclastic flows is often attributed to their ability to generate and retain high pore pressure that reduces interparticle friction for most of the emplacement. We carried out experiments on flows generated by the release of a column of fine particles (diameter = 0.08 mm) in a channel inclined at 0° to 30° and whose base was either smooth or made rough by glued beads of 3 mm diameter. A rough substrate increased significantly the flow runout at low slope angles, and at horizontal the runout was twice that for a smooth substrate, but this effect was less pronounced at higher slope angles until becoming almost negligible at 20°. Pore pressure measurements and video analysis revealed that, at all slope angles investigated, flows propagating over a rough substrate were autofluidized by an upward air flux generated by settling of particles into the substrate interstices. In contrast, air ingestion at the flow front was not evidenced, even at high inclination up to 30°. On a rough substrate, a rapid deceleration phase was observed at high slope angles and was probably caused by loss of particles into the interstices and thinning of the flow head, which limited supply of material at the front that eventually stopped motion. Experiments at inclinations close to or slightly larger than the repose angle of the granular material (25-30°) revealed the formation of a thin basal deposit that was then eroded by the overlying flowing material as the flow thickness decreased gradually.

IAVCEI (Volcanology, Geochemistry)

VS08b - VS08 Experimental Studies of Volcanic Systems

IUGG-3783

Entrainment in dilute pyroclastic density currents

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Entrainment and thermal expansion of air can result in buoyancy reversal and liftoff of pyroclastic density currents (PDCs), thus turbulent entrainment exerts a fundamental control on PDC dynamics. Turbulent length scales and timescales can describe and predict current behavior. Laboratory experiments with bulk, turbulent, and thermal scaling similar to natural currents allow us to study the effects of different boundary conditions on turbulence and entrainment. All experiments, whether in unconfined (“3D”) or confined (“2D”) geometries show decreased runout distance with increased temperature, indicating turbulent entrainment promotes liftoff. Further, all experiments show a turbulent stratification, with the lower ~half of the currents (total thickness L) forming a bypass region (of thickness Lb) that is not in direct communication with the atmosphere, and an upper entraining region in which mixing occurs. 2D experiments flowing over substrates with different roughness heights (Lr) show increases in runout until Lr≥Lb. 2D experiments show increased air entrainment near topographic barriers and buoyant plumes focus at barriers, but currents overtop barriers with height <1.5L and runout distance is unaffected. 3D experiments show air entrainment through the lateral current margins, and that lateral entrainment dominates when liftoff begins. As 3D currents encounter barriers, they efficiently entrain air from all sides and generally liftoff to form buoyant plumes immediately above the barriers. The timescales of unsteadiness in eruption rate, t, and turbulence, tau, describe whether a current is steady: currents are unsteady when t>3tau, unsteadiness decays over a distance of ~4 turbulent length scales when 3tau>t>tau, and currents are steady when t<tau.

IAVCEI (Volcanology, Geochemistry)

VS08b - VS08 Experimental Studies of Volcanic Systems

IUGG-4046

Experimental calibration of apatite as a tool for tracking multi-component fluids in volcanic systems

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Volatiles are critical to the evolution and eruption of magmas, but few direct records of pre-eruptive magmatic volatile contents exist. The phosphate mineral apatite is unique in its ability to accommodate all major magmatic volatiles (H_2O, F, Cl, CO_2 and S) within its crystal structure; as such it has excellent potential to serve as a tracer of volatiles during fractionation, ascent and degassing. Despite a growing interest in the apatite volatile record, until now a lack of experimental partitioning data for H_2O and CO_2 has inhibited the quantitative application of this tool.

We have run a series of experiments investigating the partitioning of H_2O, CO_2, F, and Cl between apatite and silicate melts at crustal magmatic conditions (2–10 kbar, 900–1250 °C). Run products are typically glasses containing 3–25 vol% apatite (± vapour and other minor phases) and have been characterised by electron microprobe and secondary ion mass spectrometry.

Apatite compositions range from near-end-member fluorapatite and hydroxyapatite to carbon-rich apatite containing 1.6 wt% CO_2. Nernst partition coefficients ($D^{ap\text{–}melt}$) for major volatile components span a range of values, because volatiles are required structural components in apatite, and there is a competition for space in the crystal. However, exchange coefficients ($K_D^{ap\text{–}melt}$) are well constrained, emphasising the importance of stoichiometry in controlling partitioning behaviour. While F and Cl are generally compatible in apatite, H_2O is highly incompatible. CO_2 partitions readily into apatite at crustal conditions and is significantly more compatible than water at high pressures ($K_D^{H2O\text{–}CO2} = 4$). We therefore infer that apatite may be a sensitive tracer of magmatic CO_2 contents, particularly in halogen-poor magmas.

IAVCEI (Volcanology, Geochemistry)

VS08p - VS08 Experimental Studies of Volcanic Systems

VS08p-580

How does wind impact entrainment rate in explosive volcanic jets rising under wind stress? – New clues from analogue experiments

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The mechanics controlling the turbulent entrainment of cold atmosphere govern the structure and maximum height of Plinian volcanic jets. Eruption columns are often influenced by ambient winds and it is commonly assumed that the extent of turbulent mixing increases in proportion to the wind speed. However, wind stresses act to deform the largest entraining eddies forming the margins of eruption columns and alter their mixing properties, in turn. Whether and how wind might increase or decrease the efficiency of entrainment and mixing across eruption columns is consequently unclear.

To build understanding of the quantitative effects of wind forcing on entrainment we use statistical analyses of tracer variance in an ensemble of analogue experiments on buoyant plumes erupted under variable cross-wind conditions. Using a combination of standard image processing techniques, principal component analysis and novel self-organizing maps we isolate entraining eddies and quantify how their size, shape, and frequency vary depending on the relative wind speed. We characterize also how these properties vary from the upwind to the downwind sides of the plume. Furthermore, we quantify the evolution of the rate of entrainment into the plume. Taken together, we identify and characterize the major effects of wind on the physics of entrainment over the full range of conditions expected in nature. In particular, we show that even for weak wind stresses, entrainment into jets is strongly asymmetric from the upwind to downwind sides of eruption columns.

Our work implies that plume structure, e.g. particles or aerosols distribution, cannot be captured by models assuming a uniform entrainment. Our results provide a critical benchmark for 2D and 3D plume models.

IAVCEI (Volcanology, Geochemistry)

VS08p - VS08 Experimental Studies of Volcanic Systems

VS08p-581

Quantifying input and output parameters of dike propagation

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Partially-automating data collection has the benefits of facilitating research and minimizing human error. Such is done for analogue experiments that focus on magmatic dike propagation, with the goal of having precise estimates of the initial conditions and the resulting geometry of the dike. The results can then be related to other types of models with a high degree of certainty. Here, visualization and processing techniques are applied to quantify the solid phase's (in our case gelatin) strength and the model dike thickness.

A key parameter of dike propagation is the Young's modulus of the solid phase, due to its relationship with both elastic deformation and fracture toughness. We estimate Young's modulus via shear wave velocity, which has a clearly defined relationship with the material's shear modulus, and thus Young's modulus. By generating and tracking shear waves, viewed in polarized light, the stresses imposed on the material can be recorded by a camera. By processing such recordings, the wave fronts' precise positions, and therefore velocities, can be determined.

Similar visualization and processing techniques can be applied to the propagation of the dike itself. Starting with a known volume of liquid, an injection is made and begins to propagate via buoyancy. When viewed perpendicular to the plain of propagation, the color saturation of the liquid reflects the relatively-thicker regions of the dike. Coupled with the volume and the directly-observable area of the dike, the thickness can be estimated. The full knowledge of the dike shape and properties of the surrounding medium will then be used to benchmark numerical models.

IAVCEI (Volcanology, Geochemistry)

VS08p - VS08 Experimental Studies of Volcanic Systems

VS08p-582

Two-layer aerated granular flows and implications for pyroclastic density current structure

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Recent studies have demonstrated the ability of continuous aeration to reproduce some aspects of long run-out pyroclastic density currents and their low aspect ratio deposits. Gas supplied to the base of thin, dense granular currents in the laboratory simulates the long-lived elevated pore-pressure which is believed to improve mobility in thick natural flows.

Similar experiments using finer materials (~45 µm diameter silica beads) show spontaneous formation of a two-layer gravity current. A dense laminar basal flow dominated by frictional granular collision is over-ridden by a turbulent powder suspension. These flows are generated by impingement of heated unaerated powder onto a sub-horizontal surface at a range of particle concentrations.

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

This work provides possible insight into the flow structure and mass-partitioning processes between the two discrete layers inferred to exist within pyroclastic density currents, which have to date proved impossible to observe or record in the field.

IAVCEI (Volcanology, Geochemistry)

VS08p - VS08 Experimental Studies of Volcanic Systems

VS08p-583

Shock-tube experiments to investigate volcanic jet dynamics

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The dynamic of pyroclast ejection is a direct consequence of the efficiency and location of magma fragmentation and the geometry of the shallow plumbing system. Because of the hostile environment and the opaque nature of volcanic edifices, the governing processes defy direct observation. In order to constrain the range of observed variation in nature, we simulated the dynamics of pyroclasts ejection using a well-controlled shock-tube.

We ejected loose particles by rapid gas expansion while controlling temperature, applied overpressure, starting grain size distribution and particle density. Additionally, we varied the gas-particle ratio, the initial distance between sample and vent surface as well as vent geometries: a cylindrical continuation of the shock-tube, two funnels with a flaring of 30° and 15° and a nozzle.

We quantified particle velocity and jet spreading angles through image analysis of high-speed movies. We observed dynamically evolving ejection characteristics. Particle velocities range from 130 to 290 m/s, gas spreading angles from 14° to 37° and particle spreading angles from 36° to 2°. Through dry mechanical sieving of the particles after the experiment, we evaluated the production of fines and found strong variations (increase up to a factor of 2).

In nature, ballistics of any size are accelerated by rapid ground deformation and drag by gas. Our experiments mechanistically mimic the process of pyroclast acceleration by drag and subsequent ejection and have shown the capability to constrain the influence of starting conditions and conduit/vent geometry. The aim of such experiments is to qualitatively and quantitatively constrain the parameters affecting the ejection dynamics during explosive eruptions.

IAVCEI (Volcanology, Geochemistry)

VS08p - VS08 Experimental Studies of Volcanic Systems

VS08p-584

Viscous sintering and welding of volcanic ash

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Volcanic ash is often hot on deposition. Volcanic ash containing glass, deposited above the glass transition interval, has the potential to sinter viscously both to itself and to exposed surfaces. Here we quantify the evolution of bulk porosity during sintering of hot ash. We use a novel optical dilatometric technique in which cylinders of packed, glassy volcanic ash, analogue glass beads or analogue angular glass powders are linearly heated to isotherms above the glass transition interval for each material. We observe a time-dependent volume change which, after confirming that glass mass and density changes are negligible, we interpret to be accommodated by porosity changes only. We use this broad data set to test and compare models for collapse of a porous medium; we distinguish regimes in which sintering is dominated by surface tension and by gravity. Finally, we compare results for purely glassy beads with those for glass beads with a well-defined surface crystallinity, to show how surface relaxation-driven sintering mechanics are retarded by the presence of a surface layer of rigid particles. We use our results to investigate how timescales of viscous sintering influence the dynamic behaviour of ash-filled cracks (tuffisites) at vent sites in glassy eruptions, and use our findings to inform interpretation of new field observations.

IAVCEI (Volcanology, Geochemistry)

VS10a - VS10/VS11/VS31 Probabilistic Volcano Hazard Analysis / Short-Term Forecasting of Volcanic Hazard: So Far, So Good? / Quantifying and Communicating Uncertainty During Volcanic Crisis

IUGG-1061

Calculation of rain triggered lahar volumes for probabilistic lahar hazard mapping

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Models to describe the behaviour, and consequent hazard, from lahars range from simple empirical solutions (e.g. Iverson et al. (1998)) to more complex single (e.g. O'Brien (2007)) or multi-phase (e.g. two-fluid model of Pitman and Le (2005)) rheology models with the possibility to incorporate downstream sediment entrainment and deposition (e.g. Fagents & Baloga 2006). Regardless of methodology, all lahar models are sensitive to uncertainties in the initial conditions; primary of these being the initial volume of material. The selection of initial volumes and initiation locations for lahar hazard assessment are typically based on historical lahar events and expert elicitation. This approach does not account for the mechanics of initiation or the dependence of rain-triggered lahars on rainfall intensity and characteristics of eruptive deposits. In this presentation, we demonstrate a method for calculating the initiation volume of rain-triggered lahars based on principles of soil mechanics and hydrology. The method presented here relies on terrain and deposit characteristics (e.g. slope angle, hydraulic conductivity) and measures of rainfall intensity and duration. A probabilistic estimation of lahar hazard is calculated through the exceedance probabilities of rainfall intensity, frequency and duration (IFD). The key data requirements, assumptions and implications for multi-hazard assessment in volcanic environments will also be discussed.

IAVCEI (Volcanology, Geochemistry)

VS10a - VS10/VS11/VS31 Probabilistic Volcano Hazard Analysis / Short-Term Forecasting of Volcanic Hazard: So Far, So Good? / Quantifying and Communicating Uncertainty During Volcanic Crisis

IUGG-2210

Towards a Proactive Risk Mitigation Strategy at La Fossa Volcano, Vulcano Island

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We present a probabilistic multi-hazard assessment for Vulcano Island (Italy) developed to asses the potential impact on the built environment, which constitutes a first step towards a proactive risk reduction strategy. Vulcano, a 21 km^2 island with two primary communities host to 900 permanent residents and up to 10,000 daily visitors during summer, shows a strong dependency on the mainland for basic needs (water, energy) and relies on a ~2 month tourism season for its economy. Detailed studies of the stratigraphy of the last 1000 years reveal a dominance of Vulcanian and Subplinian eruptions, producing a range of hazards acting at different time scales. These include tephra fallout, volcanic ballistic projectiles and primary and secondary lahars.

In order to assess the hazard in a fully probabilistic way, innovative approaches were developed to i) assess the hazard related to long-lasting Vulcanian eruptions characterized by repeated emissions of small quantities of tephra over months to years, ii) estimate the potential volumes of unstable tephra potentially remobilized into lahars by combining statistics of rainfall and various expressions of the Safety Factor and iii) probabilistically quantify the hazard related to the ejection of volcanic ballistic projectiles based on field observation, for which we propose a new model. Additionally, we developed a GIS-based method to assess the fragility of the typical flat reinforced concrete roofs to static tephra loads based uniquely on the building’s footprint. Potential rain scenarios were explored to assess the seasonal impact on the built environment following an eruption.

IAVCEI (Volcanology, Geochemistry)

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IUGG-3324

Probabilistic hazard assessment from pyroclastic density currents in the neapolitan area

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Pyroclastic Density Currents (PDCs) are among the most devastating volcanic outcomes in terms of death toll. However, a structured Probabilistic Hazard Assessment (PHA), accounting for all the uncertainties involved (from the aleatory nature of their generation and propagation to the epistemic uncertainty due to our limited knowledge) is still lacking, especially when compared to its analog from other volcanic hazards, e.g. tephra fallout. PHA from PDCs is ultimately hampered by the complexity in their generation, propagation and deposition processes, which makes their modeling either too simplified to reproduce transport and deposition mechanisms inferred from past PDC deposits, or too sophisticated to be used in hazard perspective, i.e., considering the uncertainties involved.
In this study, we first quantitatively check the ability of a simple model (Energy Cone) to reproduce the basic features of the available PDCs deposits from past eruptions of Mt Vesuvius and Campi Flegrei caldera. This model is then applied in a Monte Carlo scheme. As regards dense PDCs from Mt Vesuvius, we also run Titan2D in a PCQ scheme to reduce the number of simulations needed.
The combination of the output from these two simulation schemes allows producing a preliminary PHAs for PDCs on the Neapolitan area from the two volcanoes separately, along with a quantification of all the known uncertainties. We also attempt a very preliminary integrated PHA for PDCs from the two volcanoes insisting on the same target area, to achieve a multi-source assessment.

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IAVCEI (Volcanology, Geochemistry)

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IUGG-3942

Coupling geomorphic analyses and probabilistic modeling at Merapi volcano: Implications for hazard zonation and future eruptive activity

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Pyroclastic density currents (PDCs) are among the most dramatic, complex and dangerous volcanic phenomena. Although significant progress in understanding the fundamental dynamics of PDCs has been made over the last 30 years, many processes remain poorly understood. Fatalities continue to result from unsuccessfully anticipated flow behavior, often related to their high mobility and ability to surmount topographic barriers. Recent field studies at Merapi volcano (Central Java, Indonesia) have highlighted the existence of substantial interfluve PDC deposits on its southern flank and suggest that the generation of various types of unconfined PDCs is a common process at this high-risk volcano. The delineation of key areas at risk from overbanking processes is essential at Merapi, particularly in relation to a future sequence of dome growth and predominantly gravitational collapses or lateral explosions with a crater area open and a gorge oriented toward the south. In this respect, a new high-resolution (~2m) digital elevation model of the current topography in the southern flank has been obtained from new Pleiades satellite images. Then, a detailed geomorphic assessment of the Gendol valley (south flank) was performed to identify the potential overspill/breakout sites of valley-confined PDCs that could generate deadly overbank and/or high-energy dilute PDCs, where changes in the channel capacity and longitudinal channel gradient reach critical values. Results were compared against a new PDC probabilistic map performed using the Titan2D model with a Monte-Carlo approach. A combination of these different approaches is vital for an accurate characterization of areas prone to future unconfined PDCs at Merapi and can be potentially applied at similar volcanoes elsewhere.

IAVCEI (Volcanology, Geochemistry)

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IUGG-4289

Quantifying aleatory and epistemic uncertainties of Pyroclastic Density Currents at Mt Vesuvius (Italy) as modeled through Energy Cone

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Pyroclastic Density Currents (PDCs) stand as a double-edged issue as regards Probabilistic Volcanic Hazard Assessment. On the one hand, they are the most dangerous physical process that can occur during an explosive eruption. On the other hand, their intrinsic complexity tends to hinder probabilistic analyses since the large aleatory and epistemic uncertainties in play are difficult to quantify.

Thus, there is a patent trade-off between the degree of physical reliability of the PDC numerical simulator (i.e. the more sophisticated the longer its runtimes) and the efficiency of the Uncertainty Quantification Technique (UQT), in terms of the number of simulations needed for a robust probabilistic analysis.

Here, we opt for a simple numerical simulator, Energy Cone (EC), coupled to a common but low-efficiency UQT, Monte Carlo sampling, to obtain a quantitative description of aleatory and epistemic uncertainties related to PDCs at Mt Vesuvius (Italy).

In particular, we analyze and quantify four different sources of epistemic uncertainty which arise due to incomplete knowledge on: (1) boundary conditions (e.g. different resolution in Digital Elevation Models), termed Input Uncertainty; (2) appropriate Probability Density Functions for the simulator parameters, termed Parametric Uncertainty; (3) theoretical assumptions (i.e. possible relationships between the EC parameters), termed Theoretical Uncertainty; and (4) limitations of the simulator itself, termed Structural Uncertainty. We also compare the

contribution of each source of epistemic uncertainty to a measure of aleatory uncertainty.

We argue that future probabilistic hazard analyses can benefit from this kind of detailed epistemic uncertainty assessments.

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IUGG-5260

Investigating the effects of event scale and vent location on pyroclastic density current hazard maps of Campi Flegrei caldera (Italy)

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Campi Flegrei (CF) is an active, densely populated, caldera with very high risks associated with the occurrence of pyroclastic density currents (PDCs). Mapping of PDCs hazard in caldera settings is challenging due to the large uncertainty on future eruption scale and vent location as well as the complex dynamics of flows over caldera topography. First background probability maps of PDC invasion were produced adopting a vent-opening probability map, with associated uncertainty, of the whole caldera based on the eruptive record of the last 15 kyr. Maps were produced by a Monte Carlo approach by using a simplified inundation model based on the "box model" approximation tuned to results from 2D transient numerical simulations of flow dynamics. In this presentation we illustrate the independent effects of event scale and vent location, as well as of possible correlations between them, on the resulting invasion maps. The analysis allowed to identify areas with elevated probabilities of flow invasion as a function of the diverse assumptions made. With quantification of some sources of uncertainty in relation to the system, we were able also to provide mean and percentile maps of PDC hazard levels.

IAVCEI (Volcanology, Geochemistry)

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IUGG-0656

A statistical method for estimating eruption volumes for Mt Taranaki events

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While temporal forecasting of eruption episodes has been widely studied, forecasts of eruption size are less common. Models that incorporate eruption size depend on the availability of reasonable estimates of eruptive volumes, however, there are very few volcanoes with su?cient volume data available.

We present a Bayesian statistical approach to estimate eruption volumes for a series of eruptions from Mt Taranaki (New Zealand). Most studies focus on large widespread eruptions using isopach maps constructed from observations at exposed locations. Whereas we take a unique approach, incorporating raw thickness measurements from additional unexposed lake and swamp records. This facilitates investigation into the dispersal pattern and volume of much smaller events.

Given the general scarcity of data, and the physical phenomena governing tephra attenuation, a high-dimensional complex model is required. Point thickness observations are modelled as a function of the distance and angular direction of each location. Larger well estimated events are used as leverage for understanding the smaller unknown events, and uncertainty in thickness measurements can be properly accounted for. The model estimates, in addition to eruptive volumes, the wind and site-speci?c e?ects on the tephra deposits.

We demonstrate a means of extracting plausible volume estimates from really sparse data which opens up new vistas for hazard estimation. Resulting estimates provide a comprehensive record suitable for supporting hazard models. Preliminary examination suggests a size-predictable relationship for Taranaki events. Of course, application is not limited to Mt Taranaki. Model details could be adjusted to suit records for other polygenetic volcanoes.

IAVCEI (Volcanology, Geochemistry)

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IUGG-1315

Short-term volcanic hazard assessment through Bayesian inference: retrospective application to the Pinatubo 1991 volcanic crisis

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One of the most challenging aspects of managing a volcanic crisis is the interpretation of the monitoring data, so as to anticipate to the evolution of the unrest and implement timely mitigation actions. An unrest episode may include different stages or time intervals of increasing activity that may or may not precede a volcanic eruption, depending on the causes of the unrest (magmatic, geothermal or tectonic). Therefore, one of the main goals in monitoring volcanic unrest is to forecast whether or not such increase of activity will end up with an eruption, and if this is the case, how, when, and where this eruption will take place. As an alternative method to expert elicitation for assessing and merging monitoring data and relevant past information, we present a probabilistic method to transform precursory activity into the probability of experiencing a significant variation by the next time interval (i.e. the next step in the unrest), given its preceding evolution, and by further estimating the probability of the occurrence of a particular eruptive scenario combining monitoring and past data. With the 1991 Pinatubo volcanic crisis as a reference, we have developed such a method to assess short-term volcanic hazard using Bayesian inference.

IAVCEI (Volcanology, Geochemistry)

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IUGG-1441

Spatio-volumetric hazard estimation, with an application to the Auckland Volcanic Field

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The idea of a volcanic field 'boundary' is prevalent in the literature, but ill-defined at best. We use the strongly elliptically constrained vents in the Auckland Volcanic Field to examine how spatial intensity models can be tested to assess whether they are consistent with such features. A means of modifying the anisotropic Gaussian kernel spatial density estimate for vent location to reflect the existence of a 'hard' boundary is then suggested, and the result shown to reproduce the observed elliptical distribution. The low temporal rate of eruptions typical in monogentic fields means that the distribution of the timing and location of a future event are less useful information than those of the location and size. Hence we introduce a new idea, that of a spatio-volumetric model. Significant dependencies between the locations and erupted volumes of the observed centres are deduced, and expressed in the form of a spatially-varying probability density for eruptive volume. We find that in future, larger volumes are to be expected in the 'gaps' between existing centres. The location of the greatest forecast volumes lie in the main shipping channel between Rangitoto and Castor Bay, and on the southern approaches to the arterial Auckland Harbour Bridge. Lesser volumes are likely in the vicinity of groups of small volume centres. The results argue for tectonic control over location and magmatic control over erupted volume.

IAVCEI (Volcanology, Geochemistry)

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IUGG-3982

Long-term and short-term precursors to the 2014 eruption at Kuchinoerabujima volcano, Ryukyu Islands, Japan

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A magmato-phreactic eruption occurred at Shindake crater of Kuchinoerabujima volcano on August 3, 2014. The eruption created cracks at the west rim of the crater and fissure north-south direction over the crater. The seismicity of shallow (<500m) volcano-tectonic earthquakes has increased since July, 1999 and swarms of the earthquake repeated at interval of 1-2 years. Associated with increase in the seismicity, ground around the crater uplifted by 25 cm and moved outward from the center of the crater by 26 cm for the last 15 years, as detected by GPS campaign. The deformation was concentrated near the crater and the pressure source caused the deformation was located at 500 m beneath the crater. The inflation accompanied increase in heat flux, as observed by infrared scanner and inferred by change in geomagnetic total force. We detected 3 inflation events in 2005, 2006 and 2008, and the seismicity increased at the beginning of acceleration of the deformation. However increase in volcanic activity shown by multi-parameter observation, such as increase in seismicity simultaneous to the inflation, did not lead to any eruptions. After appearance of fumarolic activity at the south wall of the crater in October 2008, the correspondence of seismicity with inflation became ambiguous, although seismicity stayed at a high level. No significant changes were detected in seismicity and ground deformation for 3 years prior to the eruption, except sudden and short-term uplifting tilt of the crater side only 1 hour before the eruption. These indicate that precursory of the eruption was comprised of long-term preparation for 15 years and quite short-term precursor for 1 hour directly lead to the eruption.

IAVCEI (Volcanology, Geochemistry)

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IUGG-5120

Using volcanic tremor for eruption forecasting at White Island volcano (Whakaari), New Zealand

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Eruption forecasting is a challenging task because of the complexity of volcanic systems. Despite remarkable efforts to develop complex models to explain volcanic processes prior to eruptions, the material Failure Forecast Method (FFM) is one of the very few techniques that can provide a forecast time for an eruption. However, the method requires testing and automation before being used as a real-time eruption forecasting tool at a volcano. We developed an automatic algorithm to issue forecasts from volcanic tremor increase episodes recorded by Real-time Seismic Amplitude Measurement at one station and optimized this algorithm for the period August 2011-January 2014 which comprises the recent unrest period at White Island volcano, New Zealand. A detailed residual analysis greatly improved the performance of the procedure. Four out of the five eruptions reported during this period occurred within a failure window (using prediction intervals) forecast by our optimised algorithm. The probability of an eruption on a day within a failure window was 0.21, which is much higher than the probability of having an eruption on any day during the same period (0.0057). Whereas the tremor episodes preceding these four eruptions have a similar goodness-of-fit with the FFM, their spectral characteristics are different. Their duration-amplitude distributions support the hypothesis that several processes were likely occurring prior to these eruptions. We propose that slow rock failure and fluid flow processes are plausible candidates for the tremor source of these episodes. This hindsight exercise can be useful for future real-time implementation of the FFM at White Island. A similar methodology could also be tested at other volcanoes even if only a limited network is available.

IAVCEI (Volcanology, Geochemistry)

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IUGG-5300

Multiplets: A useful forecasting tool?

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Prior to volcanic eruptions, an acceleration in geophysical parameters (earthquakes, tilt, gas emissions) has often been observed. Here, we use the acceleration of low frequency seismicity (number of events and amplitudes of events) in combination with the Material Failure Law (MFL) to investigate the relationship between the accelerating precursor and large scale dome collapse events and volcanic eruptions. We show that the application of the MFL in its original context can provide an accurate forecast to the timing of collapse, but the fit of the linear regression to the inverse event rate of seismic events can be poor. We believe this is because we are not isolating a single active system at depth, and therefore have many unknown variables which could be influencing the result. Therefore, we apply a cross correlation technique to identify similar seismic waveforms (multiplets) and consequently focus on a single active system, which is then used as the accelerating geophysical parameter in the MFL. Using this technique we are able to more accurately forecast the timing of failure of a dome collapse, as well as compare each of the found families of multiplets for their forecasting potential. In some cases however no real acceleration in low frequency seismicity is seen prior to a large events. We investigate the stability of the volcanic edifice itself in this instance using Finite Element Modelling, which allows us to suggest critical slope angles and heights of the dome for instability, which is extremely useful for hazard assessment.

IAVCEI (Volcanology, Geochemistry)

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IUGG-0443

Aviation management during explosive volcanic eruptions: improvements in communication between scientists and other stakeholders

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The 2010 Eyjafjallajökull eruption in Iceland caused unprecedented disruptions of air traffic operations in Europe, and brought a great attention to impact of volcanic ash on civil aviation. This aviation breakdown pointed out some weaknesses in the management of volcanic ash episodes. In particular, communication and information flow between the stakeholders was recognized as a major concern. We identify and qualify the relationships between many actors involved in management of aviation in case of ash-forming volcanic eruptions. Due to the complexity and multidisciplinary nature of the topic, the number of impacted actors is constantly growing . In addition, the involved stakeholders are fragmented, do not constitute a proper “community”, and have intermittent collaboration given the discontinuous occurrence of volcanic eruptions. Finally, most on-going scientific and technical developments are mainly focused on specific aspects that concern homogeneous groups (e.g., modellers or aviation managers), often with little transversal interaction. First, we present the existing situation of communication between stakeholders involved in civil aviation management during explosive volcanic eruptions (field and monitoring scientists, modellers, air traffic managers, pilots and other aviation employees, authorities, etc.). Then, having performed an anonymous on-line survey to identify the needs of the stakeholders, we underline the main differences between the groups identified. The survey allows identifying the needs and priorities of different stakeholders for best-practice information flow and communication. Results provide useful insights for the development of strategies to support policy-makers in the aviation sector during explosive eruptions.

IAVCEI (Volcanology, Geochemistry)

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IUGG-1062

Building sustained volcanic crisis management capability: Building on lessons learnt from exercising the communication of uncertain volcanic advice

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The impact of uncertainty on decision making has become a pressing issue for debate in the natural hazards community. Volcanic eruptions present a particularly uncertain hazard environment, due to variations in the duration of precursory unrest, and the potential eruption scale and associated impacts that can change and evolve radically and in unpredictable ways over time. Crisis management in this context is influenced by how the individual and team situational awareness of emergency management officers accommodates external scientific advice to progressively define the problem, identify future scenarios and plan accordingly in a context in which their decision making is constrained by the epistemic (lack of knowledge) or stochastic (variability of the system) uncertainty associated with the advice.

We report here on a series of real time emergency management table top exercises (3 exercises with 5-6 practitioners) conducted to investigate how the provision of uncertain science advice influences decisions and Incident Action Plans for a hypothetical volcanic eruption. Data were obtained from recordings of group activity, questionnaires and debriefs about the processes they went through, the key issues identified, what information they were looking for during the hypothetical event, and what they would do differently. We discuss the development and conduct of these exercises and present findings covering how participants self-organised in exercise settings, and how they coped with the prevailing scientific uncertainty and corresponding disagreement amongst the group. The implications of the findings for emergency manager use, understanding and utilisation of scientific information are discussed.

IAVCEI (Volcanology, Geochemistry)

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IUGG-1454

Application of a multi-station alert method for short-term forecasting of eruptions at Etna, Italy

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From 11 January to 15 November 2011, 18 paroxysmal eruptions occurred at Etna, Italy. These events belong to a long sequence of eruptive episodes, which marked the prevalent explosive style of the volcano since the early 2000s. Applying “KKAnalysis”, a software for pattern classification that combines Self-Organizing Maps and fuzzy clustering, to the background seismic radiation (so-called volcanic tremor), we were able to detect critical changes in the spectral characteristics (amplitude and frequency content) at a very early stage of the volcano unrest. The online implementation for surveillance purposes of KKAnalysis provided automatic alert of the impending eruptive events from hours to a few days in advance. In its original version, the classifier analyzed the data stream continuously recorded at a single seismic station. By using offline a modified version of KKAnalysis, here we apply the software to the seismic signal recorded at 11 broadband stations in 2011. The seismic sensors were located at various distances (from 1 to 8 km) from the active craters. The continuous records and the optimal geometry of the seismic network offer us the possibility to track the spectral variations in time and space. We show the new results of pattern classification and propose a revised, more powerful multi-station alert method that now provides short-term forecasting also in the form of animated maps that flag the detection of changes at each station. This allows us to observe how the unrest develops in various sectors of the volcano. We discuss the performance of the method and the robustness of the eruption forecasts in the context of the complex dynamics of a volcanic system such as Etna.

IAVCEI (Volcanology, Geochemistry)

VS10c - VS10/VS11/VS31 Probabilistic Volcano Hazard Analysis / Short-Term Forecasting of Volcanic Hazard: So Far, So Good? / Quantifying and Communicating Uncertainty During Volcanic Crisis

IUGG-3878

Determining eruption onsets from geophysical data: What we know and when we know it

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Recent eruptions are studied using integrated data including seismic, infrasound and lightning to help determine the sequence of events that determine eruption onset. Seismic data reveal processes below the ground surface. Seismic waves travel quickly, several km per second, so the travel time to nearby sensors is negligible. However, seismic data are ambiguous: the same processes that lead to eruption also lead to shallow intrusion. Further, the seismic onsets of some eruptions resemble the seismic onsets of some earthquakes. In contrast, the onset of infrasound signals confirms unambiguously mass flux at the Earth's surface. There is some ambiguity because both gases and ash may constitute the mass and additional data are needed to determine the ratio or relative amounts. Infrasound waves travel slowly, ~340 m/sec, so even at close station distances of 3-4 km, the travel time is about 10 seconds. Recent instrumental lightning data reveal three types of signals: vent discharges, near vent lightning, and plume lightning. Vent discharges occur immediately at eruption onset and can be detected when there is line of sight between the sensor and the vent. The signals travel at the speed of light, which is the fastest possible speed. Recorded signals are strong and show clearly on sensors >100 km away. Near vent lightning confirms plumes of km scale, and plume lightning confirms taller ash-rich plumes. The combination of seismic, infrasound and lightning data is very useful to characterize eruption onset and subsequent plume processes. Where line of sight to the vent is possible, lightning detection offers the fastest and most unambiguous way to determine eruption onset.

IAVCEI (Volcanology, Geochemistry)

VS10c - VS10/VS11/VS31 Probabilistic Volcano Hazard Analysis / Short-Term Forecasting of Volcanic Hazard: So Far, So Good? / Quantifying and Communicating Uncertainty During Volcanic Crisis

IUGG-5066

Hybrid physical-stochastic models for real-time eruption forecasting

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The quality and utility of any forecast of eruption time based on analysis of geophysical data depends on the validity of the model used and the relevant uncertainties. Here we review the theoretical and experimental foundations for hybrid physical-stochastic models for eruption forecasting based on a material failure approach, and examine the practical limits such hybrid models place on the forecasting power. We first compare the results of a recently-published discrete element model for accelerated damage in a cylindrical digital rock with those of real laboratory rock samples. The rupture population dynamics in the numerical model closely reproduces those in real rocks, including an inverse power law acceleration of acoustic emission event rate or total energy, and power-law scaling of source energy or moment (the Gutenberg-Richter law), the correlation function of event locations, and the inter-event time. The power law exponents change systematically as a function of stress in the same way as in laboratory experiments, associated with localisation of events on an incipient fault plane. The results of the numerical model are supported by laboratory experiments and real volcanic sequences, which show a systematic increase in forecasting power as a function of deformation rate, consistent with the fact that volcanic eruptions (with higher deformation rate detectable at the surface) are easier to forecast than tectonic earthquakes. On the other hand a number of different mechanisms may control eruption onset, each with its own source of uncertainty. We then consider the implications of irreducible stochastic components for operational forecasting, and suggest methods of improving the accuracy and estimates of the precision of any failure forecast.

IAVCEI (Volcanology, Geochemistry)

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IUGG-0765

Modelling temporal uncertainty and eruptive vent clustering at Campi Flegrei caldera (Italy)

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After the large scale event of Neapolitan Yellow Tuff (~15 kyr BP), intense and mostly explosive volcanism has occurred within and along the boundaries of the Campi Flegrei caldera. Eruptions occurred closely spaced in time, over periods from a few centuries to a few millennia, and were alternated by periods of quiescence lasting even several millennia. Sometimes events also occurred closely in space thus generating a cluster of events. The most recent Monte Nuovo eruption occurred in 1538 AD after more than about 2.7 kyr from the previous one. Unfortunately, there is a remarkable uncertainty on the eruptive record, affecting the time of eruptions, location of vents as well as the erupted volume estimates. This study has the purpose of modelling such uncertainty by using a quantitative probabilistic model and obtaining quantitative estimates about the temporal and spatial distribution of the volcanism. In particular, the study adopts a time-space double stochastic Poisson-type model with a local self-exciting feature able to produce clustering events that are consistent with the reconstructed observed pattern at Campi Flegrei. Results allow to estimate the temporal eruptive base-rate of the caldera as well as its capacity to generate clusters of events. In particular the effect of the Monte Nuovo event on a possible reactivation of the system has been investigated. The analysis allows also to discriminate between the initial and main part of the eruptive epochs as well as to investigate the different behaviour of the eastern and western sectors of the caldera.

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IUGG-1440

Dynamic uncertainty in cost-benefit analysis of evacuation prior to a volcanic eruption

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Around the world, many populations lie in the shadow of dangerous volcanoes. This potential for disaster has led to constant extensive monitoring of possible precursors to an eruption, and probabilistic techniques to transform this monitoring information into eruption probabilities. Less developed are the decision models that determine at what probability level an evacuation should be called. A simple, easily communicated, static criterion exists that balances the value of life lost in a missed evacuation against the cost of economic dislocation in the case of an unnecessary evacuation. However, this neglects dynamic facets such as the distribution of time to the eruption onset, the non-zero time required for an evacuation, spontaneous evacuation and return, the possible eruption size, and political pressure on the decision maker. We show how these can be treated stochastically, and derive the resulting effect on the evacuation dynamics. This is illustrated by the example of a future eruption of Mount Vesuvius. A novel method is presented to invert a probability of eruption (in a time window) hazard into a statistical distribution for the time to eruption. The model, through an optimal cost-benefit based decision criterion, provides a probability threshold for immediate evacuation, and below this, a time window during which the event probability can be refined before a decision must be made. The baseline model has a probability threshold some 13% lower than the static model, and the sensitivity of the results to the estimated parameters is examined.

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IUGG-3910

Probabilistic approach to decision-making under uncertainty during volcanic crises: Retrospective application to the El Hierro (Spain) 2011 volcanic crisis

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Understanding the potential evolution of a volcanic crisis is crucial to improving the design of effective mitigation strategies. This is especially the case for volcanoes close to densely-populated regions, where inappropriate decisions may trigger widespread loss of life, economic disruption and public distress. An outstanding goal for improving the management of volcanic crises, therefore, is to develop objective, real-time methodologies for evaluating how an emergency will develop and how scientists communicate with decision makers. Here we present a new model BADEMO (Bayesian Decision Model) that applies a general and flexible, probabilistic approach to managing volcanic crises. The model combines the hazard and risk factors that decision makers need for a holistic analysis of a volcanic crisis. These factors include eruption scenarios and their probabilities of occurrence, the vulnerability of populations and their activities, and the costs of false alarms and failed forecasts. The model can be implemented before an emergency, to identify actions for reducing the vulnerability of a district; during an emergency, to identify the optimum mitigating actions and how these may change as new information is obtained; and after an emergency, to assess the effectiveness of a mitigating response and, from the results, to improve strategies before another crisis occurs. As illustrated by a retrospective analysis of the 2011 eruption of El Hierro, in the Canary Islands, BADEMO provides the basis for quantifying the uncertainty associated with each recommended action as an emergency evolves, and serves as a mechanism for improving communications between scientists and decision makers.

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VS10p-451

Precursors of Kamchatkan volcanoes eruptions

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Kamchatka is one of the most active volcanic regions on the planet. Large explosive volcanic eruptions, in which the ash elevates up to 8–15 km above sea level, occur here yearly. Scientists have revealed many precursors of explosive eruptions detected by different methods. These are rapid increasing of fumarolic activity or increasing number of observable hot avalanches on volcano extrusions which erupt andesite and dacite lavas; deformations on volcano flanks registered by tiltmeters, GPS and satellite data; increasing temperature of volcanic gases and higher concentration of HCl measured on a volcano; etc. Pavel Tokarev (1966, 1976, 1985, 1988) revealed seismic precursors for eruptions of Klyuchevskoy, Plosky Tolbachik, Sheveluch and Bezymianny volcanoes. Progress in space research allowed detecting eruption precursors using data from satellites. Satellite observation is very important because some volcanoes can be unavailable for other types of monitoring. For example, 19 active volcanoes in Kamchatka have no seismic stations. The articles on satellite monitoring of evolution of the 1997 and 1998 eruptions of Bezymianny volcano (Dehn, et al., 2000; Schneider, et al., 2000) are one of the first works in which variations of temperature and size of a thermal anomaly in the area of a volcano are considered to be operative precursor of strong explosive eruption. The long duration satellite monitoring of active Kamchatka volcanoes proved this precursor to be effective not only for Bezymianny volcano but also for volcanoes with different composition of erupted volcanic products.

IAVCEI (Volcanology, Geochemistry)

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VS10p-452

A short-term, forecasting-based, Volcanic Activity Level selection method for the management of volcanic crises

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Currently, volcanic crises worldwide are managed using a series of protocols generally developed for explosive stratovolcanoes and volcanoes with frequent eruptions. Such protocols cannot be easily adapted to manage volcanic unrest after long repose periods. The 2011 volcanic unrest at El Hierro Island evidenced the need of developing a specific Volcanic Activity Level procedure for short-term management and forecasting of volcanic hazards. Volcanic hazards management is usually focused to reduce the risk caused by an eruption. However, in the case of effusive volcanism, the associated seismic activity may also have a strong impact on population and cause structural damages. This short-term forecasting procedure comprises a monitoring network, the software tools for analysis of the monitoring parameters, the Volcanic Activity Level framework, and the assessment of hazard. This Volcanic Activity Level focuses on phenomena related to moderate eruptions, and on potentially destructive volcano-tectonic earthquakes and landslides. We introduce a set of new data-analysis tools, aimed to detect data trending changes, as well as instrumental failures that may be misinterpreted. The data patterns changes are translated by the scientific team into a code that is easy to use and understand by scientists, technicians and decision-makers.

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VS10p-453

Towards a map of the background spatial probability of vent opening at Somma-Vesuvius caldera

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The Somma-Vesuvius (SV) volcano has shown in its history a large variability of eruptive styles associated with a significant spatial variability of vent locations. In particular, the vent position of large explosive eruptions showed a shift within the present SV caldera. Numerical simulations of explosive eruptions with varying vent location inside the caldera indicate a major effect on the runout and dispersal of pyroclastic density currents produced by column collapse. This work summarizes the activities that have been put forward with the aim of producing a first background (also named long-term or basal) vent opening probability map for the area of the SV caldera. These activities have been focused on three main objectives: i) the collection and critical review of key volcanological features (location of past vents, distribution of faults, etc.) that can influence the spatial distribution of future vents; ii) the development of probability density maps through the use of Gaussian kernel functions on the different volcanological datasets and iii) the weighted linear combination of the density maps of the volcanological variables to produce a background vent opening probability map where uncertainties are explicitly accounted for through expert elicitation methods. Results illustrate the different influence of the volcanological variables on the final maps, the areas at higher and lower probability of vent opening and the effects of the different elicitation methods adopted to quantify the uncertainty sources. The map represents the first step to the production of maps of the probability distribution of pyroclastic flow invasion or of ash fallout for the different eruptive scenarios to be considered in the case of a next reactivation at SV.

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VS10p-454

Formalized approach to prediction of Bezymianny Volcano eruption from seismological data

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Bezymianny Volcano is one of the most active and dangerous volcanoes of Kamchatka, so the problem of its eruption prediction is actual. It's well-known, that seismic activization precedes volcanic eruptions often. So the choice of seismicity parameter and assessment of the current seismicity level using this parameter are important for formalized prediction. We used the current value of distribution function F of released seismic energy in time window dT=5 days as such parameter.

Using time series of F during 2000-2012 we determined the image of precursor as average behavior of F before 18 cases of Bezymianny eruption. The shape of this precursor is close to hyperbolic function and its duration is ~15 days.

Then we took this image as weight function for search of similar behavior of F during 1999-2014. For different level of correspondence of current F and precursor image we allocated alarm intervals. Often such alarm interval includes time before eruption, but the another situation (eruption without alarm or false alarm) is possible too. These data allow to calculate very important for any prediction technique parameters – reliability, validity, efficiency of precursor as function of precursor level.

The reliability (as ratio of number of "predicted" eruptions and total number) is changing from 0.95 to 0.33. The validity (as ratio of number of successful (or realized by eruption) precursor anomalies and total number of anomalies) is equal to 0.3–0.6. The efficiency (statistical significance) of precursor was calculated by two independence methods – by Gusev and Molchan techniques. The received values correspond to high significance of proposed precursor. The efficiency value allows to specify the probability of realization of the forecast depending on alarm duration.

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VS10p-455

Detection of volcano unrest from multiparameter pattern classification

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Short-term forecasting of volcanic unrest requires high-rate/continuous data acquisition and monitoring of multidisciplinary data. Volcano Observatories worldwide usually adopt various tools for the automatic processing of geophysical and geochemical data streams to detect changes heralding impending eruptive activity. Here we discuss the application to multivariate data sets of a free software named KKAnalysis. The software is one of the data mining tools of the European MEDiterrranean Supersite Volcanoes (MEDSUV) project, and carries out the pattern classification of data of whatever nature provided in numerical format. We explain how this software works combining Self-Organizing Maps and fuzzy clustering. Beside numerical log files, changes of pattern characteristics are visualized as output of KKAnalysis in graphical form, by creating a sequence of colored symbols. This convenient color code highlights the development in time of the characteristics of whatever multidimensional feature vector. We also present results of applications to seismic data (volcanic tremor), in-soil radon activity, and ambient parameters (barometric pressure and air temperature measurements acquired at the same site of the radon data). We explore these applications at Mt. Etna, Italy, in time spans of various duration (from months to years), in which eruptive activity ranged from short-lived (usually from tens of minutes to hours) lava fountains to long-lasting (from months to years) lava effusions.

IAVCEI (Volcanology, Geochemistry)

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VS10p-456

Activity of Kamchatkan and northern kuriles volcanoes database of Kamchatkan volcanic eruption response team

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KVERT IVS FEB RAS was founded in 1993. The goal of KVERT is to reduce the risk of aircraft encounters with volcanic ash clouds in the North Pacific area through timely detection of volcanic unrest, tracking of ash clouds, and prompt notification of airline authorities and others about volcanic ash hazards. KVERT staff work closely with staff of AVO, AMC at Yelizovo Airport and the VAACs of Tokyo, Anchorage, Washington, Montreal and Darwin to release timely eruption warnings. KVERT staff analyzes volcano monitoring data (seismic (KBGS RAS), satellite, visual and video, pilot reports), assigns an Aviation color code (ICAO) for aviation and issues VONA of eruptive activity at Kamchatkan and Northern Kuriles volcanoes. Since 1998 KVERT presented in the Internet: http://www.kscnet.ru/ivs/kvert/). Basic information about the active volcanoes of the region and their potential hazard to aviation, Aviation color codes and others are presented in the electronic catalogue: http://www.kscnet.ru/ivs/kvert/volcano.php. Since 2012, KVERT releases are preparing and mailing to users with help of the computer-aided web-system and posting on KVERT website. KVERT issues the VONA, Weekly and Daily releases about activity of Kamchatkan volcanoes: http://www.kscnet.ru/ivs/kvert/van/. Information about the state of the volcanoes, and volcanic events (ash explosions, clouds and plumes) and theirs characteristics (date, height, directions and the others) are stored in Activity of Kamchatka and Northern Kuriles volcanoes database. Current and archive data are available at KVERT-website and in the Volcanoes of Kurile-Kamchatka Island Arc (VOKKIA) Information system on the IVS FEB RAS Geoportal (http://geoportal.kscnet.ru/volcanoes/van/).

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VS10p-457

Landslides susceptibility mapping in the Campi Flegrei volcanic areaby using a multidisciplinary approach

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The Campi Flegrei caldera is an active volcanic field mostly subject to high volcanic risk both for his past high frequency explosive eruptive activity and for the high densely populated communities living in the area, including large sector of the city of Naples. In case of renewal of the volcanic activity or an earthquake occurrence, the territory can be affected by natural disastrous events as tephra fallout, pyroclastic flows and landslides. These events can seriously damage a consistent urbanized area causing in the worst case losses of human life. In order to mitigate and prevent the effect on the territory of such natural disasters we propose a study for mapping the areas affected by potential triggering of landslides. This study is based on methodological approach using the GIS environment for data integration of different source: Digital Elevation Model, Remote Sensing images and Geological and Structural Field survey. These data are stored as matrix formats combined together and resulting in a index of landslides susceptibility (ILS). This index allows us to map the areas of the Campi Flegrei and the city of Naples more prone to generate landslides, providing a valid contribution to improve the prevention of such natural calamity. The result will be compared with the available database of landslides occurred in the past to test the reliability of the methodological approach here proposed.

IAVCEI (Volcanology, Geochemistry)

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VS10p-458

"Probabilistic hazard assessment during non-magmatic unrest: Introducing BET_UNREST"

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Although most of volcanic hazard studies consider magmatic eruptions, volcanic hazardous events can also occur during non-magmatic unrest, defined as a state of volcanic unrest in which no migration of magma can be recognized. Examples are tectonic unrest (able to cause concern independently on further outcomes) and hydrothermal unrest, that may lead to eruption (i.e. phreatic eruptions). Recent events (e.g. Ontake eruption September 2014) have demonstrated that phreatic eruptions are still hardly predictable. For these reasons, it is of paramount importance to identify indicators that define the state of non-magmatic unrest. Often, this type of unrest is driven by fluids-on-the-move, requiring alternative monitoring setups, beyond the classical seismic-geodetic-geochemical architectures. We here present the new version of the probabilistic tool BET (Bayesian Event Tree) specifically developed to include the forecasting of non-magmatic unrest and related hazards. The structure of the new BET_UNREST differs from the previous BET_EF (BET for Eruption Forecasting) by adding a dedicated branch to detail non-magmatic unrest outcomes. Probabilities are calculated at each node by merging prior models and past data with new incoming monitoring data and the results can be updated any time new data have been collected. Monitoring data are weighted through pre-defined thresholds of anomaly. A major aim of BET_UNREST is to create a user-friendly, open-access, and straightforward probabilistic method to help forecast phreatic eruptions. BET_UNREST will be tested on volcanoes in non-magmatic unrest during the last decades/centuries. The research is funded by the EU project VUELCO.

IAVCEI (Volcanology, Geochemistry)

VS12a - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

IUGG-0842

Gas emissions from the Hyper-Acid Crater Lake of Poás Volcano, Costa Rica

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Magmatic gases are the primary source of heat and volatiles that sustain warm acidic crater lakes. Yet, the composition of gases emitted from these lakes to the atmosphere has been assessed for only a handful of cases. Since April of 2013, we have been monitoring gas emissions from the crater lake and high T fumaroles at Poás volcano using Multi-GAS. These instruments measure CO_2, SO_2, H_2S, H_2, and H_2O concentrations, allowing derivation of gas ratios. We have also sporadically conducted mini-DOAS walking traverse measurements along the west crater rim to determine SO_2 fluxes.

Our data show that the gas plumes from the lake and fumaroles are clearly distinguishable in both Multi-GAS and mini-DOAS measurements. The fumarolic gases are characterized by CO_2/SO_2 of 0.39±0.11, H_2/SO_2 of 0.12±0.08, and H_2S/SO_2 of 0.12±0.04, which do not vary substantially with time and most likely represent the magmatic gas feeding the lake. The lake gases are more CO_2-rich and poor in reduced gases, with CO_2/SO_2 of 1.1±0.2, H_2/SO_2 of 0.02±0.01, and no detectable H_2S, which indicate that the shallow hydrothermal/lake system scrubs sulfur gases and oxidizes reduced gases from the magmatic volatile input. The preliminary average SO_2 flux from the fumaroles is 144±63 T/day, whereas that from the lake is 57±26 T/day. The CO_2 flux from the fumaroles is comparable to that from the lake at 43±23 T/day and 35±16 T/day, respectively, suggesting that a similar amount of heat is delivered to the lake and fumaroles. During a period of intense phreatic eruptive activity from 24 April to 29 October, we observed lower CO_2/SO_2 in lake gas emissions and higher SO_2 fluxes, suggesting that gas monitoring of hyper-acid volcanic lake emissions may prove an effective method for forecasting phreatic eruptions.

IAVCEI (Volcanology, Geochemistry)

VS12a - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

IUGG-0978

Hydrogeochemical monitoring at El Chichón volcano: a tool for long-term volcanic hazard assessment. Lessons from decades of surveillance.

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The March-April 1982 eruption of El Chichón volcano, after nearly 650 years of quiescence, caused the most deadly volcanic disaster in the history of México. The explosive phases destroyed a large dome opening a 1 km wide crater, where a lake formed some weeks later. Chemical determinations of the lake water have been carried out since the early stages of its formation. Although results have shown strong fluctuations, observations since 1983 interpreted with geochemical and statistical methods allowed identifying the relative contributions of hydrothermal fluids and magmatic gases; contributions which are significantly influenced by tectonic and meteorological effects. The identification is made in terms of two main types of water, one with Na and Cl as main ions and a high degree of neutralization, and other with sulfate as main anion. From January 1983 to July, 2001 most samples were located in the active zone of the lake classification diagram proposed by Varekamp. Afterwards, samples fell in the quiescent zone. In March 2014, the lake water showed a high hydrothermal input to the lake that continued until the last sample collected in November, 2014. Notwithstanding, the 2014 samples also approached the active-volcano region of the diagram, suggesting an increase in the magmatic-gases supply probably caused by the activation of a tectonic fault transecting the crater, as evidenced by observed deformations, and seismicity detected in early 2014. The developed hydrogeochemical methodology has also allowed locating the best sampling site and determining the chemical species that should be analyzed to develop a basic, yet useful monitoring, which is particularly important in a volcano in which sampling is scarce due to a difficult access to the crater lake.

IAVCEI (Volcanology, Geochemistry)

VS12a - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

IUGG-1261

The gas membrane sensor (GMS) method: a new analytical approach for real-time analyses of dissolved gases in volcanic lakes.

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The main purpose of this study was to test and apply an innovative analytical method based on a gas membrane sensor (GMS) for the chemical analysis of dissolved gases along vertical water columns in meromictic lakes hosted in volcanic systems, where this information is of fundamental importance to characterize and monitor the hazardous gas reservoirs. The GMS method allows to overcome the disadvantages related to tedious laboratory analysis and sampling difficulties. The GMS device is easy to handle and operates via a wire line, thus it is free of any complex mechanical components. The test was carried out at Monticchio Grande and Piccolo (Mt. Vulture, Italy) and Pavin (Massif Central, France) lakes, where dissolved CO_2 and CH_4 were analyzed using both the GMS and the SH (single hose) techniques, the latter being an independent conventional method. We demonstrated that the two approaches produced comparable analytical results within the analytical errors. Using the GMS method, highly accurate in situ measurements of dissolved gas composition along vertical profiles of volcanic lakes can thus be produced. By applying additional analytical devices at the surface, the number of detectable dissolved components can be extended to all permanent gases. Real-time production of compositional data is suitable for mapping large lake areas in a relatively short time and allows to construct detailed vertical profiles of dissolved gas concentrations. A GMS sensor can also be permanently installed at one specific location at a certain lake depth to provide continuous data on a long-term basis over several years.

IAVCEI (Volcanology, Geochemistry)

VS12a - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

IUGG-1398

Variation of volcanic gas composition during transition from crater lake activity to eruption at Aso volcano, Japan

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Aso volcano started eruption at the end of November 2014 from the summit crater after dry up of the hot acid crater lake. We report variation of volcanic gas composition during the transition from a stable crater lake, dry up then to eruption. The lake water volume decrease started in early 2013 and almost dried up at the end of 2013. High temperature gas emission from the center of the crater was observed in early 2014. Continuous ash emission with small scale strombolian eruptions started in November 2014 at the center of the crater. During the quiescent period, acid gases are discharged from the surface of the hot acid crater lake (crater lake gas) and high-temperature fumaroles at the southern rim of the crater (south fumarole). The crater lake gas composition is similar to a typical high-temperature gases with high SO2 and H2 contents, suggesting that high-temperature gases continuously supplied to the crater lake. The crater lake gas and the south fumarolic gas have contrasting composition with low and high CO2/SO2 ratio, respectively and the contrasting compositions were interpreted as a results of gas-liquid separation in a hydrothermal system. The contrasting CO2/SO2 ratios, however, did not change by the transition from the stable crater lake to dry then to the eruption, implying that the contrasting compositions are not the results of the hydrothermal differentiation but imply the existence of two different magmatic gases, likely separated from a magma at different conditions. The stable gas compositions indicate that the degassing conditions remains similar during the activity transition.

IAVCEI (Volcanology, Geochemistry)

VS12a - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

IUGG-2298

Enhanced eruption hazard from a cool Ruapehu Crater Lake – perception and reality

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Systematic temperature measurements of the Ruapehu Crater Lake have been made for 50 years, initially by lake visits, but more recently by satellite telemetry. The Mt Ruapehu volcano had an active period from about 1960 until 1975. Although most eruptive activity was when the lake was hot, there were lahar-producing eruptions in June 1969 and April 1975 that occurred with virtually no warning when the lake was only about 20 °C, suggesting that the eruptions had occurred when the permeability beneath vents under the lake was reduced so producing a build-up of gas pressure.

For nearly twenty years from 1975 there was a long period with no significant eruptions, in which the Crater Lake temperature cycled more or less regularly in approximately yearly cycles in the range 10 – 55 °C without significant eruptions. With many cool periods that were not followed by eruptions, there was a decrease in the perception that a cool lake represented a high eruption hazard. In fact the major eruption sequence of 1995 followed high lake temperatures, although just before the first eruption the lake temperature was a moderate 29 °C.

A significant eruption from a cold (14 °C) lake in September 2007 injured two climbers in the nearby Dome Shelter. This eruption was interpreted as a gas-driven explosion under the lake, and so revived the idea that low lake temperatures indicate a blocked vent and hence a high eruption risk. Statistics of eruptions provide little support for this, while gas measurements and modelling suggests that gas pressure builds up on a longer time-scale than the temperature cycles.

IAVCEI (Volcanology, Geochemistry)

VS12a - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

IUGG-3735

"HCl degassing from extreme acidic crater lake waters: empirical insights from lab-experiments"

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HCl is considered (1) a conservative element in aqueous media, and (2) to degas only from water-free environment from high-temperature fumaroles. In extremely acidic crater lake waters Cl is not conservative, and will degas from an aqueous medium. This feature has been recognized in the 80-90's in a qualitative way, but has never been quantified. We here mimic an extremely acidic crater lake in the laboratory by adding NaCl (38,000 ppm of Cl) to an extremely acidic solution (H2SO4, initial pH 0.3). The solution was heated up to 40-45°C, and steadily evaporated for two days. The remnant "lake water" was sampled every hour, the sample was analyzed for its Cl and pH. pH was determined by titration with a 0.01N NaOH solution. The water loss by evaporation resulted in an increase in Cl content and decrease in pH in the remnant water, due to super-concentration of the solution in Cl and protons. With a decreasing pH (near 0), protons and Cl are also lost, stating HCl degassing from the solution. The loss of protons and Cl stoichiometrically match. The average HCl/vapor weight ratio in the gas phase is 0.02 on average, similar to the one in high-temperature fumaroles. This implies that an extremely acidic crater lake (1) can be considered a large "open-air" fumarole, and (2) is semi-transparent for the rising gas phase, which means that the lake water chemistry only reflects a snap-shot of a passing gas train, independent of lake convection. This revolutionary idea will possibly stimulate new fluid research topics and monitoring approaches on highly active crater lakes, often subject to phreatic eruption activity.

IAVCEI (Volcanology, Geochemistry)

VS12p - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

VS12p-577

Determination of sulfur species of Chichón volcano crater´s lake trough ion Chromatography

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This work informs about sulfur speciation of the water of El Chichón crater lake, focusing on the first analysis of a Polythionate (tetrathionate), a specie that has been analyzed at other volcanoes with crater lakes. Concentration variations of this specie have preceded changes in volcanic activity that may constitute a volcanic hazard. Water samples were collected in March, July and October 2014. The method developed included the sampling procedure, and the analysis methodology. Besides this specie, the analysis of: Sulfide, Sulfite, Thiosulfate and Sulfate, were also performed; all ions were detectable and quantifiable. Results of Tetrathionate analysis were very interesting since it was detected in the crater lake during the three months of sampling; so from now on it can be another geochemical parameter to help monitoring of the volcano´s activity. Preliminary conclusions:The chromatographic method for the determination of sulfur speciation was adequate for the analysis of the crater lake water, The determination of tetrathionate and sulfite (that have not been analyzed before), and a long-term monitoring may contribute to the understanding of the dynamics of the hydrothermal system, As seen in other volcanic crater lakes, sharp changes in Polithionates´ concentrations may precede changes in the volcano behavior and thus their monitoring can help to volcanic hazard mitigation.

IAVCEI (Volcanology, Geochemistry)

VS12p - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

VS12p-578

Bio-Activity Lakes: Essential features and monitoring approach

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The most commonly accepted classification for volcanic lakes refers to the activity of the hosting volcanic systems and, consequently, on the type and amount of volcanic/hydrothermal fluids received by lakes from deep source(s). High-activity lakes are those affected by strong inputs of acidic fluids, producing medium-to-high salinity and relatively high temperature. Low-activity lakes, including Nyos-type lakes, show a stable meromixis favoring the accumulation of CO_2-dominated gases at depth. At these conditions, it is commonly accepted that a limnic eruption can occur when internal and/or external triggers promote rollover events. At the light of these considerations, a large number of volcanic lakes can be classified as low activity lakes, such as Hule and Rio Cuarto (Costa Rica), Kivu (D.R.C.-Rwanda), Pavin (France), Albano, Monticchio and Averno (Italy). However, gases stored in the deep water layers of these lakes display a chemical composition significantly different with respect to that of the Cameroonian killer lakes. The latter are typically CO_2-dominated, as expected considering their exceptionally high input rate of magmatic gases. On the contrary, the gas reservoirs of the former consist of CO_2 and CH_4 in comparable concentrations. Their chemistry is thus mainly controlled by microbial activity, whereas deep gas contributions have a secondary importance. The interactions between geosphere and biosphere play a key role for the behavior of (CO_2-CH_4)-rich lake reservoirs and its related hazard. In these systems, that can be appropriately called bio-activity lakes, combination of (i) classical geochemical investigation techniques and (ii) studies concerning prokaryotic colonization is the correct approach to develop reliable monitoring programs.

IAVCEI (Volcanology, Geochemistry)

VS12p - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

VS12p-579

Bio-activity volcanic lakes: New examples from São Miguel Island (Azores Archipelago, Portugal)

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Volcanic lakes are peculiar natural systems on Earth, although they are a common feature of volcanic systems characterized by recent activity, being present in 345 volcanic structures worldwide. Following the classic physical-chemical classification, volcanic lakes can be subdivided into six classes, including the so-called low-activity lakes, where the establishment of a stable vertical stratification favors dissolved gas accumulation at depth. At these conditions, a lake overturn may cause the abrupt release of a toxic gas cloud, a phenomenon known as “limnic eruption”. Recent studies suggested to discriminate two subclasses within this lake category: 1) Nyos-type lakes, where strong CO_2-rich inputs totally control behavior and fate of the dissolved gas reservoir, and 2) bio-activity lakes, whose CO_2(CH_4, N_2)-rich gas reservoir is governed by interactions occurring between geosphere and biosphere. In this study, we present chemical and isotopic data of water and dissolved gas samples from five lakes located at São Miguel Island (Azores Archipelago, Portugal): Congro, Sete Cidades, Santiago, Furnas and Fogo. These lakes show extremely low salinity due to limited water-rock interaction. Small accumulations of dissolved CO_2 suggest low inputs of hydrothermal fluids, although biodegradation processes occurring within the bottom sediments mask the presence of deep-originated gases. Unexpectedly, CH_4 was measured in aerobic water layers. Hence, these volcanic lakes may represent a further subclass in the low-activity group, whose peculiar feature is the lack of significant microbial activity within the lake water. A seasonal stratification may occasionally produce anaerobic conditions at depth, allowing the temporary development of microbial populations.

IAVCEI (Volcanology, Geochemistry)

VS12p - VS12 Understanding Volcanic Lakes: a Multi-Disciplinary Approach

VS12p-580

50 years time series of water chemistry of crater lakes at Kusatsu-Shirane volcano, Japan

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The Kusatsu-Shirane volcano located in the central Japan is one of the most famous active volcanoes in Japan. The volcano has three crater lakes on its summit. We started geochemical studies on the Kusatsu-Shirane volcano in 1965 to understand the hydrothermal system beneath the volcano and monitor its volcanic activity. The monitoring has been conducted mainly by measuring the water chemistry of crater lakes; therefore, we have monitored the water chemistry of all three crater lakes of the Kusatsu-Shirane volcano for 50 years. Yugama, the largest and deepest one of the three, is well known as an active crater lake filled with strong acidic water due to the injection of hydrothermal fluids from the subaqueous fumaroles at the lake bottom. The chemistry of Yugama has thus fluctuated according to the volcanic activity of the Kusatsu-Shirane volcano. The concentrations of chloride and sulfate ions in Yugama have fluctuated almost independently of each other. Our observations reveal that chloride ion in Yugama is supplied directly as hydrogen chloride from the subaqueous fumaroles. The concentration of chloride ion has increased suddenly in the first half of the 1990s from 2000 mg/L to 3000 mg/L in connection with the volcanic activity, and it has been kept almost between 2500 and 3000 mg/L since then. In these years, the concentration of chloride ion shows a rising trend in response to the recent increased volcanic activity. On the other hand, the concentrations of sulfate ion and other dissolved sulfur species in Yugama have decreased substantially over the past 50 years, from nearly 5000 mg/L in the 1960s to around 1500 mg/L in these years for sulfate ion.

IAVCEI (Volcanology, Geochemistry)

VS13a - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

IUGG-1804

Evolution of environmentally-available elements in ash from the 2011 Puyehue-Cordón Caulle eruption: implications for agricultural systems

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The 2011 Puyehue-Cordón Caulle eruption dispersed ash over a wide area, covering a large amount of agricultural land. Leachate testing of fresh ash and samples collected nine months post-eruption was undertaken to assess 1) the chemical evolution of the deposit over time, 2) the deposit leachates in two distinct environmental settings (temperate Andean and semi-arid steppe), and 3) the effects remobilisation had on the epiclastic deposit leachates. Testing was undertaken according to IVHHN guidelines with the aim of contributing towards the refinement of toxicity and loss thresholds for agriculture, as well as assessing the chemical hazards to agricultural systems. Evaluation of chemical hazards showed that toxicity was not the likely cause of widespread agricultural losses, rather ash coating and damaging vegetation caused starvation and gastrointestinal blockages in livestock. However, as fluoride remained elevated nine months after the eruption, possible chronic fluorosis occurred in livestock from long-term ingestion of ash. Epiclastic deposit leachates did not differ significantly from in-situ deposits within the same environmental area nine months after the eruption. However, in contrast to the 2011 samples, ash taken nine months after the eruption showed an increase in elemental concentrations with distance from vent, related to the transition from temperate to semi-arid zones. Undertaking a full assessment of environmentally available elements from ashfall is an essential input into holistic hazard assessments. An understanding of possible chemical hazards, allows for specific mitigation techniques to be implemented. Using a standardised protocol such as the IVHHN one applied here, allows for consistent and accurate assessment of the toxicity of ashfalls.

IAVCEI (Volcanology, Geochemistry)

VS13a - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

IUGG-1883

Improving volcanic risk assessment through quantitative vulnerability assessment of critical infrastructure to volcanic hazards

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Effective volcanic risk assessment requires characterisation of volcanic hazards and vulnerabilities of exposed elements. Volcanic hazard assessment is at a relatively advanced state of understanding and is a considerable focus of volcanic scientific inquiry, whereas comprehensive quantitative vulnerability data is lacking. The available vulnerability literature and documented impacts to the built environment from volcanic hazards show these cause disruption through to complete damage depending on hazard intensity, infrastructure design and preparedness and response actions. Using existing impacts data we have developed damage state scales for all infrastructure sectors by assigning hazard intensity thresholds to four levels of damage. While this semi-quantitative approach is useful in assessing vulnerability of exposed assets to volcanic eruptions, a more quantitative approach is required for a fully probabilistic risk assessment. Fragility and vulnerability functions are the most appropriate method as these show loss and/or damage as a function of hazard intensity. We present a framework documenting the approach needed to develop fragility and vulnerability functions for different infrastructure impacted by tephra falls. This framework covers hazard intensity metrics, function form, uncertainty estimation and documentation requirements. We apply the framework and existing vulnerability data to derive new vulnerability functions for electricity supply network. Using the derived functions and a new probabilistic tephra fall model, we assess the risk to the electrical network in New Zealand from multiple volcanic sources.

IAVCEI (Volcanology, Geochemistry)

VS13a - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

IUGG-2691

The worst result in the September 2014 eruption at Mount Ontake, Central Japan

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Over 60 casualties including missing people were recorded in a phreatic eruption at Mount Ontake (3, 067 m) on 27 September 2014. This tragedy occurred in the worst situation, though the scale of eruption was small (VEI 1). The eruption began just before the Saturday noon when over 200 climbers had gathered at the mountain peak area to take rest with lunch. It was warm and best day to enjoy colorful autumn leaves on mountains. The onset of eruption was sudden without any clear surface precursory phenomena such as ground rumbling and strong smell of sulfur. Workers in the mountain huts near the peak did not notice the eruption until when climbers outside shouted it. New craters appeared on the geothermal area, approximately 500 m south down from the peak. The eruption started with pyroclastic surges descending about 2.5 km from the craters to SW and moving horizontally about 1 km to N and W beyond summit ridges. Soon the surge ash enveloped many climbers at the summit, and, then, ash rose up to 7 km high. That time, rock fragments up to 50 cm showered densely on the summit area: 20-30 cm-across fell about 1.3 km away from the craters. The emission of rock fragments repeated two times. Most casualties lost their lives by being hit by rock fragments, although some had faint burn on their backs within the surge ash. Fortunately, over 80 climbers who could escape into the huts (wooden construction with tin roofs) were safe, although the huts were deadly damaged. The main eruption ended within a few tens of minutes. The tephra volume
is smaller than that of the Ontake's 1979 eruption in which no casualty was reported. This disaster let us review the monitoring and information system, and consider how visitors and local officials prepare for climbing active volcanoes.

IAVCEI (Volcanology, Geochemistry)

VS13a - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

IUGG-4448

Crisis management in Chiles – Cerro Negro Volcanic Complex during 2014-2015: Implementation of an Early Alert System in Ecuador

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The Chiles - Cerro Negro (CCN) volcanic complex is located on the Ecuador-Colombia border. The recent activity of these volcanoes has been characterized by fumarolic activity and perennial thermal springs. However, since April 2014 the population around the area has felt a significant number of earthquakes. The Instituto Geofísico (IG) responded to this seismic crises by installing new monitoring stations around the volcanic complex and by providing training to local authorities and inhabitants via explanation of the new hazard map for these volcanoes. Community members around the CCN were nervous about the uncertainties related to the prolonged and strong seismicity, but co-operation between scientists, authorities and the community generated a good and positive responses for supporting the population´s lifelines and keeping them informed. Local Ecuadorian authorities, scientists of the Instituto Geofísico and colleagues worked together to implement at the CCN volcanic complex the successful “Vigía” program (local volunteers who report observations about surface volcano activity to the IG), as the Tungurahua case. Tungurahua volcano, in central Ecuador, has been fundamental in providing a link between monitoring scientists and communities and fortifying an Early Alert System (SAT). At CCN a SAT has been achieved with improved instrumental monitoring and the implementation of a “Vigía” network by the founders of Tungurahua´s “Vigía” network. At CCN, 8 volunteers from the communities of Tufiño (population of 1570 people) are “vigías” and they communicate via a UHF radio system. In the case of eventual eruptive activity, this network could be extended to cover a wider area west of the volcanic complex.

IAVCEI (Volcanology, Geochemistry)

VS13a - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

IUGG-4826

The 2014-2015 Fogo eruption, Cape Verde: Findings from the field

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The island of Fogo in Cape Verde, the most active volcano in the hotspot archipelago, is formed of a single large stratovolcano. The approximately 25 km wide island has a 9 km wide lateral collapse structure open to the east, within which the steep new cone of Pico do Fogo is growing. There is a flat infilled area (called Chã das Caldeiras) between Pico and the ~1 km high collapse scar headwalls, which is home to around 1500 people. Increased unrest activity in late 2014 lead to progressive raising of the alert level, and on 23 November 2014 a new eruption began from a vent on the WSW base of Pico. The eruption produced explosions and ash emissions, lava fountains and fast-moving lava flows (to 20 m/s). Over the following weeks all of the Chã residents were evacuated and lava flows destroyed >90% of the main villages, Portela and Bangeira, a large area of agricultural land, communication poles and the only road into the area. Intermittent ash explosions dispersed and deposited ash in the main city of São Filipe and across agricultural crops on the island; the airport and tourism industry were also impacted. As of February 2015, the eruption was ongoing with periodic explosions and ash plumes, and slow, intermittent lava encroachment within the remaining parts of the villages. We will report on our preliminary findings from a field impact assessment carried out in early 2015, and discuss interaction between the eruption products and structures (e.g. roads, buildings) that may inform future reconstruction on Fogo and elsewhere.

IAVCEI (Volcanology, Geochemistry)

VS13p - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

VS13p-097

Magmatic volatiles in ash leachates and environmental impact assessment of the 29-30 October 2014 eruption of Turrialba volcano

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We report data on the acidity and volatile content on ashes released by Turrialba on 29-30 Oct 2014. Turrialba (3340m a.s.l.) entered a phase of unrest in 1996. From then on, it progressively underwent enhanced seismic activity, outgassing, and an evolution on the composition of fluids toward a more magmatic dominated phase. On 29th Oct 2014, after 13 hours of continuous tremor, ash eruptions took place with columns reaching up to 2km.

Volcanic ash is a source of a range of chemicals that can be leached upon contact with water or bodily fluids. Soils and aquatic systems can become loaded with toxics affecting living organisms. Ingestion of ash and subsequent leaching to stomach acid might result in a higher fraction of volatiles and metals in the circulatory system of mammals, possibly leading to health effects such as bone fluorosis.
Data acquired from the 29-30 Oct 2014 ash leached with pure water, indicate their acidic nature (pH´s between 3,3-3,95) and high content of adsorbed volatiles (mg anion/kg of ash): F- ranging from ≈400 to 800, Cl- ≈1400 to 3100, Br- ≈60 to 120, and SO42- ≈26600 to 35000. Ashes emitted during opening of vents at the West Crater in 2010, 2011, and 2012 were rather neutral or slightly acidic. Next, a gastric leach was applied to the ashes with an HCl pH 1,5 solution at 37°C, to mimic conditions in the stomach. The amount of volatile species exceeded those found on

the ash leached with pure water as much as one order of magnitude.

The volcano ejected a fairly rough estimate of $2x10^9$*Kg of ashes, which is equivalent to* $1,6x10^6$*Kg* of F- released into the environment. Thus, it is important to assess the ash ingestion and inhalation hazards to livestock and humans, and quality of drinking water and food supplies in the vicinities of Turrialba volcano.

IAVCEI (Volcanology, Geochemistry)

VS13p - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

VS13p-098

Improving assessment and prediction of agricultural losses due to tephra fall

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Understanding agricultural impact from tephra hazards and their causal mechanisms is vital when developing mitigation and recovery strategies. It is well documented that tephra can impact agricultural systems. However, forecasting likely impacts has been challenging and focussed on creating generalised models where impacts typically increase with tephra thickness or loading. Lack of quantitative data and insufficient sample sizes of impact assessment studies restrict potential analysis. However, previous studies have identified that impacts will be governed by the complex interaction of tephra characteristics (thickness/loading, grainsize, leachates), exposed farm characteristics (farm size/type, pre-existing conditions), climate, time of year and existing risk management.

Post-eruption impact assessments (PEIA) have been used to retrospectively investigate tephra impacts to agriculture, including exploring how tephra and vulnerability characteristics of exposed farms interact. In this study, we use PEIA to investigate impacts to agricultural land from three silicic eruptions (2011 Puyehue-Cordón, 2008 Chaitén, and 1991 Hudson) in Patagonia. Analysis of 49 impacted farms suggests that the characteristics of tephra fall are important, but that the vulnerability characteristics of the farms have a stronger influence on impact. Findings show appropriate recovery strategies employed by farmers are crucial for reducing losses.

We use this analysis to: 1) derive vulnerability functions for agricultural losses from tephra; 2) recommend guidelines for collecting and recording PEIA information; and 3) present a database to aid reporting and analysis of agricultural impacts. These initiatives aim to build predicative capacity and ultimately aid disaster risk reduction strategies.

IAVCEI (Volcanology, Geochemistry)

VS13p - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

VS13p-099

Mineralogical and sulfur isotopic study on volcanic ash of the 27th September 2014 phreatic eruption at Ontake volcano

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The phreatic eruption of Ontake volcano in Japan took place on 27th September, 2014. We sampled fallout ash and carried out microscopic observation and XRD, SEM-EDS, and sulfur isotopic analyses to understand origin and mechanism of the phreatic eruption. Coarse ash grains consist mostly of intensely altered white lithic fragments with minor weakly altered dark-gray volcanic rock fragments. Minerals identified with SEM-EDS and XRD are pyrophyllite, smectite, muscovite, kaoline group minerals, quartz, cristobalite, tridymite, and alunite. Fine fraction (<10μm) contains abundant euhedral free crystals of alunite, silica, and gypsum. Isotopic ratio of sulfur extracted from bulk sample is analyzed. Sulfur was extracted in three steps, by water (leachate), HCl (sulfate), and HNO_3 (pyrite). For coarse fraction, $^{34}S/^{32}S$ ratios of sulfur extracted by HCl (sulfate), and HNO3 (pyrite) were determined. The $\delta^{34}S_{CDT}$ of leachate, sulfate, and sulfide in bulk sample are +14.7‰, +15.7‰, and -4.7‰, and those of sulfate and sulfide in coarse fraction are +9.1‰ and -4.3‰, respectively. The mineral assemblage determined with XRD and SEM-EDS implies alteration by hot and acidic fluid, which is typical of deep subvolcanic hydrothermal system. Estimated temperature with sulfur isotopic fractionation (Ohmoto and Rye, 1974) is 520±34? for the coarse fractions assuming isotopic equilibrium between sulfate and sulfide. Because coarse fragments were derived from preexisting altered rocks, the temperature implies past condition of subvolcanic hydrothermal system. The sulfur isotopic temperature assuming equilibrium between leachate and sulfide extracted from fine fraction of the ash is 308±15?, which is similar to the estimated temperature by mineral assemblage of alteration minerals.

IAVCEI (Volcanology, Geochemistry)

VS13p - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

VS13p-100

X-ray photoelectron spectroscopy analysis of volcanic ash

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From the moment of magma fragmentation until entry into receiving environments or biological systems, ash particles possess surface chemistries which are a complex product of diverse physicochemical processes. These range from mechanisms of surface generation to high temperature adsorption processes and dissolution by condensing acid aerosols in volcanic clouds. Conventional tools of ash analysis (e.g., ash leaching, bulk chemistry and mineralogy) are limited in their capacity to investigate this surface chemistry. Such techniques may be bolstered by X-ray photoelectron spectroscopy. X-ray photoelectron spectroscopy yields insight into the atomic composition and coordination of the immediate (<10 nm) ash surface. However, the utility of this technique for investigation of volcanic ash is complicated by the uncertain eruptive history and heterogeneity of ash particles. The effect of such complexities can be limited by contrasting core electron binding energy spectra of unknown samples with those which are well-characterised, or have been exposed to a known treatment. Changes in surface compositions and core electron binding energies relative to an established reference frame can thus provide insight into the complex eruptive history of ash surfaces. Here we present the results of X-ray photoelectron spectroscopy analysis of experimentally-derived and natural ash samples, interpreting differences in surface chemistry imparted by i) surface generation mechanism; ii) in-situ sample heating, and iii) aqueous leaching. Our analyses and interpretations highlight the difficulties inherent to X-ray photoelectron spectroscopy analysis of volcanic ash materials, but also demonstrate where the technique may be successfully deployed for new insight.

IAVCEI (Volcanology, Geochemistry)

VS13p - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

VS13p-101

Building damage from pyroclastic density currents during the 11 February 2010 dome collapse, Soufriere Hills volcano, Montserrat

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On 11 February 2010, a partial collapse of the lava dome involving 50 x 10^6 m^3, occurred at the Soufriere Hills volcano, Montserrat. During the event, low-particle concentration pyroclastic density currents (LPC-PDCs) caused significant damage in the villages of Streatham and Harris. Field investigations revealed that the pattern of damage was influenced more by building type and local topography, rather than distance from the lava dome despite the close proximity to the volcano (< 3 km). Building construction varied widely from reinforced concrete to timber frames and galvanised metal sheets. Of the buildings not completely destroyed, those built with concrete walls and roofs largely remained intact with only doors and windows missing. Buildings with timber roofs however, suffered severe structural and/or fire damage. Buildings located on ridge tops suffered less damaged than similar buildings at lower elevations. Of the buildings that remained, few showed signs of impacts from projectiles, and there was little or no debris immediately down-flow of damaged structures. In Harris, deposit mapping revealed a crude stratigraphy consisting of a series of coarse ash rich units. These indicated at least two pulses of LPC-PDC moved through the village. Based on the damage to structures and vegetation, PDC dynamic pressures varied considerably, from < 5 to > 25 kPa. Using velocities of 21 to 55 m s^{-1}, we estimate average current densities of 6-9 g/cm^3.

We discuss the implications of our findings for assessing vulnerability to hazards associated with LPC-PDCs in built-up areas located in close proximity to volcanic features, e.g., the Auckland Volcanic Field.

IAVCEI (Volcanology, Geochemistry)

VS13p - VS13/VS05 Environmental and Health Effects of Natural Mineral Dusts / Recent Eruption Impacts and Mitigation within Urban Areas

VS13p-102

Environmental pollution from volcanic ash particulate: Examples of ash leachates from mt Etna (Italy) and Popocatepetl (Mexico) volcanoes

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Generation and dispersal of volcanic ash during explosive eruptions can impact the environment at a serious level. Ashfall on natural waters and water supplies produces turbidity, induces pH variations and alters the natural concentrations of chemical elements. The study was carried out on different samples ash leachates of different samples of volcanic ash, in order to evaluate the different release of chemical compounds in the environment. Samples from the eruptions of Mt. Etna (Sicily) of April 24, 2011 and August 12, 2012 and Popocatépetl 2012 (Mexico) represent an opportunity to study leachates on fresh and not yet rain-washed samples.Leaching experiments were carried out using mQ-water and water samples from Lake Ohrid (Macedonia-Albania). Both waters were previously characterised using surface electrode, gas electrode, ion-chromatography and ICP-MS. During the experiments the pH variation, the concentration of chemical compounds and saturation index were determined. It was observed alkalinisation in Etna leachates samples and acidification in Popo leachates samples with different release of anions and cations; in particular Etna leachates are rich in F^- and Popo leachates are rich in SO_4^{-2}. Many of the elements that have been measured are included in the drinking water guidelines due to their potential toxicity. In many of the analysed ash leachates F^-, Mn^{+2}, SO_4^{-2} and Fe^{+2} concentrations exceed the maximum values defined by Italian law (e.g. maximum value of F=1.5 mg/l vs. F concentration in Etna leachates of 20 mg/l). Ash leachates were also used as living culture for tadpoles, and the stages of growth observed at different time intervals. The results highlight the potential impact of volcanic ash deposition on environment and human health.

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IUGG-0508

The 2012-2013 Tolbachik fissure eruption: geochemical, petrographic and mineralogical records of magma storage zone processes from lava samples

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Tolbachinsky Dol, one of the largest zones of monogenetic volcanism in Kamchatka, has formed throughout the Holocene by numerous eruptions of high-Al sub-alkaline basalts and basaltic andesites, and since 2 ka also of high-Mg medium-K basalts. A new fissure eruption happened here at the end of November 2012; it lasted for 9 months and produced about 0.56 km^3 DRE of erupted material. The high-Al basaltic trachyandesite erupted during 2012-2013 has higher alkalis and Ti contents than any previously studied rocks from Tolbachinsky Dol. Petrographic and geochemical analysis shows that over the course of the eruption few compositional changes occurred. Although rock compositions changed after the first 3 days from slightly more acid (SiO_2 up to 55.35 wt.%) to more basic ($SiO_{2av.}$ ~ 52.44 wt.%), they then remained homogeneous until the end of the eruption. Petrography of the lavas from the initial stage of the eruption document changes in the magmatic fO_2, recorded by different groundmass textures. Partly melted, reversely zoned Ol found in these lavas may be evidence for mixing processes or be inherited from the liquids pre-existed in the same magma system. The skeletal shape of Ol microphenocrysts, typical for all new lavas, resulted from relatively fast growth rates. We have used thermodynamic modeling tools (MELTS, PRIMELT) to constrain parental melt compositions and to show that the new lavas are likely related to lavas from the 1975-76 eruption, and to investigate the range of feasible processes that could occur on the timescale of the eruption, the magmatic processes that formed the Tolbachinsky Dol over time-scales of k.y., and the possible genetic relationships between the Holocene fissure activity of Tolbachinsky Dol and the older Plosky Tolbachik stratovolcano.

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IUGG-0904

Modeling eruption characteristics and tephra dispersal of the 1085 AD Sunset Crater (AZ, USA) eruption using the inversion approach

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Volcanic eruptions involving basaltic magma usually produce low explosivity events (lava flow, lava fountains, small Strombolian explosions). However, more explosive eruptions (Strombolian to Plinian) are not uncommon. The eruption of Sunset Crater volcano represents an interesting case in that it produced highly explosive eruptions, up to sub-Plinian in scale, that heavily affected the pre-historic communities in the area, and also produced intermittent episodes of lava effusion. Sunset Crater is a >300 m high scoria cone located ~25 km northeast of Flagstaff, AZ (USA), in the San Francisco Volcanic Field (SFVF). The SFVF is located in the interior of the North American continent, making this case particularly relevant in terms of predicting the impact of a possible future eruption of similar scale on the American Southwest and, possibly, on the global economy. The explosive activity produced a tephra sequence of at least eight main fall units. The eruption products are generally coarse grained, with median grain size of the main explosive event estimated to be -1.6 ± 1.2 F; the cumulative volume of the tephra deposit is estimated to be about 1 km^3non-DRE and column heights up to 20 km. We investigate explosive activity of Sunset Crater using the advection-diffusion model TEPHRA2 and an inversion method in which we iterate in order to minimize the difference between the computed and field values of deposit mass load per unit area and grain size. We focus our attention on the main eruptive parameters (volume, column height), and on the details of tephra dispersal in order to assess the impact of post-depositional remobilization processes in removing the fines fraction from the primary deposit.

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IUGG-1439

Constructing a temporal eruption record for the Auckland Volcanic Field via Bayesian age reconciliation

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For the purpose of land-use and evacuation planning in volcanic fields, the most important factor in forecasting is the location of future eruptions. While many previous vent locations are usually available, the aim of estimating present day hazard is critically dependent on an assessment of any spatio-temporal dependence in the record. It is actively detrimental to have a forecast weighted towards past, rather than future, behaviour. Assessing such dependence, which may include clustering, focusing, or drift over time, requires a record of vent ages, not just locations. The typical age-span of active volcanic fields leads to a variety of dating methods being used, each with their own degree of accuracy and reliability. In the Auckland Volcanic Field there are many C14 age determinations, and a considerable number of Ar-Ar ages. K-Ar ages are considered unreliable due to excess Ar. Regardless of method, many eruptive centres have no age information except stratigraphy, and some lack even that. However, decent volume estimates exist for most centres, and several maars have been cored, yielding a dated record of at least 22 eruptions from within the field over the last c. 80 kyr. We will show how a prior age distribution can be constructed from the age determinations using simulation. This can then be updated in a Bayesian fashion using a statistical tephra dispersion model based on the eruptive volumes and relative locations and directions of centres and maars. The estimated age record is obtained by minimizing the distance in time between the prior age and the tephra layer, and the 'distance' between the tephra thicknesses in the maars and those produced by the model. The resulting record is examined for spatio-temporal dependence.

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IUGG-1635

3D seismic analysis of a monogenetic volcanic field from the Faroe-Shetland Basin, NW Scotland

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The spatial distribution of monogenetic cones is a product of the stress regime of the volcanic field and/or pre-existing crustal structures (Le Corvec et al. 2013). Seismic data, acquired for the oil and gas industry, allows for the 3D imaging of monogenetic cones and their corresponding plumbing systems. This is a useful tool in understanding how monogenetic volcanoes are fed and how pre-existing crustal structures can be the primary influence on their spatial distribution and alignment. This study examines the structure and lithology of host-rock as an influence on cone alignment and provides insight into crustal magma reservoirs feeding monogenetic volcanic fields.

The Faroe-Shetland Basin (FSB) is a volcanic margin hydrocarbon-bearing basin in the northwest of Scotland, formed by the opening of the North Atlantic. The Ben Nevis Prospect, in the most northerly extent of the FSB, consists of a volcanic centre (large positive gravity anomaly) that has uplifted a sequence of impermeable Cretaceous claystones into a dome-like structure. The seismic data reveals multiple sills beneath the palaeo-surface, which have migrated up the flanks of the antiform and have fed a series of scoria cones (Lamba-Flett Formation) (Well 219/21-1, Shell). The result is a 10-15 km alignment of monogenetic cones.

By studying this seismic data, we have substantial evidence of monogenetic volcanoes being fed from a shallow-crustal magma reservoir and how these reservoirs are affected by the structural controls of the host-rock.

Le Corvec, N., Spörli, K. B., Rowland, J., & Lindsay, J. (2013). Spatial distribution and alignments of volcanic centers: clues to the formation of monogenetic volcanic fields. Earth-Science Reviews, 124, 96-114.

IAVCEI (Volcanology, Geochemistry)

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IUGG-3615

Jagged Rocks Complex: A window on the plumbing system of monogenetic volcanoes (Hopi Buttes Volcanic Field, Navajo Nation, Arizona, USA)

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Dikes and related intrusions formed below small volcanoes are remnants of their feeding systems. Intrusion geometry is controlled by interaction of magma-driven cracks with country rock, and reveals regional structural and stress patterns during emplacement. The Jagged Rocks Complex, in the Miocene Hopi Buttes Volcanic Field, USA, is exposed 300-350 m below the pre-eruptive surface. NW-SE striking dikes, prominent in the west of the complex, are straight with braided and en echelon patterns. Sills and inclined sheets in the eastern part of the complex have a saucer-shape geometry, with inward dips and a semi-circular outline. Two elongate massifs, and three sub-cylindrical ones, are exposed at the midpoint of the NW dike, which differs from others of the complex in having an en echelon pattern and containing coarse (up to 5 cm), resorption-rounded, pyroxenes. These massifs consist of pyroclastic deposits of layered spatter, containing highly vesicular and fluidal bombs and subordinate lapilli, with a high country rock content. There is a different expression of dike fragmentation in the SW dike, which is punctuated by several buds, and cut by a diatreme at its western end. These differences in dike geometry and development of fragmental deposits in incipient conduits are inferred to indicate that the shallow stress field changed during the time this intrusion complex was emplaced, in response to addition or removal of magma and country rock associated with surface eruptions. We infer that excavation of deep maar craters, and perhaps the construction of a scoria cone at the surface, modified the local stress patterns to favor emplacement of sills and en echelon dikes later in the complex's evolution, in contrast to simple straight dikes as the complex first formed.

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IUGG-4532

"3D Seismic tomography of El Hierro: insights into the pluming system of a monogenetic volcanic field"

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Understanding how monogenetic volcanic systems work requires to understand the local and regional stresses (i.e structural controls) that govern magma migration inside them and why they seems to change from one eruption to another. The 2011-2012 El Hierro eruption (Canary Islands) showed how the characteristics of unrest, including a continuous change in the location of seismicity, made unpredictable the location of the future vent, thus making hard to conduct short term hazard assessment. A 3D seismic tomography constructed using the seismicity occurred during the pre-eruptive unrest and latter post-eruptive seismic crisis not related to further eruptions, reveal the structural complexity of the interior of El Hierro. It shows a number of stress barriers corresponding to tectonic structures and blocked pathways from previous eruptions, which controlled ascent and lateral migration of magma and, together with the existence of N-S regional compression, reduced its options to find a suitable path to reach the surface and erupt.

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IUGG-0719

The erupted volumes of tephra from maar volcanoes and their VEI magnitude: Examples from the Newer Volcanics Province, South-Eastern Australia

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Calculating the volume of magma involved in an eruption of a maar volcano is often hindered by the uncertainty of the volumes of maar-diatremes. We calculate the eruptive volumes of several complex monogenetic volcanic centres, utilising existing geophysical models to constrain the volumes of subsurface diatremes and conduits, and digital elevation models and drill hole data to constrain the volume of the ejecta rims. We focus our calculations on several maar volcanoes within the Newer Volcanics Province of south-eastern Australia including Ecklin maar, and the Red Rock and Mount Leura volcanic complexes. Based on an average componentry of the ejecta-rim, we estimate a dense rock equivalent magma volume of 0.04 x 10^9 m^3, 0.17 x 10^9 m^3 and 0.29 x 10^9 m^3 for Ecklin maar, the Red Rock and Mount Leura volcanic complexes respectively. The Red Rock and Mount Leura volcanic complexes have magma volumes that are an order of magnitude higher than Ecklin maar, and exhibit far more complex eruptive histories with multiple vents and transitions between explosive phreatomagmatic, magmatic explosive and effusive styles. Based on the total tephra volume comparisons of observed eruptions, we estimate a VEI of 2 for Ecklin, and 3 for Mount Leura and Red Rock.

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IUGG-1056

Monogenetic phreato-magmatic volcanoes (maars, tuff cones, tuff rings) in the Mexican Volcanic Belt: Tectonic setting and hydrogeologic environment

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The subduction-related Mexican Volcanic Belt (MVB) stretches across Mexico from the Atlantic to the Pacific Ocean and traverses the Mexican Altiplano, a highland characterized by normal faulting and graben structures. The resulting basins are often occupied by shallow lakes. One particularity of the MVB is the abundance of monogenetic volcanoes (mostly scoria cones, >3000) which outnumber by orders of magnitude the large strato-volcanoes.
We present an inventory of 88 monogenetic maars located within the MVB with available data in regard to their characteristics (age, composition, etc.) in order to address questions related to the tectonic and environmental causes that might explain their distribution.
Maars are rare (3% of monogenetic vents in the MVB) and 46.6% of them is located in the Tuxtla field (a littoral setting near the Atlantic). Most of the remaining 53.4% are found clustered in only few (e.g. Serdán-Oriental) of the intermontane basins in the Mexican Altiplano.
Optimal conditions for maar formation are frequently not met in these basins despite of the availability of ground water necessary to fuel such eruptions. We hypothesise that monogenetic volcanoes are absent in the interior of many basins (e.g. Cuitzeo) because the thick sedimentary fill is less dense than the batches of rising magma. Hence, this non-compacted fill will act as a density trap and a sill will form at the base of the sedimentary pile. This would explain why in some cases (e.g. Zacapu) maars occur only near the margins and warm springs are found in the interior of the basins. In other basins maars and scoria cones occur in close proximity (they should be mutually exclusive). Climate changes and their effect on groundwater conditions might be responsible for this apparent contradiction.

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IUGG-1321

The role of phreatomagmatism in the Cenozoic intracontinental volcanic fields of the Kingdom of Saudi Arabia

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Volcanic fields (< 20 Ma) are common in the western margin of the Arabian Peninsula, along the Red Sea. While these volcanic fields are dominated by scoria cones, lava spatter cones and transitional lava fields, there is evidence that phreatomagmatic explosive eruptions occurred, either as a single eruptive phase or as the main eruption style, leading to the formation of typical maars and tuff rings. Phreatomagmatism is more evident in association with small volcanic edifices that are fed by primitive magmas, while phreatomagmatic influences during the course of an eruption are also known in association with the silicic eruptive centres in the harrats of Rahat, Kishb and Khayber. Phreatomagmatism has also been documented in volcanic fields that are dominated by scoria cones and lava fields, such as Harrat Rahat. However, phreatomagmatic volcanoes in Harrat Rahat are almost exclusively related to the smallest volcanoes. Conversely, in the c. 1.8 Ma volcanic field of Harrat Hutaymah in the NE-margin of the Arabian Shield, phreatomagmatic volcanic landforms dominate, with open and nearly completely filled maar craters over 1-km across and 300 m in depth. Phreatomagmatism is, however, not as common as expected along the Red Sea in the Harrat Al Birk, but both Surtseyan and maar-diatreme volcanoes have been identified. While phreatomagmatism has no dominant contribution to the total erupted volume of the Arabian Cenozoic intracontinental volcanic fields, the recognition of phreatomagmatism in the Arabian volcanic fields has a significance for volcanic hazards. This is highlighted by the fact that one of the youngest (~641 AD) volcanic chains of four small scoria cones near Al Madinah city initiated their eruptions through explosive phreatomagmatism.

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IUGG-1397

The role of syn-eruptive subsidence in the evolution of maar-diatreme volcanoes: examples from New Mexico and Montana, USA

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Diatremes form the underground portion of maar-diatreme volcanoes. The eruptive processes occurring in diatremes are less well known than those occurring above the ground surface in these volcanoes. Pyroclastic deposits within diatremes can be broadly classified into two types: the bedded ones, generally in the upper part of the diatreme, and the non-bedded ones, generally in the lower part. Some bedded pyroclastic deposits are thought to be deposited in craters that progressively fill-up, without requiring important syn-eruptive subsidence in the diatreme. For example, if the eruptive style changes from phreatomagmatic to magmatic, a scoria cone could be built inside, and perhaps beyond, the maar crater. But bedded pyroclastic deposits of phreatomagmatic origin, now found in diatremes at depths of 1 km or more below the pre-eruptive surface, require very significant syn-eruptive subsidence. Excellent examples of these deeply subsided pyroclastic beds, accompanied by non-bedded pyroclastic domains, will be described from diatremes in the Missouri River Breaks volcanic field in Montana (Delpit, S., Ross, P.-S., Hearn, B.C., 2014. Bull. Volc. 76, Art. 832) and the Navajo volcanic field in New Mexico. In some cases the bedded pyroclastic rocks occur as megablocks within diatremes dominantly filled by non-bedded pyroclastic rocks, whereas in other cases the diatremes are filled mostly by saucer-type pyroclastic beds cross-cut by non-bedded pyroclastic domains. Subsidence must be made possible by upward movement of material in the diatreme.

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IUGG-2089

Intraplate monogenetic volcanism in southeastern Australia – magma rise, volcano types and ages, earthquakes, faulting, uplift, subsidence and future eruptions

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Over 400 volcanoes of the Newer Volcanic Province (NVP) of southeastern Australia (Joyce 2004) are on the southern margin of the Australian Plate, and well-catalogued by type, distribution and age (Boyce 2013). Earthquake activity is low (Joyce & Gibson 2014), but youthful faulting, block and domal uplift, and major subsidence has affected the late-Tertiary marine plain and overlying volcanics.

K/Ar dating and newer techniques including cosmogenic exposure dating (see for example Matchan 2011) provide a detailed story of activity. Geomorphic and regolith mapping have been used to fill gaps and provide a more complete history. Geostatistical modelling has analysed activity over time, identifying cycles of high activity and little or no activity.

Volcanic activity began 5 Ma ago and was notably active over the last 20,000 years indicating a recurrence rate (i.e. eruption frequency) of some 2,000 years, with the most recent activity at the Mt Gambier maar volcano ~ 5,000 years BP. It is generally agreed that further eruption is possible (Joyce 2005).

The origin and history of the magma rise which produced the NVP and may still be active today has been discussed in several studies of the area, most recently using seismic tomography and geodynamic modeling to suggest an upper mantle source triggered by edge-driven convection (Davies & Rawlinson 2014).

The Newer Volcanic Province of southeastern Australia provides a study of intraplate magmatic history which may also be applicable to other monogenetic intraplate volcanic regions now under increasing study by the IAVCEI Commission on Monogenetic Volcanism.

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IUGG-3844

Intraplate basaltic volcanism across Zealandia and the HIMU conundrum.

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Intraplate volcanism across Zealandia, SE Australia, Ross Sea Embayment and Marie Byrd Land defines a magmatic province characterized by basalts where primitive rocks show high $^{206}Pb/^{204}Pb$ (>19.5, HIMU), $^{87}Sr/^{86}Sr$ (~ 0.7035±0.01), Light Rare Earth Element enrichment ($(Ce/Yb)_n > 10$), and convex-up mantle normalized incompatible element multielement patterns, peaking at Nb-Ta. Moreover, trace element ratios (e.g. Zr/Nb, Ba/Zr, Zr/Y) resemble those of Ocean Island Basalts (OIB) and are distinct from MORB, suggesting derivation from an enriched (OIB-like) reservoir.

Using geochemistry from Carnley Volcano in the Auckland Islands as an exemplar, this talk explores the petrogenesis of primitive basalts from Zealandia and adjoining, pre-Gondwana breakup, sites in Australia and Antarctica. Our preferred model envisages partial melting across the asthenosphere – lithosphere boundary, leading to an aggregated melt column. The asthenospheric mantle source is modelled using Primitive Mantle and the subcontinental lithospheric mantle (SCLM) using Depleted MORB Mantle that has been enriched by addition of 1% carbonatite. Partial melting progresses from the garnet stability field into the spinel field. The model involves “edge-driven” convective flow along the trailing edges of the Zealandia, Antarctic and SE Australian lithospheric plates. Ultimately this may be linked to the (plume driven?) break-up of Gondwana. The trailing edge of the lithospheric plates experience thermal and mechanical erosion at the interface with convecting mantle, leading to heating, decompression and partial melting. In this scenario, SCLM is the source of the HIMU signature, an argument supported by

regional peridotite xenoliths that reveal both cryptic and patent (amphibole, phlogopite) metasomatism.

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IUGG-0659

Mineral textures, zoning and chemistry: a key in unravelling the evolution of magmatic systems feeding monogenetic basaltic volcanic systems

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Analysing the crystal growth stratigraphy, i.e., the textures, zoning and chemistry of rock-forming minerals is a powerful tool in recording magmatic processes and compositions, thus it provides a unique insight into the evolution of magmatic systems. In spite of this, studies on individual eruptive units through the successions of monogenetic volcanic centres generally focus only on the analyses of whole-rock major and trace element and isotopic compositions of basaltic rocks. We carried out high-resolution investigations of the textures, zoning and compositions of olivines, pyroxenes and spinels of alkaline basaltic rocks from individual monogenetic volcanoes in the Bakony–Balaton Highland and Little Hungarian Plain Volcanic Fields located in the western Pannonian Basin. Through these detailed analyses we were able to separate distinct crystal populations which have various origins: phenocrysts, xenocrysts and antecrysts characterized by diverse textures, zoning and compositions were all recognised implying the complex ascent histories of the studied basaltic magmas.
Our results indicate that the basaltic magmas which formed the eruptive centres of the studied volcanic fields went through various deep magmatic processes such as magma accumulation and storage, magma fractionation, magma replenishments and mixing, effective magma – wall rock interaction. Differences can be detected between the evolution histories of the magmas forming the individual eruptive centres, even within a single centre, however, it can be concluded that open-system petrogenetic processes played an essential role in the evolution of the deep magmatic systems.

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IUGG-1270

The geochemical behaviour of small scale basaltic systems

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Small scale basaltic magmatic systems characteristically occur at the Earth's surface as fields of small individual volcanoes each representing a batch of compositionally discrete magma. Within volcano fields chemical composition and magma batch volume are strongly correlated; smaller batches are relatively silica under-saturated and incompatible element enriched and larger batches trend toward tholeiitic compositions which are relatively lower in incompatible elements. Individual magma batches typically show marked compositional variation from evolved (higher incompatible element abundances and often lower silica contents) to more primitive compositions, trends which commonly although not exclusively are related to near source fractionation. Systematically, more evolved compositions are erupted in the initial stages of an eruption sequence and are followed by progressively less evolved compositions and this is indicative of rapid and continuous rise of magmas from their mantle sources. A feature of the geochemistry of small scale basaltic systems is that they carry the signature of their generative processes and thus provide a unique window into the behaviour of their mantle sources. In larger scale magmatic systems these subtle geochemical features are typically overprinted by shallow (crustal) processes (magma mixing, fractionation, assimilation). In the global spectrum of basaltic magmatic systems, use of the term monogenetic applies to volcanoes produced from a discrete batch of compositionally distinct magma within a defined time period (months to years). In some cases volcanoes have produced more than one compositionally discrete batch separated by a significant time break so the term is usefully applied to the concept of a magma batch rather than to its edifice.

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IUGG-3171

Magmatic processes, time scales, and seismic unrest related to monogenetic mafic volcanism

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Monogenetic volcanoes typically produce small volume and mildly explosive eruptions of relatively short duration. However, anticipating and planning for such eruptions is difficult because there is virtually no instrumental unrest data, and they may occur at unexpected locations. Here we combine the results of a new geochemical and petrological study (olivine chemical zoning and modelling) with newly compiled seismic unrest data from monogenetic eruptions in the Canary Islands and elsewhere, to propose a general model of these events. We found three end-member cases: (1) eruptions as that of El Hierro in 2011 records evidence for mixing of two variably mafic magmas during the three months prior to the eruption according to chemical zoning modelling in olivine, and is consistent with the instrumental seismic record. In contrast, (2) the rift eruption of Chinyero (Tenerife, 1909) shows a longer seismic unrest (about 2 years according to factual accounts), and a closed system origin for the magmas (no significant zoning in olivine), and thus the eruption could be tectonically triggered, and (3) eruptions of Siete Fuentes, Fasnia and Arafo (Tenerife, 1704-05) record evidence of three magma mixing events in the olivine chemical zoning, about 1 year, 3 months and in the last weeks before eruption. Factual accounts only report seismicity in the last weeks before eruption and this time scale is also recorded in all cases of factual seismic unrest data that we have found (Tenerife 1704-05 and 1909, La Palma 1949 and 1971, El Hierro 2011, Paricutin 1943 and Jorullo 1759). The unrest time scales and magmatic processes that we have found allow for an improved anticipation and planning in areas with potential for monogenetic eruptions.

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IUGG-4007

Reconstructing the plumbing systems beneath young monogenetic mafic eruptions in an off-rift setting on the Snaefellsnes Peninsula of Iceland

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More attention has been given to how melt is stored and transported in the Icelandic rift zones because they represent the locus of active crustal accretion. Young (< 1 Ma) alkali basalts have erupted through older crust in the off-rift Snaefellsnes Peninsula, 50-150 km from the main rift zones. This off-rift zone is tectonically different, with limited extension, a lower geothermal gradient, and low magmatic productivity, which might lead to differences in magmatic plumbing: for example, more extensive sub-Moho crystallization due to the thicker lithosphere or poorly developed shallow-level chambers due to differences in upper crust structure. This project is investigating such issues through a detailed study of two eruptive centres: the ~4 ka Berserkjahraun comprised of four adjacent cinder cones and their associated lava flows, and the ~414 ka Vatnafell sub-glacial unit that lies just 5 km to the south. Petrographic observations and whole rock compositions of ~40 samples are being integrated with field data to constrain the temporal-compositional trends within the Berserkjahraun eruptions. The complex nature of the crystal cargo is highlighted by the presence of two distinct plagioclase populations (sieve-textured vs. clear) in the earliest eruptive unit. This is also seen in the highly porphyritic Vatnafell unit where glomerocryst petrography and strongly kinked crystal size distributions for olivine and clinopyroxene indicate incorporation of wehrlitic cumulates by the host magma. In both locations, mineral and glass compositions are being used to determine the depths of crystallization, in order to reconstruct the details of magma storage and ascent beneath this off-rift zone and the origins of the crystal cargos.

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IUGG-4308

The Chaîne des Puys: Complexity at all scales from source to emplacement

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The Chaîne des Puys is maybe the first monogenetic field to be studied in detail, with a comprehensive description published in the late 18th century. It is also a key location on the W European Rift's Limagne Graben, where the link between tectonics and monogenetic volcanism is exceptionally clear, even to lay visitors. The Area has been recognised by UNESCO World Heritage committee to have Outstanding Universal Value as a tectono-volcanic scale model and will be presented for World Heritage status confirmation in 2016. A striking aspect of the Chaîne des Puys is the landform variability, compositional differences and the local geological environment. Basaltic scoria cones, tuff rings and maars have complex shapes, distinct histories and is are associated with distinct deposits. More evolved volcanoes indicate crustal magma storage, ACF, mixing of magma batches, and superimposed cones of increasingly evolved magmas indicate also progressive evolution of magma batches over hundreds to many thousands of years. Domes form an essential end-member of the Chaîne des Puys compositional and morphologic spectrum and are themselves complex and variable. Lava flows have interacted with topography / erosion to create a spectrum of inverted reliefs. They have been topographically controlled to create a range of flow morphologies and flow types. Plateau-spread lavas store huge volumes, that then flood down rift flank valleys, while those descending the fault scarp pond up and accumulate in lava ponds. The chain's north-south alignment is organised into several sets of NNE-trending segments, that reflect strong structural and tectonic control. This presentation relates the holistic geometry of this classic monogenetic field.

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IUGG-3746

"First documentation of the ongoing phreatic-strombolian eruptions of Turrialba volcano (Costa Rica)"

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We report on the first strombolian eruption of Turrialba volcano since the major 1864-66 eruptive period. The eruption occurred during the night of 29-30 October 2014 as part of a prolonged unrest period manifested by recurrent phreatic eruptions and enhanced magmatic degassing that started since January 2010 and is ongoing at the moment of writing. The first phreatic vent (5 January 2010) opened in the inner wall of the SW crater, whereas the second eruption (12 January 2012) occurred from a vent along the rim between the SW and Central craters near to the Arbol Quemado gas fracture active since 2001. The third phreatic eruption (21 May 2013) involved both vents contemporaneously. The magmatic character of the October 2014 strombolian eruption was demonstrated by temperatures near 900°C measured by FLIR thermal images and throwout of ballistic scoriaceous bombs. These bombs were collected during the following days, together with ash samples in different sectors of the summit area. Petro-chemical analyses of these bombs are compared to bombs of the 1864-66 eruption in order to evaluate variations of eruptive dynamics and feeding system. Morphoscopic SEM analyses of ash products are confronted with data available on the 1864-66 ash. Early results indicate the emission of basaltic andesitic products with a similar petrography and porphyricity compared to the 1864-66 ones. Ash was mainly composed of non-juvenile material emitted during the phreatic eruptions that progressively dismantled the Arbol Quemado fracture and 2012 phreatic eruptive vent shifting now towards the Central one.

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IUGG-4248

Large-scale basic Plinian eruptions: Textural characterization, rheological studies and numerical analysis on the Pozzolane Nere eruption (Colli Albani, Italy)

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The Pozzolane Nere formation (PNR; 407 ka; 15 km^3 DRE) represents one of the seven large explosive caldera-forming eruption of the quiescent Colli Albani volcano. PNR eruption includes a basal sequence of scoria fallout overlain by a widespread low aspect ratio ignimbrite, characterized by undersaturated tephri-phonolitic magma. In order to understand the role of the internal properties of magmas in affecting and controlling the dynamics of magma ascent we performed a combined investigation of structural features of the deposits (grain-size, maximum clast size, composition), textural, physical and chemical characteristics of the juvenile material (Vesicle Size Distributions, Crystal Size Distribution, density, viscosity) and eruption parameters (ejected volume, column height and discharge rate). Several textural features support an interpretation that early history of PNR eruption was characterized by rates of ascent and decompression atypically high for basic magmas. Textural and mineral-chemical investigations have been combined with rheological studies. We demonstrated through numerical simulations that, at the very fast decompression rates derived from textural analyses and Toramaru's formulations (2006), conditions necessary for fragmentation and explosive eruptions are reached. We postulated that water-magma interaction triggered the eruption, generating fast decompression rates that allowed it to initiate and to progress into a purely magmatic stage. We suggest that changes in vent/conduit, opening of fractures and ultimately caldera collapse lead to a progressive increase in mass fluxes and decrease in ascent velocities, which produced a column collapse leading to the generation of the PNR ignimbrite.

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IUGG-4444

The hidden secrets of a Strombolian clockwork: coupled high speed imaging and seismo-acoustic recordings of explosions at Etna, July 2014.

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Seismic and acoustic surveillance is routinely performed at several persistent activity volcanoes worldwide. However, interpretation of the signals associated with explosive activity is still equivocal, due to both source variability and the intrinsically limited information carried by the waves. Comparison and cross-correlation of the geophysical quantities with other information in general and visual recording in particular is therefore actively sought. In July 2014 Strombolian-style explosive activity occurred at two adjoined vents formed along a new eruptive fissure. Visually, the activity appeared as short-lived explosions ejecting bomb- to lapilli-sized, molten pyroclasts at a remarkably repeatable time interval. The frequent occurrence and the highly repeatable nature of the explosions provided us with a rare occasion to systematically investigate the seismic and acoustic fields radiated by this common volcanic source. During July 15 and 16, 2014 we deployed FAMoUS (FAst, MUltiparametric Setup for the study of explosive activity) at about 300 meters from the vents, recording more than 60 explosions in thermal and visible high-speed videos (50 to 500 frames per second) and broadband seismic and acoustic instruments (1 to 10000 Hz for the acoustic and from 0.01 to 30 Hz for the seismic). Cross-correlation of this data set help defining better the key monitoring parameters offered by the geophysical approach (e.g., ejected mass and velocity), also adding to our general understanding of the eruptive process.

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IUGG-4599

Explosion earthquakes during the 2007 eruption of Pavlof Volcano, Alaska

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Pavlof Volcano on the Alaska Peninsula began to erupt on August 15, 2007 after a 10.7 year repose. Precursor signals consisted of low-frequency (LF) earthquakes that began on August 14 and thermal anomalies that were coincident with the beginning of the eruption. The Strombolian eruptions occurred from a new vent high on the SE flank of the volcano, separate from the NNE vent that had been active over the previous decades. Seismic activity, monitored by a network of 6 local short-period instruments, consists of LF events, explosion earthquakes, volcanic tremor, and lahar-generated signals. A high number of explosion quakes were noted during the 2007 eruption. In this study we manually counted the explosion quakes from their characteristic ground-coupled airwaves. We quantify the explosion quakes and show how the characteristic ground-coupled air waves are affected by wind direction and wind speed. Additionally this study investigates how the ground coupled air waves might be used in a monitoring or analysis effort by calculating energy release and gas mass release. Over 32,000 quakes were recorded. It was found that wind direction affects the travel time of the airwave by up to 0.7 seconds depending on station location and wind direction. Wind direction and speed however are demonstrated not to cause an appreciable difference in ground-coupled airwave frequencies or amplitude ratios. The energy release from the explosions is calculated to be 3.04×10^{11} J and the total gas mass (assuming 100% water) released was 729 metric tons. These values are compared to the literature and found to be somewhat lower than values for other similar volcanoes. Nevertheless, the tracking of explosion quakes has the potential to become a useful part of the seismic monitoring efforts.

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IUGG-5664

Explosive interaction of magmatic and hydrothermal systems during flank extension: The Bellecombe ashes of piton de La Fournaise, Réunion Island

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Piton de la Fournaise is a dominantly effusive basaltic ocean-island volcano. The Bellecombe ashes, dating to ~3000-4500 BP, record at least three explosive eruptions. The lower two deposits are centered along the west side of the modern caldera (Enclos Fouqué) and are formed by beds of lapilli breccia and ash (rich in ash pellets). The breccias are of limited areal extent but the ash deposits extend at least 3 km west of the current caldera rim. The upper Bellecombe ash is exposed in the Plaine des Sables near a line of three basaltic eruptive centers and for ~10 km to the west and north. A lithic-rich lapilli fall is present near the cones and an ash-pellet-rich deposit extends to the distal areas. The lower Bellecombe breccias contain abundant dense lava fragments with annealed cracks and rare gabbro clasts and the ash contains euhedral quartz and olivine grains. The upper deposits contain these same components, but also abundant gabbro and oceanite lapilli and the ash is rich in an intensely hydrothermally altered rock. We interpret the deposits to have resulted from lateral sliding of the volcano flank following voluminous lava eruptions. Fissures into the volcano formed at the faults and these allowed explosive ejection of material from the magmatic and hydrothermal systems, with the third eruption tapping a deeper and/or more developed hydrothermal system. These eruptions are an ongoing hazard at Piton de la Fournaise that may occur with future large eruptions of lava.

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VS14p-459

El Pozo Volcanic Complex, Mendoza-Argentina

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Approximately 200 km east of the trench at the Southern Volcanic Zone of the Andes, in the south of Mendoza province, there are three wide back-arc monogenetic volcanic fields: Payún-Matru, Llancanelo and Diamante. The two first include more than 870 pyroclastic scoria cones and voluminous lava fields that cover a large surface area. Some of them show evidence of explosive eruptions, with varying degrees of water-magma interaction. The volcanic cones consist mainly in scoria cones, tuff cones and tuff rings. Volcanic activity of these fields started at the beginning of the Pliocene.

Diamante Volcanic Field, near the Agua del Toro dam, and further north than the other two, is less developed than the others, with only 84 eruptive centers mostly of them scoria cones.

El Pozo Volcanic Complex is located in the northern part of the Diamante Volcanic Field. Is formed by three coalescent maars, placed between 10 and 60 meters below the surface. The pre-eruption surface is formed by the Asociación Piroclástica Pumícea, a large ignimbrite-plateau related with the collapse of the Diamante Caldera-Maipo Volcano, located in the boundary with Chile, with an age of 450 ka.

Pyroclastic deposits are scarce, and are mostly base surges and fallout. Wet palagonitized surges evidences the water participation in the eruption. A final magmatic event causes the growth of a small scoria cone which emits a pahoehoe lava flow with tummuli and a lapilli blanket reaching 3,5 km to the SE from the volcanic complex.

The magma involved in this episode is of olivine-basalt composition.

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VS14p-460

Understanding the hazard of a frequently vent-shifting parasitic centre of the Ruapehu volcano, the Ohakune Complex, New Zealand.

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The Late Pleistocene basaltic andesitic Ohakune complex is located in the southern ring plain of Ruapehu volcano. The complex consists of an outer E-W elongated compound tuff ring-like edifice parallel with the Ohakune Fault and three inner scoria-spatter cones. The proximal sequences of the scoria cones and the tuff ring have been exposed in many locations by quarrying and railway construction. Through these exposures it can be concluded that the volcanism began with a phreatomagmatic phase, as demonstrated by the presence of an ash-dominated, ≥5 m thick basal succession abundant in accidental lithic clasts from laharic gravel and boulder beds, indicating shallow subsurface water-magma interactions that initiated pyroclastic density currents. These units at the very proximal section are cut through by thick-bedded spatter and accidental lithic rich units separated by thin poorly sorted ash units. The discordance is evidence of a vent shifting event, while the deposits indicate that the rising magma erupted through multiple vents by lava fountain to Strombolian explosions alternated with destructive vent-cleaning phreatic blasts and phreatomagmatic explosions. This is a reflection of the quick changes in magma discharge rate, degasing and the degrees of interaction with external water. Simultaneously at the NW end of the fissure a scoria-spatter cone formed through relatively steady Strombolian to lava fountaining eruptions, depositing homogeneous, massive-bedded, often welded pyroclastic deposits. Mapping the sequence and the morphology of the tuff ring using a Terrestrial Laser Scanner we could delimit the edifices belonging to separate vents and estimate the eruption volumes of each unit utilizing the measured thicknesses and thickening trends of the obtained data.

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VS14p-461

Magmatic evolution of young, small volume mafic eruptive centers in the Chilean Altiplano utilizing in situ geochemical and isotopic data

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In the Altiplano-Puna region of northern Chile, crustal thicknesses exceed 65 km and large volumes of mid-crustal felsic magma have limited mafic magmatism in the region since the mid-Miocene. We present new data from six young, monogenetic intra-arc eruptive centers that provide constraints on mafic magma evolution and eruptive mechanisms. Olivine-phyric basaltic-andesite (SiO_2 54 wt%) from Cerro Overo maar (77 ka) represents the regional mafic end-member (MgO 7.4 wt%), though abundant silicic xenoliths indicate crustal interaction. Cerro Tujle, a previously unstudied mafic maar, is nearly aphyric and xenolith free. Tilocalár Sur and Norte are small volume aphyric flows. Two lavas (Puntas Negras, Tolonchar ridge) contain ~1-5 mm clusters of olivine and clinopyroxene phenocrysts. All lavas have groundmass of dark glass with microcrystalline plagioclase, oxides, and clinopyroxene. Olivine textures range from highly skeletal to tabular or euhedral, with abundant melt inclusions. Single crystal olivine $^{87}Sr/^{86}Sr$ from Cerro Overo (~0.7041-0.7071) define a broader range than whole rock (0.7062-0.7065). This indicates preservation of juvenile magma in olivine-hosted melt inclusions, which is lost at the whole rock scale. Bulk major and trace elements follow regional arc differentiation trends and are clearly modified by crustal magmatic processes. In contrast, olivine-hosted melt inclusions appear to record multiple distinct magmas, including potential primary melts. In situ compositional analyses of olivine and melt inclusions along with single crystal radiogenic and stable isotopes provide insight on the composition(s) of mafic magmas being delivered to the lowermost crust, deep crustal processes, and structural control for these mafic centers.

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VS14p-462

A method to estimate monogenetic cones ages based on a new morphometric analysis: applications to the Chichinautzin monogenetic field, Mexico

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We introduce a new methodology to estimate the age of monogenetic volcanoes, based on the analysis of two morphometric features of the cones. The underlying hypothesis of this method is that a correlation exists between two distinct manifestations of erosive processes and the age of the cone. It is assumed that monogenetic volcanoes acquire a characteristic conical morphology at the time of their formation and that it changes as a function of time in a way that allows comparisons among different cones in a monogenetic field that has been exposed to similar climatic conditions along time. The evolution of the cones' shape occurs in two dimensions: a vertical component, which is the well-known reduction with age of the aspect parameter H/D (height of the cone/base diameter), and a horizontal component that reflects the degree of hydrometeorological ablation of a cone over perimeters at different heights -the contour level curves- characterized by the spatial wavelength of the fluctuations of the level curve about a smooth contour line. Both morphometric parameters were calculated from a DEM model based on the high-resolution LIDAR survey made by the Mexican National Institute of Statistics, Geography (INEGI), which covered approximately 70 % of the Sierra Chichinautzin volcanic field. A linear combination of both morphometric parameters correlates well with the available radiometric ages of cones in the Sierra Chichinautzin monogenetic volcanic field, allowing a reliable estimate of the spatial distribution by age of the cones that have not been radiometrically dated.

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Evolution of a rhyolite monogenetic volcano: the perlite deposit Lehotka pod Brehmi, central Slovakia

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The perlite deposit Lehotka pod Brehmi represents one of the rhyolite volcanoes in mostly andesitic Central Slovakia Volcanic Field of the Middle Miocene age. Late stage rhyolites associate with major faults of a horst/graben structure. The volcano is situated at a graben marginal fault and rests upon a succession of volcanisedimentary rocks. Exploited perlite occurs as coarse breccia with fragments of pale to dark grey color. The pale color reflects an increased porosity – mostly tiny pores elongated strongly in planes of fluidality. Exsolution of vapor took place before fragmentation. Molecular “perlite” water content is 3.0 – 4.5 % in all types. During DTA it is lost in the interval 190 – 600 °C. The perlite breccia rests upon inward dipping succession of phreatomagmatic tuffs and agglomerates with predominating fragments of pale porous perlite, including chilled bombs and sporadic andesite pebbles. The perlite breccia filling a maar is mostly chaotic, only locally it shows incipient sorting and outward dipping beds. In the upper part of the breccia accumulation there are horizons enriched in dark fragments passing into dark brecciated outward dipping lava coulees. The breccia accumulation is covered by fall and flow type pumiceous tuffs. Phreatomagmatic activity of the volcano was initiated by contact of rising rhyolite lava with ground water in gravels of the graben. It was succeeded by extrusion of perlitic breccia into the maar depression – brecciation and hydration took place underground at increased pressure and temperature. Lava that escaped a contact with water was extruded as coulees and emplaced as cryptodome. Explosive eruptions of the vulcanian type concluded the activity. The research was supported by grants APVV-0339-12 and VEGA-162-11/138-15.

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Complex and unexpected evolution of some Czech monogenetic volcanoes inferred from combination of geophysical tomography, rock magnetism, petrography, and volcanology

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Among Central-European Cenozoic alkaline volcanic complexes, the Jicín Volcanic Field contains slightly eroded Miocene (17 Ma) olivine nephelinite and basanite volcanic cones, where feeding systems are exposed just next to remnants of erupted facies. The eruptive style was controlled by the paleo-environment as scoria cones formed on well-drained sandstones and tuff-cones grew in swampy areas on marlstones. Trosky and Zebín Hills have been closely studied combining volcanology and petrography with ground geophysics, and rock magnetics. Trosky has two rock-towers mantled by remnants of scoria deposits intercalated with lava flows. The scoria strata dip 75–80° and they are penetrated by thin dykes. Rock magnetic data were collected at 21 sites from the main plugs, dykes and lava flows and yield duel polarity magnetization and magma flow towards and away from the central conduits. These data suggest the twin-scoria cone were penetrated by two plugs of basanitic magma with increased viscosity due to partial crystallization and assimilation of quartz grains in pseudo-karst cavities. Even an ultrabasic composition could hence produce volcanic spines deforming the pyroclastic cones. Zebín Hill is a tuff cone with an exposed feeder system. Rock magnetic data were collected at 25 sites from dykes and reveal subhorizontal flow towards and away from the axial conduit in addition to both upward and downward magma flow. Ground magnetometry and paleomagnetic data indicate both normal and reverse polarity rocks are present at Zebín Hill. A complex system of branching dikes has been also observed from electric resistivity tomography. The research was

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Spatial distribution and morphology of satellite cones in the Virunga Volcanic Province (Rwanda, Uganda and Democratic Republic of Congo)

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Within the western branch of the East-African Rift Valley lies the Virunga Volcanic Province (VVP), shared by DRC, Rwanda and Uganda. While this volcanic province is dominated by eight large polygenetic volcanoes, more than 500 clearly distinguishable eruptive satellite cones lie scattered together with eruptive fissures on the volcanoes' flanks and their surrounding lava fields. Some cones lack any obvious geo-structural link to a specific Virunga volcano.
Using recent high-resolution satellite images (SPOT, Pléiades) and a newly-created 5 m resolution digital elevation model (TanDEM-X), we have mapped all satellite cones and eruptive fissures of the VVP. Based upon morphological indicators such as the presence of flank breaches and the presence of multiple or overlapping craters, we propose a grouping of the satellite cones into 4 categories. Using the MORVOLC program a set of morphometric parameters was calculated to highlight systematic spatial variation in size or morphometric ratios of the cones.
The eruptive cones display concentrations in clusters and alignments, some of which align with the regional tectonic orientations. Field observations reveal a phreatomagmatic origin for some cones close to Lake Kivu. The Lac Vert tuff complex serves as an example that reveals a stratigraphy that is more complex than expected for 'monogenetic' cones, and radiocarbon dates of intra-cone palaeosols reveal an estimated time gap of 500 to 800 years between separate eruptive episodes that constructed an apparent 'simple' eruptive complex. The Virunga examples demonstrate how small-volume eruptive cones can represent complex eruptive histories that deviate from the classical 'monogenetic' concept, and that need to be constrained through multi-disciplinary studies.

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Volcanology of a monogenetic silicic lava dome field, Tokaj Mountains, Carpathian Pannonian Region

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Calc-alkaline felsic extrusive lava domes could form fields of dispersed monogenetic volcanic forms similar as the alkali basalt volcanic areas. The Telkibánya Lava Dome Field (TLDF) evolved at the northern part of the Tokaj – Slanske Mountains Miocene back-arc system in the Carpathian volcanic arc. The subarerial lava dome and flow complex connected to a long lived (13,9-11,2 Ma) silicic reservoir as the youngest silicic event between 11,7 to 11,2 Ma. The recurring volcanic phases build up thickened successions of felsic lavas. The extrusions contributed to the NNW-SSE and perpendicular fracture network. The distribution of the domes and the pyroclastic units indicate at least two extrusion phases. The erosion of the palaeovolcanic filed revealed every lithological unit of an idealized dome-flow complex at different levels. The near-vent microcrystalline zones form eroded necks at the 2nd phase domes. The medial glassy (coherent perlite) and distal fragmented lithology units (clast supported breccias) are characteristic only at least exposed position for denudation at the 1st phase lava domes. The texture of the lithology units records multiple stages of crystallization in response to changes in undercooling related to glass transition temperature (T_g). The groundmass of the dome's interior devitrificated, re-crystallized into micro and crypto crystalline matrix (felsitic, poikilitic) above T_g. The high temperature crystallization domains (spherulites, lithophysae) are characteristic throughout the transitions zone and rhyolites. The medial zones suffered hydration with significant volume growth between T_g and rougly 400 °C to form perlite. The carapace and explosion breccias recorded a primary and secondary vesiculation event in the distal flow/dome regime.

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Spatio-temporal changes of pressure source prior to explosions at Stromboli volcano as inferred from tilt data analyses

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Stromboli volcano is one of the most active volcanoes in the world, and its eruption is characterized by rapid explosions of basaltic magma that are repeated every a few to tens of minutes. We installed three tilt meters and one broadband seismometer within a distance of 500 m from the active craters in the end of May 2014, and recorded large number of tilt data associated with explosions until September. In the present study, we analyze 26 events records with high S/N ratio to understand the magma processes before each explosion. The observed tilts at three stations show uplifts starting from about 200 s before each explosion that is detected by the onset of seismic signal. To estimate the location of the source of tilt motion, we investigate the tilt vectors. The tilt vectors roughly point to the direction of NE crater, and the direction of tilt vectors rotate about 5 seconds before the start of seismic signal. These characteristics are observed in the 22 of 26 events. To interpret the change of directions of tilt vectors, we calculate the tilt motions due to pressure change in a cylindrical open conduit taking into account the topography of Stromboli volcano. The results show that the observed rotations of tilt vectors are explained by changing the depths of pressure in the conduit: the pressure source becomes deeper just before the eruption.

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A first 2-dimensional componentry map of a diatreme: New constraints on subsurface processes from the Ngatutura Volcanic Field, New Zealand.

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Auckland, New Zealand is situated on a young monogenetic volcanic field. The Auckland Volcanic Field (AVF) has been active since c. 250 000 years ago, displaying diverse volcanism and comprises a range of eruption styles and resulting landforms. The variable nature of monogenetic volcanism is strongly controlled by hitherto poorly understood subsurface processes. Detailed exposures of the subsurface geology beneath monogenetic volcanoes to gather this information, however, are very rare. The neighbouring Ngatutura Volcanic Field 60 km south of Auckland was active between 1.83-1.54 Ma and of similar size as the AVF. It presents a unique opportunity to study the subsurface volcanology of small basaltic volcanoes in the form of diatremes because of their great preservation and exposure. We here present detailed field observations and componentry data from one of these diatremes. This diatreme shows the classic features of bedded and massive volcaniclastic sediments and debris jets. The local substrate stratigraphy (lithology, thickness, mechanical properties) are unusually well defined; respective lithologies have unique visual and sedimentological properties and can be grouped into four clearly distinguishable lithic components within the diatreme fill. Componentry analysis of the diatreme fill deposits was used to create a 2-dimensional concentration map of the distribution of respective juvenile and non-juvenile lithologies, thereby constraining the depths of explosions at depth, volumetric excavation of the diatreme and sequential deposition of volcaniclastic material. Existing mathematical and geophysical models can be assessed against these data as to re-evaluate hazards associated with diatremes.

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VS14p-469

Sedimentology, eruptive mechanism and facies architecture of scoria cones in the Auckland Volcanic Field (New Zealand)

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Scoria cones are basaltic small-volume volcanoes (e.g. 10^{-1}–10^{-5} km^3) that result from gas-bubble driven eruption styles.They can produce complex eruptions, involving multiple eruption styles. Here we investigate the eruption histories of 9 scoria cones of the Auckland Volcanic Field. The reconstructions of eruptive and pyroclastic transport mechanisms were established based on sedimentology, stratigraphy, componentry, eruptive volumes and morphologies from Digital Terrain Models. Using sedimentological observations, (degree of welding and agglutination, grain size and 2D morphology data) two end-member types were recognized; (1) lava-fountaining dominated eruption histories with periodic Strombolian activity, and (2) an eruption history involving a more explosive eruption style, such as violent Strombolian phases. Lava-fountaining and Strombolian eruption styles created pyroclastic successions consisting of medium to coarse scoriaceous lapilli beds (-2.5 to -6 phi) with prominent inverse grading and various degrees of welding and agglutination. The 2D pyroclast morphology is mostly irregular in terms of circularity, roundness and solidity. Density ranges from 1.1 to 2.3 g/cm^3 which corresponds to low to high vesicularity. The more energetic eruption styles deposited fine to medium lapilli beds (-2 to -3 phi) with coarse ash intercalations (0.5 to 1 phi) and limited degrees of welding and agglutination. The pyroclast morphologies are less irregular (e.g. higher values of circularity, roundness and solidity). These scoria cones share similar morphological signatures and eruptive volumes; however, they formed through contrasting eruption histories and this need to be integrated into the hazard assessment of this potentially active volcanic field.

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Basaltic tephra generation in large explosive basaltic eruptions from Katla volcano, Iceland

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The Myrdalsjökull glacier fills the caldera of Katla volcano and hence all eruptions within the caldera are characterized by some melt water-magma interaction. With about 300 explosive basaltic eruptions during Holocene it is an ideal place to look at phreatomagmatic basaltic tephra generation. We have studied two large basaltic eruption deposits from 1755 and 1625 CE, respectively.
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Our results reveal a surprising complexity of the tephra generation. Morphological studies indicate that magmatic degassing played a significant role in the aforementioned eruptions. Grain morphology from the 125-63 micron grain classes where studied to determine the primary fragmentation driver(s). We used the automatic shape determination method of the Particle Insight Shape Analyzer to assign shape parameters to about 20,000 randomly selected and oriented tephra grains. Analysis of the parameters shows that a spectrum from blocky to vesicular and elongated grain morphologies is present in both deposits. The prevalent morphology changes throughout both eruptions. The Katla 1755 eruption is characterized by blocky to moderately vesicular grains, which changes to slightly more irregular vesicular grains by the last phases of the eruption. The Katla 1625 eruption is conversely characterized by fairly irregular vesicular grains in the first phases of the eruption, but changes to more blocky and equant grains towards the final phases. The variation in grain morphology suggests that the eruptions were driven by a combination of phreatomagmatic magma-water interaction and a varying extent of magmatic degassing. The more irregular vesicular grains of the 1625 eruption deposit suggests that magmatic degassing played a bigger role in this eruption than in the 1755 eruption.

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VS14p-471

The Chaîne des Puys and Limagne Fault UNESCO World Heritage Project: An ambassador for monogenetic volcanism

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The Chaîne des Puys and Limagne Fault was acknowledged by UNESCO World Heritage in June 2014, to have outstanding universal value – the quality required for the World Heritage list. The project is based on the area's uniquely representative qualities for representing 'major stages of Earth History, significant geological, geomorphic and physiographic features'. Specifically continental rifting and monogenetic volcanism. The project was given a 'referral', because of a wide gap between the scientific community's assessment and that of the IUCN, mandated to examine the project. Differences were founded on the lack of appreciation by the IUCN of the geomorpological and geological complexity of the Chaîne des Puys and its link to the Limagne Rift fault. (For example, the terms 'dome' and 'fault' did not appear in the assessment). We restate the exceptional qualities, concentrating on monogenetic aspects. This analysis can be adapted to link to other recent initiatives, e.g. the world map of monogenetic volcanoes, and other monogenetic geoheritage sites, to form a global link between monogenetic fields. Geoheritage is based on sound geological science, and thus all work defining monogenetic volcanism and exploring its processes impacts on the geoheritage. In turn geoheritage forms a portal to bring our research greater outreach. We''ll show how the UNESCO project has invigorated research in the Chaîne des Puys, and instigated wider research into monogenetic volcanism that will continue to flourish as the project progresses. We invite the monogenetic community to come and study the Chaîne de Puys, using facilities in place, present knowledge base, and the exceptional variability tackle some of the questions posed in this session.

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Dynamics of strombolian eruptions at Batu Tara volcano (Indonesia).

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In September 2014, high-speed imaging and acoustic data were acquired at Batu Tara volcano (Indonesia) during a field experiment aimed at investigating its degassing and explosive dynamics. The small isolated island of Batu Tara in the Flores Sea (about 50 km N of Lembata) is very similar to the Italian Stromboli Volcano in both eruptive style and edifice morphology. It is characterized by several strong episodic strombolian and vulcanian eruptions with recurrence time of minutes to hours. We temporarily deployed in direct view of the active vent one high-speed visible camera acquiring images at 500 frames per second (fps), one thermal infrared (FLIR) camera acquiring at 50-200 fps, two broadband microphones (range of tens of kHz to 0.1 Hz), synchronized with the cameras, one visible time-lapse camera. The main information retrieved from the observations are: i) gas and pyroclast ejection processes, their acceleration and interaction with the atmosphere; ii) acoustic emissions in the explosions. ‘Typical’ strombolian explosions ejected decimeter to meter sized lava bombs to 100-300 m above the crater. Ash venting was also frequent, with minor amounts of incandescent material. Significantly more powerful blasts, emitted very large spatter and hot blocks, several hundreds of meters in all directions. These latter eruptions created rarefaction waves and loud detonation sounds. Comparison of the observed behavior with other similar volcanoes (e.g., Stromboli and Etna) is provided.

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A multi-disciplinary method for the understanding of melt distribution in the subsurface at distributed volcanic fields

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Distributed volcanic fields contain a large number of small-volume basaltic volcanoes that are short-lived and one or more long-lived, silicic central volcanoes. How these two types of volcanic activity are related in terms of melt distribution and magma pathways in the subsurface is yet not well understood. To better understand the subsurface distribution of melts in Lassen Volcanic field (California), we propose to combine statistical analyses of volcanic features (vents, volumes), geophysical models (magnetotelluric, gravity) and numerical models of magma transport in the crust. Statistical analysis of the spatial intensity of volcanism and flux (vents and volume per unit area, respectively) inform about melt distribution, preferential magma pathways and volume flux. Outputs are in the form of probability density functions (PDFs) assumed to represent flux of melts at the surface. Clusters of vents revealed in maps of spatial intensity of volcanism and the presence of polygenetic edifices denote zones of high magma flux and recurrence rate, whereas areas of dispersed mafic volcanism represent zones of lower flux. Maps of volume flux also reveal zones where erupted volumes are higher, revealing preferential areas of magma focusing and higher recurrence rates. We also model bulk magma transport in the crust as the non-linear flow of a viscous fluid within a homogeneous porous medium using Darcy’s law. The crust and reservoirs conductivity can be adjusted based on magnetotelluric data. By comparing outputs from numerical simulations and spatial intensity analyses, we gain insights into the processes in the subsurface controlling the location of distributed vs. focused volcanism.

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VS14p-474

Variability of the monogenetic concept exampled by the Grand Sarcoui dome (Chaîne des Puys, France)

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The Chaîne des Puys, a quaternary volcanic field of about 80 volcanoes in the center of France, is often given as an example for illustrating monogenetic volcanism. However, a few major volcanoes of the Chaîne des Puys do not really fit typical 'monogenetic' features reminded by the IAVCEI Commission for Monogenetic Volcanism (https://vhub.org/groups/iavcei_cmv), which are being small cones formed within a short timescale. It is the case for the Grand Sarcoui, a trachytic lava dome with a height of about 250 m and a basal diameter of about 800 m. The emplacement of the dome occurred circa 12.6 ky ago but a delayed and limited summit eruption covered it with a layer of lapilli and ashes, with the same magma as the dome, about 2 ky later. This uncommon time span implies considering a late reactivation of the plumbing system of Sarcoui. Despite its modest volume, the late event contributed to the construction of the volcano, mimicking at a lower scale the story of large complex volcanoes.

Furthermore, the dome which seems to be as regular as a bowl is nevertheless composite. It was initiated by an explosive aperture of a vent. Then, it was mostly constructed by endogenous growth and partly by actual lava flows. In addition, a significant syneruptive flank collapse occurred, generating a pyroclastic flow accompanied by a blast. The flow ran on a wet surface and produced hummocks and secondary phreatic craters like, e.g., at Mount St Helens in 1981.

Therefore, Grand Sarcoui can be considered as a reduced scale model for phenomena which are common for large complex volcanoes. It is illustrative of the wide range of variables beyond the monogenetic concept.

The study benefited of an especially dedicated airborne LiDAR survey and of combined geophysical investigation.

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Porosity-permeability relationships in explosive basaltic andesite lapilli from Okmok Volcano, Aleutians Islands, Alaska

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Magma vesiculation and degassing processes are important in controlling eruption style. This study focuses on how degassing controls eruption style through an experimental and natural sample investigation of permeability development in mafic magmas, targeting the July-August, 2008 and mid-Holocene Middle Scoria violent strombolian, subplinian, and phreatomagmatic eruptions from Okmok volcano, Aleutian Islands, Alaska. Lapilli samples from the basal 2008 (55 wt. % SiO_2) and Middle Scoria (54 wt. % SiO_2) deposits (Wong and Larsen, 2010) were analyzed for bulk density, porosity, connected porosity, and permeability in the UAF Petrology Lab. Middle Scoria samples have connected porosities that range from 41 to 69 vol. % and viscous permeabilities from 5.9×10^{-13} m^2 to 5.6×10^{-11} m^2. The 2008 lapilli have connected porosities from 42 to 76 vol. % and viscous permeabilities from 5.5×10^{-14} to 7.2×10^{-12} m^2. Porosity-permeability relationships from Middle Scoria lapilli are fit well by percolation theory (Saar and Manga, 1999), predicting a critical porosity of ~25 vol. %. The 2008 lapilli have porosity-permeability relationships that do not fit percolation theory well and trend towards lower permeabilities than predicted by comparison with the Middle Scoria data. Although the two eruptions began with similar intensities and eruption styles, the data indicate significant differences in vesicularities when the magmas fragmented. After an approximately 4-hour-long opening phase, the 2008 eruption quickly transitioned into a strongly phreatomagmatic eruption style. It is possible that the influence of groundwater on fragmentation during the 2008 eruption resulted in much lower and more variable permeabilities in the 2008 lapilli, compared with the drier Middle Scoria eruption.

IAVCEI (Volcanology, Geochemistry)

VS14p - VS14/VS07 Unlocking the Enigma of Monogenetic Volcanism from a Historic Perspective to the Most Novel Recent Approaches / Explosive Basaltic Eruptions on Earth and other Planets

VS14p-476

Magma mixing and compositional variation through the Surtsey eruption, 1963-1967

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The island of Surtsey formed during a 3.5-year-long eruption that began in November 1963. During the course of the eruption three lesser known volcanic edifices also grew from the seafloor along a discontinuous fissure extending 4.5 km, with two of them forming islands that washed quickly away – Syrtlingur lasted 5 months, and Jolnir 11 months. Surtla edifice grew to within meters of the sea surface but formed no island. The separate eruptive centers along the Surtsey fissure produced edifices totalling ~0.15 km^3 (Syrtlingur and Jolnir ~ 0.07 km^3 each; Surtla ~0.01 km^3), nearly half the volume of Surtsey below sea level (~0.3 km3). Although Surtsey's explosive activity ceased after 6 months, it was more than 3 years into the eruption when the last pyroclastic activity at Jolnir ceased, and during most of the time that Syrtlingur and Jolnir were erupting, there was no subaerial eruption at Surtsey. Whole-rock compositions became progressively more magnesian as the eruption progressed (rising from 7 to 12% MgO), with a subtle concomitant reduction in potassium (0.7% to 0.4%). Glass compositions show considerable variation early in the eruption at Surtsey (~4.5-6.2 % MgO; 46.5-48.2% SiO_2), but changed little through the remainder of the eruption (~7% MgO; 48% SiO_2) at all sites. Glasses from Jolnir and Syrtlingur have overlapping compositions that form a separate cluster from those of Surtsey (more calcic, less potassic). Surtla, represented by only one sample and erupted at the greatest distance from Surtsey, has slightly more-evolved glass (lower MgO, higher FeOt). We infer that mixing of alkalic EVZ magmas with minor Reykjanes Ridge magmas best explains the volumes, patterns, and petrographic features of the clinopyroxene-impoverished Surtsey eruption series.

IAVCEI (Volcanology, Geochemistry)

VS15a - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-1023

Interpreting water contents of submarine pumice: attempting to see through the veil of hydration

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Studies of submarine eruptions are hindered by the logistical difficulties and costs of directly observing and sampling submarine volcanic edifices, and by the difficulties of identifying the eruption source of pumice rafts that may drift for great distances. Many questions remain about the impacts of the overlying water column on eruption processes and, in particular, at what depth explosive pumice-producing eruptions can occur. H_2O solubility in magma increases with increasing pressure so if the magma is saturated with respect to H_2O, the dissolved H_2O content of volcanic glasses provides a way to estimate the pressure at the time of quenching; hence the eruption depth. Silicic pumice however is particularly susceptible to post-eruption hydration by seawater at ambient temperature, which causes high glass H_2O contents with anomalous H_2O speciation. Obtaining meaningful data thus requires distinguishing between the original dissolved magmatic H_2O content and the H_2O subsequently added via post-eruption hydration. H_2O speciation data may enable us to do so. Since H_2O added during hydration is added in the form of molecular H_2O (H_2O_m), and the species interconversion reaction between H_2O_m and hydroxyl (OH) species is negligible at ambient temperature, the measured OH content of hydrated pumice should remain unaltered. Using H_2O speciation models, the corresponding original H_2O_m content can be estimated from the measured OH content, thereby allowing reconstruction of the original H_2O content of the glass. By measuring H_2O speciation in silicic submarine pumice by FTIR, we will examine whether this methodology provides a means to get at the magmatic H_2O content, which can then be used to estimate eruption depths and help locate potential sources of rafted pumice deposits.

IAVCEI (Volcanology, Geochemistry)

VS15a - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-2563

Contrasting mechanisms of magma fragmentation and degassing during coeval magmatic and hydromagmatic activity revealed by dissolved volatile concentrations

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We explore mechanisms of magma-water interaction (MWI) by examining tephra from the 2500BC Hverfjall Fires within the Krafla fissure system, Iceland. Here, coeval fissure vents spanned sub-aerial (Jarðbaðshólar scoria cones) to shallow lacustrine environments (Hverfjall tuff cone), resulting in both dry magmatic and variably wet hydromagmatic activity. Major element compositions are uniform, indicating a shared initial magma composition and evolution. Differences in the size and morphology of pyroclasts thus reflect fragmentation mechanisms under different near-surface conditions, which we explore further with measurements of sulphur (S) concentrations in matrix glasses.

The transition from hydromagmatic fall deposits to base-surges is generally thought to be indicative of more extensive MWI due to a decrease in the eruption rate. Contrary to this hypothesis, we find no change in S composition between hydromagmatic fall and surge deposits, or vertically through the eruption sequence. These data are consistent with fragmentation under similar conditions for the range of styles of hydromagmatism. However, matrix glass S concentrations are consistently elevated in hydromagmatic ash (600–1500 ppm, approaching melt inclusion compositions) compared to magmatic ash and scoria lapilli (200–500 ppm). We propose that vesiculation of the magma that fed the Hverfjall vent was interrupted and that elevated S concentrations reflect greater fragmentation depths and/or more rapid quench rates. To discriminate between these scenarios, we compare S data to (a) bubble size distributions, and (b) volatile species (Cl, F, H_2O, and CO_2) with different pressure-dependent solubilities. Diffusion profiles around bubbles place constraints on the timescales of shallow magma ascent.

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IUGG-2847

The fracture behavior of volcanic glass and relevance to quench fragmentation and formation of hyaloclastite

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Quench fragmentation can occur when magma is super-cooled to glass and thermally shocked upon contact with ambient water (e.g. when magma is erupted subaqueously, flows into water, or intrudes water-saturated sediments). Materials engineering literature provides insight into the behavior of glass when thermally shocked. Rate of super-cooling of magma through the glass transition determines if it remains coherent or quench fragments, and depends on the thermal conductivity of the magma and water (liquid and steam) and heat capacity of water. Superheating of the water well above the Leidenfrost temperature forms a stable vapour film that moderates heat loss rate and allows the magma to cool slowly, forming coherent glass. Water temperature only slightly above the Leidenfrost temperature, leads to vapor film instability and collapse, extreme cooling rates of the magma, and extreme contractional strain rates. Tensile stress above the ability of the glass to recover elastically, leads to brittle failure. A network of contractional, extensional fractures propagate into the quenching glass and magma, forming hyaloclastite. Cooling rate controls crack spacing and grainsize, temperature difference controls crack shape, cracks propagate perpendicular to the cooling surface and to each other, and are arrested by intersecting other cracks, chemical reaction between water in the cracks and glass enhances crack propagation, crystals in glass increase the resistance to thermal shock, but vesicles have the opposite effect. Hyaloclasts are typically angular and are bounded by planar to curvi-planar surfaces, reflecting brittle fracture within an isotropic glass. Pumice hyaloclastite forms non-explosively when a magma vesiculates to a high level before quench fragmentation occurs.

IAVCEI (Volcanology, Geochemistry)

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IUGG-4977

Thermal modeling of the large Pleistocene subglacial fissure eruption of Snæb*lishei*i, Iceland

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Icelandic volcanism produces volcanic landforms that reflect waxing and waning of ice sheets. Recent subglacial eruptions reveal glaciers' important role in shaping volcanic edifice morphology and eruption style. Here we model the response of an ice sheet to a large-scale subglacial basaltic fissure eruption using geological, glaciological, and thermodynamic principles. The Snæbýlisheiði volcanic unit makes up a NNW-SSE elongate, sinuous flat-topped ridge in the highlands of south central Iceland; its source area is within the EVZ ~7 km ESE of Torfajökull volcanic center. The ridge is 300-100 m high, ~7-3 km wide, and ~34 km long (26 km^3) and inferred to have formed in a single ~Laki-scale eruption. At the source area comprising the first 1-3 km of the ridge subaerial deposits such as accretionary lapilli tuff and spatter occur high on the edifice. Down-ridge, accretionary lapilli tuff crops out at 6 km, and variably welded scoriaceous coarse lapilli tuff breccia/ spatter at 7.6 and 9 km. These observations constrain estimates of ice-sheet size at the time of eruption. We assume that most of the energy released during eruption is expended in melting overlying ice. To first-order approximation, then, the thickness of ice melted scales simply from eruptive-deposit thickness when ice is thick and bedrock and ice surfaces have gentle slopes. Assuming a parabolic ice sheet, the possible melt-through of the ice sheet for the thickest part of the deposit (out to 7-9 km from the vents) can be reconciled with ice sheets extending 20-40 km S/SE beyond the tip of Snæbýlisheiði, to near the location of the present coast. This modeled ice sheet is more similar to the Younger Dryas or the Preboreal ice sheets than to those in current models for the last glacial maximum in Iceland.

IAVCEI (Volcanology, Geochemistry)

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IUGG-5012

Hyaloclastite fragmentation below the glass transition: example from El Barronal submarine volcanic complex (Spain)

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Submarine felsic volcanoes are dominated by hyaloclastic piles hundreds of meters thick, the origin of which, in terms of how and when they form, is far from being completely understood. Here we present a study of the thermal remanent magnetization of the Miocene high- K dacitic El Barronal hyaloclastites (Cabo de Gata, Spain), showing that their formation is dominated by in situ fragmentation with small or negligible transportation and/or rotation of different clasts after their formation. Data indicate that fragmentation progressed down to 210–390 °C, well below the glass-transition temperature estimated at 560–750 ºC depending on the water content of the high-K dacite. Hence, hyaloclastite fragmentation in thick lavas may occur over most of the cooling history, as a result of the progressive access of sea water toward the lava interior by development of a complex network of contraction fractures.

IAVCEI (Volcanology, Geochemistry)

VS15b - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-0852

The influence of a shallow water body on eruption mechanisms: Case study of the Ngozi Caldera, Rungwe Volcanic Province, Tanzania

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Phreatoplinian eruptions and their deposits remain poorly understood because of their low frequency of occurrence and limited number of observations made in the historical or geological records. A stratigraphic study on Ngozi volcano in Tanzania revealed that its three most recent major ignimbrite-forming eruptions show systematic involvement of external water during the onset of the eruption whereas the older eruptions display classical dry magmatic deposits. Ngozi is therefore an interesting case study for detailed studies of the relationship between phreatomagmatic and dry magmatic deposits in one large explosive eruption.

Ngozi is a 3-km-wide, trachytic collapse caldera, located approximately 15 km SE of Mbeya city in SW Tanzania. The caldera is occupied in its southern part by the 2.75 x 1.5 km Lake Ngozi. Recent research revealed that Ngozi has had multiple major explosive eruptions in the Holocene - Late Pleistocene with an important pyroclastic density current component present in each eruption. This is in contrast with the neighbouring Rungwe volcano which has only had fall-producing Plinian-style eruptions despite highly similar tectonic control and magma composition to Ngozi.

The eruptive products of Ngozi that show involvement of external water suggest a variety of deposition mechanisms, from fallout to dilute and dense flows. The influence of external water disappears upward in the eruptive sequence of each eruption. We suggest that this transition from phreatomagmatic to dry magmatic deposits corresponds to the depletion of a shallow water body, in this case Lake Ngozi. The involvement of external water in potential future eruptions should be taken into account for assessing the hazards and risks that Ngozi might pose on the surrounding communities.

IAVCEI (Volcanology, Geochemistry)

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IUGG-0856

A different perspective: How magmatic strain influences the local hydrology and what we can learn from the aquifer response.

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Reports of well water level changes associated with volcanic eruptions exist throughout literature. Often interpreted as a result of pore pressure changes in the aquifers due to poroelastic deformation, they are likely linked to subsurface magmatic processes. But whether and to what extent wells can be used to monitor strain at a volcano is a question yet to be answered.

Previous works combine estimated aquifer strain sensitivities with simple deformation models to derive eruptive processes from well level changes – however, these methods can fail to fully explain observations.

We present a suite of more detailed geophysical models that investigate how inflating magma chambers affect close-by hydrological systems. Flow and deformation processes are fully coupled and numerically simulated time-dependently. The use of Finite Element Analysis allows us to include different chamber shapes and crustal heterogeneities in our extensive parametric studies.

Results show that the pure strain induced by a recharging magma chamber can cause centimeters to meters of hydraulic head changes in overlying aquifers. The models also simulate the previously neglected flow-induced change in time of both strain and head change in the aquifer. Allowing the chamber to be a non-Mogi source drastically changes results – source morphology and crustal heterogeneity are crucial influences on the aquifer response. Especially the elastic stratigraphy should be considered when inverting signals: In certain elastic settings, the resulting hydraulic head change is of opposite sign than what would be expected from poroelastic theory for a homogeneous earth.

Our models provide new insights into poroelastic phenomena at volcanoes and are a platform to study and test hypotheses for reported real cases.

IAVCEI (Volcanology, Geochemistry)

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IUGG-3108

Recent eruptions at White Island, New Zealand: Dynamics of ballistic ejections, pyroclastic surges and the rate of deposition erosion

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White Island erupted in two very short bursts on 4th August, 2012 and 11th October, 2013 both after intense periods of unrest. The larger of the two eruptions occurred at ~ 8 pm on October 11. Both events were captured by the camera near the old sulphur factory under low light conditions, which allowed us to determine the rates of plume ascent and surge flow rates crudely.

We focus on the October eruption where we have assessed photographs of the crater floor to determine the number and size of ballistic impacts, coupled with ground-based measurements. We then used the area of altered ground from photographs to determine the deposit extent, again along with ground-based thickness measurements. These data are used to describe the dynamics of the eruption.

A serendipitous sample was collected near the camera site that would otherwise have been lost from the depositional record. This sample represents the elutriated portion at the margins of the pyroclastic surge that would otherwise be transported out of the crater once effective mixing between the surge and atmosphere took place. This is a rare example where we can calculate the amount of material lost from the geological record days to years after the eruption.

IAVCEI (Volcanology, Geochemistry)

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IUGG-3408

Mineral indicators of events in the 2012 hydrothermal eruptions of Te Maari crater, Tongariro, New Zealand

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On 6 August 2012 a hydrothermal eruption occurred from the Upper Te Maari crater on Mt Tongariro. Intrusion of magma about 3 months prior to the eruption charged the hydrothermal system with gas and heat. The south west flank of Upper Te Maari crater failed, creating a debris avalanche, triggering tephra emission (northern lobe), and surges from a rift located above the crater. Surge deposits went first to the east, then to the west. Seconds later an 8-10 km high plume was ejected from the Upper Te Maari crater itself, which subsequently dispersed to the east to form the eastern and main tephra lobe. The surges and the plume events were accompanied by ejection of ballistics.

Preliminary XRD data showed differences in mineralogy of the north and east tephra lobes. Ash deposits and source area hydrothermal material contained cristobalite, tridymite, quartz, feldspar, pyroxene, pyrite, gypsum and kaolin minerals. Kaolin dominated highly altered zones in the source areas while gypsum and pyrite were more abundant in less weathered materials. This study examined mineralogical assemblages in a wider range of samples from the Te Maari events. The north tephra lobe contained gypsum and pyrite with little kaolinite and is thought to be associated with the initial destruction of the hydrothermal cap. The surge deposits contain kaolin and no gypsum or pyrite, suggesting deposition of the north tephra lobe was not a result of ash generated by surge emplacement. The east lobe also contains kaolin and little pyrite or gypsum, suggesting that the surges and the eastern tephra tapped a more highly altered part of the hydrothermal system than the northern lobe tephra. The mineralogical data thus provides constraints on event relationships in this short duration eruption episode.

IAVCEI (Volcanology, Geochemistry)

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IUGG-4887

The 2012 hydrothermal eruption of Upper TeMaari, New Zealand: Experimental constraints on the energy budget and the ejection of ballistics.

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At 6th August 2012 a hydrothermal eruption occurred at Upper Te Maari within the Tongariro volcanic complex (New Zealand). The eruption comprised a series of short-lived explosions, laterally directed density currents and a vertical ash plume. All explosions were accompanied by ballistic ejection, some of which impacted NZ’s most popular hiking trail and a mountain lodge in a 1.4 km distance.

Detailed mapping of the ballistic strew field revealed first insights into the eruption dynamics. Ballistics could be discriminated into four main lithology groups and traced back to specific explosion-source locations in the vent region. We used the main lithology types for rapid decompression experiments mimicking hydrothermal explosions under controlled laboratory conditions. The heterogeneity of the brecciated lithologies necessitated an experimental setup for large samples (34 mm diameter, 70 mm length). The experiments were conducted in a temperature range from 250°C – 300°C and applied pressure between 4 MPa – 6.5 MPa. Within this range we tested rapid decompression of pre-saturated samples from both the liquid-dominated field and the vapor-dominated field. Further we tested dry samples at the same PT-conditions. Clasts were ejected with velocities of up to 180 m/s as recorded with a high-speed camera. The resulting fragments were analyzed for their grain size distribution, shape and lithology. Besides a few larger clasts (in analogy to ballistics), a large amount of fine and very fine (<63 µm) ash was produced in all experiments. Experimental studies of this kind facilitate better constraints on the ejection characteristics of ballistics and their associated hazard. Furthermore they shed light on the energy conversion and partitioning during hydrothermal explosions.

IAVCEI (Volcanology, Geochemistry)

VS15c - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-0390

Volcaniclastic sedimentation- witness of the interaction between volcanism and sedimentation in the Oas-Gutâi Neogene volcanic area (Eastern Carpathians, Romania)

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The Oas-Gutâi Mts. of the Neogene-Quaternary Eastern Carpathians volcanic arc were built up by combined, volcanic and sedimentary processes. A complex calc-alkaline felsic and intermediate volcanism developed during Miocene (15.4-7.0 Ma), along with contemporaneous volcaniclastic and terrigeneous sedimentation in the adjacent submarine basins (Oas, Baia Mare and Maramures), as extensions of the Pannonian Basin towards the North-East. The long lasting volcanic activity dated by K-Ar age determinations is witnessed by various coherent and fragmental, non-explosive or explosive deposits. Syn-eruptive and post-eruptive volcaniclastic sedimentation recorded the deep and shallow marine and lacustrine settings confirmed by the interlayered sediments rich in fauna and flora of Middle Miocene age (Badenian-Pannonian). Hundreds of deep (700-1400 m) boreholes which crosscut the pile of the volcanic and sedimentary deposits throughout the entire Oas-Gutâi volcanic area revealed the presence of large volumes of volcaniclastic sediments in between the upper thick volcanic pile and the lower terrigeneous succession. The information provided by core logs and outcrops enabled the recognition of the original, volcanic-driven fragmentation processes as well as the subsequent, subaqueous sedimentation mechanisms. The volcaniclastic debris flows and hyperconcentrated flows of pyroclastic origin emplaced by “en masse freezing” or progressive aggradation are predominant and indicative of the below wave base deep marine or lacustrine setting. The subaqueous setting is also suggested by typical soft deformations identified at the interface of the sub-aerially erupted volcaniclastics and fine grained-sediment beds of the basins.

IAVCEI (Volcanology, Geochemistry)

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IUGG-0775

'Dry' explosive rootless littoral eruptions: a new kind of volcanic activity?

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The term “littoral cone” has become synonymous with phreatomagmatic activity at rootless vents associated with the interaction between lava and sea water as lava flows into the ocean. In this paper we describe two littoral cones, `Au`au Point and Pu`u Ki South Cone, located on the southwestern flank of Mauna Loa, Hawai`i that show no evidence of lava-water interaction during their main cone-forming phases. These cones are dominated by clastogenic lavas and thermally oxidised, welded lapilli and bombs. They differ greatly from observed examples of phreatomagmatic rootless littoral cones, and are similar to the products of explosive activity driven by magmatic volatiles found elsewhere on Hawai`i. We provide strong evidence that the genesis of these cones was ‘dry’, meaning that the interaction between lava and external water did not play a role in driving the eruption. They were formed by persistent hornito-style activity at a tube-fed, rootless vent driven by magma pressure built up in response to damming and/or blocking of the lava tube down-flow. Because rootless littoral cones can form from both phreatomagmatic and dry explosive processes the term “littoral cone” is best used in a descriptive geographical sense.

IAVCEI (Volcanology, Geochemistry)

VS15c - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-1678

Submarine pumice lapilli-ash offshore Montserrat: products of submarine eruption, raft deposit, or hot density currents that travelled over the sea?

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An unusual 1.2-m-thick bed of pumice lapilli-ash occurs at ~122 mbsf (~4 Ma) at Site U1396. The substantial thickness and unusual facies of this interval brings questions on how it was erupted, transported, and sedimented. The pumice lapilli-ash interval is stratified into two main units, and subtly differ in colour, grading, componentry, fines content, and grain size distribution. The pumice lapilli comprises abundant white, highly vesicular, sub-angular pumice clasts, glass shards, crystal fragments, lithic clasts and foraminifer tests. Componentry shows perfect density grading over the interval. The coarse clasts are dominated by pumice clasts, with subdominant crystal fragments and lithic clasts. The pumice glass has dacitic composition and Pb isotopes suggest a Soufriere Hills (Montserrat) origin. Weighing, SEM and micro-tomography data reveal a high porosity (64–85 vol.%), two types of bubble size distributions and that most vesicles are extremely small (<20 um). Floatation experiments at 20°C show unusually high rate of waterlogging, and a correlation between floatation time and clast porosity. In contrast, the floatation time of these pumice clasts correlates with the long-axis clast length during hot (600°C) floatation experiments. The pumice lapilli-ash interval has a clear pyroclastic origin, however the vent water depth, and transport and sedimentation processes associated with this interval remain poorly constrained. Several contenders are proposed: (1) proximal deposit derived from density currents and submarine pyroclastic fall from an unknown submarine volcano; (2) submarine density currents originated from proto-Montserrat seamount; (3) complex pumice rafts; (4) Montserrat island-sourced pyroclastic density currents that travelled over water.

IAVCEI (Volcanology, Geochemistry)

VS15c - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-2307

Architecture, structural control, and hazards associated with the formation of the Aljojuca and Tecuitlapa axalapazcos (maars), Eastern Mexican Volcanic Belt

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Maar volcanoes in Mexico are known as xalapazcos (if dry) or axalapazcos (if lake inside). The Aljojuca and Tecuitlapa axalapazcos are located in the Serdán-Oriental Basin of the Eastern Mexican Volcanic Belt (EMVB), where bimodal volcanism comprises rhyolitic domes, basaltic- to basaltic andesitic cinder cones, and maar volcanoes. Aljojuca forms the westernmost volcano of a E-W chain of three cinder cones, whereas Tecuitlapa has a chain of cinder cones inside the crater. The crater of these axalapazcos have elongated shapes. These alignments reveal a strong regional tectonic control of the monogenetic volcanism by shallow crustal fractures, following the orientation of the active fault system that characterizes the central part of the MVB, and indicates a progressive migration of the eruptive vents from east to west. The two axalapazcos (maars) were built on a sequence of volcaniclastic deposits dominated by fine-grained pyroclastic deposits mixed with sedimentary lenses of fluviatile origin, which have been collectively named the “toba café”. At Aljojuca, the toba café is overlain by a thick vesicular basaltic andesite lava flow. Between that lava and the maar-forming deposits is a thin soil, dated at ca. 2 ky. The stratigraphy of the Aljojuca axalapazco reveals rapid fluctuations of the magma-water interactions following a general trend from mostly wet to dry and then to wet conditions. In contrast, Tecuitlapa shows a general trend evolving from wet to dry conditions, including post-maar strombolian and hawaiian activity. The recent activity of the Aljojuca and Tecuitlapa axalapazcos has important implications for hazard assessment of the monogenetic volcanism of the EMVB, where the possibility of rapid lateral movement of the vent must be considered.

IAVCEI (Volcanology, Geochemistry)

VS15c - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-4256

Marine sediments as an archive of arc volcanic history: Montserrat and Guadeloupe, Lesser Antilles

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Understanding the long term evolution of arc volcanism from the on-land record alone is difficult; older deposits become progressively buried by successive activity, obscured by vegetation, or eroded out. A complimentary approach to this problem is provided by study of marine sediment cores. For example, it has been suggested that ~75% of material erupted from Soufrière Hills, Montserrat, from 1995-2005 ended up in the Caribbean Sea, thus marine sediments may contain a more complete record of volcanic activity. In March 2012 IODP expedition 340 obtained cores from ~30 km SW of Montserrat at site U1396. This core contains >150 tephra layers, extending back ~4.5 Ma. The first task in studying these sediments is to determine their provenance, as tephras of site U1396 may be derived from one of multiple nearby volcanic islands. We show that a combination of trace element and Pb isotope data can be used to distinguish between the tephra layers of each of these islands. Using this approach we show that tephra within the top 90 m of core U1396C is mostly derived from Montserrat and Guadeloupe, with minor input from Nevis, providing us with access to the long-term eruptive history of two volcanic arc islands. Comparisons with terrestrial exposure studied during recent fieldwork on Montserrat reveal a discrepancy between the deposit types of the two records. The terrestrial record of the Centre Hills volcanic centre (active during at least c. 950-550 ka) is dominated by pumice rich fall-out and flow deposits, whereas the marine record is dominated by pumice-poor fall-out and flow deposits. This highlights the importance of examining both marine and terrestrial records in the development of a comprehensive eruptive history of an island or coastal volcano.

IAVCEI (Volcanology, Geochemistry)

VS15c - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

IUGG-4284

Palaeocene-Eocene volcanism in the Arctic: Basin development and continental breakup constrained by ash layers in Svalbard

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The Central Tertiary Basin (CTB) in Spitsbergen, Svalbard was a sedimentary basin that formed during the early Palaeogene. The spreading centres in the Arctic and the nascent North Atlantic led to the strike-slip detachment of Svalbard from Greenland, accompanied by an orogenic belt and an adjacent foreland basin. Throughout this sedimentary sequence are prominent 1-30 cm thick ash layers, preserved as bentonite clay horizons. A total of 52 well preserved and representative ash layers were sampled from nine drill cores across the CTB and investigated for remnants of a primary mineral assemblage for dating and geochemical affinities. Whole rock geochemistry suggests that despite the poor preservation, original tephra compositions varied from basaltic to rhyolitic. Euhedral zircons, where present, were U-Pb radio-isotopically dated to between mid-Palaeocene to during the Palaeocene-Eocene Thermal Maximum (PETM). However, the majority of the volcanism is of mid- to late-Palaeocene in age. Unaltered feldspars were analysed by electron microprobe, with chemistries varying from K-rich sanidines to Ca-rich plagioclases. Whole-rock rare earth element (REE) analyses show further differences between ash layers. Basal ashes have a large negative Eu anomaly, while subsequent ashes have either no anomaly or a slight negative anomaly. Most ashes have a moderate La/Yb slope typical of an evolved melt, while occasional layers have a flatter slope more characteristic of a primitive melt. The basal ashes with a strong negative Eu anomaly match REE patterns from the Kap Washington Volcanic Province in North Greenland, suggesting this is the likely source. Later Palaeocene and Eocene ashes are likely to have originated from the spreading axes to south and/or northwest of Svalbard.

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VS15p - VS15/VS30/VS34 Water and Magma / Volcaniclastic Sediments: Modern Applications for Marine and Earth Sciences / Effects of Water on Subaerial Volcanic Eruptions and Ash Dispersal

VS15p-477

Non-explosive and explosive magma - water interaction in the volcanic evolution of Oas-Gutâi Mountains (Eastern Carpathians), Romania

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A Miocene calc-alkaline intermediate/andesitic volcanism took place in the Oas-Gutâi Mts. (13.4-7.0 Ma) from the Eastern Carpathians. Non-explosive and explosive magma-water interaction processes developed during the main volcanic phase, which evolution was predominantly subaqueous (11.8-9.0 Ma). The dominant non-explosive magma-water interaction processes are related to: 1) fissure-fed eruptions in volcano-tectonic depressions (subaqueous grabens) which formed extended lava flows/plateaus with in situ and resedimented hyaloclastites interlayered with typical reworked volcaniclastics suggesting quench fragmentation (e.g. the northern part of Gutâi Mts.) and 2) subaqueous dome growth which formed flat-topped extrusive domes, lava domes and dome coulees, with marginal quench fragmentation witnessed by hyaloclastic carapaces and in situ and resedimented volcaniclastic and sedimentary deposits interlayered (e.g. Oas Mts.). The explosive magma-water interaction by phreatomagmatic processes is suggested by the presence of the in situ and resedimented phreatomagmatic volcaniclastics with or without accretionary lapilli, spread throughout the entire volcanic area of Oas-Gutâi Mts. No typical phreatomagmatic volcanic structures like maars or tuff rings have been found, likely suggesting small magma volume phreatomagmatic euptions or rootless explosions conducted by water injection along joints through still hot lava domes or flows. Failed phreatomagmatic explosions caused by the intrusion of magma into wet sediments are well developed in the southern part of Gutâi Mts. where breccia pipe and breccia dyke structures of various sizes are formed.

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VS15p-478

The great lahar deposit "Mera" in the upper Amazon basin--formed by transformation of a volcanic avalanche in Ecuador´s Sierra.

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The area east of Ecuador´s Cordillera Real has received eruptive phenomena from many of the volcanic eruptions that have occurred in the Real and Western Cordilleras. Many of these phenomena, but particularly lahars, have traveled through deep and narrow canyons to then be deposited in the upper Amazon basin. The great lahar deposit 'Mera' is mapped in the areas of El Topo, Cumanda, Mera, Shell, Madre Tierra, Puyopungo and Santa Ana. The deposit has a thickness between 30 and 70 meters, is monolithologic and is described as a matrix-supported breccia (70%) of reddish gray color, well consolidated, with gray and reddish andesitic clasts,

Geochemically this breccia has a range between 57.3-61.2 wt% SiO_2 (andesite), falling in a calc-alkaline series with mean values ??of 1-1.52 wt% K_2O. A field with little variation is defined, indicating that it has only one source.

Dating of wood found inside the Mera deposit gave an age of > 43,500 aBP. Also, comparisons with petrographic, microscopic, granulometric and geochemical studies indicate that the best candidate for the lahar´s formation is the avalanche of Huisla volcano (located S of Pelileo) and whose age is >40,000 aBP.

The DAD-Huisla descended the Patate river to the intersection with the Chambo river where it forms the Pastaza river. The DAD´s dam reached a height of about 250 m; lacustrine deposits are located > 10 km upstream.

We hypothesize that seepage or other triggers caused the dam´s disintegration and subsequent remobilization of the breccia; enroute it transformed to the Mera lahar.

The actual mapped deposit is a remnant of the initial deposition, with an average thickness of 40m. We estimate a minimal volume of 1.20 km^3 for the remnant deposit now lying in the foothills of the Amazon Basin.

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VS15p-479

Late cretaceous hydrovolcanism of Haţeg Country Dinosaurs Geopark, Romania

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Ha?eg Country Geopark has two great ambassadors for geo-education and conservation: Late Cretaceous dinosaur fossils and volcanoes. The study of this extinct volcanism is important especially that with the exception of geochemical data and age dating there is no published information concerning its nature and evolution.

The volcanism took place in an extensional setting in Gosau-type basins and is associated with the development of a fluvial-lacustrine environment. Epiclastic deposits characterised by rhythmic conglomerates with andesitic and rounded metamorphic components and ash-based matrix, indicative of underwater mass flow processes are prevailing. Four E-W small-size andesitic volcanoes can be inferred. The most spectacular occurrence is a phreatomagmatic volcano, presently dissected by a fault and situated in the westernmost part. Only half of it is well preserved, showing successions dominated by cm-dm size surge deposits with andesitic juveniles and accretionary lapilli deposits, and subordinate pyroclastic flows and lahars. This is suggestive of hydrovolcanic Surtseyan-type volcanism. The distal facies is the best developed and characterized by stratified arenites rich in volcanic material (sometimes preserving plant remains), rarely interbedded with m-dm size accretionary lapilli deposits. A notable isolated occurrence is a massive highly unsorted lithoclast-dominated conglomerate with ash matrix; the lithoclasts are composed mainly of andesitic massive rounded clasts and pillow-lavas (elliptical, cooling crust, showing internal oriented vesicular structures) with subordinate rounded metamorphic clasts. This is interpreted as a reworked deposit generated from the downfall of a pillow-lava structure and suggests the proximity of a volcano vent.

IAVCEI (Volcanology, Geochemistry)

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VS15p-480

Source fluid conditions inferred from mineralogy in eruptive products derived from subvolcanic hydrothermal systems

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At volcanoes in subduction zones, a majority of phreatic and phreatomagmatic eruptions are caused by expansion of thermal fluid derived from sub-volcanic hydrothermal systems. Volcanic ash therefore contains abundant accidental lithic fragments from the systems. Mineral assemblages in the fragments reflect physical and chemical conditions of the hydrothermal fluid that is potentially identical to that discharged by the eruption. We have determined physical and chemical conditions of hydrothermal fluids based on mineralogiy and, in some cases, with sulfur isotopic analysis. Meanwhile, Ohba (2011) classified the hydrothermal-related eruptions into two types according to presence of associated landslide. Each type is further subdivided into two subtypes according to presence of associated magma intrusion. We determined hydrothermal conditions by means of mineralogy in eruptive products of three eruptions, exemplifying the landslide-triggered eruption with magma intrusion (4.7-3.3 ka eruptions at Tokachidake), the landslide-triggered eruption without magma intrusion (the Tokachidake 1926 eruption), and the eruption without landslide or magma intrusion (the Ontake 2014 eruption). Characteristic mineral assemblage of altered lithic fragments from Tokachidake 1926 eruption is cristobalite + alunite. This volcanic ash is also characterized by lack of quartz. Other two eruptions are characterized by the mineral assemblage of quartz +pyrophyllite. The mineralogy implies that all three eruptions were derived from sulfuric acid hydrothermal fluid. Only the Tokachidake 1926 eruption was derived from a shallow, near-surface, and low-temperature hydrothermal system (c. 100 C), whereas other two eruptions were derived from deep (1 -2 km) and hot (> 300 C) hydrothermal systems.

IAVCEI (Volcanology, Geochemistry)

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VS15p-481

Insights into the tectonic nature of the Altai-Mongolian terrane from the early Paleozoic meta-sedimentary sequences along its northern margin

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The early Paleozoic meta-sedimentary sequences along the northern margin of the Altai-Mongolian terrane were investigated on their provenance, source nature and depositional setting to understand the geodynamic evolution of this terrane in the early Paleozoic. Four samples were selected for detrital zircon analysis. They show similar zircon populations that are composed mainly of late Neoproterozoic to early Paleozoic grains and less of early Precambrian ones, indicating multiple tectono-thermal events in the source area. Comparison with surrounding tectonic units suggests that the Tuva-Mongolian terrane and its adjacent island arcs probably provided substantial detritus during the sedimentation. The similarity of detrital zircon age patterns with those from typical active continental margins further implies that these early Paleozoic meta-sedimentary sequences were possibly formed in an active continental margin, rather than in a passive regime surrounding a micro-continent. This conclusion is consistent with the whole-rock geochemical results, which suggest that the sediments were mainly sourced from nearby intermediate-acidic igneous rocks without obvious sedimentary recycling and sorting. Importantly, the studied meta-sedimentary sequences from the northern Altai-Mongolian terrane are indistinguishable in provenance and depositional setting with their counterparts from the Chinese Altai and Tseel terrane. We conclude that the whole Altai-Mongolian terrane probably represented a coherent subduction-accretion complex built upon the active margin of the western Mongolia in the early Paleozoic.

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VS15p-483

Mineralogical study of non-juvenile material in volcanic products of the 1926 and the 4.7-3.3 ka eruptions at Tokachidake volcano, Japan

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Temperatures, depths, and fluid chemistry of sub-volcanic hydrothermal system were estimated based on mineralogical analysis of eruptive products of the 1926 and the 4.7-3.3ka eruptions at Tokachidake volcano. The deposit of the 1926 eruption can be divided into three layers according to volcanic phenomena; the lower debris avalanche deposit, the middle hydrothermal surge deposit and the upper debris avalanche deposit. The deposits of the 4.7-3.3 ka eruption occur as four pyroclastic flow deposits layers; one from the 4.7 ka eruption and other three from the 3.3 ka eruption. Every deposit contains abundant hydrothermally-altered lithic fragments, and the three layers of the 1926 eruption exclusively consist of altered lithic fragments without any juvenile fragments. Minerals identified in the bulk sample of the 1926 eruption deposit are cristobalite, smectite, sericite, kaolinite, alunite, gypsum and pyrite, and those in the deposits of the 4.7-3.3ka eruptions are cristbalite, tridymite, quartz, sericite, pyrophyllite, alunite, plagioclase and hyperthene. Mineral assemblages of individual fragments were also determined with combination of SEM-EDS and XRD. The 1926 eruption product is characterized by coexistence of cristobalite, alunite and/or smectite in the fragments, whereas the 4.7-3.3 ka eruption product is characterized by coexistence of pyrophyllite and quartz. The mineralogical contrast implies difference in hydrothermal condition between the 4.7-3.3 ka and the 1926 eruptions. The former eruption was derived from the 1-2 km and > 230 C hydrothermal system and the latter from the near-surface and < 100 C hydrothermal system, although both volcanic products are characterized by sulfuric acid fluid which is typical in hydrothermal systems at volcanic centres.

IAVCEI (Volcanology, Geochemistry)

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VS15p-484

The temporal changes of the shallower resistivity structure associated with the eruption on 2011 at Aso volcano, Japan.

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Aso volcano is an active volcano which located on central Kyushu Island, Japan. On this volcano, an eruption was occurred on 2011. Before and after this eruption, we carried out the repeated electromagnetic survey around active crater (Nakadake crater).
On Aso volcano, many researches have been made to detect the subsurface structure and to obtain the information about the distribution of the subsurface hydrothermal system. From the high-density AMT survey, Kanda et al. (2008) found a low resistivity area that localized just beneath the Nakadake crater. This area is considered as a chamber of the hydrothermal fluid which is formed by a part of the hydrothermal fluid which is supplied from the deeper magma.
Associated with the eruption, it is expected that the distribution of the subsurface hydrothermal fluid is changed and subsurface resistivity structure will be temporally changed. In order to detect such a temporal change, we carried out the repeated control sourced electromagnetic survey around the Nakadake crater using ACTIVE observation system (Utada et al., 2007). In these observations, we installed electric current transmitter on 1 km NNE from the crater, and induced magnetic field receiver were also installed on the 4 points around the crater. From our repeated observations, we obtained the data that suggests a temporal change of resistivity structure. The result of the 1-D analysis shows that the resistivity was changed on 200 to 300m depth after eruption was occurred and this is corresponding to the depth of the upper end of the localized low resistivity area beneath the crater which was found by Kanda et al. (2008). In our presentation, we will show the observation data and the detail of the resistivity structure obtained by the 1-D analysis of our data.

IAVCEI (Volcanology, Geochemistry)

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VS15p-485

Magma degassing and fragmentation during the 1918 Katla eruption

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The last eruption of the restless, ice-covered Katla volcanic system in south Iceland was a 1 km^3 (DRE) explosive subglacial basaltic event in 1918, which released a 8 km^3 meltwater flood.

We have sampled both the 1918 jökulhlaup deposit and airfall tephra preserved on Sólheimajökull. Sampling of multiple layers allows examination of discrete phases of eruption/emplacement. Tephra was sieved and clasts thin sectioned to analyse bubble textures, and for compositional analysis using electron probe microanalysis (EPMA) and laser ablation inductively coupled mass spectrometry (LA-ICP-MS). Part of the clasts were analysed for volatile contents using fourier transform infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA).

Jökulhlaup samples show evidence of interaction with water; the glass is microlite-poor with ~0.2-0.3 wt.% H_2O consistent with quenching under elevated pressure. Some air-fall clasts are microlite rich, completely degassed (~0.1 wt.% H_2O) and have interior bubbles that are significantly larger than those at the clast margin. We interpret this as post-fragmentation degassing. These clasts should have taken seconds to cool had they quenched in water. Hot-stage experiments show average bubble growth rates of ~1 $\mu m\ s^{-1}$, suggesting that such clasts have had very little/no interaction with water. Many clasts show repeated episodes of fragmentation and/or degassing, suggesting recycling of material in the upper conduit and/or vent. Preliminary LA-ICP-MS data hints that the magma chamber may have been compositionally stratified.

Further work will quantify internal textures and external clast morphologies to determine the relative roles of magmatic and phreatomagmatic fragmentation for the various phases of the eruption.

IAVCEI (Volcanology, Geochemistry)

VS16a - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-2119

High-resolution analyses of morphological variations of ash grains in the 2006 subplinian tephra deposit of Tungurahua volcano

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The past two decades have witnessed significant technical improvements for image acquisition, automated image analyses and computer processing of large data sets, which help improving the characterization of ash particle shape. This has conducted to refine our understanding of ash formation, transport and deposition of modern and ancient eruptions. We developed an analytical protocol to obtain fast and routine morphometric analyses of apparent (2D-projected) shape of volcanic ash particle (APASH), using an innovative optical analyzer, a morpho-grainsizer that determines the size and shape (e.g. aspect ratio, convexity, circularity) of thousands of particles in 35 minutes. Here, we focus on the paroxysmal 16 August 2006 pyroclastic flow-forming eruption of Tungurahua volcano (Ecuador). This short-lived (~6 hours) VEI-3 subplinian eruption consisted in a 17-18 km-high tephra column, whose plume drifted west. In this study we investigate the influence of complex componentry assemblages on bulk morphological signatures of ash samples, as well as shape-related fractionation effects in the plume.

We selected a set of 14 ash fall samples distributed 8 to 20 km from the vent in the widespread 2006 deposit. We acquired morphological results in the size-range 3.75-0.5 phi (75 to 710 µm). Preliminary results reveal that (1) particles present different morphologies in the northern, southern and near-to-axis sectors; (2) particles in the 0.5 phi size-range show increasing irregularity with distance from vent; (3) particles in the 2 phi size-range show sub-constant morphological characteristics regardless of distance. In summary, these results point to lateral variations of ash morphology in the deposit, and to shape-dependent fractionation effects in plume with grains phi size.

IAVCEI (Volcanology, Geochemistry)

VS16a - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-3183

Lab-scale ash production by abrasion and collision experiments of porous volcanic samples

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In the course of explosive eruptions, magma is fragmented into smaller pieces by a plethora of processes before and during deposition. Volcanic ash (fragments < 2mm) has near-volcano effects but may also cause various problems over long duration and/or far away from the source. We quantify the efficiency of ash generation during experimental fracturing of pumiceous and scoriaceous samples subjected to shear and normal stress fields. Fracturing within volcanic conduits, plumes and pyroclastic density currents (PDCs) was simulated through a series of abrasion (shear) and collision (normal) experiments. An understanding of these processes is crucial as they are capable of producing very fine ash (<10µm). From the experiments we establish that abrasion produced the finest-grained material and up to 50% of the generated ash was smaller than 10 µm. In comparison, the collision experiments (mainly normal stress) produced coarser grain sizes. Results were compared to established grain size distributions for natural fall and PDC deposits and good correlation was found. Energies involved in collision and abrasion experiments were calculated and showed an exponential correlation with ash production rate. Projecting these experimental results into the volcanic environment, the greatest amounts of ash are produced in the most energetic and turbulent regions of volcanic flows, which are proximal to the vent. Finest grain sizes are produced in PDCs and can be observed as co-ignimbrite clouds above density currents. Finally, a significant dependency was found between material density and the mass of fines produced, also observable in the total particle size distribution: higher values of open porosity promote the generation of finer-grained particles and overall greater ratios of ash.

IAVCEI (Volcanology, Geochemistry)

VS16a - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-3931

Aggregation in the cold: Laboratory experiments elucidate sticking efficiency of charged volcanic particles in sub*-zero conditions

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Recent advances in the study of tephra aggregation have indicated that (i) far field effects of tephra sedimentation are not adequately resolved without accounting for aggregation processes that preferentially remove the fine ash fraction of volcanic ejecta from the atmosphere as constituent pieces of larger particles, and (ii) the environmental conditions (e.g. humidity, temperature) prevalent in volcanic plumes may significantly alter the types of aggregation processes at work in different regions of the volcanic plume. The current research extends these findings to explore the role of ice-ash and ash-ash aggregation in various plume environments. Laboratory experiments allow us to parameterize tephra aggregation rates under the cold (0 to -50 C) conditions prevalent in the upper regions of volcanic plumes. We consider the interaction of tephra particles with both ice coated and tephra coated surfaces over a range of temperatures and particle sizes. As ash interact collisionally, the interaction is recorded by a number of instruments, including high speed video to determine if aggregation occurs. The electric charge on individual particles is examined before and after collision to examine the role of electrostatics in the aggregation process and to examine the charge exchange process. We are able to examine how sticking efficiency is related to the magnitude of the charge carried by the tephra particle and the collisional kinetic energy of the interaction. We here present results of these experiments, the first to constrain aggregation efficiency of ice-ash and ash-ash interactions at cold temperatures, parameters that will allow tephra dispersion models to use near real time meteorological data to better forecast particle residence time in the atmosphere.

IAVCEI (Volcanology, Geochemistry)

VS16a - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-4839

Sacrificial fragmentation: A new model of volcanic ash generation by superheated foaming

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The most common occurrence of explosive volcanic activity is at lava domes, which experience frequent gas-and-ash explosions. Here, we integrate microstructural analysis of volcanic ash at Santiaguito (Guatemala), geophysical signals of explosive activity, experiments and geochemical modeling to demonstrate a new model of volcanic ash generation by superheated foaming along fault zones: Sacrificial fragmentation.

Examination of dome activity at Santiaguito reveals that gas-and-ash explosions are concordant with inflation/deflation cycles that are faster than during simple outgassing episodes. Although frequent, these explosions usually leave the dome intact as strain is accommodated along marginal faults. QEM-SCAN analysis of thousands of ash particles reveals their tendency to be blocky, crystal-rich and contain bimodal bubble size distributions (1% at 50 microns and <30% at ~3 microns); these suggest that foaming has occurred rapidly. Textural analysis using SEM images documents the presence of chemically heterogeneous melt filaments emerging from crystals in the ash generated in these events. The same texture is observed in friction experiments on Santiaguito dome lava. We find that heat produced experimentally by fault friction can melt crystals in lavas after mere centimetres of slip, and yield foaming of the interstitial melt adjacent to the slip zone. We model thermal input during faulting and conclude that gas-and-ash explosions exhibited in the dome at Santiaguito are controlled by the inevitable frictional heating which results from tenacious strain localisation, whereby lava is

'sacrificially' fragmented along faults in order to preserve the bulk of the dome. We discuss how this new fragmentation trigger may underlie the most common type of explosive activity.

IAVCEI (Volcanology, Geochemistry)

VS16b - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-0382

The precursors of Strombolian explosions and how they betray the shallow conduit characteristics

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The variety of normal active degassing was monitored at Stromboli (Aeolian Islands, Italy) using a thermal high speed FLIR SC655 (200 frames per second, 15 cm wide pixels). The high temporal and spatial resolution was used to distinguish the individual ejection events and to characterize the volume, exit point, temperature and rise velocities of the expelled material. A total of 12 vent activities observed during three field campaigns in 2012, 2013 and 2014 are portrayed.

Sustained puffing was visible on 7 cases, with typical discharge frequency ranging between 0.4 and 1.5 Hz, expelled volumes from 0.1 to 100 m^3, velocities around 5-10 m/s and observed temperature anomalies from 1 to 500 K. On the other hand, regular Strombolian explosions, ejecting bombs and sometimes ash, are reported in 6 cases, 2 of them simultaneously presenting a puffing activity, with a frequency never exceeding 10 events per hour and velocities up to 200 m/s. One vent activity was hybrid between puffing and Strombolian explosions, with frequent explosions (1 Hz) ejecting numerous pyroclasts at an intermediate velocity (15 – 30 m/s), suggesting that explosions and puffing are driven by a common mechanism modulated by vent conditions and/or gas supply.

In some cases, explosions were preceded by precursors, usually lasting about 1 second but occasionally reaching 10 seconds. While the inflation of the visible vent surface may be associated to the expansion of the slug, the emission of low pressurized gas plumes and the increase of the puffing activity before the explosion suggest the existence of a shallow high viscosity plug limiting gas expansion. We hypothesize that this plug may generate a shallow bubble rich layer, significantly influencing on the gas release and on the pyroclast generation.

IAVCEI (Volcanology, Geochemistry)

VS16b - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-2215

The contrasting grain size distributions of the Hekla 3 and Hekla 4 eruptions, Iceland.

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Hekla is the third most active volcano in Iceland, with 18 eruptions since the island was settled around 871 AD. Explosive eruptions produced at least 9 of the 22 most prominent and widely-distributed ash marker layers found in European soils and lakes. The Hekla 3 (2879+/-34 14C BP) and Hekla 4 (3826+/-12 14C BP) are the two largest of the Holocene and both are important teprochronological markers in Europe.

We present the a modern re-evaluation of the eruptions. New isopach maps give freshly-fallen volumes of 11.2 and 13.3 km3 for Hekla 3 and Hekla 4, respectively. This contrasts with previous estimates of 12 and 9 km3. These can be subdivided into phases of differing composition (basaltic andesite to rhyolite). Total deposit grain size distributions will be presented for each. The results show that the Hekla 4 eruption produced much more fine ash than the Hekla 3 eruption. Possible explanations for this difference, including magma-water interaction and vesicle coalescence, will be discussed. Unlike examples from Mt St Helens and El Chichón, the deposits are uncontaminated by co-ignimbrite ash and may therefore be the most representative data so far on fragmentation during rhyolitic plinian eruptions.

IAVCEI (Volcanology, Geochemistry)

VS16b - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-2414

"Studying ash and ash deposits"

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Ash is a common product of explosive volcanism; it may represent a large percentage of the total mass erupted during high intensity eruptions, and it is dominant in many long-lasting, intermediate-scale eruptions. The study of sedimentological, physical, compositional, morphological and textural features of ash represents the first, indispensable step to introduce any other study implying the understanding of the processes of ash production. Field studies may provide information about the mechanisms of ash dispersal and deposition, as well as are needed in order to plan sampling strategies and to build a complete dataset for defining the volume and the total grain size distribution of the erupted material. While ash morphology has been used for long time as the main descriptor to infer about fragmentation processes, recent studies have clearly demonstrated how ash fragments from a single eruption form different populations, each characterized by important differences in terms of morphology and compositional and textural features. All these features, when collected together on single ash grains, can give a more in-depth understanding on the mechanisms of magma ascent, degassing and final fragmentation. Finally, the interpretation of data can be strongly biased by "side" processes that can obscure the original characteristics of the magma (the effect of grain size on crystal and vesicle distribution), the original textural and compositional features of the clasts (clast recycling), or the real total grain size distribution (aggregation, irregular dispersal). All these processes should be discussed in detail whenever we try to interpret the characteristics of ash deposits.

IAVCEI (Volcanology, Geochemistry)

VS16b - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-4430

What can pyroclastic deposits really tell us?

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Explosive volcanic eruptions are inherently dynamic, likely responsible for high variability of the boundary conditions acting during magma break-up, transport and deposition. Eruptive processes cannot be observed directly because of the hostile nature close to the eruptive vent(s) and the opaqueness of the volcanic edifice and suspended ash. Detailed observation of on-going eruptions and thorough descriptions of the related deposits have allowed for empirical relationships between eruption and deposit characteristics.

Magma evolves during its ascent as a response to horizontal and vertical gradients of stress and temperature. This commonly results in strong vertical and horizontal gradients in crystallinity and porosity, potentially accentuated by heterogeneous strain distribution during flow. As a result, the ratio of dense to porous magma and the geometry of the gradient are largely unknown. Magma disintegration is largely controlled by its textural properties and the applied stress, leading to considerable variability in the fragmentation timescales and efficiency.

Many deposits are investigated primarily through the analysis of key properties and selected grain size classes. As flow deposits tend to show a higher variability, most quantitative analysis of explosive eruptions is done via the analysis of fall deposits. Their apparent homogeneity is largely due to transport-related sorting and does not represent a general view of magma textures. For a qualitative reassembling of the magma column and a better understanding of the observed eruption dynamics, the described magma heterogeneity and the related response during an eruption has to be taken into account.

IAVCEI (Volcanology, Geochemistry)

VS16b - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

IUGG-5013

Reconstructing total grainsize distribution of explosive volcanic eruptions

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The size distribution of pyroclasts is a crucial parameter controlling tephra dispersal, and it is probably the hardest to constrain among the input parameters for plume dispersal simulations. It is typically derived averaging the grainsize distributions at individual locations and it is very sensitive to the number and distribution of outcrops, requires large datasets for great accuracy, especially to define the tails of the distribution. It is controlled by magma fragmentation, which is driven by multiple simultaneous processes depending on magma properties (viscosity, porosity and permeability), and flow-controlled parameters such as shearing and gas expansion rates.

The amount of observations considerably increased during the last decade and grainsize distributions from eruptions of different styles (Hawaiian to Strombolian, Vulcanian to subplinian and Plinian) are now better characterized. This allows for a comprehensive review and testing of previous theoretical, experimental and empirical models describing the distribution of pyroclasts formed by magma fragmentation.

Distributions are often bimodal and could be fitted by two lognormal sub-populations, whose properties show no systematic variations with eruption style or magma compositions. Further statistical analyses confirm previous studies suggesting that most of the distributions could be fitted by exponential-like or log-logistic functions, which have a fractal behavior on a wide size range. Fractal analysis shows that at commonly least two exponents are necessary to describe accurately the data confirming the bimodal nature of the distributions.

Results are then used to develop a strategy to assess total grainsize distributions of steady, long lasting, explosive eruptions for monitoring and modeling purposes.

IAVCEI (Volcanology, Geochemistry)

VS16p - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

VS16p-390

The driving forces of the eruption styles of AD 934 Eldgjá, southern Iceland

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The Eldgjá fissure vent system in South Iceland erupted around AD 934 for up to six years. It is the largest fissure eruption in Iceland in the last 1100 years, producing 1.3 km^3 (DRE) of tephra and 18.3 km^3 of lava. With time activity propagated from the southwest to the northeast to form the 75 km-long vent system, initially erupting through the Mýrdalsjökull glacier via subglacial fissures and later in a subaerial setting. Consequently, the eruption produced both phreatomagmatic and magmatic tephra roughly in equal proportions.

In order to investigate the relative roles of external water versus magmatic gases in the explosive activity during the Eldgjá eruption, two key sections, one representing the magmatic and another the phreatomagmatic deposits, were logged and sampled for grain- and vesicle-size analysis. A 3.7 m section at Skælingar, 0.5 km southeast of Eldgjá proper, is typical of the magmatic products. It contains 9 subunits of magmatic lapilli tephra. The phreatomagmatic products are represented by a 2.7 m thick section at Stóragil, located 10–15 km east of the subglacial segments of the vent system. The logged and sampled phreatomagmatic part of the section is 1.1 m thick and contains 4 phreatomagmatic subunits.

As expected, grain-size data show a narrow distribution for the magmatic samples and a broader distribution for the phreatomagmatic samples. In contrast vesicle-size data show no significant difference between the magmatic and phreatomagmatic tephra in terms of either number densities or size or volume distributions. These results indicate that, while the addition of external water greatly decreased grain-size of the phreatomagmatic products, the explosivity of the Eldgjá phases was driven primarily by release and expansion of magmatic volatiles.

IAVCEI (Volcanology, Geochemistry)

VS16p - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

VS16p-391

Magma fragmentation and sintering timescales of tuffisites: A study from Volcán de Colima

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Tuffisites are veins of variably sintered, fragmented particles that form in magma columns and lava domes during explosive activity. Localised fragmentation events that produce ash-laden explosions are responsible for tuffisite generation. Tuffisites observed in-situ on the dome of Volcán de Colima during quiescence in 2012 range from failure-nuclei with fragmentation horizons and evidence of post-formation viscous flow, through to variable-thickness veins of poorly sintered granular aggregates. Examination by optical microscopy and X-ray computed tomography reveals complex “fracture” and “channel” patterns in the tuffisites and grain size of 10-400 microns. Tuffisites show a wide range of porosity and permeability. To investigate the process of tuffisite formation, andesite from the Volcán de Colima lava dome was crushed and sieved to 35-350 microns before sinterin at 940^{o}C for different lengths of time (<200 hrs). We assess the healing ability by measuring porosity and permeability evolution, and compare this to natural tuffisites. This study shows that tuffisite formation locally increases permeability, allowing passive degassing. Subsequent sintering reduces permeability over time, trapping gas and enabling pressure build-up. The hours-to-days timescale of sintering of pyroclastic fragments correlates well to the repeat interval of small magnitude Vulcanian explosions that occurred at Volcán de Colima during 2010-11 on a 2-7 hr basis and to the cycling of vent locations sometimes observed. These results reflect the role of tuffisite formation during ash-laden explosions that occur along multiple degassing pathways available in the upper edifice and dome. This has important consequences for the modelling of Vulcanian explosions, common at many dome-forming volcanoes.

IAVCEI (Volcanology, Geochemistry)

VS16p - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

VS16p-392

Abrasion in pumice rafts

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Pumice rafts are accumulation of buoyant pumice clasts over a body of water (lake, ocean). These rafts can be several m thick, and consist exclusively of pumice clasts that can float for months. Swell and waves produce repetitive movements, and ash is produced by gentle abrasion of the surface of pumice clasts, which become rounded. Wave-tanks experiments reproduced the dynamic of pumice rafts and allow characterisation of raft-generated ash beds in the geologic record. Pumice abrasion is quantified, and the raft-generated ash shows relationship to the fabric of the original pumice clasts. Raft-generated ash mostly consists of very fine grained bubble walls, and minor euhedral crystals and pumice fragments. Pumice rafts are dispersed by oceanic currents, which have a substantially different dispersion pattern than wind, therefore raft-generated ash isopachs are very different from ash released by subaerial eruption plumes. Results from our experiments show diagnostic features that allow distinguishing marine raft-generated ash beds from marine ash fall deposits derived from subaerial eruption plumes.

IAVCEI (Volcanology, Geochemistry)

VS16p - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

VS16p-393

Fragment structure from vapor explosions during the impact of molten metal droplets into a liquid pool

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High-speed video imaging, at frame rates up to 50 kfps, is used to study the impact of a molten metal droplet into a liquid pool. Three different regimes have been identified as nucleation boiling, film boiling or vapor explosion. Following vapor explosion, fragmentation of the metal occurs and different melt textures result. It was observed that using tin alloy leads to the formation of a porous result whereas using a distinctive eutectic metal, Field’s metal, micro beads form instead of a porous byproduct. Moreover, parameters have been altered such as the liquid surface tension using surfactant, liquid properties using perfluorohexane and the molten metal temperature in order to assess the role they play on the texture of the molten metal explosion’s byproduct and the explosion dynamics.

IAVCEI (Volcanology, Geochemistry)

VS16p - VS16 Mechanisms of Volcanic Ash Generation: from Lab to Field

VS16p-394

Textural characterization and numerical models of the Agnano-Monte Spina eruption dynamics (Campi Flegrei, Italy)

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The 4.1 ka B.P. Agnano-Monte Spina eruption is the highest magnitude event of the past 5 ka at Campi Flegrei caldera. The six members of this eruption represent a sequence of pumice- and scoria- falls and flows well preserved at proximal locations. We analyzed the textural characteristics and physical properties of the three major fallouts (A1, B1bottom and top, D1) and of the respective PDCs phases (A2, B2, D2) of the AMS eruption. The textural features of the deposits were related to variations of intrinsic parameters of the magma in order to investigate how the fluid dynamics of the magmatic mixtures may have influenced both the phases of sustained column and the following phases of column collapse and generation of PDCs. A combination of field, grain-size, density, VSD, CSD, fine-ash morphologies and numerical simulations were carried out. Each transition fallout/PDC is accompanied by distinctive changes in textural properties of the magma, with drops in VNDs of about one order of magnitude (from 10^8 to 10^7 cm^{-3}), as confirmed by calculated decompression rates. Numerical simulations, taking into account decompression rates derived from textural analyses, are able to reproduce the strong decreases in exit velocities responsible for such transitions in eruptive styles. We demonstrate that distinctive decompression rates, initial water content and minor changes in compositions are able to explain the different column height and volume erupted through the A1, B1, and D1 sequence of the eruption. From the simulation results, both a change in intrinsic properties of the magma (water content decrease) and/or a change in conduit/vent geometry, could be responsible for the sudden drop in magma ascent rate and the generation of the pyroclastic density currents.

IAVCEI (Volcanology, Geochemistry)

VS17a - VS17 Dynamics of Eruption Clouds

IUGG-2642

Inter-comparison exercise of volcanic eruption column models

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Volcanic plume heights are key observable data for estimating crucial parameters such as mass flow rate, and they are commonly used as input for dispersal models of tephra particles. Therefore, quantitative relationships between plume heights and eruption conditions are required. During the last decades, many 1D, 2D, and 3D models of volcanic plume have been proposed. In order to investigate the dependence of plume dynamics on the models and their assumptions, we coordinated an inter-comparison exercise of the recent plume models (nine 1D models based on the buoyant plume theory and four 3D models). The exercise consists of numerical simulations for four cases: strong plume in a stationary environment, strong plume in a wind field, weak plume in a stationary environment, and weak plume in a wind field. First, for a fixed mass flow rate, the maximum height of plume and the altitude of neutral buoyancy level are simulated. Secondly, the mass flow rate is estimated so that the fixed maximum plume height is explained. As a result, in the strong plume cases, most models provide similar results (i.e., estimated values of plume heights or mass flow rate) although they are quite sensitive to the assumption on cross-wind entrainment parameterization. On the other hand, in the weak plume cases (especially in the windy case), the calculation results largely depend on the model. These results indicate that the dynamics of weak plume are sensitive to the assumptions and details of model, whereas those of strong plume is relatively insensitive to them. The results also reveal that the effects of wind and cross-wind entrainment should be thoroughly evaluated, especially on weak plume dynamics.

IAVCEI (Volcanology, Geochemistry)

VS17a - VS17 Dynamics of Eruption Clouds

IUGG-3514

Non-equilibrium processes in volcanic plumes: New insights from 3D multiphase flow simulations and open issues

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In the context of the model inter comparison activity, we analyze non-equilibrium processes occurring in weak (mass eruption rate = 1.5e06 kg/s) and strong (m.e.r = 1.5e09 kg/s) volcanic plumes by adopting the three-dimensional multiphase flow model PDAC (Esposti Ongaro et al., Parallel Comp., 33, 2007). Model results describe non-equilibrium effects such as preferential concentration of particles by turbulent eddies, the settling of particles and the role of pressure disequilibrium leading to underexpanded jets and shock waves.

Despite the valuable information available from three-dimensional multiphase flow models, some important issues are left open, such as the role of grid resolution, numerical accuracy and sub-grid turbulence model on the Large Eddy dynamics in the stratified atmosphere. We discuss these topics (and the associated uncertainty in model predictions) in the framework of recent advancements in the numerical simulation of gas-particle turbulent flows.

IAVCEI (Volcanology, Geochemistry)

VS17a - VS17 Dynamics of Eruption Clouds

IUGG-4094

A volcanic column model subject to external winds

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The estimation of the mass flow rate during volcanic eruptions is of paramount importance for the simulation of ash dispersal. Typically, mass flow rate is estimated starting from the observations of the column height and the use of, often simplified, volcanic plume models. However, it is known that, for a given column height, if wind effects are not properly accounted for, the values of the mass flow rate can be significantly underestimated. Here, we present FPLUME: a numerical model for eruption columns, based on the Buoyant Plume Theory, which accounts for the effect of the atmospheric wind, resulting in the bending over of the plume and in the increases of the entrainment of ambient air. The model solves the equations for the conservation of mass, momentum and energy in terms of averaged variables, accounting for fallout and re-entrainment of tephra into the column. Moreover, the model accounts for particle aggregation in different physical conditions. The model can be used to determine the height at which volcanic plumes spread in the atmosphere (the height of the neutral buoyancy level), given the mass flow rate at the vent, or to estimate the mass flow rate when the eruption column height is known. Results from a parametric study show the importance of the main parameters in controlling the dynamics of the volcanic columns. Finally, we present a comparison among the model calculation and other proposed semi-empirical relationships, between the plume height and the source mass flux, that account for the atmospheric wind effect.

IAVCEI (Volcanology, Geochemistry)

VS17a - VS17 Dynamics of Eruption Clouds

IUGG-4750

Three dimensional numerical simulations of volcanic plumes: particle non-equilibrium, turbulent entrainment and acoustics

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Two dynamics of weak (mass eruption rate = 5e06 kg/s) and strong (m.e.r = 5e09 kg/s) volcanic plumes have been studied by using a new three-dimensional (3D) code based on a fast Eulerian, Large Eddy Simulation model of turbulent, gas-particle volcanic plumes. The model is based on the equilibrium-Eulerian approximation (Ferry and Balachandar, Int. J. Multiph. Flow 2001; Cantero et al., J. Geophys. Res., 2008) for a polydisperse flow. This approach describes the first order non-equilibrium dynamics of a polydisperse particle distribution and its interaction with turbulence.

Numerical results describe the disequilibrium between the ash and the gaseous part of the volcanic mixture and key phenomena like preferential concentration and plume entrainment. The influence of grid resolution and turbulence subgrid models on the dynamics of the plume and on the air entrainment rate is discussed and a quantitative analysis of the influence of input parameters on the plume development has been carried out by analyzing the averaged fields, but also the fluctuations and the infrasonic field generated by the plume.

To compare 3D with integral 1D plume models (e.g., Morton et al 1956) we apply to 3D datasets the same averaging procedure used to develop 1D models. By this way, results can be coherently compared allowing calibration for the faster 1D models through the slower but more accurate 3D simulations.

Results from 3D numerical simulations have been averaged over time and space in order to obtain the mass, momentum and buoyancy fluxes and the equivalent entrainment coefficient. We have found that the entrainment coefficient has values compatible with experimental results but, interestingly, it becomes negative when the plume begins to reach the neutral buoyancy level.

IAVCEI (Volcanology, Geochemistry)

VS17a - VS17 Dynamics of Eruption Clouds

IUGG-4938

3-D numerical simulation of strong versus weak plumes – Results from the IAVCEI volcanic column model intercomparison exercise20

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We present results from the Active Tracer High-resolution Atmospheric Model (ATHAM), which was used to simulate two different eruption scenarios – a strong plume (based on the 1991 eruption of Pinatubo, Phillippines), and a weak plume that was bent-over by the wind (Shinmoe-dake, Japan, in 2011). Our primary goals are to establish the factors that influence plume heights and entrainment rates in these scenarios and to compare the model results with observed eruption dynamics. In 3-D models of bent-over plumes, entrainment rate has been notoriously difficult to obtain because the plume centerline changes in time and space. We propose a method to track the plume centerline by following the sharpest gradient in SO_2 concentration. This enables us to define variables, such as particle concentration and ice content, in a way that is more comparable to 1-D approaches. Some intriguing features emerged in the form of complex 3-D structures that cannot be resolved with 1-D models. For example, In the Shinmoe-dake case, counter-rotating vortices developed immediately in the bent-over plume, altering the entrainment of air and downwind spreading of the plume. In the Pinatubo case, our simulation shows gravitational fallout of particles and decoupling of the SO_2 cloud, which would have important implications for remote-sensing detection and tracking of the ash. We examine these features in detail, targeting the roles of convective instabilities in leading to downdrafts and ash aggregation, and implications for understanding the aircraft encounters that occurred during this eruption. Furthermore, by changing the amount of surface water incorporated into the volcanic plume (from 5 to 10 wt.%), we also consider the relative roles of ice formation on cloud development.

IAVCEI (Volcanology, Geochemistry)

VS17a - VS17 Dynamics of Eruption Clouds

IUGG-5387

An integral model for unsteady, wind affected volcanic plumes

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Models of volcanic plumes are useful tools to explore the physical controls on plume dynamics. Integral models are particularly appealing as the simple mathematical structure allows solutions to be readily obtained, facilitating inversion studies to determine source conditions from observations of the plume. However, the majority of plume models assume a steady setting, and therefore unsteadiness in the volcanic source conditions or the atmospheric forcing are not described.

Here we formulate an integral model of unsteady wind-blown volcanic plumes to explore the effect of temporal changes in source and atmospheric conditions on the plume dynamics. Our model predicts generic structures that occur due to temporal variations in the source conditions and which differ from those caused by changes in atmospheric conditions. Dynamic flow structures predicted by the model are compared to transient features identified from visual observations of the volcanic plume from the 2010 eruption of Eyjafjallajokull, Iceland. A broader investigation of the form and timescale of source and meteorological wind field fluctuations is used to identify regions of parameter space that result in plume collapse (erupted material does not become buoyant before expending initial momentum) and super-buoyancy (heating of entrained air causes plume acceleration).

The model is also tested against a dataset of field observations for Vulcanian eruptions at Santiaguito Volcano, Guatemala. Model input includes ultra violet imaging to constrain the gas and ash mass fluxes from the vent, and thermal infra-red measurements for the source temperature. Observed plume front propagation is reproduced by the unsteady model, suggesting that the underlying plume dynamics are well captured.

IAVCEI (Volcanology, Geochemistry)

VS17b - VS17 Dynamics of Eruption Clouds

IUGG-0901

Mass loadings of the 2011 Cordón Caulle volcanic ash clouds. A quantitative comparison between MODIS and numerical simulations with Fall3D.

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We perform a quantitative comparison between the FALL3D volcanic ash dispersion model and satellite retrievals during the first days of the 2011 Cordón Caulle eruption. The ash dispersion model was initialized using WRF-ARW meteorological fields with 15 km horizontal resolution and eruption column heights estimated using GOES-13 Imager radiances and the Global Forecasting System (GFS) thermal profiles. The satellite retrievals were based on the microphysics of the ash cloud, captured by the parameter β(12/11 μm), i.e. ratio of extinction coefficients at the corresponding wavelengths. By using microphysical relationships, it is possible to retrieve the effective particle radius (r_{eff}) and the 11-μm extinction cross-section (σ_{ext}). Mass loadings (g/m^2) were obtained by combining these parameters with the aerosol optical depth and the density of ash particles. Pixels with a BTD (11 – 12 μm) < -0.7°K were considered to be contaminated by volcanic ash. Retrievals and simulations showed a general good agreement for both the shape of the ash clouds and the mass loadings. However, observed and modeled cloud locations showed a lag, particularly near the vent. This could be attributed to the uncertainties in the estimated column heights, in the vertical distribution of mass along the column and in the driving wind fields. Regarding mass loadings, we were able to find good statistical resemblance both for the whole and different sectors of the ash cloud. The results encourage the operational implementation of strategies that combine satellite retrievals and

dispersion models together with inverse modeling schemes in order to improve our capabilities to cope with the hazards posed by volcanic ash.

IAVCEI (Volcanology, Geochemistry)

VS17b - VS17 Dynamics of Eruption Clouds

IUGG-1837

Detection of particle segregation from bending plume; limitation of classic advection diffusion model for tephra fall forecast

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Tephra fall forecast (TFF) is one of the most important technologies for volcanic disaster mitigation and several models have been proposed. In some countries including Japan, TFF was put into practical use; however, forecasting of area and quantity of ash fall is still far from perfect. Here we show the oversimplification of ash source (i.e. eruption plume) model causes such failure.

The 2011 Shinmoedake eruption at Kirishima volcano group in Japan comprised three sub-plinian events and dispersed tephra to ESE of the source vent. We conducted sampling and grain size analysis for 55 locations widely distributed in the down wind area. Based on an advection-diffusion model named Tephra2, which assumes vertical ash source, the granulometric data and wind data based on mesoscale analysis of Japan Meteorological Agency, particle segregation as a function of column height was reconstructed. The reconstructed source model shows that the principal ash segregation took place lower than 5 km in height, which is consistent to the satellite image analysis.

Using Tephra2 code, we calculated ash fall distribution based on the optimum particle segregation and the wind model and found that the model failed to reconstruct the ash fall for the area more than 20 km from the source vent. In the area, ash fall along the distribution axis was significant in the observation; however, it is negligible in the model. The distribution axis is parallel to the wind direction of approximately 4 km in height. This means that the ash landed in area more than 20 km from the source vent originated from bending plume that drifted approximately 4 km in height. This example shows that considering horizontal source and estimation of its height is one of the keys to improve TFF.

IAVCEI (Volcanology, Geochemistry)

VS17b - VS17 Dynamics of Eruption Clouds

IUGG-2850

The effect of temperature fluctuations on the spread of a buoyant plume

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Representing dispersion from buoyant sources in a Lagrangian framework can present a difficult challenge. Practical Lagrangian dispersion models treat the fluid particles as independently moving particles whereas the buoyancy of the flow depends on the contribution of all the particles. In order to overcome this difficulty, hybrid Lagrangian stochastic models have been proposed that are a coupling of a classical plume model with a stochastic differential equation (sde) for the velocity fluctuations (Webster & Thomson, Atmos. Env., v.36, p.5031, 2002). Here we extend this model to include the effects of temperature fluctuations. The novelty lies in the addition an sde for the temperature perturbation suitably coupled to the sde for the velocity fluctuations. The model requires as input the root-mean-square temperature and its decorrelation time scale. The former is assumed to be proportional to the temperature difference between the centreline temperature of the plume and the ambient temperature. The constant of proportionality is tuned by comparison with equivalent statistics from large-eddy simulations (LES) of buoyant plumes in a uniform crossflow and constant stratification. The decorrelation time scale is assumed to be equal to the plume radius divided by the centreline velocity. The scalar concentration computed from the model is compared with the equivalent LES results and generally compares well both in terms of the height reached by the plumes and their spread. The exception to this occurs when the crossflow velocity becomes very weak. The model is extended to allow for realistic profiles of ambient wind and temperature and the results are compared with LES of the plume that emanated from the explosion and fire at the Buncefield oil depot in 2005.

IAVCEI (Volcanology, Geochemistry)

VS17b - VS17 Dynamics of Eruption Clouds

IUGG-4363

Plinian and co-ignimbrite phases of the Campanian Ignimbrite super-eruption

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The caldera-forming Campanian Ignimbrite (CI) super-eruption was the largest eruption of the last 200 ky in Europe. CI deposits show the eruption had two main phases, Plinian and coignimbrite, typical of many caldera forming eruptions. Previous studies have reconstructed tephra fallout of this momentous event through inverse modelling without discerning between the two phases and neglecting the gravitational spreading around the neutral buoyancy level of the eruption column. This simplification could lead to inaccurate estimations of the eruption parameters. Here we use a novel computational inversion method that account for both Plinian and coignimbrite phases allowing us to assess the corresponding volumes and durations with high accuracy. Our results reveal that the co-ignimbrite phase accounts for 3/4 of the total fallout volume. At its climax the eruption would have reached a column height of 44 km and then formed a co-ignimbrite column of about 37 km dispersing ~211 km^3 (~88 km^3 DRE) of tephra over ~3.7 million km^2 over 23h. Because of the intense wind field, tephra transport would have been dominated by wind advection beyond a few hundreds of km. This contrasts with most super-eruptions, where gravity-current can be expected to be the dominant transport mechanism and explains the good performance of previous studies that neglected such effect. Furthermore, we found that the eruption would have injected a maximum of 320-360 Tg of sulfuric aerosols into the stratosphere causing greater cooling that previously reported and a short but intense ecosystem acidification.

IAVCEI (Volcanology, Geochemistry)

VS17b - VS17 Dynamics of Eruption Clouds

IUGG-4590

Dynamics of wind-affected volcanic plumes: The example of the 2011 Cordón Caulle eruption, Chile

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The 2011 Cordón Caulle eruption represents an ideal case study for the characterization of long-lasting plumes that are strongly affected by wind. The climactic phase lasted for about one day and was classified as subplinian with plumes between ~9-12 km above the vent and Mass Flow Rate (MFR) on the order of ~10^7 kg s^{-1}. Eruption intensity fluctuated during the first 11 days with MFR values between 10^6-10^7 kg s^{-1}. This activity was followed by several months of low-intensity plumes with MFR <10^6 kg s^{-1}. Individual phases of the eruption range between VEI 3-4, while the cumulative deposit related to June 4-7, 2011, is associated with a VEI 4-5. Plume dynamics and rise were strongly affected by wind during the whole eruption with negligible up-wind spreading and sedimentation. The plumes developed on June 4-6 and 20-22 can be described as transitional plumes, i.e. plumes showing transitional behavior between strong and weak dynamics, while the wind clearly dominated the rise height on all the other days resulting in the formation of weak plumes. Plume dynamics was characterized based on a scaling parameter representing the ratio between the radial-entrainment and the wind-entrainment terms. Crosswind cloud and deposit dispersal of the first few days are best described by a linear combination of gravitational spreading and turbulent diffusion, with velocities between 1-10 m s^{-1}. Downwind cloud velocity for the same days is best described by a linear combination of gravitational spreading and wind advection, with velocities between 17-45 m s^{-1}. Results show how gravitational spreading can be significant even for subplinian and small-moderate eruptions strongly advected by wind.

IAVCEI (Volcanology, Geochemistry)

VS17c - VS17 Dynamics of Eruption Clouds

IUGG-1791

Plume Tracking Algorithm: Parameterisation of Strombolian Plume Dynamics

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Volcanic plumes are turbulent mixtures of particles and gas which are injected into the atmosphere during a volcanic eruption. Depending on the strength of the eruption, plumes can rise from a few tens of metres up to many tens of kilometres above the vent.

Classical models show that the entrainment of air is a key parameter in predicting the motion of the plume. However, recent studies suggest that inertial particles have a large role to play in determining entrainment dynamics. Models have been applied, with considerable success, to describe the dynamics of Plinian plumes, but they are also applicable to less explosive events. Whereas violent eruptions produce a large amount of very fine ash, less energetic eruptions produce much larger particles so the potential for affecting turbulent entrainment is great.

We present a case study of Strombolian eruptions. An algorithm developed to detect and follow the motion of a convective plume was applied to thermal images. We computed plume parameters, such as height, width and spreading angle at regular intervals of time. These properties have previously been used to retrieve the characteristics of explosion dynamics from thermal video at Stromboli and Santiaguito. We are also able to provide an estimation of the velocity and density of the plume at the vent. These parameters allow us to relate the local conditions of entrainment to those set at the source, allowing us to calculate an entrainment coefficient and obtain information about the entrainment efficiency in Strombolian eruptions. Using the eruption conditions at the vent, and a simple entrainment model based on the classical theory, we gain a deeper understanding of the entrainment processes in plumes formed by low energy explosive eruptions.

IAVCEI (Volcanology, Geochemistry)

VS17c - VS17 Dynamics of Eruption Clouds

IUGG-1984

Observations of Sakurajima Volcanic Ash Column with X-band Polarimetric Radar and Ka-band Doppler Radar

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X-band polarimetric radar and Ka-band Doppler radar data from two explosive eruptions of Sakurajima volcano were analyzed to reveal the inner structures of their respective volcanic ash columns. The first case analyzed was the eruption that occurred on August 18, 2013. The ash column height during that event was 5.5 km above the crater, and falling ash hindered surface traffic visibility in the downtown area of Kagoshima City, which is located about 13km west of the Showa crater. A linear interpolation in time and space was applied to the X-band polarimetric radar data, with 5-minute intervals and 12-tilt elevation angles, to construct a three-dimensional distribution of the radar parameters with a one minute interval and a 250m spatial resolution. The three-dimensional distribution of reflectivity in the ash column reveals a non-uniform structure; the ash column consists of several reflectivity cores which correspond to individual explosions. The pyroclastic material ascent speed, detected from Doppler velocity analysis, was about 60 ms^{-1} just above the crater. Analyses of reflectivity, differential reflectivity, and co-polar correlation coefficient suggest that the uniformity of ash particle size distribution and particle shape proceeds due to a size sorting mechanism in the ash column when it is moving in a down-wind direction. In the second eruption analyzed, which occurred on May 10, 2014, the ash column reached a height of 4500m above the crater. This eruption was observed by a Ka-band research Doppler radar, set up 3.6km from the crater, and an X-band operational polarimetric radar. RHI scanning of the ash column with the Ka-band radar showed it to have a fine kinematic structure.

IAVCEI (Volcanology, Geochemistry)

VS17c - VS17 Dynamics of Eruption Clouds

IUGG-3552

Exploring the capability of GPS radio occultation for detecting and monitoring volcanic clouds

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Global Positioning System (GPS) Radio Occultation (RO) has been successfully used in recent studies for detecting the cloud top altitude of convective systems and tropical cyclones with high accuracy. Here, we apply the same anomaly technique to volcanic clouds (ash or SO_2) for exploring the GPS RO capabilities in this field. GPS RO has several advantages in comparison to other satellite measurements: atmospheric parameters are provided with high vertical resolution, high accuracy, global coverage, and in essentially all weather conditions during day and night.

We analyzed the two biggest volcanic eruptions of the last decade: Puyehue 2011 and Nabro 2011. The main reasons of this choice are that those two eruptions were characterized by different types of clouds (Puyehue mainly ash and Nabro mainly SO_2). For locating the volcanic clouds we used independent radiometric measurements: the Atmospheric InfraRed Sounder (AIRS) ash index for the Puyehue ash cloud and SO_2 data from the Ozone Monitoring Instrument (OMI) for the Nabro SO_2 cloud. We found 1109 RO profiles co-located with the Puyehue cloud and 248 RO profiles co-located with the Nabro cloud.

For detecting the cloud top altitude we analyzed the vertical bending angle anomaly profiles and we validated the RO cloud top altitude estimates with backscatter measurements from the satellite sensor Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP).

We found seven RO–CALIOP co-locations for the Puyehue cloud and three for the Nabro cloud. Good agreement was found between cloud top estimates from RO and CALIOP, with a root mean square error of about 900 m and a correlation of 0.94.

Thanks to these promising results we plan to further investigations for developing a dedicated algorithm for detecting volcanic clouds.

IAVCEI (Volcanology, Geochemistry)

VS17c - VS17 Dynamics of Eruption Clouds

IUGG-4398

Settling dynamics of natural ash particles: Insight from laboratory high speed imaging

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Existing experimental and numerical models of ash sedimentation from volcanic plumes consider aerodynamic properties of particles as a function of their shape, density and size. However, rather than individually, particles are often observed to settle through zones of high particle concentration associated with gravitational instabilities where sedimentation is controlled by the properties of the bulk down-flow of settling particles. In order to investigate the differences in the aerodynamic behaviour of ash particles when settling individually or in mass, we performed systematic large-scale ash settling experiments.Natural basaltic ash from Etna (Italy, sampled in July 2014) and trachytic, pumiceous ash from Laacher See (Germany,12.900 y BP), in the classes 125-500 µm and 500-1000 µm, respectively, was used as starting material. For each class, we released 40-500 g of sample from a height of 5 m with different, controlled volumetric flow rates, in an unconstrained open space and at minimal air movement.All experiments were recorded with a high-speed camera at 2000 fps. After release, particles were observed to cluster, leading to locally enhanced fall velocities. High-speed imaging, manual and automatic tracking analyses were used to provide full characterization of particle settling dynamics as a function of particle concentration in the flow, density and particle size. The measured settling velocities of individual particles increase with increasing particle concentration. This suggests that particle dispersion during fallout may be one reason explaining larger than theoretical depletion rates of fine particles from volcanic ash clouds.

IAVCEI (Volcanology, Geochemistry)

VS17c - VS17 Dynamics of Eruption Clouds

IUGG-4415

The complex dynamics of the 18 May, 1980 Mount St. Helens eruptive plumes: impact of the early co-blast plume

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Despite being a textbook case of a Plinian eruption that has been used to test plume dispersion models, the May 18, 1980 eruption of Mount St. Helens had unusual dynamics and produced a complex fallout deposit. The eruption started with the blast a cryptodome which fed a pyroclastic surge that uplifted in a co-blast plume. 30 minutes later, activity started at the vent and fluctuated in intensity for ~ 9 hours. The resulting fallout deposit presents some striking features: 1) displacement of the overall deposit to the north of the vent; 2) secondary thickness maximum at ~300 km from vent; 3) total grain size distribution with a large amount of fine ash (62 wt% of the deposit finer than 125 µm); 4) grain size distributions that vary dramatically in the cross-wind direction from strongly bimodal to skewed unimodal.

We use a new deconvolution of the grain size distributions and componentry analyses of selected cross- and down-wind samples to define the deposit characteristics. Comparison with reanalysis data of the atmospheric wind field and satellite images of the spreading ash cloud, suggests that ash transport and depositional processes were strongly affected by the dynamics of the fine-grained co-blast plume, which is characterised by a high overshoot height, settling controlled by gravitational instabilities rather than the behaviour of individual or clustered grains, and eastward dispersion via strong winds low in the stratosphere (~10-15 km). The contrasting initial grain size of the different plumes, the northern momentum of the co-blast plume, and the atmospheric conditions explain both the cross-wind variation in deposit characteristics and the difficulties experienced by prior workers in modelling the deposit characteristics using only advection-diffusion models.

IAVCEI (Volcanology, Geochemistry)

VS17c - VS17 Dynamics of Eruption Clouds

IUGG-4420

Characterisation of volcanic plume dynamics using high-speed imagery

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Parameterizing the physical processes responsible for ash injection and plume dynamics is crucial to constrain numerical models and forecasts of potentially hazardous ash dispersal events. In this study we present preliminary results from a new method based on visible and thermal high-speed video processing from unsteady plumes. High speed cameras allow us to identify different dynamics of ash injection and dispersal, and the different phases during volcanic plume dispersion with a time resolution down to 1 ms. The use of this tool allow us to be more accurate with our observations and to better define already studied features and new ones. Quantitatively we pre-process our records to highlight the plume from the background by using different types of filters without altering the data, to allow us to use manual and automated procedures to track volcanic plumes. In this study we extract data from these videos (plume high, velocity, temperature, mass, volume,...) using different software in function of the parameter expected. Doing this allow us to be able to define and constrain the main parameters and processes, and to define eruptions and explosions types, but also to find correlations between parameters and establish empirical relations. We defined range of values for each parameter and their respective impact on plume dynamics and stability, to be able to obtain characteristic fields of values for each case and link it to explosions type and evolution.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-103

Three-Dimensonal Radar Data Analysis Tools of Volcanic Ash Cloud

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Analysis tools of weather radar data are developed to investigate the internal structure of volcanic ash clouds. The analysis tools calculate statistical parameters, three-dimensional distribution of polarimetric radar parameter which can be used to retrieve inner structure of ash column and ash clouds, echo top height, ash amount, and ascent or descent speed of pyroclastic materials. The analysis tools are applied to 31 explosive eruptions of Sakurajima volcano in 2013, which were selected with the condition that ash column height is higher than 3000m from the rater. The radar data were collected by operational X-band polarimetric radar, which was located approximately 10 km south-southeast of the volcano. The analysis of temporal change of histogram of radar parameters in ash clouds shows interesting results. While both reflectivity and differential reflectivity have no peak just after the eruption they began to exhibit the normal distribution with time. While reflectivity decreases its peak value depending on the time due to the sorting mechanism, the differential reflectivity increase its peak value probably due to the uniformity of ash particle shape. The specific differential phase is less than 0.5?km^{-1}. Doppler velocity measured above the crater can be used to estimate the speed of pyroclastic materials which is useful information on ash column height.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-104

Quantification of the erupted volume and total grain size distribution of the 23 February 2013 Etna lava fountain

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The majority of the plumes produced by explosive eruptions from Mt. Etna, in Italy, are affected by winds oriented from West to East that drive the volcanic ash over the sea, allowing erupted tephra to be sampled at relatively proximal area around the volcano only, i.e. within 20-25 km from the crater. This makes the quantification of fine ash content and the Total Grain Size Distribution (TGSD) very difficult and highly uncertain. Five lava fountain episodes occurred on the New South-East Crater of Mt. Etna from 17 to 23 February 2013. On the 23 February, there was a paroxysmal phase that lasted less than 1 hour, producing magma jets higher than 500 m and an eruption plume that reached at least 4-5 km above the crater. The plume was mainly advected by winds oriented from South-West to North-East. This plume produced an extended tephra fallout deposit, allowing lapilli and ash to be sampled at several locations between the slope of Etna and the Puglia region, at about 400 km from the volcano. Here we first quantify the TGSD and the fine ash content for this paroxysmal episode. Then, we use meteorological fields, column height estimation, and TGSD to initialize a computational model of tephra dispersion. Finally, the model simulations are compared with ground measurements and airborne observations allowing us to estimate Mass Eruption Rate and Total Mass through a best fit procedure.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-105

On-line transport of volcanic particles using multiscale meteorological models: an improvement on classical off-line models

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On-line coupled meteorology atmospheric chemistry models have mainly been developed by the air quality modeling community. However, these models are also of great interest for tephra dispersal modeling and numerical weather prediction as they can consider not only the driving mechanisms of meteorology on the transport of volcanic ash and aerosols, but also the potentially important feedback effects of these chemicals on weather. This unified modeling system contrast with the classical off-line dispersal approach, which only allows one-way coupling from the meteorology at sampled fixed time intervals. The amount of information lost using the simplified off-line approach could be significant for long-lasting eruptions and for long-range dispersal because this uncertainty tends to increase with distance from the source.

The aim of this talk is to quantify the uncertainty associated to off-line models, and to improve the tephra dispersal forecast by means of a novel fully coupled Chemical Transport Model model for volcanic particles. As a test case, we reconstructed the 2011 Cordón-Caulle eruption using the non-hydrostatic NMMB/BSC-CTM model. The model is capable of simulating emission, transport, dispersion, transformation and sedimentation of particles released during volcanic activities, both on-line and off-line. The off-line approach was validated comparing the model results with those of the FALL3D tephra dispersal model. The final tephra transport and sedimentation was validated against satellite data.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-106

In-situ measurement of the jet velocity and mass flux at Volcán de Colima, Mexico, with a Doppler radar

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On 21 November 2014 (18:24 UTC) the so far most energetic event recorded with a Doppler radar occurred at Volcán de Colima, Mexico. The corresponding ash cloud rose to an altitude of at least 7-8 km and drifted ENE (Smithsonian/USGS Weekly Volcanic Activity Report 19-25 November 2014). The Doppler radar measures the velocity of ejecta (>0.5 mm) and the reflected energy, that is a proxy for their cumulative size within the eruption cloud. These data constrain the dynamics of the eruption cloud between 100-200m above the vent, where the field of view is located. The recorded dynamics include the signatures of (1) multiple explosion jets, (2) a pyroclastic density current (PDC), (3) a co-ignimbrite-cloud , and (4) the pulsating buoyant uprise of the eruption cloud. Using the spatial resolution of the Doppler radar, we are able to follow the PDC down the flank up to 900m of its 3 km run-out distance. We are also able to deduce the mean particle size of settling ash as a function of distance from the crater. Settling ash was detected with the radar up to 11 minutes after the beginning of the event.

Volcán de Colima is currently in an active phase at the end of an observed near-centennial cycle of activity, typically culminating in sub-Plinian or Plinian eruptions. After several dome extrusion and destruction episodes beginning in 1998, the extrusion of a new dome commenced in January 2013. Since extrusion and explosive has been variable in its intensity with a peak occurring in November 2014. In February 2009, we installed a permanent Doppler radar monitoring station, to explore the dynamics of the volcanic explosions that accompany dome growth. It has proved itself to be a highly valuable monitoring tool.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-107

The paroxysm of Etna (Italy) on 23rd November 2013: Ballistics shower and hazard zones implications

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On 23rd November 2013, a paroxysmal eruption occurred at Etna's New SE Crater (NSEC). A powerful eruptive column was developed and reached several km high, leading to the fallout of material on the NE flank. The ash reached as far as the S coast of Italy. During the climax phase there was a huge shower of dense ballistic clasts >0.2 m. These covered a distance of >5 km between the Rif. Citelli, Mt. Sartorius and Due Monti, where they destroyed roofing tiles, solar panels, windows of cars and slightly injured some hikers; the pyroclastic material with a diameter up to 2 cm reached about 30km. We studied 30 samples from sites ranging between 5-25 km from NSEC. For the >5 km range, it is impossible to distinguish the clasts falling from the eruptive column from the clasts erupted from the vent following ballistic trajectories. The trajectories of smaller blocks (d<0.1m) are not purely ballistic, since these can be carried in the eruptive column. They are then dispersed by the finger-like projections from the jet-thrust region of the column from where they fall or produce gravity currents in the surrounding region of the eruptive column. Furthermore, the gas expansion in the column reduces the drag force on particulates and assists their vertical-lateral transport. The composition of magma erupted proves to be more primitive than that emitted during the 2011-2013 paroxysms. This aspect could be important factors to explain the highly explosive paroxysm of 23rd November, 2013. Finally, compared with 180 paroxysms in the past 15 years, this event has generated one of the most significant pyroclastic deposits in terms of thickness, amount of material on the ground, particle size and dispersion of products erupted and raises some significant implications regarding hazard zones.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-108

Comparison of volcanic ash deposition simulations using a general purpose dispersion model (HYSPLIT) and a specialized ash deposition model (ASHFALL)

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One of the main sources of error in modelling volcanic ash deposition is the representation of the wind field. GNS Science currently forecasts the ash deposition from actual and potential volcanic eruptions in New Zealand volcanoes with the ASHFALL program, which uses 1-D wind profiles at the vent location derived from Numerical Weather Prediction (NWP) model output supplied by MetService. This has been shown to give fairly good results for coarse ash falling within100km or so from a volcano, but is likely to have significant errors for more distal ash deposition.

HYSPLIT is a hybrid Lagrangian dispersion model, developed by NOAA/ARL, that is used by MetService in its role as a Volcanic Ash Advisory Centre, to model airborne volcanic ash, with meteorological data provided by external and in-house NWP models. A by-product of the HYSPLIT volcanic ash dispersion simulations is the deposition rate at the ground surface. This study compares the results of HYSPLIT and ASHFALL, to see the effect of a more accurate wind model in typical weather situations. The aim is to see whether routine modelling at GNS Science should be done with a 3-D meteorological fields as is done by HYSPLIT.

This has required us to compare other features of the two models, including the fall velocities for different ash sizes, and the initial distribution of ash in an eruption column, to enable us to properly compare the results from the two models, and to find out what changes are required in HYSPLIT to provide improved volcanic ash deposition simulations.

IAVCEI (Volcanology, Geochemistry)

VS17p - VS17 Dynamics of Eruption Clouds

VS17p-109

Aircraft measurement results of the Bardarbunga-Holuhraun eruption plume compared with the weather research and forecast model calculations

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The eruption in Bardarbunga-Holuhraun is the largest producer of lava and gas in Iceland since 1783. In view of this fact an airborne measurement campaign was performed including 10 flights and two aircraft. During this measurement campaign emissions of SO2 and ash concentrations were measured at the source and at the far plume. It could be demonstrated that the SO2 concentration at the source reached extreme high values, compared to other airborne volcanic campaigns. Levels of SO2 concentrations could be measured, which can potentially be harmful to human health. The measured volcanic ash consisted of very fine particles, but the concentration was low when compared to other recent eruptions. Measurements of the far plume showed that scavenging is very active. The dispersion of the plume was successfully modeled with the Weather Research and Forecast (WRF-chem) model. The analysis using the model showed that a large amount of the sulphur was precipitated in the Icelandic highlands.

IAVCEI (Volcanology, Geochemistry)

VS18p - VS18 Rock Physics in Crustal Processes

VS18p-486

The response of visco-elastic crust and mantle to magmatic activities; The numerical experiments based on 3D finite element model

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The development of satellite observations (GPS and/or InSAR) has allowed precise measurement of the crustal deformation associated with movement and/or accumulation of magma. It is however still necessary to evaluate how the magmatic activities are reflected in the observations, for which quantitative investigation is required to distinguish the component of magma-induced deformation. This study employs a parallelized 3-D finite element code, OREGANO_VE [e.g., Yamasaki et al., 2014, J. Geophys. Res., 119, 3678-3699], to examine the response of visco-elastic crust and mantle to spatiotemporal development (inflation and/or deflation) of sill. A rectangular modelled box comprising visco-elastic layer overlaid by elastic layer adopts the linear Maxwell constitutive law with constant elastic parameters and a constant viscosity in the visco-elastic layer. The development of sill is implemented by the split node method of Melosh and Raefsky [1981, Bull. Seism. Soc. Am., 71, 1391-1400]. Our numerical experiments predict geodetically detectable surface deformation caused by the development of sill, depending on the thickness of the elastic layer, a depth at which the sill is developed and the volume of magma, and that it is relatively easier to detect the horizontal movement of magma than the vertical movement, but ascending magma may possibly be captured by such an observation that a horizontal extent over which the surface deformation remarkably appears becomes narrower. Post-inflation (and/or -deflation) visco-elastic relaxation, however, abates the signatures, suggesting to parameterise the model behaviour according to a relative time-scale of magmatic process to the relaxation time of the crust and mantle.

IAVCEI (Volcanology, Geochemistry)

VS18p - VS18 Rock Physics in Crustal Processes

VS18p-487

Deformation of dry, weak, volcanic rocks: A source of Long Period seismicity?

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In recent years great progress has been made in identifying long period (LP) events, or volcanic tremor, which are signals peculiar to volcanic settings. Subsequently, similar signals have been identified in and around subduction zones, with high pressure/velocity fluid movement suggested as the mechanism. Recently, however, alternative generation mechanisms has been put forward for volcanic settings. These include models invoking stressing rate in dry materials (Dmitrieva et al., 2013) and the material properties alone (Bean et al., 2014) to provide the characteristic resonance observed but without the presence of fluid. In either case, a slow rupture occurs in poorly consolidated or “weak” rocks commonly found in the top few 100m of a volcanic edifice.

To examine this further, we present new rock deformation experiments designed to simulate shallow volcano-tectonic conditions using a triaxial deformation cell. Dry samples of a weak volcanic tuff from Naples, Italy, were tested by instrumenting them within a rubber jacket equipped with 12 Acoustic Emission sensors to detect laboratory seismicity during triaxial deformation at a range of confining pressure from 0.5 – 2 MPa, simulating the upper 100m in a rock mass.

We recorded a resonant frequency of around 90 kHz which accompanies a continuous strain softening phase in the sample. This behaviour is the same as that identified in numerical models of the slow rupture process (Bean et al., 2014). Locating the source of the resonance indicates that signals predominantly originate from the damage zone, and we additionally conclude that the high attenuation of the rock type is not a barrier to signal detection. Calculating the apparent attenuation from our AE data will form the subject of this continuing research.

IAVCEI (Volcanology, Geochemistry)

VS18p - VS18 Rock Physics in Crustal Processes

VS18p-488

Laboratory simulations of fluid-induced seismicity in shallow volcanic faults

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Seismicity is a key tool used for monitoring fracturing and faulting in volcanoes. A range of seismic events are identified by their spectral characteristics and duration: Long Period (LP) and tremor events, thought to be linked to fluid movement at depth, and Volcano-Tectonic (VT) signals representing low magnitude earthquakes.

To better understand these signals, and the switch between them, we present new rock deformation experiments designed to simulate shallow volcano-tectonic conditions using a triaxial cell equipped with a 12 channel Acoustic Emission (AE) array and high speed pore pressure data-logger. A two-stage process allows us to simulate a rapid pore pressure release through an established fracture damage zone. Firstly, experiments are conducted to generate a through-going shear fracture, with pore fluid connectivity to this fracture enhanced via a pre-drilled axial conduit. The second stage vents the pore-fluid pressure.

We find that this second stage is accompanied by a swarm of Low Frequency (LF) activity akin to Long Period (LP) events. We measure a significant change in the dominant frequency of LF events as pore fluid pressure decreases through, and beyond, the water boiling point under the pressure conditions imposed, when the superheated water turn to vapour. We also observe a significant dependence of the recorded LF upon the fluid flow rate. Data are used to forecast the final time of failure via the fracture forecast methods of Kilburn (2004), showing a good correlation between measured sample failure time and the forecast time based on AE event rate. Our data showed little change in forecast accuracy when using LF data compared to regular VT data, illustrating the importance of newly fracturing surfaces in the application of such models.

IAVCEI (Volcanology, Geochemistry)

VS18p - VS18 Rock Physics in Crustal Processes

VS18p-489

The imaging of Brittle Ductile Transition beneath the Campi Flegrei-Ischia Volcanic District and its impact on natural seismicity

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The thermo-rheology properties of the rocks are a crucial point to understand the mechanical behaviour of the crust in young and tectonically active area. As a consequence, several studies have been performed since last decades in order to understand the role of thermic state in the evolution of volcanic areas. In this context, the knowledge of the Brittle-Ductile transition inside the crust may provide insights to verify the roles that some hypothesized mechanisms, such as slab pull, crustal delamination might have played in the evolution of a tectonically active region. The goal of our study was the 3D imaging of the crust rheology beneath the active Campi Flegrei-Ischia Volcanic District and its impact on natural seismicity. Despite many works have been done on the internal structure of the active volcanoes, the determination of the 3D rheological stratification of the crust below the caldera has not yet been tackled. To fill this gap of knowledge, we proposed for the first time the 3D geometry of the Brittle-Ductile transition calculated numerically on the basis of geological, geochemical, and geophysical data. We first performed a 3D numerical modelling of thermal field by using the a priori geological and geophysical information by consideration of thermal proprieties and mechanical heterogeneities of the crust beneath the caldera. We developed a 3D conductive/adventive time-dependent thermal numerical model solving the Fourier equation and further we used the retrieved thermal model to image a 3D rheological stratification of the shallow crust below the volcanic district.

IAVCEI (Volcanology, Geochemistry)

VS18p - VS18 Rock Physics in Crustal Processes

VS18p-490

Mobility of bi-dispersed granular flows and the dominant role of the basal boundary

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Pyroclastic flows and landslides are often characterised as granular flows, where the dynamics are controlled by the interaction of constituent solid particles. These flows constitute destructive natural hazards, and a key challenge from the perspective of prediction and mitigation is understanding the mechanical origin of the surprisingly high mobility of such fows.

In this contribution, we analyse the behaviour of model granular flows in two dimensions using discrete numerical techniques. We focus on effects arising from the flow consisting of different grain sizes, and use the simulations to quantify the resulting structuring of the flow due to segregation, and its modified rheological properties. In particular, we make a systematic comparison of the possible contribution of these mechanisms to mobility, as compared with the effect of changing the underlying surface conditions.

Our results show that the dominant contribution to mobility is the conditions at the base of the flow, rather than in the flow interior. The basal slip velocity provides the dominant control on the flow dynamics, as compared to bulk properties. This result highlights the need to correctly describe basal flow conditions for the prediction of the resulting flow dynamics, and provides an explanation for the success of depth-averaged flow models in predicting geophysical granular flow dynamics.

IAVCEI (Volcanology, Geochemistry)

VS21a - VS21 Volcanic Ash Aggregation

IUGG-2195

Gravitational instabilities and their role in enhancing fine-ash deposition

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Our poor understanding of fine-ash sedimentation is directly reflected in large uncertainties in forecasting of volcanic ash dispersal and deposition. Gravitational instabilities forming at the bottom of spreading volcanic clouds have been observed in many explosive eruptions. Ash accumulates at the base of volcanic clouds, which can become denser than the underlying atmosphere, leading to the formation of density-driven instabilities. Here we present the first quantitative description of the dynamics of such instabilities, and correlate this with the characteristics of the fall deposit, for observations of the 4th May 2010 Eyjafjallajökull eruption (Iceland). Gravitational instabilities initially took the form of downwards propagating ‘fingers’ that formed continuously at the base of the cloud and appear to be advected passively at the crosswind speed. Measurements of finger propagation are consistent with initial conditions inferred from previous studies of ash cloud dynamics. Dedicated laboratory analogue experiments confirmed that finger downward propagation significantly exceeded the settling speed of individual particles, demonstrating that gravitational instabilities provide a possible mechanism for enhanced sedimentation of fine ash. Our field study provides direct evidence of the relation between aggregation and convective instabilities; indication of aggregates is not found more proximally than the region of convective instability transport to the ground. Our observations challenge the view that aggregation is the primary explanation of proximal fine ash sedimentation, and give direct support for the role of gravitational instabilities in providing regions of high particle concentration that can promote aggregation.

IAVCEI (Volcanology, Geochemistry)

VS21a - VS21 Volcanic Ash Aggregation

IUGG-2745

Volcanic ash aggregation in the lab - can we mimic natural processes?

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Explosive volcanic eruptions release large amounts of particles into the atmosphere. Volcanic ash (particles < 2mm) can be distributed around t40he globe. Under certain circumstances, ash particles can cluster together and build ash aggregates. During growth, weight, density and aerodynamic properties change, leading to a significantly different settling behavior compared to individual ash particles. We collected numerous ash aggregates and analyzed their textural, chemical and mechanical properties. Based on this knowledge, we have designed experiments using the ProCell Lab System® of Glatt Ingenieurtechnik GmbH, Germany. In this device, a continuous fluidized bed can be applied on solid particles and simulate gas-particle flow conditions as they would be expected in volcanic plumes or pyroclastic density currents. The geological record and direct observations have shown that both processes are able to produce ash aggregates. As starting material we used Na-glass beads as an analogue and volcanic ash from Laacher See Volcano, Eifel Volcanic Field, Germany. We define parameters such as grainsize, specific surface area and concentration of the starting material, degree of turbulence, temperature and moisture in the process chamber and the composition of the liquid phase to influence form, size, stability and production rate of aggregates. We were able to experimentally produce round, unstructured ash pellets up to 5mm in diameter. A detailed textural description highlights the strongly different properties of single ash grains and ash aggregates. These experiments aim at experimentally constraining the boundary conditions required for the generation of strong ash aggregates. A better mechanistic understanding will serve for more adequate ash mass distribution modeling.

IAVCEI (Volcanology, Geochemistry)

VS21a - VS21 Volcanic Ash Aggregation

IUGG-3880

Volcanic lightning: Updated global observations and constraints on source mechanisms

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New data on volcanic lightning from the Smithsonian Volcano Reference File are added to an existing database and expand the number of cases available for study. Lightning has now been documented at 154 volcanoes in association with 394 eruptions, a significant increase from the earlier numbers of 89 volcanoes and 240 eruptions. Lightning and electrification at volcanoes are important because they represent a hazard in their own right, are a component of the global electrical circuit, and contribute to ash particle aggregation within ash plumes. The role of water substance (water in all forms) in particular has not been well studied. The Volcanic Explosivity Index (VEI) was determined for 177 eruptions. Eight percent of VEI=3-5 eruptions have reported lightning, and 10 percent of VEI=6, but less than 2 percent of those with VEI=1-2, suggesting consistent reporting for larger eruptions but either less lightning or under-reporting for small eruptions. Ash plume heights (142 observations) show a bimodal distribution with peaks at 7-12 km and 1-4 km. The former are similar to heights of typical thunderstorms and suggest involvement of water substance, whereas the latter suggest other factors contributing to electrical behavior near the vent. The distributions of the latitudes of volcanoes with lightning and eruptions with lightning roughly mimic the distribution of all volcanoes; flat with latitude. Meteorological lightning, on the other hand, is common in the tropics and decreases with increasing latitude as the ability of the atmosphere to hold water decreases poleward. This finding supports the idea that if lightning in large eruptions depends on water substance, then the origin of the water is primarily magma and not entrainment from the surrounding atmosphere.

IAVCEI (Volcanology, Geochemistry)

VS21a - VS21 Volcanic Ash Aggregation

IUGG-3908

Subsurface aggregation and sintering of rhyolitic ash within the 2011-12 Cordon Caulle vent drove prolonged ash emission from self-sealing nozzles?

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Prolonged tephra emission from the rhyolitic 2011-12 Cordón Caulle eruption, Chile, led to sustained local impact. Energetic ash venting from incipient lava domes coincided with >10 months of lava emission, creating typically 1.5-7 km ash plumes. Observations of venting[1] revealed repeated, explosive opening of several elongate and nozzle-like structures on ~10-100 s timescales, between which sealing briefly halted gas and ash emission. Nozzle sealing and reopening processes appear key to the longevity of explosive degassing.

Vent visits in January 2014 and 2015 revealed two ~50 m-wide rubble-strewn domains of fractured, disrupted lava, adjacent to pancake-like obsidian domes. Prominent red ash-coated fracture surfaces match observed active nozzles, occurring both as linear, ~10 m-long tensional gashes akin to crease structures, and steeply-dipping ~metric curviplanar surfaces. Ash coatings are <10 μm to >10 mm thick, and consist of variably-sintered aggregates of extremely fine-grained glassy clasts (<2 μm) that adhere to fracture surfaces in crystal-rich lava. Veneer thicknesses increase deeper within nozzles, where they form a glassy, densely-sintered matrix that cements brecciated, crystalline vent lava.

As limited secondary precipitation occurred we propose that aggregation and particle binding were assisted by electrical charging and frictional heating during pulsatory ash emission through narrow pathways. Rapid sintering of heated sub-micron particles then sealed gas escape routes, driving repetitive, violent disruption of the upper conduit and leading to prolonged ash emissions. The subsurface onset of multi-stage, multi-scale ash aggregation may therefore influence eruption mechanisms, as well as atmospheric tephra dispersal.

1. Schipper CI et al 2013 JVGR.

IAVCEI (Volcanology, Geochemistry)

VS21a - VS21 Volcanic Ash Aggregation

IUGG-4754

Volcanic lightning: In nature and in the lab

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Ash-rich volcanic plumes injecting large quantities of aerosols into the atmosphere are often associated with intense electrical activity. Monitoring electrical discharges associated with explosive eruptions can provide crucial information on the dynamics and structure of the plume as well as on the mass eruption rate and cargo of erupted fine ash. In addition they are regarded as one cause of ash aggregation in the volcanic plume. Our understanding of volcanic lightning is still limited due to lacking of both i) systematic instrumental observation and ii) the limited number of experimental investigations.
We recently contributed to the understanding of both these aspects by performing multi-parametric observation of volcanic lightning at Sakurajima volcano in Japan and by achieving volcanic lightning in particle-laden jets generated in the lab.
At Sakurajima volcano we combined high-speed imaging with magnetotelluric and acoustic measurements of ash-rich plumes generating electrical discharges and compare our observation with maximum plume height measurement and atmospheric soundings. We complement the field observation by performing rapid decompression experiments of ash samples and analogue materials. The experiments have a similar character to the cannon-like explosions observed at Sakurajima and show how lightning is controlled by the dynamics of the rapidly expanding particle-laden jet. Two main conditions are required to generate lightning: 1) triboelectrification of the particles and 2) clustering of the particles driven by the jet fluid dynamics. As observed in nature, the size of the flashes scales with the dimensions of the evolving jet and the presence of fine ash in the jet is key for the generation of electrical discharges.

IAVCEI (Volcanology, Geochemistry)

VS21b - VS21 Volcanic Ash Aggregation

IUGG-1289

New insights on modeling volcanic ash aggregation from field and numerical experiments

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Particle aggregation is considered as a key process that may affect dispersal and sedimentation of volcanic ash, with significant implications for the associated hazards. So far the theoretical description of volcanic ash aggregation is commonly related to the solution of the Smoluchowski Coagulation Equations, a set of Ordinary Differential Equations (ODEs) which basically describe the change in time of an initial grain-size distribution due to the interaction of “single” particles. Nevertheless, field data show that this general description lacks of completeness, mainly due to the peculiarities of the volcanic context with respect to other fields (aerosol and pollution sciences). We propose an improvement of the general theoretical model in order to take into account the new insights from field observations. In particular, we focused on the problem of different densities between single particles and aggregates. This algorithm has been applied to observed volcanic eruptions (i.e. Eyjafjallajokull 2010, Sakurajima 2013 and Mt. Saint Helens 1980) to investigate the sensitiveness of our model with respect to the input parameters (total grain-size distribution, collision kernels, sticking efficiencies). Constrains on these parameters come from field observations and laboratory experiments.

IAVCEI (Volcanology, Geochemistry)

VS21b - VS21 Volcanic Ash Aggregation

IUGG-1664

Aggregation of Volcanic Particles: Constrains Provided by Field and Numerical Investigations

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Dispersal and deposition of ash during volcanic explosive eruptions strongly affect the surrounding environment and distal atmosphere, with disruptive consequences on inhabited communities and aviation transport. Nevertheless, accurate forecasting of the potential impacts remains challenging mainly due to our poor understanding of particle dispersal and aggregation. Aggregation processes are well known to affect sedimentation of fine ash (<63 μm) by considerably reducing its residence time in the atmosphere. Even so, fundamental questions remain unanswered, such as how fast and where does aggregation occur?, how does it evolve?, and how does it affect sedimentation? In addition, ash forecasting is also affected by our incapability of explaining deposition of large particles (~100 μm) hundreds of kilometres from the volcano. Here, we applied High-Speed-High-Resolution imaging combined with in-situ particle-collection and numerical modelling to understand better the aggregation process. First, numerical inversions of field observations show how aggregates only need 100 seconds to form from eruption onset. Second, High-Speed-High-Resolution imaging evidence for the first time that aggregation decreases the residence time of particles <100 μm, while simultaneously results in the sedimentation of coarse ash at distances significantly larger than expected (i.e. rafting effect). Our new findings demonstrate how accurate risk assessments of the impact of ash dispersal on our societies can only be achieved if the two fold effect of particle aggregation generating both a premature fallout of fine ash and a rafting effect on coarse ash is rigorously parameterized.

IAVCEI (Volcanology, Geochemistry)

VS21b - VS21 Volcanic Ash Aggregation

IUGG-3192

Lidar monitoring of Etna volcanic plumes during lava fountain events

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Mt. Etna, in Italy, is one of the most active volcanoes in the world. Since 2011, the New South East Crater has produced lava fountains that formed eruption columns rising up to several kilometers above the sea level and fine ash was dispersed hundreds of kilometers away from the central craters. Some of these events were well retrieved by a portable Raman scanning Lidar system during and immediately after the lava fountain activity. The Lidar named AMPLE is a portable multiwavelength scanning lidar system able to carry out high quality 3D maps of particle optical and microphysical properties and their time evolution. The laser source is a doubled and tripled diode pumped Nd:YAG laser, with a repetition rate of 1KHz. The Lidar system detects the elastic Lidar returns at 355nm and the N2 Raman Lidar echoes at 386nm. Each signal is acquired with a raw spatial resolution varying from 30cm to 30m. The Lidar is operated at Serra La Nave, only 7 km away far from the Etna summits, and during the winter season at the INAF-Astrophysical Observatory in Catania. We selected some eruptive events and analyze the results. Results of the measurements show different layers corresponding to smaller not depolarizing particles of local origin and depolarizing particles related to volcanic ash coming from Etna. A discrimination between spherical and non-spherical particles and differences in the aerosol size and typology in the volcanic plume is clear from the measured profiles of the lidar ratio and depolarization values in the sounded atmospheric column. Lidar measurements presented in this work show new insights on the plume dynamics during Etna lava fountain events.

IAVCEI (Volcanology, Geochemistry)

VS21b - VS21 Volcanic Ash Aggregation

IUGG-3274

PlumeMoM: A moments-based computational plume model with ash aggregation

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In the past decades, numerical simulations of volcanic eruptions have greatly advanced and models are now often able to deal with the multiphase nature of volcanic flows. Despite this, the polydisperse nature of such flows is often largely simplified. For instance, in plume dynamics the grain-size distribution of pyroclasts is modeled with a discretization in a finite number of classes and for this reason, although ash aggregation is observed at many volcanoes and is recognized as important in determining the residence time of ash in the atmosphere, this process is still oversimplified in many numerical models. Recently, a theoretical and computational framework, namely the method of moments, have been developed to track the evolution of the particle size distribution described by a population balance equation. Such equation is formulated in terms of a density function and some integral quantities of interest (i.e. the moments) are derived and their transport equations are formulated. Here we present a model for volcanic plume based on the method of moments, where aggregation is introduced in the population balance equation with the approach of Smoluchowski. The functions adopted for the aggregation efficiency and the aggregation kernel are based on laboratory experiments describing the behavior of ash particles transported in turbulent, low humidity suspension and filmed while colliding, aggregating and disaggregating. An empirical relation of the aggregation efficiency as a function of collision energy is then derived. The effects of particle aggregation, in terms of variation of the parameters of the grain-size distribution along the plume, are illustrated and discussed with the aim to better characterize the parameters of the source in ash dispersion model.

IAVCEI (Volcanology, Geochemistry)

VS21b - VS21 Volcanic Ash Aggregation

IUGG-4751

Retrieving volcanic vent parameters by global inversion of Thermal Infrared videos of volcanic plumes

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We present a methodology for the retrieving key vent parameters and their related uncertainly by analyzing Thermal Infrared (TIR) videos of volcanic plumes (Cerminara et al. JVGR 2015). We have applied this inversion procedure to an ash plume at Santiaguito (Santa Maria volcano, Guatemala). In particular, our methodology allows for estimation of vent parameters such as mass flow rate, plume velocity, plume temperature, gas/ash mass ratio, Sauter diameter of the total particle grain size distribution and the plume turbulent entrainment rate.

The methodology is based on a coupled fluid-dynamic (FD) and electromagnetic (EM) model for volcanic ash plumes. In a forward approach, the model is able to simulate the plume dynamics from prescribed input flow conditions and generate the corresponding synthetic TIR image. In the inversion procedure, model parameter space is sampled to find the optimal set of input conditions which minimizes the difference between the experimental and the synthetic image.

The adopted FD model is based on a one-dimensional, stationary description of a self-similar turbulent plume. The EM emission/absorption model is based on Schwarzschild's equation and on Mie's theory for disperse particles.

The presented method is general and, in principle, can be applied to the spatial distribution of particle concentration and temperature obtained by any fluid-dynamic model, either integral or multidimensional, stationary or time-dependent, single or multiphase. The method discussed here is fast and robust (less than 1 min on a standard laptop), thus indicating potential for applications to real-time estimation of parameters which are crucial for model-based forecasts of the volcanic ash dispersal process.

IAVCEI (Volcanology, Geochemistry)

VS21p - VS21 Volcanic Ash Aggregation

VS21p-395

Morphometric fractionation of tephra in a volcanic plume revealed by high-resolution ash particle shape analyses

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Determining the dynamics of explosive eruptions requires in-depth knowledge of the processes that control tephra formation and dispersal. Transport and sedimentation processes are directly influenced by the shape of the ash particles. Here we focus on the apparent (2D-projected) shape of ash particles (APASH). A complex ash grain outline controls for instance the drag coefficient and thus how far a particle can be transported by wind. We developed an analytical protocol to obtain fast and routine morphometric measurements (e.g. circularity, convexity) for volcanic APASH that allow, in particular, to investigate the distance-shape relationship on the APASH signature. This study focuses on the ash fall deposits from the 2001 eruption of Tungurahua volcano (Ecuador), whose ongoing activity since 1999 is punctuated by successive eruptive crises.

We first selected a set of 3 tephra samples in order to study APASH variations with distance from vent (3.8 to 16 km) below the plume axis. Our morphometric results are summarized as follow: (1) aspect ratio values decrease with phi size; (2) convexity and circularity values are similar for the 3 samples and decrease constantly with phi size down to 2 phi, (3) and then diverge at lower values for particles < 2 phi; (4) crystals and dense juvenile particles are rare in more distal deposits. Finally, these results suggest that shape-dependent ash particle fractionation in the plume is limited for particles > 2 phi. However, a distance-dependent morphological fractionation is evidenced for particles < 2 phi. APASH constitutes then a useful distance marker for analyses of ash fall deposits. Thus, the APASH signature can be potentially used as a distance-related marker for past tephra deposits.

IAVCEI (Volcanology, Geochemistry)

VS21p - VS21 Volcanic Ash Aggregation

VS21p-396

Quantifying ash aggregation processes during the 26 April 1979 Saint Vincent eruptive event

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This study uses the accurate field observations of the products of the explosive eruption of Saint Vincent de la Soufrière occurred the 26 April 1979 (Brazier et al., 1982) to calibrate a computational model for volcanic ash aggregation and get insights into the processes characterizing ash aggregation in very wet regimes. During the 26 April 1979 eruption, accretionary pellets were observed then sampled and analyzed together with tens of tephra loading measurements that allowed Eruption Source Parameters (ESP) to be assessed. We use such information on ESP and the reanalysis meteorological data for this event to model plume evolution and tephra dispersal using the Fall3D code. In particular such a well-constrained case allow us to calibrate an ash aggregation model based on a simplified solution of the Smoluchowski equation implemented into the tephra dispersion code. The goal is to explicitly model ash aggregation generalizing previous models to very wet conditions assessing the fraction of fine ash that aggregates and their aerodynamic properties. All the available field observations and analysis, together with laboratory experiments, are used to calibrate the model and constrain the processes that lead to the production of accretionary pellets.

Reference :

Brazier, S., Davis AN, Sigurdsson H, Sparks RSJ. 1982. Fallout and deposition of volcanic ash during the 1979 explosive eruption of the Soufrière of St. Vincent. Journal of Volcanology and Geothermal Research 14:335-359.

IAVCEI (Volcanology, Geochemistry)

VS21p - VS21 Volcanic Ash Aggregation

VS21p-397

Estimation of the airborne ash density for Sakurajima using PUFF model

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Airborne volcanic ash is a danger object for the aviation safety. Once the jet aircraft encounters the ash cloud and engine failure occurs, the damage is estimated to reach to a billion of US dollar. Hence the real-time monitoring and estimation of the airborne ash density is an important research subject. According to ICAO report, the ash density above 2 mg/m3 is a threshold for the danger zone of the aircraft. A system to predict the airborne ash density is desired to develop in urgent based on the real-time observation of the emission rate and plume height. In this study, we conducted numerical simulations of volcanic ash dispersal from Sakurajima volcano using the real-time volcanic ash dispersion transport model PUFF for one year period in 1985 when volcanic activity was considerably high. According to the numerical simulation by the Lagrangian formulae of PUFF model for one year given the observed emission rate and plume height, the total particle number of the ash fallout was 1,962,976. On the other hand, the total amount of the observed ash fallout for one year period was 28,870,000 ton. The comparison shows an important measure of the particle mass, which is estimated as 14.7 ton/particle in the PUFF model. Based on this mass measure, we are now able to estimate the airborne ash density as a function of 3D space and time. The developed new system at Sakurajima volcano will now be applied to other volcanoes in Indonesia under the SATREPS project by JST and JICA.

IAVCEI (Volcanology, Geochemistry)

VS22a - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-1063

Enhancing scientific response to volcanic crises: Social, psychological and organisational evidence and NZ practice

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Effective multi-agency collaboration during a volcanic crisis involves understanding how information interacts with social, psychological, and organizational characteristics that affect its interpretation and use. For science advisers, their role must extend beyond identifying the types of expertise needed, to understanding end user needs and developing coordinated programmes in which advisors and agencies can practice ways that enhance their capability to provide advice in complementary ways. Organizational culture, inter-agency trust, mental models, information management, communication, and decision making competencies and processes need to be understood and accommodated in crisis management planning and delivery. We review science advisory processes within New Zealand (NZ), and discuss lessons learnt from research into the inter-organisational response to historical eruptions and exercises in NZ. We argue that team development training is essential and review the different types of training and exercising techniques (cross training, positional rotation, scenario planning, collaborative exercises, and simulations) which can be used to develop a coordinated capability in multiagency teams. We argue that to truly enhance the science response, science agencies must learn from the emergency management sector and embark on exercise and simulation programs within their own organisations, rather than solely participating as external players in emergency management exercises. We thus propose a science-led tiered exercise program, with example exercise scenarios, which can be used to enhance both the internal science response and the interagency response to a national or international event, and provide direction for the effective writing and conduct of these exercises.

IAVCEI (Volcanology, Geochemistry)

VS22a - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-2211

TephraProb: a toolbox for the probabilistic hazard assessment of ground tephra accumulation

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We present a toolbox designed to assist each step of the compilation of comprehensive hazard assessments for ground tephra accumulation using the advection-diffusion model TEPHRA2. This operating system-independent toolbox is written in Matlab and comprises series of graphical interfaces. Key features of this toolbox are (i) modules to generate and collect necessary input data (i.e. calculation grid, wind data from the NOAA and ECMWF), (ii) modules to process grainsize data (e.g. empirical aggregation), (iii) modules assisting the identification of eruptive scenarios based on the Global Volcanism Program in case limited field data is available, (iv) modules to statistically analyse wind conditions, (v) modules to run the model in a range of scenarios, (vi) modules to process and display output data (i.e. probability maps for a given tephra threshold, isomass maps for a given probability of occurrence, hazard curves) and (vii) modules to export hazard maps (i.e. ArcGIS, Google Earth).

This toolbox allows the compilation of hazard assessments using a wide range of eruption scenarios, including fully deterministic to fully probabilistic approaches, Plinian and Vulcanian eruptive styles and short- and long-lasting eruptions. It facilitates each step of probabilistic hazard assessments for tephra fallout, from the gathering of input parameters from disparate sources to the post-processing of the output data. Additional modules for the processing of input parameters help the user to define the best scenario to adopt on a case per case basis (i.e. seasonal assessments, elaboration of scenarios with variable availability of field data). This toolbox is therefore an operative tool that can be used to rapidly produce comprehensive hazard assessments for tephra fallout.

IAVCEI (Volcanology, Geochemistry)

VS22a - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-2304

Assessing vulnerability of infrastructure to volcanic tephra hazard: A methodology for quantitative interdisciplinary collaboration

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Modern societies rely on services such as power, water, transport networks and manufacturing. Infrastructure may be sited to minimise exposure to natural hazards but not all can be avoided. The probability of long-range transport of a volcanic plume to a siteis comparable to other external hazards that must be considered to meet regulations. Recent advances in numerical models of plume dispersion and stochastic modelling provide a formalized and transparent approach to probabilistic assessment of hazard distribution. To understand the risks to critical infrastructure far from volcanic sources, it is necessary to quantify their vulnerability to different hazard stressors. However, infrastructure assets (e.g. plants and operational facilities) are typically complex systems in themselves, with interdependent components that may differ in susceptibility to hazard impact. Usually, such complexity means that risk either cannot be estimated formally or that unsatisfactory simplifying assumptions are prerequisite to building a tractable risk model.

We present a new methodology for estimating risk by bridging expertise of physical hazard modellers and infrastructure engineers.We use a joint expert judgment approach to determine hazard model inputs and constrain associated uncertainties. Model outputs are chosen on the basis of engineering or operational concerns. The procedure facilitates an interface between physical scientists, with expertise in volcanic hazards, and infrastructure engineers, with insight into vulnerability to hazards. The result is a joined-up approach to estimating risk from low-probability hazards to critical infrastructure. We describe our methodology and show results for vulnerability to volcanic hazards at a major UK infrastructure facility.

IAVCEI (Volcanology, Geochemistry)

VS22a - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-3815

Preparing for the next local volcanic eruption in Auckland, New Zealand

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The Determining Volcanic Risk in Auckland (DEVORA) research program is a multi-agency, multi-disciplinary effort with a mandate to investigate the Auckland Volcanic Field (AVF), a (mostly) monogenetic volcanic field which spatially coincides with Auckland, New Zealand's most populous city. DEVORA has three main themes: the geological context of the AVF, its volcanic hazards, and the risk these pose to Auckland. Here we discuss how volcanic hazard and risk research, specific to Auckland and also more generically, is used to evaluate volcanic risk for Auckland, and how DEVORA findings are used by emergency managers and policy and decision makers to prepare the city for a future volcanic eruption. Following a detailed hazard evaluation, the DEVORA team is developing and populating a suite of volcanic fragility functions quantifying damage, loss of functionality, and clean up from basaltic eruptions expected in Auckland. These, along with hazard intensity maps for the volcanic edifice (tuff rings and scoria cones), pyroclastic surges, lava flows, tephra fall, and ballistics, will be input into RiskScape, New Zealand's multi-hazard risk assessment tool. In the first instance, only impacts from specific eruption scenarios will be evaluated; probabilistic risk assessment will be developed in the future. DEVORA research findings are being used to inform the revised AVF Contingency Plan, a local government document which guides decision making in the case of volcanic unrest and potential eruptions. In the next few years, DEVORA will continue to ensure fundamental science forms the basis for key decision-making in the preparation for and response to a future AVF eruption.

IAVCEI (Volcanology, Geochemistry)

VS22a - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-4539

Notes from a small island: response to the 2014 Hunga Tonga Hunga Ha'apai eruption, Tonga and challenges for aviation

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We present the impact of the Hunga Tonga Hunga Ha'apai eruption in Tonga between December 2014 and January 2015. While the eruption started below sea level in December 2014, it quickly breached the ocean's surface and formed a small island. Sustained phreatomagmatic activity during several weeks caused substantial disruptions to the aviation in the SW Pacific. A key challenge during the response to eruptions in such small island nations is to assess and provide to the regional VAAC quality information and observation about plume height and ash content. We present how these challenges were overcome during the reponse to this eruption and what lessons can be gained for small island nations susceptible to volcanic hazards.

IAVCEI (Volcanology, Geochemistry)

VS22a - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-4824

Potential volcanic ash impacts on St Vincent, West Indies: Scenario planning

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Soufrière St. Vincent is the youngest and northernmost volcano on St. Vincent island in the West Indies, and has produced frequent explosive eruptions, most recently in 1718, 1812, 1902, and 1979. Preparing for a future explosive eruption from Soufrière requires a number of hazards to be considered but, as on the neighbouring island of Montserrat, volcanic ash is expected to have significant and repeated impact for livelihoods and daily life. Assessment of the ash hazard and the likely impacts will therefore provide information that is important for emergency planning. As part of the STREVA project, an interdisciplinary workshop was held on the island of St Vincent in March 2015 to tackle this. A key goal of the workshop was to develop a strategy for producing high-resolution hazard outputs that are useful for planning, and to investigate to what extent the available evidence base for impacts could inform associated future impact scenarios. The long-term aim is to provide a detailed suite of likely hazard and impact scenarios that can be used to inform preparedness and mitigation efforts. Here we will report on our preliminary scientific findings from the workshop, highlighting challenges and knowledge gaps that affect scenario planning for volcanic ash and its associated impacts.

IAVCEI (Volcanology, Geochemistry)

VS22b - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-3845

Volcanic hazard assessment support system and Asia-Pacific region earthquake and volcanic hazard mapping project

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The Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER) project aims to formulate strategies to reduce the risks caused by earthquakes, tsunamis and volcanic eruptions worldwide. The G-EVER volcano hazard assessment WG is developing a useful system for volcanic eruption prediction, risk assessment, and evacuation strategy at various volcanic eruption stages. The G-EVER volcanic Hazard assessment support system (http://volcano.g-ever1.org/) is based on volcanic eruption history datasets, volcanic eruption database and numerical simulations. The G-EVER volcanic hazard assessment support system that can run energy cone and Titan2D simulations at any volcano in the world is available since 2013. The system using ASTER Global DEM in the world and 10m DEM dataset is used in Japan region. Links to major volcanic databases, such as Smithsonian GVP are available from each volcano on the map. Almost all volcanoes in the world can be evaluated using this volcanic hazard assessment support system.
The Asia-Pacific region earthquake and volcanic hazard mapping project aims to make an advanced online information system that provides past and recent earthquake and volcanic eruption information and risk assessment tools for earthquake and volcanic eruption hazards. The hazard mapping system (http://ccop-geoinfo.org/G-EVER/) provides useful information about earthquake and volcanic hazards in an interactive and user-friendly interface. Past and recent large-scale earthquakes and volcanic eruptions, tsunami inundation areas, active faults distributions, and major landslides are shown on the map. This project will be implemented with the cooperation of major research institutes and organizations in the Asia-Pacific region.

IAVCEI (Volcanology, Geochemistry)

VS22b - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-4127

Colima volcano activity in the period 1999-2014 and updating volcanic hazard map

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The Colima volcano is an andesitic stratovolcano, located in western Mexico (19° 30.696´ N, 103° 37.026´W and 4000 masl) began its current eruptive process in February 10, 1999. The volcano showed intense activity during 2005-2007 but this did not exceed VEI 3. On 16 August 2014 the volcano increases its effusive stage with the formation of a new dome which forms 4 lava flows. November 21, an explosion that reached 3200 m above the top of the volcano occurs, forming pyroclastic flows by W, S and SE slopes, reaching 3.24 km, the ash cloud spread N and NE to 84 km away from volcano. In January seismicity at Colima volcano indicated 121 events explosive of low magnitude which have reached heights between 200 and 2500 m above the dome, with continuing emissions of water vapor and gas, including ash some times; Incandescence and falling of the lava blocks from the dome are constant and visible at night.
This activity is similar to what was presented in the years between 1890 and 1905, which was prior to the Plinian eruption of January 20, 1913. The seismic energy released by the explosive events of November 2014 and January 2015 were two orders of magnitude less than the 2005 explosions.
During the twentieth century and so far this century, the vulnerability has gradually changed due to the expansion of the agricultural frontier on the E and SE slopes of the volcano the population in the risk zone is 17,500 inhabitants, with an annual growth rate of 1.6%, the region also shows an increase in the risk of economic activities, because its constant development supported by the construction of roads, pipelines and electrical infrastructure. These elements were used to update the risk map of Colima volcano, built in GIS and scales of 1: 25,000 and 5000 for urban areas.

IAVCEI (Volcanology, Geochemistry)

VS22b - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-4925

Numerical study of clast transport of 2014 ontake eruption, Japan

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We present an estimate of the ejection conditions and energy of clasts at the deposition points during the 2014 phreatic eruption of Ontake volcano, Japan. When Ontake volcano erupted around noon on September 27, a fine day of the high season of mountaineering, many people were up around the summit of the mountain. 57 people died and 6 people are still missing. 55 out of 57 people died from an injury of clast hitting. In our study, we searched ejection conditions and energy of clasts at the deposition point based on the distributions of clasts and numerical simulations. Multi-particle numerical model including particle-particle collision are used for simulating clast transport. We tried three types of transport conditions. First is a purely ballistic transport, second is a transport with plume, and third is a transport with blast. By considering results of simulations and video images of the eruption together, we found that the third condition is a reasonable estimate. We would like to discuss about the impact energy of clasts and a possible measure for its damage. This study contribute to the establish a standard to prepare for a damage by a clast release from the vent, for example, constructing shelters around vent or putting a restricted area when the seismicity increases.

IAVCEI (Volcanology, Geochemistry)

VS22b - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-5153

Gaining acceptance of hazard map by adding community knowledge: Canton Buenos Aires case study, at Santa Ana (Ilamatepec) Volcano

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Santa Ana (Ilamatepec) Volcano is an active composite volcano located in the Apaneca Volcanic Field located in western part of El Salvador, Central America. The volcano is surrounded by rural communities in its proximal areas and the second (Santa Ana, 13 km) and fourth (Sonsosante, 15 km) largest cities of the country. On October 1st, 2005, the volcano erupted after months of increased activity. It generated an estimated 10 km high plume. Ash was deposited to the western and north-western part of the country. Small pyroclastic density currents and major lahars were observed in the eastern part of the volcano. These processes killed at least 9 people that were working the fields at the time of the events. Following the eruption, volcanic mitigation projects were conducted in the region, but the communities had little or no in put on them. This project aims to create a new set of probabilistic and scenario based volcanic hazard map for the Canton Buanos Aires on the northern part of the volcano by incorporating the community's knowledge from prior events. The work with the community consisted in several meetings where the community members recounted past events like the 2001 earthquake of magnitude 7.7, the 2005 eruption, and several debris flows and lahars which destroyed roads, and left them incommunicated for several days during 2010 and 2011. They were asked to map the outcomes of those events using either a hillshade relief map with a topographic map of the area overlay on top of it, a Google Earth image, and a blank paper poster size. These maps have been used to identify hazard areas, the formation of new Barrancas and Quebradas, and for model validation. These maps were presented to the communities and they accepted, including other maps.

IAVCEI (Volcanology, Geochemistry)

VS22b - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-5169

Arriving at a new generation of volcanic hazard maps: The collaboration between VHub and el Servicio Geologico Colombiano

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VHub is a multidisciplinary and multinational group created to enhance and facilitate collaborative volcano research and risk mitigation. Since 2013, several VHub membershave traveled to Colombia for working meetings where members of the Servicio Geológico Colombiano (SGC) were trained and advised on the capabilities of VHub online tools. A group of SGC members is currently working on the elaboration and update of volcanic hazard maps by using models, geological knowledge and field data, to develop hazards scenarios and maps. The VHub tools used were Titan2D, Wind Reanalysis, Tephra2, Energy Cone, Eject 1.4, and Lava_PL. During the first meeting, VHub was introduced to the group, and basic hands-on examples were run and taught for most models. This laid the foundation for subsequent meetings that are ongoing. In the following meetings, SGC members started to present results of their modeling to VHub members who then provided feedback and suggestions on how to improve or what to do next. Field trips to some volcanoes were made, in order to discuss and learn from the deposits, improving modeling and selection of parameter values. This collaboration is application-driven in that it seeks to gather and consolidate knowledge that can enable better understanding of volcanic hazards that will advance the reliability of numerical modeling, and subsequently improve our ability to perform volcanic hazard mapping and assessments.

IAVCEI (Volcanology, Geochemistry)

VS22b - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

IUGG-5600

VOLCANBOX: a new software platform to minimise volcanic risk

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One of the most important tasks of modern volcanology is to minimise the risk of volcanic eruptions. Their impact can affect considerably human life and the environment. It is clear that a volcanic eruption, although it can be at the same time fascinating and impressive, presents similar or even more problems than more frequent natural events. It is possible to live near a volcanic area if we consider the benefits that volcanoes can gives us, but it is important to be aware of the existing threat and to know how to minimise the risk. Understanding the potential evolution of a volcanic crisis is crucial for designing effective mitigation strategies. In this work we present an integrated software platform specially designed to assess and manage volcanic risk, VOLCANBOX. This new platform contains user-friendly free e-tools able to be used with personal computers specifically addressed to long- and short-term hazard assessment, vulnerability analysis, decision-making, and volcanic risk management. E-tools are developed in QGIS, the more widely used free open source Geographic Information System, and are designed to be implemented before an emergency, to identify optimum mitigating actions and how these may change as new information is obtained. Furthermore, e-tools contained in the VOLCANBOX allow to identify the most appropriate probabilistic and statistical techniques for volcanological data analysis and treatment in the context of quantitative hazard and risk assessment. Forecasting volcanic eruptions and predicting the most probable scenarios are subjected to a high degree of uncertainty, which needs to be quantified and clearly explained when transmitting scientific information to decision makers.

IAVCEI (Volcanology, Geochemistry)

VS22p - VS22 Volcanic Risk - Bridging Hazard Assessment, Modeling Volcanic Processes, and Society

VS22p-585

Convective thermal influence of cold lithic clasts on hot gas flow in pyroclastic currents and insights into the risk

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Explosive volcanic eruptions can eject lithic clasts of different origin, besides juvenile particles, crystals and gases, forming a multiphase and multicomponent mixture (pyroclastic flow). The lithic counterpart derives from erosion of the volcanic conduit and vent, or derives from the country rocks in deep explosions. Juvenile particles, crystals and gases are hotter than lithic clasts, then thermal exchanges occur after ejection between the lithic and all other components, through energy variations by thermal conduction and convection. What is not so understood, among other phenomena, is the thermal influence that accidental lithic clasts may have on pyroclastic flow, in terms of cooling of the gas through interphase energy exchanges. Such exchanges act on gas flow temperature, as well as reflect into pyroclastic deposits. In this contribution, new results of the thermal effect of lithic clasts in pyroclastic flow are presented. The geometrical condition is that of high sedimentation and flow interaction with a building, which physically is a risk scenario by pressure and temperature. The scenario for such numerical analysis depicts flow-building interaction, in which both high sedimentation and forced convection occur. This is of particular interest in the current volcanological literature. By the present study integrating concepts from combustion sciences, and isolating the abovementioned thermal effect on volcanic (dusty) gas, some guidelines for urban planners and civil engineers are proposed, to reduce the risk of hot gas on any values exposed in stagnation points during flow-building interaction, while or immediately after eventual evacuation.

IAVCEI (Volcanology, Geochemistry)

VS23a - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-1258

Viscosity measurements of crystallizing andesite from Tungurahua volcano (Ecuador)

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Viscosity has been determined during isothermal crystallization of an andesite from Tungurahua volcano (Ecuador). Viscosity was continuously recorded using the concentric cylinder method and employing a Pt-sheathed alumina spindle at 1 bar and from 1400 ºC to sub-liquidus temperatures to track rheological changes during crystallization. The disposable spindle was not extracted from the sample but rather left in the sample during quenching thus preserving an undisturbed textural configuration of the crystals. The inspection of products quenched during the crystallization process reveals evidence for heterogeneous crystal nucleation at the spindle and near crucible wall, as well as crystal alignment in the flow field. At the end of the crystallization, defined when viscosity is constant, plagioclase is homogeneously distributed throughout the crucible with the single exception of experiment performed at the lowest temperature. Under the stirring conditions of these viscosity determinations the crystallization kinetics appear to be strongly affected. A TTT (Temperature-Time-Transformation) diagram illustrating the crystallization “nose” for this andesite under stirring conditions and at ambient pressure has been constructed. We further note that at a given crystal content and distribution, the high aspect ratio of the acicular plagioclase yields a shear-thinning rheology at crystal contents as low as 13 vol.%, and that the relative viscosity is higher than predicted from existing viscosity models. These viscosity experiments hold the potential for delivering insights into the relative influences of the cooling path, undercooling and deformation on crystallization kinetics and resultant crystal morphologies, as well as their impact on magmatic viscosity.

IAVCEI (Volcanology, Geochemistry)

VS23a - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-2987

Effects of magma rheology changes and mechanical interactions with host rocks during magma ascent in volcanic conduits

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The fluid dynamics of magma flowing in a volcanic conduit are strongly influenced by the rheological changes due to microphysical processes such as vesiculation, crystallization, and local temperature variations. During ascent, magma can undergo a complex history of crystallization. Increase in crystallinity can lead to a strong increase in magma viscosity dramatically affecting the eruptive style of a volcano. Because of the strong coupling between viscosity and temperature, magma dynamics are also drastically controlled by thermal effects due to heat generation by viscous dissipation and loss to the walls by conduction. A heat-loss-dominated regime, an intermediate regime, and a viscous-heating-dominated regime can be identified. Temperature layering due to heat loss by conduction can lead to local crystallization and magma solidification whereas viscous dissipation can be responsible for crystal resorption and remelting of wall-rocks. On the other hand, conduit geometry and the coupling between magma pressure, flow, and conduit wall deformation have major controls on the eruptions dynamics. Comparison of simple 1D models of explosive flows in cylindrical conduits and in dykes shows that in the latter case a marked difference between the lithostatic and magma pressures at the fragmentation level can lead to abrupt deformations of the dyke width creating a constriction that in some cases may promote wall-rock failure or even close the dyke stopping the eruption. Flows through a dyke connected to a near-surface cylinder exhibit stabilized explosive flows and have flow rates much higher than a system with the same cross-section area as a simple dyke or cylinder. I will give an overview of these nonlinear processes and challenges they pose to the volcanology community.

IAVCEI (Volcanology, Geochemistry)

VS23a - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-3104

Rheology of bubble- and crystal-bearing magma: New analogue experimental data and an effective-medium model

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Magma is a multiphase suspension: a complex mixture of a viscous silicate melt, a solid phase (crystals), and a gas phase (bubbles). The degree of interaction between bubbles and crystals, and the relative proportions of these phases, exert a major control on the bulk flow behaviour of the magma or lava. Characterizing, modelling, and predicting the flow of such a suspension requires a constitutive rheological model, encapsulating the viscosity of the suspension as a function of the properties of the suspending liquid and the volume fraction and properties of the suspended phase(s).

In this study, we present new experimental data on the rheology of a suspension of bubbles and particles in a Newtonian liquid, and develop a model for three-phase suspensions undergoing steady flow. We adopt an ‘effective-medium’ approach in which the bubbly liquid is treated as a continuous medium which suspends the particles. The resulting three-phase model combines separate two-phase models for bubble suspension rheology and particle suspension rheology. The model is validated against the new experimental data, collected in the low bubble capillary number regime. Good agreement is found across the experimental range of particle volume fraction (0-0.5) and bubble volume fraction (0-0.3).

IAVCEI (Volcanology, Geochemistry)

VS23a - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-3155

Mobilizing magma mushes to produce the largest volcanic eruptions

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Many of the largest volcanic eruptions involve magma that is very crystal-rich, such that it would be expected to be rheologically ‘locked’ in the magma chamber, and therefore un-eruptible. As a magma cools, it crystallizes, and once the suspended crystal fraction reaches a critical limit – the maximum packing fraction – the crystals form an interconnected framework, and the magma becomes locked. It is thought that many magma chambers spend a significant proportion of their existence as a locked crystal mush. Existing models for mobilizing a locked magma focus on processes, such as heating, which reduce the viscosity of the melt component of the magma, but do not adequately explain how the crystal network is unlocked. We propose that the formation and growth of exsolved volatile bubbles throughout the magma, for example through ‘second boiling’, provides a highly effective mechanism for unlocking the crystal mush, and for increasing its mobility as the bubbles grow.

Using analogue suspensions, we find that the growth of bubbles alone is sufficient to mobilize an initially locked particle suspension, and that further bubble-growth dramatically reduces their viscosity. We demonstrate the application of our physical model to a natural situation using the well-known Fish Canyon tuff as a case study. We demonstrate that second boiling can easily provide sufficient bubble volume to mobilize the parental magma; indeed, the transition from static to mobile for the Fish Canyon magma occurs with the addition of only 1.3 vol.% bubbles, requiring the exsolution of only a small fraction of the volatile content of the melt.

IAVCEI (Volcanology, Geochemistry)

VS23a - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-4071

Taking the magma chamber to the IMAX: Quantifying dynamic rheology and strain localisation using high-speed x-ray tomography

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Magmatic cargoes of crystals and bubbles are critical controls on magma mobility and rheology, but vary in time and space, making local and bulk behavior strongly heterogeneous. Tracking their evolution and interactions during deformation is a critical challenge in volcanology, as these processes control many phenomena, including melt-crystal segregation, degassing, strain localization, and fragmentation. The only methodology available to track these processes in real time, at the appropriate scales is x-ray tomography, which allows rapid acquisition of sequential 3D images. We utilize in situ tomographic methods to perform deformation experiments on synthesized three phase systems at magmatic temperatures: observing the microstructural evolution of a synthesized anhydrous basaltic melt seeded with a variable concentration of non-reactive crystals and bubbles (30-70 volume %), at 800-1000C at deformation rates of 0.25-5.00 microns/second. Each 3D image took ~3 seconds to acquire. We demonstrate how the real-time data can be used to trace the location and local distribution of each crystal and bubble within an experimental charge and present qualitative and quantitative analysis of the 5-15 minute deformation cycles. We track the local bubble, crystal and melt concentrations on a range of spatial scales, and calculate spatially heterogeneous and dynamic local viscosity. We will show how this real time 4D information can be used to quantify the dynamics of magma motion, discuss the implications of spatially and temporally variable rheological behaviors, and show how this novel technique can be integrated with other volcanology methods to improve our understanding of volcanic and magmatic processes.

IAVCEI (Volcanology, Geochemistry)

VS23b - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-0343

Integrating geomechanical rock properties to monitor catastrophic collapse at an active volcano

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Since the sector collapse of Mount St. Helens in May of 1980, the structural failure of volcanoes has been widely recognized as a pervasive, and potentially devastating, phenomenon. One mitigation strategy for such an event is to monitor preceding surface deformation. To accurately interpret and model this geodetic data, reliable estimates of rock mechanical properties are crucial. Often, these properties are simplified or estimated because of a lack of data. One such case where rock properties are imperative for accurately analyzing hazard scenarios is that of Pacaya Volcano in Guatemala. In May of 2010 during a VEI-3 eruption, Pacaya's SW flank slid 3m. This is the largest measured slope instability witnessed in a single event at a volcano that did not result in a catastrophic landslide. This is particularly concerning given the persistent activity and the history of sector collapse at this volcano. This study focuses on the challenge of characterizing volcanic materials for the numerical analysis of such events. To do this, we evaluated rock samples from Pacaya through a variety of laboratory experiments, including room temperature, high temperature, and cyclically-loaded uniaxial compressive strength tests on unaltered and thermally-treated rock samples. High velocity rotary shear tests were also used to better constrain frictional properties to understand landslide initiation and runout. With geomechanical data that more accurately represents such dynamic systems, we can better understand and monitor large-scale deformation at volcanoes.

IAVCEI (Volcanology, Geochemistry)

VS23b - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-2487

Experimental permeability at volcanic temperatures and pressures: an insight into silicic magma degassing

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Experimentally determined permeability observations have provided the basis for numerous theories of magmatic degassing. Recent enhancements to the High Temperature Triaxial Deformation Cell (HTTDC) at UCL have enabled us to make permeability measurements on 25mm x 75mm core samples at both elevated temperature and hydrostatic pressure (Gaunt et al, 2013). Specifically, we present the results of several suites of permeability data on samples of dome dacite from the 2004-08 eruption of Mount St Helens, measured under an effective pressure of 5 MPa (confining pressure of 10 MPa and pore fluid pressure of 5 MPa) and temperatures up to 900°C. Most recently, the capabilities of the HTTDC apparatus have been further extended to enable permeability measurements to be made during triaxial deformation of test samples under similar temperature and pressure conditions. Initial results from this entirely new methodology will also be presented.

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

Castro et al 2014. EPSL **405** 52-61
Gaunt et al 2013. IAVCEI Sci. Con. (1W_2K-P6)

IAVCEI (Volcanology, Geochemistry)

VS23b - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-4072

Going down the tubes: Complex kinematic indicators in tube pumices revealed by X-ray tomography

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Understanding the physico-chemical conditions and mechanisms that operate during explosive volcanism is essential if we are to forecast and mitigate volcanic behavior. Rhyolitic pumices reflect highly vesiculated magma, and the bubble geometries provide kinematic indicators that indicate the state of stress and the late stage deformation history immediately prior to fragmentation. Here we present a suite of high resolution (1-15µm/voxel) 3D x-ray tomography data from tube pumice samples, and show that while simple shear ($\sigma 1$) is dominant, the samples have experienced complex and spatially variable deformation during ascent. We show how it is possible to piece together this complex deformation history and strain using features that would not be preserved during traditional sample preparation, and would not be visible using routine 2D image analysis techniques. Qualitative visualization and quantitative geometric analysis of each individual bubble (up to 400,000 per 3D volume) in the high resolution images reveals complex internal morphologies and bubble interactions, and identifies multiple stages of brittle and ductile deformation. All samples contain tubes with strong deformation perpendicular to the tube axis ($\sigma 2$, $\sigma 3$) and populations of smaller bubbles which show extremely variable geometries. The data indicate a complex and poly-phase response to a changing stress field, and significant strain localization, even in samples that do not preserve late stage “kink” deformation. We quantify relationships between bubble size, geometry, elongation and the magnitude and orientation of deformation within a variable stress field. We discuss these findings in terms of the full life cycle of bubble formation, growth, coalescence, secondary nucleation and collapse.

IAVCEI (Volcanology, Geochemistry)

VS23b - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-4400

Magma flow dynamics and coupled host-rock deformation in a developing volcanic plumbing system

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The dynamics of magma ascent in the crust are important in the development of volcanic plumbing systems; from the establishment of magma chambers at depth, to the initiation of conduits to facilitate flow to the surface. We present results from a series of analogue experiments that use solidified gelatine injected by water to study dyke and sill formation. Particle Image Velocimetry (PIV) and Digital Image Correlation (DIC) are used to characterise the dynamics of fluid flow within the dyke or sill and contemporaneous deformation of the host gelatine. The gelatine is seeded with neutrally buoyant fluorescent particles during preparation. Seeded water is then injected into the gelatine from below at a constant flux or head pressure. A dyke propagates through the gelatine, either stalling during ascent to forming a sill along a weak interface or going on to erupt at the surface. A vertical high-powered laser sheet positioned along the centre of the tank is triggered to illuminate the seeding particles with short intense pulses, and two Dantec CCD cameras record images. Vector fields of fluid flow and strain within the gelatine host is calculated by cross-correlation between successive images at a defined time interval. Prior to eruption, dyke propagation is characterised by rapid centralised and upwards fluid flow with downflow at the intrusion margin. Deformation is focused at a small head region of the dyke, with the tail remaining relatively static. Upon eruption, rapid centralised fluid evacuation occurs with contemporaneous contraction of the dyke and relaxation of the elastic host material.

IAVCEI (Volcanology, Geochemistry)

VS23b - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

IUGG-5527

How constant is mass flux at volcanic vents?

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Most of the commonly used models to simulate volcanic eruptions, i.e. the input of mixtures of ash and gases into the atmosphere assume a steady state or a stationary mass flux. Here we review Doppler radar retrieved tephra velocities from 5 different volcanoes (Mt. Erebus, Yasur volcano, Stromboli volcano, Santaguito and Volcan de Colima) spanning a wide range of compositions and typical eruptive activity. Mt. Erebus –being the simplest system- provided a direct view onto the magma surface and reveals mainly 2 types of eruptions: (I) a straight acceleration of the magma surface, and (II) two acceleration phases (Gerst et al., 2013, doi:10.1002/jgrb.50234). At Yasur and at Stromboli volcano eruptions occur in pulses and vary between ash rich and ash free explosions. Pulse frequencies are dependent on the eruptive regime. The intriguing observation now is that in case of a direct view onto the magma surface we do not observe pulses, while when the source of the eruption surface is not visible, and gas and tephra is transported an unknown length through a conduit, the eruptive regime is pulsed. Sources for the origin of the pulses will be discussed. In higher silicic systems we also observe pulsed behavior directly at the vent (Santiaguito), as well as slightly above the vent (Colima). Pulse frequency are about 0.3 Hz (Scharff et al., 2014, doi:10.1093/gji/ggu069) but in this case the source of the pulsation must be somewhere inside the conduit below the eruption surface. Sources for this pulsation will also be discussed. Regardless of the source location of the pulses, it is clear that mass flux at volcanic vents is by no means constant and must be taken into account in any model for eruption dynamics to properly predict the evolution of eruptive processes.

IAVCEI (Volcanology, Geochemistry)

VS23p - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

VS23p-586

Physical characteristics of conduit plug rocks during vulcanian eruptions at Cotopaxi and Tungurahua volcanoes, Ecuador.

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Vulcanian eruptions are characterized by violent short-lived explosions that usually result from sudden decompression of an over-pressurized magmatic column. The mechanism for generating such violent explosions is considered to be the accumulation of gas pressure below a dense crystallized plug of magma. Tungurahua volcano, Ecuador frequently experiences large vulcanian-style events, characterized by impulsive seismic events and large acoustic energies. Equally, historical eruptions of Cotopaxi Volcano are thought to have been largely vulcanian in nature. These sudden and highly hazardous explosions pose a significant threat to local population; here we present new mechanical data to enhance our models of conduit sealing mechanisms and gas pressure build up to improve the mitigation of hazards from future eruptions at these volcanoes.

The key to gas loss or gas pressurization is permeability. In dense, degassed and often highly-crystalline lavas, permeability is directly related to fracture density. A microstructural description of the permeable network in these plug rocks using SEM images reveals a relatively isotropic micro-fracture network. Coupling of the fracture density to theoretical permeability analysis indicates the control of the fracture network on outgassing. Permeability tests were also performed to corroborate this view and assess the samples' potential for gas release and storage. Complementary thermo-mechanical analyses were used to constrain microstructural changes that likely occur due to the repeated intrusion of hot magma in the shallow conduit. Results from this integrative study suggest that despite being permeable, these micro-fractured rocks cannot efficiently outgas a magmatic column when they are compressed and heated by a new batch of magma.

IAVCEI (Volcanology, Geochemistry)

VS23p - VS23 Rheological and Mechanical Influences on Volcanic Eruptions

VS23p-587

Brittle-ductile magma deformation and explosive-effusive behaviour: Insight from tuffisite veins and water concentrations in Icelandic rhyolitic dykes

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We have completed textural analysis and multi-scale water concentration mapping within shallow rhyolitic dykes[1] at Torfajökull, Iceland. This provides insight into the influence of brittle-ductile deformation on degassing and explosive-effusive behaviour during the waning stages of an explosive-effusive >1km^3 silicic eruption.

The 10 m wide dykes are now predominantly filled with vesicle-free obsidian that houses anastomosing >10 m long tuffisite vein networks. Textural evidence is presented for interactions between bubbles and tuffisite veins (ash-filled fractures) and the collapse of bubbly magma to form dense obsidian. In addition, dissolved magmatic H_2O systematically decreases with increasing elevation, over 35 m, demonstrating that H_2O escaped from dyke magma during equilibrium degassing. Our findings illustrate that ultimately dense lava may ascend as a permeable foam and that sustained gas loss may occur through connected bubble networks, whilst brittle failure of the bubbly portions of the magma may facilitate explosive activity synchronous with lava effusion[1]. Bubbles appear to enable a brittle response to gas overpressure, with newly-formed fractures evolving via quarrying of the bubbly magma into intrusive pyroclastic bodies that vent jets of ash and gas. Subsequent blocking and welding of the tuffisite veins occurs, and the process is repeated. Ultimately, bubble networks collapse. Bubble collapse migrates from the dyke margins to the centre with time, as the zone of shear-induced bubble coalescence migrates during progressive magma accretion.

1. Tuffen H & Dingwell DB (2005) Fault textures in volcanic conduits. Bull Volc 67, 370–387
2. Castro JM et al. (2014) Explosive origin of silicic lava. EPSL **405**, 52-61.

IAVCEI (Volcanology, Geochemistry)

VS24a - VS24 Volcano Geology

IUGG-1685

Integrating the volcanic facies concept with the lithostratigraphic approach to mapping ancient volcanic areas. Examples from the East Carpathians, Romania.

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Facies models of stratovolcanoes, were devised for individual edifices by considering a central source of eruptive material distributed in an axi-symmetric centrifugal pattern. Facies merging, juxtaposition and superposition in various combinations, associated with facies-unrelated (e.g. debris avalanche) deposits were identified in the case of closely spaced Miocene composite volcanoes from the East Carpathians, Romania. While the proximal cone facies of composite volcanoes in the Calimani, Gurghiu and Harghita Mts. (CGH) are lava-dominated and form recognisable topographic features at the outer slopes of individual edifices, their medial facies mostly composed of volcaniclastic deposits are interfering to each other at their peripheries. Petrographic, geochemical and geochronologic investigation of the volcanic rock assemblages is diagnostic for the volcanic sources to which a particular volcaniclastic formation belongs. Adjoining debris avalanche deposits, found tens of km away from their source edifices could be distinguished from each other based on clast studies. Since volcanism migrated progressively in space and time along the CGH volcanic range, medial facies volcaniclastics, sometimes of the same type and of similar composition, belonging to different volcanoes are found in superposition to each other. One of the major findings of our recent studies at Miocene composite volcanoes in the East Carpathians is that their medial facies mainly composed of primary pyroclastics are volumetrically dominated on the western side by facies unrelated debris avalanche deposits and associated debris-flow deposits. The volcanic facies approach to volcano mapping, as an additional tool to the lithostratigraphic approach, can easily be applied to other type of volcanoes too.

IAVCEI (Volcanology, Geochemistry)

VS24a - VS24 Volcano Geology

IUGG-3752

Using GIS to investigate the 3-dimensional architecture and volcano-stratigraphy of the Deccan large igneous province.

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The Deccan large igneous province was erupted around 66 million years ago, coinciding with the end-Cretaceous mass extinction event. Many other large igneous provinces have been temporally linked to mass extinction events. The mechanism is thought to be global climate change caused by the huge, long lived eruptions, but quantifying the extents of these eruptions to test this hypothesis has proved extremely challenging.
GIS is an underused tool in the study of large igneous provinces. However, it is the perfect tool with which to integrate the large amount of research that has been carried out on the Deccan, covering aspects such as: field mapping, volcano-stratigraphy, geochronology, chemostratigraphy, geochemistry, palaeomagnetics, magnetotellurics, hydrogeology and seismics, amongst others. Integration of these published data, and field data collected by myself, into a GIS will give us the opportunity to interrogate these data in a 3-dimensional fashion and allow us to maximise their potential to constrain the volumes and extents of individual and groups of eruptions, the geochemically-defined formations, and the province as a whole. The study will, also provide combined database unprecedented in the study of large igneous provinces. This presentation will showcase examples of the GIS approach to investigating large igneous provinces.

IAVCEI (Volcanology, Geochemistry)

VS24a - VS24 Volcano Geology

IUGG-4518

Are continental flood basalt (CFB) provinces volcanoes?

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Although the term ‘volcano’ may be loosely defined, there are a number of facets that a volcano should possess. 1) Formed over a fixed (narrow?) time period; this may be up to several millions years for caldera complexes (CC) or systems. 2) The vents are focused within a restricted region or area; this may be up to several thousand square kilometers for CCs. 3) The magmas emitted cover a range of genetically related types. 4) An edifice is constructed, although in the case of CCs, this may be extremely low-profile and have a depression at the top.

It is contended that CFB provinces fit all of these facets:

1) Most provinces form over several million years, with one or two short pulses << 1 Ma long yielding most of the volumetric output.

2) While the vents of most provinces are not known, those in the CRB and Deccan (based on dike distribution) are restricted in one dimension while long in another (dike-swarms).

3) Most provinces are volumetrically dominated by tholeiitic basalt with a small range of genetically-related basaltic lavas; some provinces also erupt silicic magmas due to crustal melting.

4) A super-low-profile edifice (or series of edifices) does develop but is sometimes masked by isostatic subsidence.

Therefore many CFB provinces should be considered as a volcano, or a volcanic system. If this is the case, CFB province are Earth’s largest sub-aerial volcanoes attaining areal dimensions of hundreds of thousands to millions of km^2 and volumes of millions of km^3.

IAVCEI (Volcanology, Geochemistry)

VS24a - VS24 Volcano Geology

IUGG-4882

A multi-discliplinary approach to understanding volcanism and geodynamic evolution of the Miocene Cabo de Gata volcanic field, southeast Spain

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The Miocene Cabo de Gata (CdG) volcanic zone covers ~40 km^2 in southeastern Spain. A wide variety of volcanic features together indicate eruption in shallow-subaqueous to emergent conditions. Our studies have encompassed physical volcanology, geochronology, geochemistry, and geophysics in order to provide a four-dimensional view of a minimum of 5 Myr of volcanic activity and the geodynamic controls on magmatism.

Well-preserved facies indicate a subaqueous depositional environment. Dome volcanism predominates; in general, domes spilled passively onto the sea floor, with related feeder dikes and sills common. Facies comprise massive, columnar-jointed and locally flow-banded lava that commonly grades into hyaloclastite that in turn progresses outward to resedimented breccia. Debris-avalanche deposits represent collapse of these domes; in general avalanches did not travel long distances and locally contain megaclasts. Pumice deposits represent both vesiculated carapace and reworked explosive deposits, although the latter are more rare.

The oldest rocks in the CdG zone are to the SW and are likely somewhat older than Serravillian (~13.5 Ma), based on our oldest $^{40}Ar/^{39}Ar$ dates; the youngest, to the NE, are Tortonian (~8.5 Ma) although the majority of volcanism had ended by 10.5 Ma. Shoshonitic to high-K calc-alkaline rocks dominate the early stages of volcanic activity, whilst calc-alkaline basaltic andesite to rhyolite prevail in the late stages. Whole rock and trace element geochemistry along with Sr and Nd isotopes indicate that each pulse of magma differentiation started from a different parent. These parental magmas were produced by partial melting of a heterogeneous mantle wedge metasomatized by recycled subducted sediments.

IAVCEI (Volcanology, Geochemistry)

VS24a - VS24 Volcano Geology

IUGG-5436

Geological map of Nevado de Toluca Volcano (Mexico - 1:50,000 scale)

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We present the geological map of the Nevado de Toluca at 1:50,000 scale based on stratigraphic units (synthemic and lithostratigraphic units). The Nevado de Toluca is a Pliocene-Holocene volcano, located 80 km WSW from Mexico City, an area with more than 25 million inhabitants. We carried out the fieldwork at 1:25,000 scale, using litostratigraphic units and, later, grouping them in synthemic units according to the guidelines suggested by ISSC. The stratigraphic reconstruction allows us to outline the complex evolution of Nevado de Toluca, where six synthems have been recognised. Each synthem is bounded by an angular unconformity, often related to an erosional phase or a temporal hiatus, often associated to a change in the eruptive style.

The volcanic succession starts with Jabali synthem, composed of andesitic domes associated to lava flows dated at 2.6 Ma. The following synthem (Las Lagrimas Synthem) is constituted of a thick and widespread block and ash flow deposit, while Raton Synthem is made of thick dacitic lava flows. Putla Synthem is composed again of large andesitic lava domes associated to lava flows, but located in a distal area. Andesitic to dacitic lava domes, few of them associated to lava flows (Cuervos Synthem – 1.3-1.0 Ma) overlap the previous volcanic edifices. After a prolonged hiatus occurred between 1 and 0.1 Ma the volcanic activity, represented by Nevado Synthem, resumes with thick andesitic lava flows, followed by mainly pyroclastic deposits (pumice fall deposits interlayered with wide and thick pyroclastic flow successions, block and ash flow deposits, debris avalanche and debris flow deposits).

This geological map allows also to realize the first volcanic hazard zonation of the Nevado de Toluca and its surroundings (Capra et al. 2008).

IAVCEI (Volcanology, Geochemistry)

VS24a - VS24 Volcano Geology

IUGG-5473

Preliminary geologic map of the Acoculco caldera, Puebla, Eastern Mexico

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The Acoculco caldera is located in the eastern part of the Trans-Mexican Volcanic Belt within the State of Puebla. During the eighties, this caldera was widely studied by the National Power Company (Comisión Federal de Electricidad = CFE) who considered it as hot-dry reservoir with geothermal potential. In order to reassess this geothermal potential we began a systematic volcano-stratigraphic study of the caldera combined with geochemical, petrological, and isotopic studies. The caldera was described as a 12.6 km wide sub-circular structure of Pliocene-Pleistocene age for which 1.27-0.24 Ma K-Ar dates were published. Digital topography, shaded relief models, anaglyphs and SPOT imagery were used to prepare a preliminary map. The morphology of Acoculco presents hills with heights up to 100 m with low slopes dissected by subdendritic radial rectangular drainage. This drainage is generally offset by a normal-E-W fault pattern that have formed small lakes. These volcanic units have been checked in the field in more than 100 stratigraphic sections from which we have dated 25 rocks through ^{40}Ar-^{39}Ar and prepared them for different types of analyses (e.g. Sr-Nd-Pb isotopes, whole-rock, and mineral chemistry). With this information we have defined 45 volcanic units much of which have not been previously recognized in previous maps. The caldera is bounded by post-caldera lava domes with rhyodacitic composition, and scoria cones with basaltic composition. The interior of the caldera consists of rhyodacitic ignimbrite, basaltic andesite lava flows and dacitic to rhyolitic domes. We also identified hydrothermally altered areas inside the caldera located in dacitic domes and basaltic andesitic lavas where CFE based its exploration wells.

IAVCEI (Volcanology, Geochemistry)

VS24b - VS24 Volcano Geology

IUGG-0412

Statistical, geochemical and petrographic study of the debris avalanches from Sangay volcano, Ecuador

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Sangay is one of the most active volcano in Ecuador and in the world. The study of the debris avalanche deposits that are located in SE Ecuador in the Amazon Basin, indicates at least two avalanche events occurred. DAD-S1 is the older deposit (250-100 Ka as reported by Monzier et al., 1999) and DAD-S2 is the younger deposit (29 Ka, ^{14}C dating); these avalanches have a run-out of more than 60 km from the crater.

Statistical analysis of the 541 hummocks counted and the distribution of the morphology shows that the largest hummocks are located in the middle run-out of the area, between 40 and 50 km from Sangay volcano. This is probably because the avalanche impacted with a ridge of 500 m relief, located to the SE of the volcano. For this reason the flow was redirected around this zone of elevated topography, concentrating the largest hummocks at more than 40 km NE of Sangay's peak.

The deposits of the debris avalanche have a blocky, mixed and intermediate facies. The rocks have a composition between 54.26 and 62.43 SiO_2 wt%. The matrix is composed of pyroclastic material: 50% beige pumice, 40% free crystals, 10% lithics and exogenous (non-volcanic). The petrological and geochemical characteristics of the avalanche deposits suggests that their most probable source is from Sangay volcano.

The past characteristics of Sangay that led to the generation of such large avalanche deposits could have been similar to the current state of the volcano. The volcano is continually active and there is a thick accumulation of pyroclastic material on the volcano's flanks which have a slope of around 37° and more than 4000 m of relief above the surrounding area. Thus, there is a possibility that future activity of this volcano could include large debris avalanches.

IAVCEI (Volcanology, Geochemistry)

VS24b - VS24 Volcano Geology

IUGG-0906

"The Vicuña Pampa Volcanic Complex, Southern Central Andes"

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The Vicuña Pampa Volcanic Complex is located at the southeastern edge of the Altiplano-Puna Plateau (Central Andes). It is peculiar not only for its location, but also because of its composition, which varies from basaltic to dacitic. Previously it was interpreted as a collapse caldera because of its caldera-like morphology, although confirmed calderas of this composition are unknown in the Central Andes. No straightforward evidences to classify this volcanic structure are found. The features that favour its interpretation as a collapse caldera are its subcircular shape, a central depression and the shallow slopes of the outer deposits. On the other hand, features typical of a collapse caldera such as intra- and extra-caldera pyroclastic flow deposits, or ring faults are lacking. The walls of the depression are formed by a ca. 12 Ma sequence of basaltic to basaltic andesite, massive to poorly stratified matrix-supported monolithologic volcanic breccias up to 300 m thick, overlaid by at least two lava flows of trachybasaltic andesite to trachydacitic composition. The deposits within the depression are mostly covered by reworked material. Its eastern part is formed by igneous-metamorphic basement, whereas the central and western sectors show volcanic conduits and volcanic breccias, the latter probably related to hydromagmatic to purely magmatic activity of lava domes. In summary, although Vicuña Pampa has one of the most caldera-like shapes of the Central Andes, no deterministic features to definitely prove it are found. A preferred interpretation is an eroded shield-like volcano showing its roots within a central depression superposed with a renewed episode of volcanic activity limited to its SW portion.

IAVCEI (Volcanology, Geochemistry)

VS24b - VS24 Volcano Geology

IUGG-3176

Lithofacies and depositional processes in a Miocene pyroclastic sequence, Tokaj-Mountains, Carpathian-Pannonian region

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The petrographic and quantitative studies of the lithic rich pyroclastic units and facies provide useful tool for understanding the explosion dynamics and depositional processes on volcanic slopes. The Miocene ca 11,7 Ma old Abaújvár-Telkibánya ignimbrite representing the last pyroclastic accumulation event around Telkibánya Lava Dome Field in the Tokaj-Slanske Mountains (NE Carpathian volcanic arc). Grain size measurement techniques (sieve, image analysis) were applied to evaluate particle averages, spatial variations in sorting and relative proportion of the component to define the main lithofacies units. Lithofacies types: 1. Massive, poorly sorted non-welded lithics bearing (obsidian, rhyolite) lapilli tuff. The total accumulation sequence of the high particle concentration clouds is more than 50 meters. The gas segregation pipes as well as the carbonized branch remnants are common. 2. Massive ash with variable abundance of pumice and lithic lapilli and/or blocks (juvenile, lava dome derived). The lithic rich concentration zones is dominated by particle interactions which overlaid by an ash-cloud surge turbulent part. Short distance between lithic rich layers refers fast sequence of small granular pulses within successive pyroclastic density currents. 3. Diffusely stratified lapilli and massive ash lithofacies without successive lithic concentration layers refer another transportation regime with a lower dense high particle concentration zone. 4. Silicified, fine grained volcanogenic (pumice rich) sandstone derived from epiclastic reworking of the ignimbrite coupled with hydrothermal activity in the sedimentary basin. 5. Massive poorly sorted lithic breccias with rounded blocks probably originated from reworking of the lithoclast rich deposits.

IAVCEI (Volcanology, Geochemistry)

VS24b - VS24 Volcano Geology

IUGG-4167

"The structural development of the nested summit craters of Láscar volcano studied with a Terrestrial Laser Scanner."

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Láscar volcano is the most active volcano of the Central Volcanic Zone in the Chilean Andes. The 5600 m high composite stratocone hosts five NNE-SSW trending summit craters that are partially overlapping (nested). The two craters of the western edifice are considered dormant, whereas the three craters of the eastern edifice are historically active, such as in 1993 and 2013. Details on the evolution of the different craters are unclear, and also the structural control that explains the crater alignment remains debated. Understanding the structural development of these nested craters is relevant for assessing potential future eruption sites, thus making Láscar a dynamic target for a detailed morphology study.

To create a robust dataset, Terrestrial Laser Scanner (TLS) data were collected during a field campaign in November and December 2013, using a RIEGL LMS-Z620 terrestrial laser scanner. Almost the complete eastern edifice is visible from two viewpoints on the crater rim. The resulting pointclouds were merged to create a topographic data set, consisting of more than 15 million data points with a RMSE of a few centimeters.

Here, we describe the technical realisation of crater mapping, in order to detail morphological features and structural lineaments determined in the slope map and quantify crater dimensions and slip vectors. Results allow us to propose a process responsible for the alignment and activity of the nested craters. Our data suggest that the nested craters have all three been modified since the last major eruption in 1993, mainly forced by near surface effects associated with cooling, compaction and gravitational sliding.

IAVCEI (Volcanology, Geochemistry)

VS24b - VS24 Volcano Geology

IUGG-5069

Insights into the effusive-explosive transitions from geological data: the example of Monte dei Porri, Salina Island (Italy)

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Explosive and effusive eruptions are frequently observed, and, considering an adequate timescale, the alternating eruptive styles are the responsible of the construction of most of volcano edifices around the world. To date, the transition between eruption styles during single volcanic eruptions or eruptive cycles are poorly understood, especially when considering the complex influence of local tectonic stress on eruption dynamics. A good example of cone building, alternating explosive and effusive activity, is provided by the Monte dei Porri succession (Salina Island, Italy).

New stratigraphic data allowed the reconstruction of the activity responsible of the construction of the Monte dei Porri cone. Alternating explosive and effusive activity, which emplaced fall and pyroclastic density current deposits, and lava flows, form the volcanic cone. The magma composition that fed the different phases of the Monte dei Porri eruptive cycle is poorly evolved to intermediate (basaltic, basaltic andesite and andesite), with the exception of that of the initial phase (dacitic). Hydromagmatic fragmentation cannot be claimed for explaining large variations in explosivity deduced from the stratigraphic succession, being excluded by SEM image analysis on coarse ash from the different pyroclastic units. This suggests that mechanisms responsible of eruption style transitions have to be searched in timing of magma rising. Mechanisms able to control timing of magma rising include variations in local tectonic stress in combination with variable magma chamber overpressure, which need to be investigated in detail in the next future.

IAVCEI (Volcanology, Geochemistry)

VS24b - VS24 Volcano Geology

IUGG-5470

A detailed geological map and eruptive history for Tongariro National Park, New Zealand: Integrating mapping, geochronology, geochemistry, paleomagentism and glaciology

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Research for the first detailed volcanic geological map for Tongariro National Park (Ruapehu and Tongariro volcanoes) has led to new insights into their evolution. Both stratovolcanoes have hosted ice caps for much of their eruptive history, controlling landform development. Mapping included field work analysing deposits and contacts, sample collection, and checking geomorphology mapped from aerial photos and a new high resolution Digital Surface Model. New geochemical analyses, combined with Ar-Ar dating, paleomagnetic data and previously published geochemistry allows for correlation of eruptive units and development of a comprehensive eruption stratigraphy linking effusive and explosive phases. New high-precision (± 1ka) groundmass Ar-Ar age dates show Ruapehu has been consistently active from 50 ka to present. Paleomagnetic study of flows dated between 45 and 39 ka bracket anomalous magnetizations consistent with the Laschamp excursion. There are extensive complex moraine and lava sequences over much of both volcanoes. The extent of lava flows and pyroclastic deposits have been heavily controlled by ice distribution at the time of eruption. We recognise widespread features of volcano-ice interaction including fine-scale lava margin jointing, intercalated stacked moraines and perched lavas, sub-glacial lavas, Holocene valley-floor lavas mantling glacial features, and features apparently due to sub-glacial lacustrine volcanism. The tephra cover on moraines is being studied: stratigraphic constraints are being combined with cosmogenic ^{3}He surface exposure dating of moraines to ascertain the relative and absolute timing of volcanic events and their relationships to past ice configurations. This study sheds new light on the timing and growth of late Pleistocene cones.

IAVCEI (Volcanology, Geochemistry)

VS24c - VS24 Volcano Geology

IUGG-0757

Geochronology and evolution of the youngest volcano in the Carpathian-Pannonian Region

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The Ciomadul volcano in the Eastern Carpathians represents the youngest activity in the Carpathian-Pannonian Region. The evolution and eruption ages of the volcano are poorly known despite the potential that the volcanic activity might continue in the future. The volcanism was characterized primarily by lava dome extrusions and related PDC deposits although medium to large explosive eruptions also occurred. The stratigraphy of the volcanic products is hard to determine due to this type of activity and small number of outcrops as well as the petrologic homogeneity of the erupted products. Here, we present combined $^{238}U/^{230}Th$ disequilibrium and (U-Th)/He zircon ages (ZrHe) for pyroclastic deposits and lava domes. According to the disequilibrium corrected ZrHe eruption ages the volcanic activity occurred from 150 ka to 32 ka. Two main active phases were identified with a ~40 ka hiatus between them. The first phase was characterized by lava dome activity which was followed by a more explosive eruption phase with minor effusive activity at 56-32 ka when subplinian to plinian eruptions produced volcanic ash clouds that blanketed extended areas. Around this young complex there are further isolated lava domes which were built up before the activity of the Ciomadul. Noteworthy, the obtained ZrHe eruption ages for these older lava domes (e.g., 580 ka for Bálványos) are significantly younger than the previous K-Ar ages (0.9-1.0 Ma). This could be explained possibly by excess argon in the analysed samples. Our study indicates that zircon He thermochronology produces more accurate results for middle-late Pleistocene volcanoes and can be used to evaluate the stratigraphy of volcanoes where field data is limited.

IAVCEI (Volcanology, Geochemistry)

VS24c - VS24 Volcano Geology

IUGG-2539

Tephrostratigraphic framework of Western Europe: Contribution of lateglacial and holocene tephras from the French Massif Central.

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Introduce in 1940's, tephrostratigraphy is presently used in many fields from Earth and Environmental sciences.

Tephra layers studies allow to complete the chronology of the activity known volcanic fields. Furthermore, as tephras are precise and widespread time-markers, tephrostratigraphy allows the correlation of sedimentary and ice sequences. These correlations are useful for palaeo-environmental studies which need reliable and precise chronologies.

In Europe, the tephrostratigraphic framework for the Mediterranean basin is well known thanks to several studies of Italian and Aegean tephra layers observed in lacustrine and deep sea Mediterranean, Adriatic and Aegean sedimentary sequences. Tephrostratigraphy for northern Europe was established on the occurrence of Icelandic and Eifel tephras that are widespread over Central Europe as far as Poland, northern Alps and eastern France. Presently, little is known about tephras due to the Chaîne des Puys volcanic activity. In Western Europe, there is no sedimentary sequence containing Mediterranean, Icelandic, German (Eifel) and French (Chaîne des Puys) tephra layers. However, the Chaîne des Puys volcanic field, situated just westwards form the Alps, should be a key for the correlation of northern and southern Europe tephrostratigraphic frameworks.

Studies carried out since few years show that part of the tephra fallouts coming from the Chaîne des Puys reached the Jura area. Recently, unknown tephra layers from Chaîne des Puys have been discovered in eastern French Massif Central and allow to establish a new tephrostratigraphic framework for eastern France. This set of tephras is one of the keys for the establishment of a general tephrostratigraphy for the whole Europe, which is a priority of the INTIMATE working group.

IAVCEI (Volcanology, Geochemistry)

VS24c - VS24 Volcano Geology

IUGG-3885

Re-evaluation of andesitic pyroclastic deposits on Dominica, Lesser Antilles, with implications for volcanic hazard

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Stratigraphic correlation of volcanic deposits plays a critical role in evaluating the frequency and magnitude of eruptions. However, in regions with hilly terrain, high rainfall and fast weathering rates, the patchy preservation of loose pyroclastic deposits limits field-based reconstructions, especially where there is a paucity of material for radiometric dating. This is especially true for island arc regions where much of the volcanic material is preserved offshore. The island of Dominica in the Lesser Antilles hosts several ignimbrites, including the Roseau Tuff, thought to represent the largest eruption in the Caribbean in the past 200,000 years. Here we re-evaluate the current stratigraphic framework of ignimbrite- and dome-forming eruptions on the island based on whole-rock, glass and mineral geochemistry and (U–Th)/He (in zircon and apatite) eruption ages of subaerial deposits. Many of the pumice clasts from ignimbrites in Dominica have near indistinguishable groundmass glass and mineral chemistry, making correlation of any deposits difficult. New (U–Th)/He eruption ages, however, allow identification of separate explosive eruptions, stressing the importance of geochronology in correlation. In particular, Roseau Tuff deposits yield ages between 24 and 61 ka, and we suggest that the large volume inferred for this unit actually represents a composite of six smaller, geochemically homogeneous eruptions. This work has implications for tephrochronology and hazard assessment in the Lesser Antilles.

IAVCEI (Volcanology, Geochemistry)

VS24c - VS24 Volcano Geology

IUGG-5088

Cotopaxi's most recent rhyolitic eruptions, 2400 yBP

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Cotopaxi Volcano, Ecuador, is a glacier-clad symmetrical andesitic stratocone that produces rhyolitic magma about every 2000 yrs.; most of it emitted as domes, tephra, or pyroclastic flows. The most recent rhyolite event, called Peñas Blancas, erupted about 2400 yrs. ago, following 2600 yrs. of andesitic eruptions. Proximal products from Peñas Blancas eruptions are scarce and mostly crop out on the NW and W flanks of the cone. Pyroclastic deposits contain vesicular white pumice with 73 wt.% SiO_2 and obsidian fragments. Because preservation of these deposits is poor, we had previously underestimated the eruption´s significance.

Peñas Blancas stratigraphy includes dome-collapse deposits and lahars containing the distinctive rhyolitic pumice both N and W of the volcano. Voluminous lahars originating on the NW-W flank descended the volcano´s SW drainage, and traveled 75 km through the now populated InterAndean Valley. Lahar inundation was 3 km width and was up to 30 m deep, values much greater than those of lahars produced during Cotopaxi´s andesitic eruptions. Total volume of this lahar deposit is 2–4 km^3.

Comparison of petrography and geochemistry of Cotopaxi's rhyolites suggests that the Peñas Blancas magma source is similar to that of Cotopaxi´s rhyolitic eruptions of 6300–7400 yBP, but is different from that of its immediate predecessor, the Canyon Colorado series of 5000 yBP, which has contributions from the magma reservoir of nearby Chalupas Caldera. We aim to identify the trigger of the Peñas Blancas eruption by examining its products' geochemistry, petrography and isotopic signature. Understanding the genesis of the Peñas Blancas event is important, because repose intervals of Cotopaxi´s Holocene siliceous eruptions average 2000 yr., and that period is past.

IAVCEI (Volcanology, Geochemistry)

VS24c - VS24 Volcano Geology

IUGG-5302

Magmatic activity at Islas Marias archipelago: Key events for understanding gulf of California tectonics.

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Islas Marias Archipelago consists of four islands located in the mouth of the Gulf of California. Lithologically three of them (Maria Madre, San Juanito, and Maria Cleofas) are quite similar with a 165-170 Ma metamorphic basement, 75-85 Ma intrusive and extrusive rocks, and a sedimentary sandstone cover, which according to its foraminiferous content recorded multiple uplift and subsidence events related to the opening of the Gulf. These units are absent on Maria Magdalena island which is positioned between the other islands. Here, instead, gabbroic sills are intercalated with sandstones and some minor pillow basalts with geochemical and isotopic characteristics similar to N-MORB. The gabbros have not been dated so far, but detrital zircons in the sandstone layers are not older than 22 Ma. Magdalena island was obviously uplifted separately from the other islands of the archipelago, probably along a now hidden transform fault system along the East Pacific Rise. Metamorphic and igneous rocks of the other islands can be correlated to lithologically similar units in the Los Cabos Block, Baja California, or to the continental margin units in Sinaloa, Nayarit and Jalisco states when looking at their geochemical and geochronological signatures. Paleomagnetic studies on 35 sampling sites from all 4 islands and covering most of the lithologies are in progress and results will also be presented. These results will be compared with data from the Los Cabos Block and the Puerto Vallarta batholith, to discuss their regional tectonic implications. Data from the different islands will be also discussed with respect of potential relative and small scale tectonic movements.

IAVCEI (Volcanology, Geochemistry)

VS24c - VS24 Volcano Geology

IUGG-5321

The last 1000 years of the eruptive history of Ceboruco volcano (Nayarit, Mexico) – new contributions based on paleomagnetic dating

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During the last 1000 years of its eruptive history, Ceboruco volcano has experienced a major magnitude (VEI 6) rhyodacitic Plinian eruption, at 990-1020 cal AD (as the best fit overlap range of ten radiocarbon samples), followed by at least 7 other eruptions of lower magnitude involving andesitic to dacitic magmas. Additionally, there has been minor activity restricted to the inner crater (diameter of ~1.5 km), leading to the construction of lava domes and pyroclastic cones.

This period of very intense volcanic activity still lacks precise dating of the individual events, which hinders a subsequent hazard evaluation. Of the at least 7 post-Plinian eruptions only the youngest, occurring in historical times during the years 1870-75, is quite well known and described. Dating the other 6 eruptions by classic methods, such as radiocarbon or Ar/Ar dating, has been impossible due to the lack of suitable material because of the very high frequency of eruptions during that interval leaving no time for a significant development of soil and/or vegetation cover and large errors, respectively.

The description of the landscape preserved in historical documents from the Spanish conquerors, indicates that the 6 eruptions occurred between 990-1020 cal AD (Plinian eruption) and the year 1528.

The results obtained during this study, applying paleomagnetic dating, suggests an emplacement immediately after the Plinian eruption, which is in contrast to the previous results, which were mainly based on morphological aspects, vegetational cover of the individual lava flows and pre-hispanic legends.

These new findings have implications for aspects of the magma system and the hazards related to this volcano and require further study.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-581

Explosive volcanic eruptions in the Upper Ordovician of the Siberian Platform

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Eight K-bentonite beds have been discovered in the Upper Ordovician of the Tungus basin on the Siberian Platform. All the beds were identified in the outcrops of the Baksian, Dolborian and Burian regional stages, which correspond roughly to the Upper Sandbian, Katian and probably lowermost Hirnantian Global Stages. The 4 lowermost beds are represented by thin beds of soapy light gray or yellowish plastic clays and usually easily identifiable in the outcrops. The beds were traced in the outcrops over a distance of more than 60 km along the Podkamennaya Tunguska River valley. Modeling of the XRD tracings showed the samples consist of R3 ordered illite-smectite with 80% illite and 20% smectite plus a small amount of corrensite, which is a regularly interstratified chlorite-smectite. The K-bentonites provide evidence of intensive explosive volcanism on or near the western margin of the Siberian craton in Late Ordovician time.

The K-bentonite beds from the Baksian and Dolborian regional stages (Katian) of the southwestern part of the Tungus basin in Siberia are thus derived from the alteration of volcanic ash falls. All four beds contain volcanogenic euhedral zircon and apatite phenocrysts. Zircon crystals from the uppermost K-bentonite bed within the Baksian regional stage provides a 206Pb/238U age of 450.58±0.27 Ma. The timing of volcanism is surprisingly close to the period of volcanic activity of the Taconic arc near the eastern margin of Laurentia and it appears that the Taconic arc has its continuation along the western continental margin of Siberia. This contradicts popular palaeogeographic interpretations and points to the position of a subduction zone along the western but not the eastern margin of the Siberian palaeocontinent at this time.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-582

Advances in the Tephrostratigraphical characterization of the Post-glacial explosive activity of Melimoyu volcano, Southern Chile

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Characterization of pyroclastic fall deposits from explosive eruptions reveal a number of relevant information from eruptive events. This work is focused on the explosive activity of Melimoyu which is a poorly-known large ice-covered stratovolcano, located in a very remote area of southern Chile. Fall deposits related to at least two large eruptions suggest that explosive activity have occurred during the late Holocene.

The study area covers a segment of the southern part of the Southern Volcanic Zone (SSVZ), which corresponds to a continuous volcanic arc segment, generated by the subduction of Nazca oceanic plate under the South American continental plate. In this region, the eruptive record is bounded to the postglacial period, given the substantial presence of ice fields during the uppermost Pleistocene. Recently, there have been significant advances on the tephrochronological record for Chaitén-Michinmahuida and Hudson volcanoes. However, pyroclastic deposits derived from volcanoes located between 42.5°S and 44.5°S (where Melimoyu volcano is placed), remain poorly studied, being only documented in a regional study.

The aim of this work is to present new stratigraphic control points and detailed descriptions of fall deposits in order to better estimate the magnitude and eruptive parameters for the identified eruptions. Fieldwork was done trying to incorporate points in all directions from the volcano, and therefore the western side was reached by boat. This information reveals new insights on the magmatic system of Melimoyu volcano as well as potential for future activity in the region. It also highlights the importance of extensive fieldwork even in remote and rugged areas, in order to obtain accurate estimates of magnitude and eruptive rate of past eruptions.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-583

Stages of development of the magmatic system of Shiveluch Volcano: geochronological and termobarogeochemical results.

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The Sheveluch volcanic massif (Kamchatka) is located near the northern boundary of the Pacific plate . Currently, it is one of the most active volcanoes of the peninsula .The volcanic massif can be divided into four main complexes different structure and age: an initial mostly pyroclastic complex (up to 80000 y.a.), lavas of Old Shiveluch (up to 16000 y.a.); Baydarny center of tephra and lavas (up to 12000 y.a.) and mostly pyroclastic Young Sheveluch (up to date).

The boundaries between different strata of pyroclastic complexes are marked by the deposits of major debris avalanches.

The Age of these complexes were determined by carbon-14 dating of tephra. In addition, we studied melt inclusions in minerals from tephra associated with each of the stages of the volcano.

HREE-depleted dacitic melts we founded in rocks of the earliest and most resent stages. Basaltic andesite and andesitic melts enriched in HREE are characteristic of the Old Sheveluch and Baydarny centers.

Melt compositions from rocks of various ages, as well as the lack of inclusions of different types in a single complex may indicate that the system consist of multiple magma chambers, involve different dominant magma generation processes (fractionation basic melts or partial melting of crustal metabasites).

The activity of these chambers changes almost instantaneously (on the geological time-scale). 'Awakening' of a magma chamber could be caused by catastrophic events - possibly an high magnitude earthquakes, which are recorded by marker horizons of avalanche-driven debris.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-584

Automated statistical matching of multiple tephra records

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Establishing a detailed record of past volcanic events is important for probabilistic volcanic hazard forecasting, as well as for understanding the dynamics and history of a wide range of other geomorphic, climatic, soil-forming and environmental processes. Compiling detailed tephra records is complicated by: highly variable tephra distribution over time; difficultly in correlating tephras based on physical and chemical properties from site to site; along with uncertainty in age determinations. Multiple sites are needed to build the most accurate composite tephra record, but correctly merging them by recognising events in common and site-specific gaps remains complex.

We present an automated statistical procedure for matching tephra sequences between multiple deposition sites, using stochastic local optimization techniques. This approach eliminates implausible matches through careful reasoning, while heuristically searching over the remaining alternatives. If individual tephra age determinations are not significantly different between sites, they can be pooled to derive a more precise date of each eruption. The known stratigraphic constraints and compositions of the tephras can be used to verify possible matches returned by the procedure.

Our method of identifying plausible matches is demonstrated through the application to five long sediment cores from the Auckland region (New Zealand). These sites include tephras from local Auckland Volcanic Field eruptions as well distal units erupted from Taupo, Okatania, Mayor Island, Taranaki (Egmont), and Tongariro volcanic centres. The new correlated record compiled is statistically more likely than previously published arrangements from this area.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-585

New data from Chaiten's volcano plinian events in the Holocene

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Chaiten Volcano is located in the Southern Volcanic Zone of Andes (SVZ), Chile. The only well-documented eruption corresponds to a Plinian eruption in May 2008, which severely affected Chilean and Argentinian towns due to lahars and tephra fallout, impacting people´s health, as well as livestock and agriculture. Despite the lack of historical events, several studies have documented that the volcano has been very active during the Holocene.
Chaiten volcano is a relatively small centre (ca. 1100 m asl). It consists of a 3 km-wide caldera partially filled by a 0.8 km3 rhyolitic dome emplaced during 2008-2009. All products identified during the Holocene correspond to high-silica rhyolites (ca. 75% SiO2), which represent a unique magmatic composition in the zone. Detailed analyses from several stratigraphic sections around the volcano have shown that the 2008 eruption corresponds only to a moderate-size event in the volcano history. In particular, the so-called Cha1 (~10 ka) and Cha2 (~5 ka) events are considered the largest eruptions at Chaiten since the LGM. Tephra fall deposits of those eruptions are very similar and recognized by the presence of white near-aphyric pumice with elongated vesicles, which show remarkably similar compositions. In addition, obsidian lithics from previous domes are abundant within the deposits. The only difference found is the presence of basement metamorphic clasts in deposits associated with Cha1.
In this contribution we present results from extensive fieldwork and analytical techniques, indicating that both eruptions (Cha1 and Cha2) are much larger than the 2008 eruption. The volumes erupted during these events make clear the potential size for future eruptions at Chaiten, which is essential for the evaluation of volcano hazards.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-586

The Neogene Breiddalur Volcano, East Iceland, revisited

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From 1955 to 1966 George PL Walker and students undertook the challenging task of mapping the volcanic succession in East Iceland. They identified three core structures in the succession; flood lava (i.e. plateau basalt) sequences, dyke swarms and central volcanoes. These findings advanced the understanding of volcanism in Iceland and similar regions around the world. The exceptional outcrops in East Iceland provide a near-perfect 3D view of the ~10 Ma Breiðdalur volcanic succession and the associated dyke swarm. Thus, it is an ideal place for examining in detail a volcanic succession, along with the magmatic and volcanic processes that contribute to the construction of Neogene Volcanic Systems (i.e. central volcano + dike swarm) in Iceland.

In order to take Walker's original work at Breiðdalur to the next level, we have posed the following research question: Which came first, the central volcano or the dyke swarm? We aim to answer this question via comprehensive study of the Breiðdalur volcano, which includes detailed logging and mapping of the volcano succession, full geochemical characterisation of Breiðdalur's volcanics and intrusions, including major, trace and rare earth element plus isotope measurements, along with Ar-Ar age determination of strategic formations. We will present new data on the stratigraphy of the Breiðdalur volcano, chemical composition and geochronology of its products. For example, we will demonstrate that the volcano was capped by an 8-9 km-diameter caldera and that some of the youngest formations at the volcano are composite lava flows and large, shallow level mafic sills.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-587

The deposits of Pululahua Volcanic Complex (PVC), Ecuador: estimation of the erupted magma mass/volume.

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The mass/volume estimation of a primary volcanic deposit is essential to quantify the magnitude and intensity of eruptions as well as the global magma emission rates in a volcano. This study took into account Pululahua Volcanic Complex (PVC) located to 20 km north-west of Quito (Ecuador's capital) because it provides a unique opportunity for this type of analysis due to: 1) a quite homogeneous magma petrography and geochemistry , 2) a well-known, simple geological history (<100 kyBP), related to two eruptive dynamics: a former "effusive period" characterized by dome growth and block and ash flow deposits and a latter "explosive period" defined by ignimbrite deposits (≈2500-2200 yBP).

Geological mapping at 1:25000 scale supplied extension and thickness data of the different stratigraphic units. This information was analyzed in a Geographic Information System and three interpolation methods were applied to estimate the total deposit volume: 1) linear interpolation, 2) Voronoi polygons and 3) kriging. Additionally, deposit and rock density measurements were performed, 'in situ' and at laboratory. These parameters allowed the estimation of the mass of magma extruded by the volcanic complex by means of the relation: mass=density*volume.

Thus, three different values for each parameter (volume & mass) were obtained for PVC stratigraphic sequences using the methods mentioned before. Therefore, we concluded that the best method is the geostatistical "Kriging" interpolation because the data measured in the field is spatially related. The results obtained for the block and ash deposits are 0.76 km^3 and $1.78x10^{12}$ kg, meanwhile for the ignimbrite deposits are 0.29 km^3 and $2.28x10^{11}$ kg. The addition of geochronological data will later provide figures on the magma emission rates at PVC.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-589

Development of a new volcanological tag-based database for geo-science research

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The ACRIFIS-EHAI (AIG Collaborative Research Institute for International Study on Eruptive History and Informatics, Fukuoka Univ., Japan), which was established from April 2012, aims to construct a new database system not only for academic purposes but also for general interests. Our first goal is that we develop a database system to collect and use information of outcrops and local data that researchers have, for geologists and ordinary people. To achieve this goal, we have previously developed two sites for different targets and released for public as test cases using Open Source Software. There however are some limitations due to use of existing web packages. For example they are low flexibility of data format, lack of some functions to deal with big-data, and so on. So we developed new geo-database platform with MongoDB, which is one of the document-based database management systems. On the other hand, the most difficult issue for constructing such a database system is that it requires much time and effort of editing various information and categorizing each data manually. To cope with this issue we propose a tag-based database management system built on our new platform. This system can deal with various data not only by user-generated tags like keywords or key-phrases derived from comments but also by automatically added metadata like GPS information. So editors can add arbitrary keywords without being troubled by data format and can use automatic categorization using similarity calculation between tagged data.In this presentation, we introduce a part of geological database platform and a new database service for geo-science research.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-590

GeoLog2 : A public outcrop database for geo-science research and its supporting environment

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The ACRIFISI-EHAI (AIG Collaborative Research Institute for International Study on Eruptive History and Informatics, Fukuoka Univ., Japan) aims to construct a new database system not only for academic purposes but also for general interests. Our first goal is that we develop a database to collect and use information of outcrops and local data that researchers have, for geologists and ordinary people. To realize this goal, we adopted new data collection policy. For traditional approach, we decided to sacrificed accuracy, orderliness and comprehensiveness for resolving some issues of outcrop database editing. Outcrop information is essentially atypical and flexibility data. So, editing outcrop database needs professional knowledge and a lot of time and costs. Our approach gives priority to record the existence of outcrop easily and share it widely. According to this approach, we developed an outcrop database that we named GeoLog2, and released it on the Internet. GeoLog2 is a public database based on web-style for outcrop. Anyone can browse the stored outcrop information in GeoLog2, such as a photo image, comment, and geographical location. Furthermore, anyone can post new outcrop information to GeoLog2 with some steps. At the same time, we provide its supporting environment to collect outcrop information. Discovering the outcrop is fieldwork in the open air. In this situation, PC-less easy recording method is important. To support fieldwork, we developed mobile applications for GeoLog2. The applications can be used on your smartphone and tablet. When you find a new outcrop, you can record easily photo images of the outcrop and its geographical location and also post it to GeoLog2 on the spot. In this presentation, we introduce "GeoLog2" and its supporting environment.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-591

Complex emplacement of the 1802 AD volcanic debris avalanche at Tutupaca volcano, Southern Peru, as revealed by surface deposit structures

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We present a coupled hydrothermal and magmatic related volcanic landslide at Tutupaca volcano (Southern Peru). Around 1802 AD, the hydrothermal system under Tutupaca's growing dacite dome failed, creating a landslide-debris avalanche and triggering a large explosive eruption whose deposits cover that of the avalanche (see Samaniego et al. this meeting). The landslide scar at Tutupaca is ~1 km wide and has an inner bowl shape, opening to a shallow outer scar and slide plane with a 25° inclined slope. The debris avalanche deposit reaches ~6-8 km from the scar and is composed of two different units. The first unit is a typical debris avalanche hummocky unit formed out of rock from the dome foot. It is covered by a second unit that displays longitudinal ridges at the surface and that has two contrasting facies: a fine-grained, hydrothermally-rich breccia with spare plurimetric blocks, and a coarse-grained, dome-rich unit with many large prismatic jointed blocks. The ridges are 10-1000 m long, 10-30 m wide, and 1-5 m high, and fan slightly outward. Cross-sections reveal coarser cores and finer troughs, suggesting grain size segregation during emplacement. Ridge morphology and granulometry are consistent with fingering in a granular flow, but some ridges are also associated with large blocks that had differential movement with the rest of the flowing mass. Ridged and hummocky deposits formed during the same event show that multiple mechanical behaviours may coexist in one landslide as different lithologies combine and collapse sequentially, leading to contrasting emplacement physics.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-592

Pattern classification: a promising tool for the characterization of volcanic products at Mt. Etna

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Active basaltic volcanoes furnish a large quantity of information on changes in the composition and magma transport, improving our understanding of on-going magmatic and eruptive processes. Pattern classification tools allow to handle efficiently compositional data of volcanic products, complying with their multivariate nature. In the framework of the European MED-SUV project, we explore the application of various data mining methods to volcanic products erupted at Mt. Etna, Italy. Considering 13 major and trace elements for each sample, groups with similar geochemical composition were identified. The set of samples analyzed covers the time span from 2006 to 2012, during which there were two major episodes of effusive activity (2006, 2008-2009) and 25 lava fountains (2011-12). Our approach allows a convenient visualization of the multi-component characteristics of magma in just a single picture, using a color code and cluster membership values. This result offers an important advantage with respect to classical analyses, which require many low-dimensional diagrams (78 possible combinations in conventional 2D graphs).The synoptic information provided by pattern classification easily allows us i) to identify trends of evolution with time even within each eruptive center, and ii) the immediate comparison of the compositional features with all products analyzed in the past.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-593

First geological data of an unknown historical eruption (218 ± 14 aBP) at Tutupaca volcano (Southern Peru)

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The little known Tutupaca volcano (17°01’ S, 70°21’ W), located at the southern end of the Peruvian arc, is a dacitic dome complex that experienced a large explosive eruption during historical times. Based on historic chronicles and our radiometric data, this eruption occurred 218 ± 14 aBP, probably between 1787-1802 AD. This eruption was characterised by a large sector collapse that triggered a small debris avalanche (<1 km^3) and an associated pyroclastic eruption whose bulk volume was 6.5-7.5 x 10^7 m^3. Both units were emplaced synchronously and spread onto the plain situated to the northeast of Tutupaca volcano. The spatial and temporal relationships between the debris avalanche and the pyroclastic density current deposits, coupled with the petrological similarity between the juvenile fragments in the debris avalanche, the pyroclastic density current deposits and the pre-avalanche domes, indicate that juvenile magma was involved in the sector collapse. In addition, large amounts of hydrothermally altered material are also found in the avalanche deposit. We interpret this sequence of volcanic deposits as follows. The ascent of a dacitic magma batch, coupled with the fact that the Tutupaca dome complex was constructed on top of an older, altered volcanic sequence, induced the destabilisation of the hydrothermally active edifice, producing the debris avalanche and its related pyroclastic density currents. This eruption probably represents the youngest debris avalanche event in the Andes. Due to its well-preserved surface structures, it represents a unique place for studying the dynamic behaviour of the volcanic debris avalanches (see Valderrama et al., this meeting).

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-594

The eruptive chronology of the Ampato-Sabancaya volcanic complex (Southern Peru)

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On the basis of extensive fieldwork, and a large dataset of geochronological (^{40}K-^{40}Ar and ^{14}C) and geochemical data, we reconstructed the eruptive chronology of the Ampato-Sabancaya volcanic complex (Southern Peru). The Ampato compound volcano consists of a Basal Edifice constructed during at least two cone-building stages lasting between 450-400 and 230-205 ka. After a long period of quiescence, erupting activity resumed and constructed the basal sequence of the Ampato Upper edifice since 80-75 ka and then the three successive peaks (Northern, Southern and Central) of Ampato. The Southern peak, which represents the most important cone of this edifice, is composed of several effusive episodes spanning between 45 and 25 ka and was affected by the Pleistocene glaciations (roughly before 25-17 ka).Then, at the ned of its evolution, this edifice experienced large plinian eruptions. The last cone-building stage of Ampato constructed the Central cone since ~15-20 ka until the Pleistocene-Holocene limit. During Holocene, eruptive activity migrated to the NE and constructed the Sabancaya edifice, which is mostly composed by andesitic and dacitic blocky lava flows. This evolution shows a very low bulk eruptive rates for Ampato (< 0.11 km^3/ka), which contrast with the high values estimated for Sabancaya (0.8-1.0 km^3/ka). This change suggest that eruptive rates are not homogeneous thought the volcano's history. The Late Holocene Sabancaya activity was characterised by strong vulcanian events with a local ash fallout impact. We identified at least 6 ash-fallout layers during the last 4-5 ka, including those corresponding to the historical AD 1750-1784 and 1987-1998 eruptions.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-595

FACIOLOGY OF NEOPROTEROZOIC (EDIACARAN) VOLCANIC SUCCESSIONS IN THE NW PORTION OF THE SUL-RIO-GRANDENSE SHIELD, SOUTHERNMOST BRAZIL

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Well preserved Neoproterozoic volcanic succesions associated to sedimentary continental sequences are correlated to strike slip basins NW of the Sul-Rio-Grandense Shield, southernmost Brazil. This ancient volcanism comprises a sequence of effusive, hypabyssal and pyroclastic rocks, dominantly acid in composition and sodic-alkaline affinity, whose genesis is linked to post-collisional stages of the Brasiliano/Pan-African orogenic cycle.This area has the northernmost exposure of this volcanic episode and, despite its age, effusive and pyroclastic deposits are well preserved in two hills (cerros): Tupanci and Picados. The first is a sub-volcanic intrusion represented by porphyritic rhyolites with phenocrysts of sanidine and quartz surrounded by a equigranular-fine-grained to aphanitic quartz-feldspar matrix, showing spherulites/axiolites as high-temperature devitrification processes. Border regions of this intrusion show strong flow foliation with rotated grains, microfolds and microbreccia, in a “tuff-like” texture.Similar rhyolites occur as lava flows in Cerro dos Picados, with aphanitic to glassy matrix. Pyroclastic deposits at Cerro dos Picados are rhyolitic ignimbrites, rich in juvenile fragments and separated in two facies: lithic-rich ignimbrites, with mostly lapilli-sized pyroclasts, few devitrified and poorly elongated pumice and crystal fragments; and reomorphic, highly welded, with mostly ash-sized grains, abundance of devitrified pumices in adetachable eutaxitic texture, generating a “lava-like” structure, crystal fragments and rarely lithic fragments. These features suggest a caldera environment, with associated intrusions, or a dome collapse. In both cases, ignimbrites are linked to pyroclastic flows of high-temperature and generated at low eruption columns.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-596

A detailed study of a Debris Avalanche Deposit on a poorly constrained volcano: the case of Meru, Tanzania.

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Debris avalanche deposits (DAD) result from large-scale volcano flank collapses. The DAD behaviour during emplacement and the deposit characteristics are complex to study because they depend on various parameters, such as the nature of the rocks involved, the surrounding topography, and the presence of water.

Although being an active volcano, the Meru (Tanzania) and its numerous satellite cones has been poorly studied. Field survey enabled to highlight 3 major sector collapses along Meru flanks; the youngest, referred to as Momella collapse, has an estimated volume of 16 ± 2 km^3 and covers an area of 1250 km^2. In order to assess the nature of the DAD, and to understand the emplacement mechanisms of this massive collapse event, we conducted a detailed field work and systematic sampling on the Momella DAD and the accessible parts of the collapse scar. Information from petrography, geochemistry and grain-sized analyses were retrieved. We also performed structural study of the deposit at various scales (satellite images, outcrop, and thin sections). All these information are combined to characterise the deposit and understand how the avalanche emplaced.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-597

Seafloor mapping of Palinuro Seamount, a volcanic ridge in Southern Tyrrhenian Sea

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The Tyrrhenian Sea is a oceanic back-arc basin of the Mediterranean Sea related to the passive roll-back of the subduction system of the NW-dipping African lithospheric slab under the Apennines, Calabrian Arc, and Maghrebides orogenic belts (i.e. Malinverno and Ryan, 1986). Palinuro Seamount is an elongated, N100E oriented, volcanic complex formed by several coalescent edifices. It is 70 km long, 25 km wide and its top is located at 80 m b.s.l. (Passaro et al., 2010; Milano et al., 2012). In the last 10 years, Pleistocene lavas with a calcalkaline affinity (i.e. Trua et al., 2004) and hydrothermally derived products (i.e. Lupton et al., 2011, Ligi et al., 2014) were recorded at the apical sector of PS and geochemically analysed. Currently volcanic environments are still poorly characterised by acoustic backscatter derived from multibeam surveys, which instead represents a powerful tool for a rapid and detailed seabed mapping useful to improve the interpretation of the morphological and volcanic-structural processes.
This contribution shows a seafloor mapping realised on Palinuro Seamount. The geophysical data acquired during two oceanographic cruise (Aeolian 2007 and 2010), was carried out with a multibeam sonar system and then processed in order to preserve data accuracy and resolution. The realised mosaic was geo-referenced and imaged using a gray scale. In order to calibrate the backscatter facies recognised on the base of homogenous reflectivity values, the lithology and grain size of seafloor sediments were evaluated. The final map realised will be useful for future morphological interpretations of the apical sector of the Palinuro volcanic ridge.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-599

Devils Tower (WY, USA) - A Lava Coulée Emplaced Into a Maar-diatreme Volcano?

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We have investigated the mode of emplacement of iconic Devils Tower, which is a phonolite porphyry monolith in the state of Wyoming in the western United States. Our field survey of this structure and its geological setting, its radiometric dating and the tectonomagmatic evolution of the region suggest a new genetic interpretation of the volcaniclastic rocks in the area and provide a basis for a new hypothetical emplacement scenario for Devils Tower. This interpretation was inspired by an analogy of the Tower with a similar phonolite “butte” in the Cenozoic volcanic region in the Czech Republic and analogue modeling using plaster of Paris combined with finite element thermal numerical modeling. Our results indicate that the Devils Tower is a remnant of a coulée or low lava dome that was emplaced into a broad phreatomagmatic crater at the top of a maar-diatreme volcano.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-600

Petrochemical characteristics of volcanic rocks of historic era at Mt. Baekdusan, Korea

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The genesis and magma evolution were investigated with respect to volcanic rocks erupted for historical era from summit caldera at Baekdusan volcano, using a comprehensive data set of major and trace elements, Sr, Nd, and Pb isotopic compositions. Based on the geological survey for summit caldera, historic eruption materials are mainly composed of pumice, and trachyte and alkali rhyolite of the Baekdusan stratovolcano is overlain by this historic pumice. Total alkali content change for an increase of the SiO2 indicates a differentiation tendency of alkali basalt magmas, and corresponds to the high-K-series. REEs pattern normalized to the chrondrite can be divided two group, group-A(1 ka Millennium pumice, 1668 and 1905 pumice) and group-B(40ka trachyte, 17ka obsidian comendite, 25ka pumice, 1702 pumice) according to the relative enrichment of HREEs. The geochemical characteristics and modelling result indicated that fractional crystallization of plagioclase, pyroxene, hornblende, and biotite occurred from trachybasalt to trachyte in composition, but fractional crystallization of K-feldspar is more important factor from trachyte to rhyolite. Within magma chamber, the upper part has been to be more mafic and the lower part to be more felsic by the fractional crystallization. The felsic magma eruption with more vapour component took place prior to the mafic magma eruption. Volcanic activity in Mt. Baekdusan summit during historical era was resulted from intraplate magmatism and trace elements do not indicate significant contributions from a subduction slab. Sr, Nd, Pb isotope ratios with same to basalt of the lava plateau indicate that lavas in summit were originated by melting of the same source material without little or no assimilation-contamination of crust material.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-601

Physical and mechanical characterization of hydrothermal altered rocks of the Acoculco Caldera, Puebla, Mexico.

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A study of the geology, stratigraphy, and petrology of the Acoculco caldera in eastern Mexico is under way to reassess its geothermal potential as part of the Centro Mexicano de Inovación en Energía Geotérmica (CEMIE-geo) project P15. It is a 12 km wide resurgent sub-circular caldera with activity recorded from the Pliocene to the Pleistocene (1.27-0.24 Ma). Detailed mapping of the southern and central parts of the caldera revealed hydrothermal altered zones, principally composed by andesitic lava domes. The loss of mechanical properties of altered lavas with respect to fresh ones has been characterized. Particularly, we analysed the influence of hydrothermal alteration on the strength and deformability of the rocks by means of uniaxial tests. Ultrasonic tests were also employed in order to measure changes in porosity and/or the mineralogical content. The porous system characterization was carried out by X-ray image tomographies. The hydric properties of the rocks will be used to construct conceptual models of the water flux and their relationship with the geothermal reservoir. The hydric behaviour was quantified by the capillarity and permeability coefficients. Finally, all these properties were compiled in an engineering-geological map projected on a combination of multispectral and panchromatic SPOT images with 10 and 2.5 m of resolution, respectively, to evaluate their evolution in regard to alteration grade.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-602

Contribution of an airborne high-resolution Lidar survey to unravel the complexity of a monogenetic volcanic field (Chaîne des Puys, France)

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An airborne Lidar survey has been performed, in March 2011, on the central part of the Chaîne des Puys (Central Massif, France), a monogenetic volcanic field composed of scoria cones, domes, maars and associated effusive or explosive deposits, showing a huge variability of landforms. The Lidar data consists in more than 200 million points over a surface of about twenty square kilometers, making it possible to calculate a DTM of a 0.5 m mesh with altimetric and planimetric precisions better than 10 cm.

This high resolution Lidar-derived DTM is of major interest for the scientific community implied in geophysics, archeology, and volcanology research programs on the Chaîne des Puys. For example, the TOMUVOL collaboration is currently carrying out experimental surveys on the Puy de Dôme volcano to develop an operational muograph, a particles detector dedicated to the three-dimensional radiography of volcanoes using atmospheric muons.

Another important application of the Lidar DTM relates to the volcano-structural studies of the Chaîne des Puys, in complement with the volcanological field studies that have been done since almost forty years. Here, we will focus on the morpho-structural decrypting of a few outstanding features of the area. Among those, we present a reinterpretation of the emblematic Puy de Dôme, a trachytic lava dome, and its environment, thanks to the quantitative analysis of the Lidar which allows bringing new morphotectonics constraints. In addition, we also discuss about two others specific case studies, (1) the main morphological features related to a lava flow emplacement and (2) the polyphased eruptive history of the Puy de Pariou, exhibiting the complex relationship between a tuff-ring structure, a temporary lava lake and two basaltic scoria cones.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-603

Reconstructing the 1730 - 1736 Timanfaya eruption (Lanzarote, Canary Islands) using tephrostratigraphy

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The AD 1730 - 1736 Timanfaya eruption on Lanzarote, Canary Islands, is one of the largest historical basaltic eruptions, producing an estimated 3–6 cu. km. of lava along a 15 km E-W trending fissure. Despite incomplete contemporary reports, previous work has proposed a likely eruptive sequence, and identified an usual progression of magma composition from basanite to tholeiite [1, 2]. Here we present tephrostratigraphic, geochemical, and porosity data to reconstruct the eruptive sequence and physical parameters (e.g. plume height, bulk and DRE volume) of the Timanfaya eruption. Results reveal significant dispersal of tephra: proximal outcrops consisting of medium to coarse lapilli (grain size > 10 mm) exceed 1.5 m in thickness over 5 km from the fissure. Distally, tephra (chiefly coarse ash to fine lapilli) in excess of ~6 cm thick are found up to 20 km north-northeast of the vents, despite Lanzarote's climate be dominated by trade winds out of the northwest. Tephra deposition therefore impacted over 50% of the island's surface, likely due in part to changing wind directions over the course of the eruption. Tephra isopachs, isopleths, and chemical correlations provide new constraints on the eruption chronology, volume, and plume(s) height. Our results have important implications for the eruption's volatile budget and the evaluation of its potential climate impact [3, 4].

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IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-604

Coupling long- and short-term ground deformation at Campi Flegrei (Southern Italy) to constrain the current dynamics of the caldera

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The Campi Flegrei caldera is an active volcanic field and one of the highly populated volcanic risk areas of the world. Due to presently changing in monitored parameters, as ground deformations, Civil Defence Protection has moved the caldera to at an attention level. A new detailed reconstruction of the relative movement between sea level and ground deformation of the central sector of the caldera has been carried out. The detailed stratigraphic and paleoecological study of key deposits sequence of La Starza marine fossil sea cliff allowed to reconstruct the paleoenvironment evolution of the area. These data together with tephra correlations to well-known Campi Flegrei eruptive events and already available geochronological data show that the most uplifted sector of the caldera was produced by a complex paleoenvironment evolution alternating marine transgression and emersion phases marked by both continental volcanic and/or palustrine/lacustrine sediments. A significant submersion phase occurred in about 3.000 years between 8.5 and 5.5 ka during a sea level rise and a very high rate of subsidence (~20 mm/yr) and was followed by an uplift of about 100 m between 5.5 and 3.5 ka at rate of 40–50 mm/yr, recording also a brief inversion around 4.5 ka. This vertical displacement represents the permanent recorded deformation linked with a volcanism period in which ~2 km^3 of magma (DRE) were erupted by vents within the caldera.

We highlighted that the ground uplift larger than 3 m occurred since 1905/1907 shows a constant deformation pattern comparable to the normalized uplift shape of the unrest preceded volcanism at ~4.5 ka, supporting the main involvement of magmatic sources in ground deformation at Campi Flegrei caldera.

IAVCEI (Volcanology, Geochemistry)

VS24p - VS24 Volcano Geology

VS24p-605

Geologic map, volcanic stratigraphy and structure of the Cabo de Gata volcanic zone, Betic-Rif orogen, SE Spain

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The geologic map of the Neogene Cabo de Gata volcanic zone is presented together with a comprehensive volcanic stratigraphy and structure based on logging, correlation and mapping. Volcanic rocks are interbedded with sedimentary rocks throughout the Cabo de Gata volcanic zone. The volcano-sedimentary succession of Cabo de Gata has been divided into formations according to lithology, age, composition and stratigraphic position. The contacts between sedimentary units and volcanic units and between formations are unconformities. Sedimentary units were deposited during periods of volcanic repose. The depositional environment of volcanism in Cabo de Gata is characterized as shallow-water submarine to emergent based on lithofacies of volcanic rocks and on fossil content and sedimentary structures of sedimentary rocks. The eruptive style in Cabo de Gata is dominantly effusive, although small-volume explosive eruptions due to magma-water interaction processes and to explosions of lava flow and domes complexes occurred.

IAVCEI (Volcanology, Geochemistry)

VS25a - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-0822

"Topographic change at Reventador Volcano, Ecuador, 2000-2010: Comparison of field and satellite radar measurement"

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In November 2002 a VEI 4 eruption occurred at Reventador volcano, the most explosive historical eruption in Ecuador since 1886. This was followed by 12 years of intermittent explosive and effusive activity. Between 2002 and 2009, lava flows were emplaced on the northern and southern flanks of the active cone and near the caldera rim. The thickest lavas (~40 m) were emplaced in the Southeastern section of the caldera. Thickness measurements from field campaigns conducted in 2012 were compared with all available ASTER images to map the in-situ lava flows. We compare this flow map to lava thicknesses derived from a small set of interferograms (2007-2010) corrected with the Shuttle Radar Topography Mission (SRTM) digital elevation model from 2000. We estimate total lava volumes of $88x10^6$ m^3 and $75x10^6$ m^3 from field methods and interferograms, respectively. Mean effusion rate between 2002 and 2009 was between 7.4 and 8.7 m^3/s, significantly higher than lava effusion rates during previous eruptions in 1972, 1973 and 1976. The subsidence rate of the young lavas is highest over the thickest parts of the flows and had a rate of -5 cm/yr between 2007 and 2009. Field measurements and topographic change from Remote Sensing (RS) data complement each other: while the uncertainties of field thickness measurements are much lower than those retrieved from Interferometric synthetic aperture radar (InSAR), they were point measurements that required interpolation to estimate flow-field volumes. Although uncertainties in RS-retrieved thicknesses are higher, the shape of the flow field is retrieved more accurately. The combination of the two methods leads to improved estimations of lava volume, effusion flux and flow morphology.

IAVCEI (Volcanology, Geochemistry)

VS25a - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-1488

Mapping lava surfaces of Nyamuragira volcano by means of spectral mixture analysis

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As the most active African volcano in D.R. Congo, Nyamuragira has a high eruption frequency and a rapid vegetation recovery after eruptions. In order to map the lava surfaces of Nyamuragira through satellite remote sensing, we made use of linear spectral mixture analysis (LSMA) with 30 m resolution Landsat Enhanced Thematic Mapper Plus (ETM+) and Advanced Land Imager (ALI) imagery for spectral unmixing and 2 m Pleiades data for validation. In addition to vegetation, we identified three lava spectral endmembers in both the ETM+ and ALI feature space. These contrasted lava endmembers proved to correspond to lava surfaces of different age and could be spectrally distinguished through biological and chemical weathering.

As expected, the vegetation fraction increases as lava ages. At Nyamuragira, vegetation starts to significantly colonize lava flows ~15 years after eruption, and occupies over 50% of the lava surfaces ~40 years after eruption. Our case study of Nyamuragira's volcanic field demonstrates that LSMA enables characterization of lava surfaces and vegetation colonization, which is particularly useful for volcanoes poorly known or not easily accessible for fieldwork.

IAVCEI (Volcanology, Geochemistry)

VS25a - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-4498

"Post glacial mapping of holocene basaltic lavas in Iceland through the integrated proximal and remote sensing approach"

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In this paper we present an experimental methodology that originates from the need to apply common remote and proximal sensing techniques to areas were mainly basaltic rocks are present (Iceland). A systematic detailed mapping of Icelandic post glacial lavas is currently still missing: it is difficult to discriminate very similar basaltic units through classical geological field survey and petrology/chemical analyses. An interdisciplinary approach for characterizing typical features of geological units, such as morphology, vegetation cover distribution and other distinctive aspects, can be the key for understanding the geological asset of the area. Remotely sensed images, purposely processed, can allow to detect different volcanic unit especially if images interpretation can be supported by field spectro-radiometric data.For this reasons, we used a remote and proximal sensing original approach to map the recent (<8000 yBP) basaltic lava outcropping in the Northern part of Thjorsa valley (~20x20 km area). We collected field spectra with a portable spectroradiometer, slowly walking on the studied geological units. Then, we averaged the field-collected areal spectra and used them as reference for processing Landsat 8 multispectral images.Atmospheric correction, enhancing techniques and unsupervised classifications were applied in order to understand the lithological framework of the scene. Finally, a Spectral Angle Mapper classification was applied to obtain a 'distribution' map of the different geological units. The classification proved to be an important instrument for reviewing, updating but also producing a geological map for the area, as it has been possible to discriminate really subtle differences in basalts (whose spectral responses are very low and similar).

IAVCEI (Volcanology, Geochemistry)

VS25a - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-5075

Mapping and measuring lava flow volume of the 2012-13 Tolbachik, Kamchatka fissure eruption using double differential SAR interferometry

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After more than 35 years of quiescence, the Tolbachik volcanic complex in Kamchatka started erupting on November 27, 2012 for about nine months until August 27, 2013. According to reports from the Kamchatka Volcanic Eruption Response Team (KVERT), very fluid lava effused from two fissures along the W side of Tolbachinsky Dol and traveled 17-20 km to different directions (west, south, and east) away from the fissure. At least five new cones were built during the eruption along the fissure. We analyzed data sets acquired by the bistatic TanDEM-X radar satellite mission to map and calculate the amount of material erupted during the 2012-13 Tolbachik eruption. The TanDEM-X mission consists of the two nearly similar satellites TerraSAR-X and TanDEM-X, which built a large synthetic aperture radar (SAR) interferometer typically separated by a distance between 250 and 500 m. As two images are acquired simultaneously, digital elevation models (DEMs) with a relative vertical accuracy of 2 to 4 m and a relative horizontal resolution of 3 m can be generated. The short repeat-interval of 11 days allowed generating multiple DEMs of the Tolbachik fissure zone. We differenced the DEMs acquired prior, during, and after the volcanic activity had stopped, which enabled us to map and calculate the lava flow volume of the different phases of the eruption. The total lava volume calculated is 0.51 ± 0.07 km^3.

IAVCEI (Volcanology, Geochemistry)

VS25a - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-5661

Ground vs. space, when are we blind, and when are we deaf?

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Violent volcanic eruptions are common in Southeast Asia. However, the physical conditions at the eruptive vent are difficult to estimate. New methods are therefore required to tackle this problem. Among them, satellite imagery and infrasound may rapidly provide information on strong eruptions triggered at volcanoes which are not closely monitored by on-site instruments. An infrasonic array located at Singapore will enable us to quickly identify erupting volcanoes based on the characteristics of the recorded signal. Results will be combined with ash dispersal models to estimate the likelihood of ash at any location in SE Asia.
Due to the location of Singapore close to the equator, seasonal changes in the wind velocity structure of the atmosphere will strongly affect the potential to detect small volcanic eruptions at certain azimuths. So one may want to look at satellite data. The average cloud cover for each zone has been obtained using MODIS data, to assess the possibility to combine infrasound with satellite imagery at a given time to improve our detection capabilities. According to its location, each volcanic zone will be associated with a threshold value (minimum detectable VEI and Energy) depending on the seasonality of the wind velocity profile in the region and the cloud cover.

IAVCEI (Volcanology, Geochemistry)

VS25b - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-0306

Photogrammetric mapping and parameters estimation for the current dome growth at Molodoy Shiveluch Volcano, Kamchatka

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Molodoy Shiveluch Volcano is the most active andesitic volcano on the Kamchatka Peninsula. In 1980 new lava dome began to grow within the avalanche caldera, formed by the November 12, 1964 catastrophic eruption. Since 2001 the dome has grown mostly exogenously: numerous lava lobes and crease structures have been extruded at its different sectors. This process is accompanied by large explosions with ash columns up to 10 km high and partial failures of the dome up to 0.28 km^3 in volume. We have made a detailed description of the dome morphodynamics for the latest period of growth (2001 – present). On the basis of photogrammetric processing of the 2001, 2003, 2005, 2010, and 2012 aerial photographs, we created Digital Terrain Models and topographic maps of the caldera, and calculated the volumes of the dome for 2001 (0.19 km^3), 2003 (0.46 km^3), and 2010 (0.79 km^3). The reason of change in type of the dome growth from endogenous to predominantly exogenous may be in the intensification of lava output: over the periods of the 1980–1981 and 1993–1995 endogenous growths the extrusion rates hadn't exceeded 0.1 km^3/year; during the 2001 exogenous units formation the extrusion intensity became approximately equal to 0.25 km^3/year. Due to intensification of eruptive processes, Molodoy Shiveluch now is too dangerous for direct observations, therefore, remote sensing, in particular photogrammetry, is the most appropriate way of monitoring its current activity.

IAVCEI (Volcanology, Geochemistry)

VS25b - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-1029

Semi-automatic mapping of volcanic landforms based on object-based image analysis and geomorphometry

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Detailed mapping of volcanoes provides key information for initial hazard assessments. By utilising remote sensing (RS) data a low-cost route to volcanic mapping in remote or inaccessible environments can be harnessed. However, despite the wealth of RS data, volcanic mapping still primarily relies on time consuming, manual analysis instead of automated mapping techniques.

This study presents a semi-automatic mapping technique of glaciovolcanoes based on their morphometric characteristics extracted from slope and profile curvature maps derived from a digital elevation model (20m/pixel). The detection of glaciovolcanic landforms was conducted in eCognition 8.8 software (Trimble), which provides a object-based image analysis modular programming environment, where hierarchical rule sets of customized algorithms is built [1]. More than 600 rule sets were tested adjusting parameters and hierarchy in order to evaluate their sensitivity to the classification results. The accuracy of each classification result was evaluated by an error matrix, where the classification result was tested against a geological reference map[2]. Overall very good results are obtained by simple segmentation and classification procedure on slope maps. The accuracy is most sensitive to the assigned slope values, but with slope values of 8-14, and scale parameters 3-18 the overall proportion of area correctly classified and correctly unclassified is > 90%. The classification results are exported as shapefiles and can easily be directly incorporated in classical mapping procedures in the GIS environment.

[1] Benz et al. (2004) ISPRS 58, 239-258. [2] Sæmundsson et al. (2010) Iceland GeoSurvey,1:100.000.

IAVCEI (Volcanology, Geochemistry)

VS25b - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-2039

Application of Structure from Motion technology to three dimensional mapping of volcanic and intrusive features

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Three-dimensional characterization of exposed volcanic and intrusive features provides important insights into the processes of intrusion, eruption, and subsequent erosion. We present a novel application of Structure from Motion (SfM) analysis to create high-resolution digital elevation models (DEMs) and structural models of these features in the San Francisco and Hopi Buttes volcanic fields, Arizona, USA. SfM constructs the fine-scale topography and texture of a scene from overlapping 2-D photographs. Resolution can be much higher than publicly available DEMs and satellite images, and costs and processing times are significantly less than those for airborne LiDAR. We demonstrate the following applications: (i) different lava flow types can be distinguished based on surface roughness; (ii) dike widths are measured more accurately from 1 cm-resolution orthophotos compared to 15 cm-resolution Google Earth images, which artificially skew the data toward larger values; and (iii) steep erosional features on cinder cones associated with agglutinated crater rims and channel development are readily distinguished in the SfM-derived data, but could not be identified in existing 10 m-resolution DEMs. The advantage of combined SfM and field analyses is that measurements are not biased toward places that are easier to access, and the whole extent of well-exposed features can receive full, detailed coverage. Furthermore, the ability of SfM to rapidly and digitally reconstruct topography and texture of

geological outcrops, and digitally archive field data, highlights its exciting potential for both research and virtual fieldtrips.

IAVCEI (Volcanology, Geochemistry)

VS25b - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-2122

Remote sensing mapping of ash fall impact on vegetation: The Oldoinyo Lengai 2007-08 eruption

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Impacts from ash fallout on the environment can be widespread and long lasting, even from moderate-size eruptions. Assessing ash impact on vegetation and its spatial variation is often difficult in the field. We present a study assessing how satellite data can help to map vegetation affected by ash and how temporal analysis enables characterization of vegetation recovery rate. The 2007-08 eruption of Oldoinyo Lengai, north Tanzania, is here used as a case study. An 8 year-long (2005-2012) time series of half-monthly average of the Normalized Differential Vegetation Index (NDVI) is constructed at 250 m spatial resolution from the Moderate Resolution Image Spectro-radiometer (MODIS) sensor. Interpolated rainfall data is used to isolate NDVI values departing from the normal seasonal cycles. Month-to-month NDVI comparison, linear temporal trend analysis and Principal Component Analysis enable to identify a 11 x 24 km area over which ash fallout significantly affected the state of the vegetation. After the eruption's end, time series of various recovery indices highlight a circumferential pattern in vegetation recovery. The estimated recovery time varies from more than 5 years to less than 6 months with increasing distance from the volcano. A moderate, but statistically significant, relationship is found between the recovery indices and the spatial variation of ash thicknesses measured in the field. Combining field and remote sensing constraints enable to re-assess the volume of the eruption to ~2×10^7 m^3. The method applied here opens the scope to document impact and intensity of ash fallout in areas where systematic field work is difficult and to support recovery plans for populations affected by ash fallout.

IAVCEI (Volcanology, Geochemistry)

VS25b - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-2638

The Mt. Etna Volcanic Plumes Detection by GPS

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Mt. Etna (Italy) is very active and, in the last years, powerful lava fountain events have generated volcanic plumes that rose up to several kilometres above sea level. Their detection is important to improve our understanding on dispersal processes, reduce risks to aviation operations and alert the population living around active volcanoes. Nowadays, the volcanic plume detection is carried out by using different approaches such as satellites, radars and lidars. Recently, the ability of Global Positioning System (GPS) to retrieve volcanic plumes is one of the new challenges of the last years in volcanic plume detection. In this work, we analyze the GPS Signal to Noise Ratio (SNR) data of the Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo network, located on the Mt. Etna flanks. Today's the Etna GPS network is made up of 42 GPS permanent stations that provide a dense cover of most areas of the volcano edi?ce, making Mt. Etna a good test site to analyze how the variation of volcanic plume density can affect the SNR signal. We analyse the 23 November 2013 eruption, from the New South East Crater (NSEC). The eruptive activity began late afternoon the day before with strombolian activity that increased at about 7:00 on 23 November. A high eruption column formed and volcanic ash was dispersed toward the North-East/East-North-East direction. Results demonstrate that during the 23 November 2013 eruption, the SNR signal showed the presence of volcanic ash. We found that the strength of the SNR signal variation depends on the distance of the station from the volcanic vent. The nearest station clearly shows higher SNR variations.

IAVCEI (Volcanology, Geochemistry)

VS25b - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

IUGG-3019

Evaluating the convergent photogrammetry with historical data for determination of volumetric changes in volcanic areas

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Historical changes in the volcano morphology can be studied by comparative of Digital Elevation Model. In these cases the use of intermediate techniques that require map scanning, vectorization of contour lines, surface interpolation or changes in terrestrial reference or projective systems are necessary steps to obtain data from the old maps. These procedures usually added errors, thereby lessening the final accuracy of the data. The only way to avoid this error accumulation would resort to initial data, which in the case of old maps are frames from a photogrammetric flight. With the stereoscopic pairs, the restitution process requires expensive software and information about the flight or the camera is sometimes difficult to find. Currently the convergent photogrammetry, ie direct linear transformation, has begun to be used in UAV with non- metric cameras. What is proposed in this study is to see the validity of this technique applied to old fotogrametric digitized frames, where data of the camera and flight are unknown, to obtain a DEM, and comparing their results with studies performed on cartography. The study area is Deception Island and its eruptive process from 1967 to 1970.

IAVCEI (Volcanology, Geochemistry)

VS25p - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

VS25p-482

The NASA Volcano Sensor Web: Using EO-1 to monitor the 2014-2015 eruptions of Nornahraun (Iceland) and Kilauea (Hawai'i, US)

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The NASA Volcano Sensor Web uses notifications of pending or ongoing volcanic activity to autonomously re-task the Earth Observing-1 (EO-1) spacecraft to obtain multispectral and hyperspectral data of the volcano in the short wavelength infrared. Data thus obtained are downlinked, processed and quickly made available to end users. The entire process is autonomous. In the wake of the 2010 Eyjafjallajökull eruption, it was recognized that eruption data collected by EO-1 would be of best value if the products were expected by end users. A link was therefore established between the VSW (based at JPL) and seismic sensors on Icelandic volcanoes which subsequently acted as a trigger, enabling observations close to the onset of the 2011 Grímsvötn and 2014 Nornahraun eruptions. Importantly, paths of direct communication and points of contact were established when unrest under Bárðarbunga was detected in mid-2014. Since eruption onset on 31 August 2014, an intensive observation campaign with EO-1 has been in operation. By February 2015 over 70 EO-1 Advanced Land Imager and Hyperion observation pairs have been collected of Nornahraun, aiding the ongoing monitoring of the eruption and the mapping of the emplacement of the lava flow field by identifying areas of new activity. Another volcano under close observation is Kilauea, Hawai'i, which is regularly observed by EO-1. Expedited data processing and release to the USGS Hawaiian Volcanoes Observatory increases the latency of these observations for identifying and mapping new lava breakouts along the 2014-2015 '27 June' lava flows. Part of this work was performed at the Jet Propulsion Laboratory-California Institute of Technology, under contract to NASA. EO-1 is managed by the NASA Goddard Space Flight Center.

IAVCEI (Volcanology, Geochemistry)

VS25p - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

VS25p-491

Raman spectroscopic setup for the remote monitoring of high temperature volcanic solids and fluids

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Raman spectroscopy was recently proved to be a useful tool for remote probing of materials in extreme conditions [1-2]. This spectroscopy, based on inelastic light scattering, needs a laser excitation and allows identification and/or structural characterization of solid, liquid and gas targets. Therefore, it should be a suitable technique for monitoring of volcanic gas emission and sublimate identification [3]. Moreover, Raman intensity depending of the thermal population of atomic vibrators inside the material, one can calculate the absolute temperature of the probed materials from the Raman spectra. Finally, this spectroscopy should be a suitable transverse technique of solid, fluid identification and temperature estimation in extreme environments.

The ANR RAMANEXT project (2014-2017)[4] has for objective to develop a field Raman setup for the on-site characterization of high temperature volcanic materials.This paper proposes to introduce the Raman technique, the project, its last advances and future applications.

[1] A. Canizarès, et al. Journal of Raman Spectroscopy, 43: 1492-1497, 2012

[2] G. Guimbretière, et al. Applied Physics Letters, 103, 041904, 2013

[3] G. Guimbretière, et al.in 11th International GeoRaman Conference. (St. Louis, USA, 2014) http://dx.doi.org/10.13140/2.1.3413.1203.

[4] http://ramanext.extremespectroscopy.eu/

IAVCEI (Volcanology, Geochemistry)

VS25p - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

VS25p-492

Mapping volcanic deposits: Topographic change on Montserrat and associated ground deformation

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Since 1995, the eruption of Soufrière Hills Volcano (SHV), Montserrat, has generated over a cubic kilometre of andesite lava. Most of that material has been re-distributed via pyroclastic and epiclastic density currents, leaving substantial subaerial and submarine volcanic sediments around the SHV’s flanks. Re-distribution of the deposits has involved in-filling of deep valleys punctuated by isolated dome collapse events. Knowing the distribution of deposit thickness is important for understanding and forecasting secondary volcanic hazards, such as lahars. Recent models also shows that the weight of the deposit can cause significant deformation of the volcanic edifice due to gravitational loading. Topographic change has been recorded during the eruption at SHV by combining data from numerous survey methods.

We measure the thickness of deposits emplaced around SHV over 15 years by differencing topographic and bathymetric survey data and derive a surface load estimate. A sediment distribution budget is thus derived for onshore and offshore deposits. We use finite elements to model the crustal response to the gravitational load of the deposits, in terms of associated ground deformation. We show the sensitivity of loading-derived deformation for a range of plausible configurations of crustal rheology. Results are compared to continuous GPS timeseries data recorded on Montserrat throughout the eruption. We discuss the extent to which sediment loading contributes to the observed ground deformation and the relevance for interpreting geodetic data from SHV. Finally, we present an approach to reconstructing the topographic change timeseries on Montserrat by combining mapping data with records of mass wasting events.

IAVCEI (Volcanology, Geochemistry)

VS25p - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

VS25p-493

Population estimation in hazardous areas based on high resolution remotely sensed images

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Accurate mapping of population distribution is essential for efficient risk management in hazardous areas. However, in many countries, especially in developing regions, population data are not collected on a yearly basis and they are rarely available at a high spatial resolution. In this study we propose a remote sensing based approach to overcome these limitations by estimating population density from high resolution remotely sensed imagery. In our approach, it is assumed that the number of inhabitants per house and their socio-economic characteristics can be related to the type of dwelling and that population estimates at neighborhood level can be inferred from the morphological characteristics of the built-up area as obtained through remote sensing. This will enable an assessment of population at risk and vulnerability.

The method presented is applied on the volcanic Ngazidja Island (Comoros Islands). It makes use of high resolution images as an input for object-based classification of built-up areas. This allows extracting the footprint of dwellings in areas with a low built-up density or delineating neighborhoods with similar morphological characteristics in areas with a higher built-up density. Morphological information extracted from remotely sensed data is combined with socio-economic data on households living in different types of dwellings. Calibration of the method is done using data from a field survey of 1000 households. Results obtained are validated based on independent census data.

In this contribution, we will present the results obtained for a sample of villages. The aim is to extend the use of the technique to the whole island. This will provide spatially detailed information on population exposure which is an essential input for mapping volcanic risks.

IAVCEI (Volcanology, Geochemistry)

VS25p - VS25/VS09 Remotely Sensed Mapping of Volcanic Regions / Statistics in Volcano Remote Sensing

VS25p-494

Using statistical measures of surface roughness to differentiate basaltic lava textures

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Basaltic lava flow textures include: aa and pahoehoe end-members as well as a range of transitional lava types. The particular texture of solidified lava is related to parent flow's emplacement dynamics. If other factors such as slope and viscosity are equal, then aa texture is indicative of high volumetric flow rate, whereas pahoehoe is indicative of lower volumetric flow rate. In the field, a volcanologist can readily distinguish flow textures in fresh and degraded lava flows and use that knowledge to infer emplacement dynamics. However, reliable methods for distinguishing lava texture in remote sensing data remains elusive. For instance, aa is easily confused with slabby and rubbly lava, as they are all rough at the meter-scale. However aa forms by viscous tearing of a cooling crust, whereas slabby and rubbly lava forms when pahoehoe is disrupted by subsequent flow processes. Consequently, inferences drawn from roughness can lead to inaccurate interpretations about emplacement styles and flow rate. This project aims to quantify patterns in surface roughness that are unique to each lava flow texture. Data were collected on the December 1974 lava flow from Kilauea Volcano, Hawaii, USA using airborne (1 m/pixel) and tripod (centimeter- to decimeter-scale) LiDAR. Surface roughness was calculated from the LiDAR topography by removing regional trends and then co-occurrence statistics (e.g., homogeneity, mean, and entropy) were used to quantify 2D patterns in surface roughness. Pahoehoe was found to be more homogenous and less random at the meter-scale, whereas slabby lava is more random than pahoehoe at all scales that were examined. This work demonstrates that statistical measures of surface properties can aid in volcano remote sensing.

IAVCEI (Volcanology, Geochemistry)

VS26a - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

IUGG-1436

A revised thermal evolution of Mars from remote-sensing chemistry and new experimental data in the 0.5-2.5 GPa pressure range

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Four billions year of volcanic activity are exposed at the surface of Mars. Remote-sensing data have revealed systematic variations of chemistry and mineralogy with age that are consistent with deepening of the source region, and slow cooling of the mantle with time in agreement with the thermal evolution of stagnant-lid planet [1,2]. These conclusions were based on thermodynamic modeling of batch melting below the lithosphere of a primitive mantle source composition [3], with pressure-independent corrections based on experimental data at 1.5 GPa [4]. New experiments were recently achieved for a primitive mantle source between 0.5 and 2.2 GPa [5]. These new constraints confirm the initial proposals that Si and Fe concentrations on Amazonian and Hesperian volcanic provinces (0 - 3.7 Ga) inferred from Gamma-Ray-Spectrometer data are (1) compatible with the composition of primary melts of a primitive mantle source (Mg# 75) and, (2) indicate mantle cooling and thickening of the lithosphere as a function of time, though depths of melting need to be revised toward higher values. These new results from remote-sensing data will be compared with independent estimates of mantle potential temperatures and depth of melting from Martian meteorites chemistry [6] or in-situ data of Noachian rocks at Gale and Gusev craters, [7,8].

1] Baratoux et al. 2011 Nature doi:10.1038/nature09903 [2] Baratoux et al. 2013 JGR-Planets doi:10.1029/2012JE004234 [3] Dreibus, G., and H. Wänke 1985, Meteoritics, 20, 367–381. [4]. Bertka and Holloway 1994 Contribution to Mineralogy and Petrology 115:323-338. [5] Collinet et al., in prep. [6] Filiberto et al. 2011 doi:10.1016/j.epsl.2011.02.029. [7] Monders et al. 2007 Met.Plan. Sc. 42, Nr 1, 131–148. [8] Filiberto 2014 JGR-Planets, in press.

IAVCEI (Volcanology, Geochemistry)

VS26a - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

IUGG-1558

Granodiorite and alkaline suite at Gale crater: continental crust on Early Mars ?

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The Curiosity rover landed at Gale, a crater formed within Noachian terrains on Mars. The rover encountered a great variety of igneous rocks which are float rocks or clasts in conglomerates. Textural and compositional analyses using MastCam and ChemCam Remote micro Imager (RMI) and Laser Induced Breakdown Spectroscopy (LIBS) lead to the recognition of 53 massive igneous targets, both intrusive and effusive, ranging from mafic rocks to felsic samples. Five different groups have been identified: (1) a basaltic class with shiny aspect, conchoidal frature, no visible grains (less than 0.2mm) ; (2) a porphyritic trachyandesite class with light-toned, polygonal crystals 1-20mm in length set in a dark gray mesostasis; (3) light toned trachytes with no visible grains sometime vesiculated; (4) microgabbro-norite (grain size < 1mm) and gabbro-norite (grain size >1mm); (5) light-toned diorite/granodiorite showing coarse granular (>4 mm) texture. Overall, these rocks comprise 2 distinct geochemical series: (i) an alkali- suite: basanite, gabbro, trachy-andesite and trachyte including porphyritic and aphyric members; (ii) quartz-normative intrusives close to granodioritic composition. The former looks like felsic clasts recently described in two SNC meteorites (NWA 7034 and 7533), the first Noachian breccia sampling the martian regolith. It is geochemically consistent with differentiation of liquids produced by low degrees of partial melting of the primitive martian mantle. The latter rock-type is unlike anything proposed in the literature for Mars but resembles Archean TTG’s encountered on Earth related to the building of continental crust. This work provides thus the first in situ

detection of low density leucocratic igneous rocks on Mars in the southern highlands.

IAVCEI (Volcanology, Geochemistry)

VS26a - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

IUGG-1574

Surface and subsurface cryovolcanism on Europa and other icy satellites

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The past eruption of liquid water on to, or close to, the surface of Europa is suggested by smooth plains and chaos features. Whether of not liquid water plays a role in the ongoing eruption at Enceladus remains controversial. Erupting liquid water is challenging because it is more dense that ice.

We address processes that allow water to rise through the ice shell and the features this water might form. First, we calculate how deep cracks can penetrate in an ice shell. We then compute the pressures in oceans under the ice shell as the ice thickens over time. These are large enough to cause water to reach the surface on Enceladus, but not on Europa unless some other process such as gas exsolution enhances buoyancy.

If liquid water does not reach the surface it may form sills within the ice shell, and may create pits, domes and small chaos on Europa. We model this process and examine the evolution of surface deformation. We assume that water spreads within the elastic part of the ice shell. At shallow depths, water makes room for itself by lifting the overlying ice and water weight promotes lateral spreading. In contrast, a deep sill bends the underlying elastic layer and its weight does not affect spreading. As a result, the sill lateral extent is limited to about a few to a few tens of kilometers by the fracture toughness of ice. In that case, the sill can thicken substantially, until the feeder dyke closes. Preexisting stresses in the elastic part of the ice shell increase to the point that they disrupt the ice above the sill (small chaos), allowing for partial isostatic compensation of water weight, leading to a topographic depression (pits), of the order of $\sim 10^2$ m. Finally, complete solidification causes expansion and uplifted topography (domes) of $\sim 10^2$ m.

IAVCEI (Volcanology, Geochemistry)

VS26a - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

IUGG-1643

Why do Martian scoria cones vary in shapes from terrestrial analogues?

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The most common volcanoes on Earth are scoria cones (<few km in diameter). Although their existence on Mars as well as their basic morphologic characteristics was predicted decades ago, they were only recently reliably identified in a new generation of high-resolution images. They are located as parasitic cones on the flanks of larger volcanoes (e.g. Pavonis Mons), or as clusters in volcanic fields (e.g., Ulysses Colles in Tharsis, Hydraotes Colles in the chaotic terrains, on the floor of Coprates Chasma, and in the northern lowlands). Images and derived digital elevation models enable us a comparative morphological investigation of their shapes.

We found that the morphometry of Martian scoria cones is distinct from terrestrial analogues. They have larger basal diameters and heights, and they are more voluminous by one to two orders of magnitude. But they have shallower flank slopes (typically <20°) as compared to terrestrial scoria cones (~30°). This difference may be partly explained by the lower gravity and atmospheric pressure on Mars, enabling wider dispersion of pyroclasts from the vent. Moreover, larger volumes may be linked to the lower gravity as the formation of larger ascending magma bodies and wider feeder dikes would together tend to favor more voluminous monogenetic volcanic activity.

Even though Martian scoria cones are more voluminous than terrestrial analogues, their flank slopes are not ruled by avalanching of scoria and, consequently, its angle of repose (~30°), as it is commonly the case on Earth. Instead, their flanks have been formed by direct ballistic emplacement of ejected particles. This allows us to reconstruct the process of their origin and growth numerically by tracing ballistically ejected particles and modeling their accumulation over time.

IAVCEI (Volcanology, Geochemistry)

VS26a - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

IUGG-1726

The Io Volcano Observer (IVO): A spacecraft mission proposed to the NASA Discovery program.

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The Io Volcano Observer (IVO) spacecraft is being proposed to NASA's Discovery program to investigate Io's active volcanism, geological history, and interior structure. IVO would launch in 2021 and arrive at Jupiter in early 2026. IVO includes five core instruments: narrow- and wide- angle cameras (NAC and WAC) with UV-NIR channels, dual fluxgate magnetometers (DMAG), a thermal-infrared mapper (TMAP), and particle environment package for Io (PEPI) consisting of an ion and neutral mass spectrometer (INMS) and a plasma ion analyzer (PIA). A student collaboration instrument—a mid-infrared hotspot mapper (HOTMAP)—is also proposed. IVO's highly elliptical orbit is inclined >40° relative to Jupiter's orbital plane, providing opportunities to observe Io's poorly explored high latitudes and minimizing its total ionizing radiation dose. During the nominal mission phase, which includes nine encounters, the NAC would obtain >20 images of key volcanic structures at 5–50 m/pixel. The apoapse period of each orbit provides extended monitoring of Io and Europa at high phase angles (>120°), which is best for observing Io's volcanic plumes and high-temperature hotspots. Four of the encounters are designed for optimal measurement of induced magnetic signatures from Io's internal "magma ocean", and two encounters can be used for gravity science. The camera design is optimized for measuring eruption temperature from lava fountains and lakes. The final flyby would fly-through Pele's plume, if it is active, to sample composition. Encounter periods last ~1 week, including global monitoring and four Io eclipses, with distant monitoring and data playback near apojove. IVO will collect >20 GB of science data per encounter—returning 900 times more data for Io than the entire (8-year) Galileo tour.

IAVCEI (Volcanology, Geochemistry)

VS26a - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

IUGG-1969

Volcanism on Terrestrial Bodies Through Time and Space: A Comparison

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Volcanism proves that a planetary body is still hot and active. Volcanic landforms witness this activity, and its record may stay preserved on the surface of larger planetary bodies. These volcanically formed surfaces can be dated and provide a record of heat release through time and space. The relationship of volcanic landforms to the topographic and geoid expressions of the terrestrial planets and the Moon allows determination of mantle convection patterns. Mantle convection distorts internal interfaces and results in dynamically driven topography, revealed in the gravity field and geoid. Hot upwelling material and decompression melting in areas of extension cause volcanism. The correlation of geoid and topography depends on the existing viscosity structure of the planet. Correlation between volcanically formed topography and the geoid links internal processes to the surface, but the elastic behaviour of the lithosphere and plate tectonics on Earth complicate the estimation of this correlation back in time.

We will describe and discuss the commonalities and differences between the volcanic record and interior dynamics of terrestrial bodies.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-110

DEM-based analyses of the morphometry of lava domes; a case study from the Taupo Volcanic Zone, New Zealand.

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The Taupo Volcanic Zone has about 300 silicic lava domes and coulees, emplaced over the last 500 000 years. In comparison with scoria cones, the syn-eruptive morphometry of lava domes is much more diverse due to the greater variability in the physical and chemical properties of the erupting magmas. The shape of a growing lava dome is influenced mostly by the viscosity of the erupting magma, the inclination of the pre-eruption surface and erosive processes, such as collapses, but other factors have an influence, such as magma yield strength, cooling rates, degassing processes, effusion rates and the duration of the eruption. The Taupo Volcanic Zone provides an ideal location for the geomorphological characterisation and classification of lava domes. Domes related to the Taupo Volcanic Zone caldera system are generally aligned and clustered around the NE-trending fault system, and are distributed across a number of volcanic centres of varying ages, yet all have experienced similar well defined climatic conditions. In our study, we define, using Digital Elevation Models (DEMs), the morphometric features (e.g. slope, height, volume, circularity, orientation etc.) of lava domes and attempt to determine relative ages for the Peléean and Low Lava Domes in the Taupo Volcanic Zone. At some locations the examined slope features and morphometry also record varying eruptive processes and events where the magma characteristics changed abruptly during dome growth, creating compound lava domes, coeval domes or erosive events such as collapses or small mass flows.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-111

Visible and infrared hyperspectral survey of volcanic lava flows on Tenerife (Canary Islands, Spain)

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Spaceborne hyperspectral remote sensing has been used in the volcanology, yet its application is still constrained by the coarse spatial resolution of the image data. A better understanding of the spectral characteristics of volcanic surfaces requires field spectroscopy. For this reason, two field spectroscopy campaigns were carried out on Tenerife (Spain) in November 2013 and September 2014 with an ASD FieldSpec 3 to document the reflectance spectra of different types of volcanic surfaces.

In total, 47 sites distributed over different types of volcanic surfaces were measured, most of which focused on lava flows. Lava surfaces differ in age, roughness, weathering level and coverage by vegetation and lichens. We compared the field spectral data after pre-processing and found that reflectance spectra of lava are controlled by various factors: (1) Old lava surfaces in general tend to have higher reflectance than fresh lava surfaces. (2) Smooth lava surfaces usually have higher reflectance than rough lava surfaces but the spectra are similar in shape. (3) Growth of vegetation (dominantly green ferns) contributes to a red-edge effect in the lava spectra. (4) Lichen coverage causes a gradual increase in the visible and near infrared region of spectrum. (5) Chemical weathering changes the composition of the lava surfaces inducing a decrease in the shortwave infrared part of the spectrum.

In addition to observations of spectral data, efforts were also made to investigate the comparability of field-based hyperspectral data and Hyperion hyperspectral imagery. Agreement between the satellite and field measurements is significant although the former is sensitive to atmospheric correction and purity of satellite pixels. Hence we provide solutions for improving the comparability.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-112

Flood lava volcanism on Mars: Age estimation of the Cerberus Fossae 2 Unit in Elysium Planitia using crater size-frequency distributions

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Geologically recent volcanic eruptions on Mars have occurred within Elysium Planitia during the Late Amazonian Epoch. Investigating these young flood lava flows is important because it provides valuable information about the thermal evolution of the planet and the current state of its interior. Initial age estimates suggest that the Cerberus Fossae 2 unit, the second youngest major flood lava unit on Mars, was erupted ∼125 Ma ago, with a factor of ±2 uncertainty. It has a total exposed area of ~500,000 km^3, and a typical thickness of 30 m, which implies a total volume of 15,000 km^3. For comparison, the Columbia River Flood Basalts (CRFB) on Earth have a total area of ~164,000 km^2, with a total volume of 174,000 km^3. However, the CRFB were emplaced as ~300 flow units erupted over 11 Ma (from 17–6 Ma ago), with some individual flow units having volumes of 3,000 km^3, or possibly up to 5000 km^3. However, 80% of the total CRFB volume was erupted in <1 Ma, around 16 Ma ago. This raises a fundamental question regarding the history of Elysium Planitia. Were enormous flood lava units in this region really emplaced during infrequent, but massive eruptions; or, should the total volume of lava be attributed to a larger number of smaller events? To test these hypotheses we are examining the spatial variation in modeled impact crater retention ages within the Cerberus Fossae 2 unit—using a regional mosaic of over 500 Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) images, with a resolution of 6 m/pixel.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-113

Using Lava Tube Skylights to Derive Eruption Temperatures on Io

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The eruption temperature of Io's silicate lavas constrains Io's interior state and composition [1] but reliably measuring this temperature remotely is a challenge that has not yet been met. Previously, we established that eruption processes that expose large areas at the highest temperatures, such as roiling lava lakes or lava fountains, are suitable targets for this task [2]. In this study we investigate the thermal emission from lava tube skylights for basaltic and ultramafic composition lavas. Given that tube-fed lava flows are common on Io, skylights could also be common. Unlike the surfaces of lava flows, lava lakes, and lava fountains which all cool very rapidly, skylights have steady thermal emission on a scale of days-months. The thermal emission from such a target, measured at multiple visible and NIR wavelengths, can provide a highly accurate measure of eruption temperature. However, the small size of skylights means that close flybys of Io are necessary, requiring a dedicated Io mission [3]. Observations are ideally made in darkness (night or eclipse) but it is not necessary to spatially resolve the skylight. Multiple observations are the key to distinguishing stable skylights from more ephemeral breakouts. We thank the NASA OPR and PG&G Programs for support. This work was performed at the Jet Propulsion Laboratory-California Institute of Technology, under contract to NASA. References: [1] Keszthelyi et al. (2007) Icarus, 192, 491-502. [2] GRL, 38, L21308. [3] McEwen et al. (2015) The Io Volcano Observer (IVO) for Discovery 2015, LPSC-46 abstract 1627.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-114

New map of io's volcanic heat flow

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We have created a global map of Io’s volcanic heat flow from 242 non-outburst thermal sources [1] indicative of ongoing or recent volcanic activity. We account for ≈54% of Io’s yearly volcanic heat flow, which emanates from ≈2% of Io’s surface [1]. This map provides a snapshot of Io’s volcanic activity and distribution during the Galileo epoch. Averaged heat flow from the non-active surface is 1 ± 0.2 W m^2. This quantification of volcanic heat flow provides constraints for modelling the magnitude and location of the internal heating of Io by tidal dissipation. The observed heat flow distribution is the result of interior heating and volcanic advection, the delivery of magma to the surface regardless of its depth of origin. As noted previously [1, 2] the distribution of heat flow is not uniform, which is not unexpected. However, the volcanic heat flow does not match the expected distributions from end-member models of both the deep-seated (mantle) heating model (which predicts enhanced polar heating) and the shallow (aesthenospheric) heating model, which predicts enhanced thermal emission at sub-jovian and anti-jovian longitudes, nor using mixtures of these models. Heat flow using a bin size of 30° shows a longitudinal offset from the shallow heating model prediction by some tens of degrees [2]. We compare regions of peak heat flow with where volcanic centres [3] cluster. Io’s internal heating and advection processes are more complex than originally thought. We thank the NASA OPR Program for support. Part of this work was performed at the Jet Propulsion Laboratory-California Institute of Technology, under NASA contract. Refs: [1] Veeder et al. (2015) Icarus 245 379-410. [2] Veeder et al. (2012) Icarus 219 701-722. [3] Hamilton et al. (2013) EPSL 361 272-286.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-115

2014 stromboli effusive activity monitored by TET-1 satellite

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Thermal monitoring of effusive volcanic activity provides useful information on the temporal evolution of volcanic activity. Most common are observations from metrological satellites. The advantage of many meteorological satellites is the availability of appropriate spectral bands. Monitoring of lava flows is best done at 3–4 micrometre (MIR) and 9–12 micrometre (TIR) wavelength. However, the spatial resolution of meteorological satellites is usually very coarse. This may cause significant errors in analysing the data.

We present the first long term satellite monitoring of an active lava flow on Stromboli volcano (Aug.–Oct. 2014) at high spatial resolution (160 m). The data were retrieved by the micro-satellite TET-1 developed at the German Aerospace Center (DLR). It carries three cameras: one operating in VNIR, one in MIR and one in TIR spectrum. MIR and TIR cameras are dedicated for monitoring of high temperature events. High resolution data in MIR spectrum are often saturated when observing fresh lava. TET-1 provides also on board processing which makes it possible that in the case of saturation the instrument gain is adjusted to avoid saturation.

During the effusive activity of Stromboli, TET-1 we retrieved 27 datasets. Most of them were very useful for monitoring of the lava flow shape, temperature and its radiant power. To constrain the accuracy of the satellites observations, we simultaneously observed the lava also by ground measurements using a pair of infrared cameras measuring in SWIR (2–2.5 micrometre), MIR and TIR spectra.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-116

The influence of magma system properties and edifice load on volcano growth

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In this work we developed a simple model for the construction of a volcano edifice by multiple additions of lava flow units. We applied the model using morphological parameters from volcanoes of the Andes of Chile. We tested how the magma system properties such as depth and volume of the magma chamber and magma rheology control the resulting morphology of the volcano. Our analysis shows that the shape profile, height and base extent of a volcano will depend on the dynamics of the lava flow advance which in turn is controlled by the magma system properties and the effects of the volcanic edifice load on the pressure gradient of the ascending magma.

Voluminous volcanoes (> 200 km^3), with heights in excess of 2,000 m, with concave-upwards profiles and with a base radius >10 km are fed by strongly over-pressurized magma reservoirs deep in the crust (>15 km depth). In these volcanoes, erupted volumes and final lengths of individual lava flows are kept constant through time. Examples of this kind of edifices are the Villarrrica and Llaima volcanoes in the Southern Andes of Chile. On the other hand, small volcanoes (<50 km^3), with heights less than 1,500 m, straight line topographic profiles and base radius < 5 km are constructed by weakly over-pressurized surficial magma chambers (<8 km depth). The erupted volume and final length of lava flows decrease with time. Examples of this type of morphology are Lascar and Lonquimay volcanoes in the Central and Southern Andes. Our results provide a methodology to extract magma chamber parameters from the morphologic characteristics of a volcano are in good agreement with previous estimates. Our model can be used to study extraterrestrial volcanoes to image their magma system.
Acknowledgements to FONDECYT project N°11121298.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-117

Automated detection of new impact craters on Mars using Bayesian models

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The ongoing Mars Reconnaissance Orbiter (MRO) mission has returned enormous volumes of data and revolutionized our understanding of the planet's dynamic surface and atmospheric processes. Among the instruments onboard MRO, the Context Camera (CTX; 6 m/pixel) and High Resolution Imaging Science Experiment (HiRISE; 0.3 m/pixel) have surveyed ~85% and ~2% of the planet's surface, respectively. This growing dataset contains >48,000 CTX images (>3.7 TB) and >33,000 HiRISE images (>23 TB), including numerous overlapping image-pairs. During the past decade, 500 new impact craters have been identified on Mars, and we have developed a Bayesian inference system to automatically search for more examples within the MRO database. The key innovation in our generative modeling approach is to formulate the change-detection problem as one seeking to explain differences in image-pairs using Bayesian inference. To achieve this goal we have created a likelihood function that describes geologic and atmospheric processes as a set of stochastic parameters that compete to explain observed changes using Markov Chain Monte Carlo sampling. Specifically, our method employs three steps: (1) automatic co-registration of image-pairs; (2) development of probabilistic models of crater morphology using examples from natural images and synthetically illuminated digital terrain models (DTMs); and (3) implementation of the change detection model to identify new craters. New components can also be easily added to this Bayesian model, thereby providing the ability to scale it to increasingly complex environments on Mars, and other planetary surfaces.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-118

Retrieving reliable lava temperatures on Earth and Io using multispectral VNIR image data

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Active silicate eruptions have been observed on Jupiter's Moon, Io, but information about Io is restricted to remote sensing data. One of the most basic parameters of an eruption, the temperature of the molten lava, is a challenge to determine remotely. This is because (1) newly exposed molten lava cools rapidly, (2) there are sub-pixel thermal heterogeneities, and (3) there is uncertainty in the spectral emissivity of molten lavas. Lava temperatures on Io contribute to knowledge of a putative magma ocean and the composition of Io, which in turn provide constraints on tidal heating of all the Galilean satellites and on the formation of the Jovian system. The remotely retrieved lava temperatures on Io indicate silicate volcanism, but there are uncertainties in the retrieved lava temperatures – leaving uncertainties in the composition of Io's dominant magma (e.g., mafic or ultramafic). We have conducted field imaging experiments on active basalt lava flows in Hawai'i and Iceland using a high-speed (60 fps), multispectral, VNIR camera capable of near-instantaneous wavelength separation and image acquisition. The camera was calibrated using a high-temperature (600-1500 ?C) blackbody. Both brightness temperatures and 2-channel-ratio color temperatures were retrieved for comparison. For the Hawaii data, the resulting maximum temperatures (1087-1109 ?C) were close to the in situ measured temperature (1140 ?C), providing confidence in the method. The data were analyzed to assess the error in retrieved temperature caused by time differences in multichannel measurements used to derive color temperature, and to determine how much time can pass between acquisition of two spectral images used to derive color temperature and still obtain a reliable lava temperature.

IAVCEI (Volcanology, Geochemistry)

VS26p - VS26 Volcanic Landscapes across the Solar System: from Field to Remote Sensing Analysis

VS26p-119

Evidence for Amazonian highly viscous lavas in the southern highlands on Mars

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We have identified small-scale volcanic edifices, two cones and three domes with associated flows, within Terra Sirenum, a region situated in the martian southern highlands. Based on thermal, morphological, and morphometrical properties, and the determination of absolute model ages, we conclude that these features were formed by volcanic activity in the mid-Amazonian epoch, relatively recently in martian history. If our hypothesis is correct, this small volcanic field represents rare evidence of young volcanic activity in the martian highlands situated far from any known major volcanic centres.

Observed edifices show the steep-sided morphologies which suggest that highly viscous lava formed them. Our conclusion is that observed edifices are martian equivalents of terrestrial lava domes and coulées. On Earth, such landforms are usually formed by highly viscous evolved lavas, i.e., andesitic to rhyolitic, for which observational evidence is sparse on Mars. More recently, however, based on orbital spectroscopic observations and rover-based in situ measurements, several studies indicate that evolved magmas may have been generated on Mars, but there are only few direct observations of kilometre-scale edifices that may be composed of evolved magmas. Hence, this field might be one of only a few localities where martian evolved lavas might be investigated in detail. Further investigations are required to elucidate the origin of these edifices; they clearly represent ideal candidates for detail spectroscopic observations. But if this field is really composed by evolved magmas, such lavas seem to be more widespread on Mars than previously thought.

IAVCEI (Volcanology, Geochemistry)

VS28a - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-2310

Igneous body construction and magma chamber evolution: insight from field observations, geophysics, geochronology, petrology and modelling

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A series of different conceptual models of magma chambers are used by geophysicists, petrologists or field geologists. However, when the observations issued from different disciplines are taken together, a coherent model of shallow magma bodies construction emerges. According to this model, igneous bodies grow incrementally by addition of horizontal or inclined magma sheets and the size of the associated magma chamber evolves as a function of the sheet emplacement rate.

Laboratory experiments exploring the conditions for dyke conversion into sill provide physical support for this model. Heat transfer calculations show that the rate of magma transfer through a feeder dyke is much higher than the growth rate of intrusive bodies inferred from high precision zircon geochronology. This implies that the construction of those intrusive bodies is incremental. Repeated addition of sills or dykes bending progressively into sills or inclined sheets account for the tabular or funnel shape of plutons as inferred from geophysical and field studies.

The Torres del Paine Intrusive Complex provides an example where the contacts between increments are visible in the field and its history can be reconstructed based on field observation, geochronology and numerical simulation. At Soufrière Hills volcano, we used seismic tomography of the magma chamber and numerical simulations constrained by petrological, geochronological and geodesic data to estimate intrusive fluxes.

The information on magma chambers and melt reservoirs we access have been modified and filtered. They are often affected by late-stage processes. Nevertheless, by confronting a large number of diverse observations we draw a progressively clearer picture of what magma chambers are and how they evolve.

IAVCEI (Volcanology, Geochemistry)

VS28a - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-3769

Stress changes, focal mechanisms and earthquake scaling laws for the 2000 dike at Miyakejima (Japan)

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Faulting processes in volcanic areas due to diking intrusion result from a complex interaction of fluid-filled cracks with the host rock and local and regional tectonic setting. There is a need for models linking the mechanisms of dike intrusion and the induced seismicity in terms of the physical processes involved. Here we use focal mechanisms data of the swarm induced by the 2000 dike intrusion at Miyakejima (Japan), to study the relation between 3D dike-induced stresses and characteristics of the seismicity. We identified the families of focal mechanisms (FMs) through a clustering analysis and relate them to the dike stress field and to the scaling relationships of the earthquakes. The clustered families show predominately normal and strike-slip component of the slip. We find that the tension axes of all FMs is consistent with the dike-induced extensional stresses while Pressure and Null axes cover all possible value from normal to strike-slip mechanisms. We demonstrate this is consistent with optimally-oriented faults according to the expected pattern of Coulomb stress changes induced by the dike. We calculate the frequency-size distribution of the clustered sets finding that focal mechanisms with a large strike-slip component are consistent with the Gutenberg-Richter relation with a b-value about 1. Conversely, events with large normal faulting components deviate from the Gutenberg-Richter distribution with a marked roll-off on its right-hand tail suggesting a lack of large magnitude events ($M_w>5.5$). This can be interpreted as resulting from the interplay of the limited thickness and lower rock strength of the layer of rock above the dike, where normal faulting is expected, and lower stress levels linked to the faulting style and low confining pressure.

IAVCEI (Volcanology, Geochemistry)

VS28a - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-4410

Structural and kinematic analysis of dyke propagation and magma flow direction in glassy rhyolite dykes: Arran, Scotland

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We use abundant mesoscale kinematic indicators within a 5-14 m thick, flow-banded rhyolite dyke in Arran, Scotland, to reconstruct the directions and style of dyke propagation and subsequent magma flow. Concave-inward dyke margin segments with plumose-like structures record vertical and horizontal propagation of lobes which inflated, and linked to form a through-going sheet. Glassy central parts of the dyke are flow-laminated and preserve folded and refolded isoclinal, intrafolial folds and sheath folds that record sustained progressive deformation. Marginal zones at bends in the dyke are devitrified, showing gentle to open folds that record relatively low strain approaching the dyke margin. The inner interface between the glassy and lithoidal facies is abrupt and marked by elongation lineations and mullion structures. Fold axes in the glassy rhyolite plunge 27° NE, along the dyke, and are parallel to elongation lineations. Combined with shear sense indicators (sigma and delta objects; sheared vesicles and asymmetric folds), lineations indicate magma flow was obliquely upwards, to the SW, locally ≤60°to the propagation direction of the dyke. The distribution of structures within the rhyolite indicates local accretion of the (now) devitrified material to the margins, and flow localization into the dyke centre. Mullions indicate that accreted magma at dyke margins had developed significantly higher viscosities, even while magma flow continued along the centre. Post emplacement devitrification has locally obscured the early magma flow record, but preserves later deformation (as open folds and buckle folds) induced by the sustained flow along the remaining central part of the conduit.

IAVCEI (Volcanology, Geochemistry)

VS28a - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-4881

What arrested the 2000 dike intrusion at Miyakejima (Japan)?

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Magma stored beneath volcanoes is sometimes transported laterally by diking. The driving force for lateral dike propagation is generally a combination of a lateral tectonic stress gradient, the stress gradient due to the topography, and the overpressure of the magma chamber. The intensity of the resulting driving force generally decreases with the distance from the magma chamber, favouring dike arrest. Additional processes may contribute to arresting a dike: one of the most poorly known is dike-fault interaction.

The 2000 dike intrusion at Miyakejima volcano, Izu arc, Japan, propagated laterally for about 30 km before hitting a strike-slip fault system, sub-perpendicular to the dike plane, an area where the topography slope was changing from downhill to uphill. The dike arrest concided with a M>6 earthquake. After the arrest, the dike continued to inflate, indicating that there was no shortage of magma supply from the reservoir.

Here we investigate whether the dike was arrested by the earthquake, by the inversion of the topographic profile, or whether both processes are needed to explain the dike arrest. We use a boundary element approach to quantify the effect of topographic inversions and dike-faulting interaction with a pre-stressed fault on a propagating dike, with application to the Miyakejima intrusion. We find that the topographic stress gradient alone cannot explain the arrest at the observed location. Dike-faulting interaction can explain the arrest, but cannot explain the pattern of the induced seismicity.The joint effect of the topography and the stress induced by the strike-slip fault is consistent with the observed dike arrest and inflation phase, and with previous findings based on inversion of GPS measurements and seismic data.

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VS28a - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-5511

Rate of lateral magma migration beneath submarine volcanic arcs derived from earthquake swarm analysis

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This contribution deals with subduction-related submarine magmatism. We are offering a tool to contribute to delimitation of domains of current magma unrest at convergent plate margins and to better understand behaviour of magma beneath the Earth's surface: a detailed analysis of teleseismic earthquake occurrence. A specific seismicity pattern has been observed beneath submarine portions of several volcanic arcs at convergent plate margins (Andaman Sea region, southern Ryukyu area). We have found three arguments that allowed us to interpret such a seismicity pattern as a magma-driven process: (i) clustering of medium-size earthquakes (M~5) in space and time in shallow earthquake swarms; (ii) rapid migration of seismic activity during the swarms (comparison of epicentral maps of individual stages of the swarm development showed consistently that earthquake epicenters migrate laterally at a rate of several hundred meters per hour); (iii) correlation of epicentral zones of the swarms with distinct seamounts and submarine ridges (current seismically active intrusions probably propagate along plumbing systems that served as a conduit of magma to the surface in the past). The repeated occurrence of magma unrest at shallow depths reflected by earthquake swarm occurrence favors the studied areas – the Andaman Sea region and the southern Ryukyu area – to be potential sites of submarine volcanic activity.

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IUGG-0829

Detection and characterization of shallow magmatic intrusions in terrestrial planets

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The transport and storage of magma depends primarily on the magma and crust relative buoyancy. On the Earth, the volume of intrusive magmatism, stored within the crust, is estimated to be 5 to 10 times the volume of extrusive lavas. The crust of the Moon was formed by floatation of light plagioclase minerals on top of the magma ocean. The lunar crust is thus characterized by a particularly low density, which should favor magma storage at depth, preventing its eruption. On the contrary, the crust of Mars seems particularly dense, which should favor magma ascent and eruption at the surface at the expense of magma storage.

Shallow magmatic intrusions make room for themselves by lifting their overlying roof. We develop a model for magma flow below an overlying elastic layer characterized by a flexural wavelength L and study the dynamics and morphology of the magmatic intrusion. We demonstrate that, depending on its size, the intrusion can show two different shapes: a bell shape when its radius is smaller than 4 times L or a flat top with small bended edges when its radius is larger than 4 times L. These characteristic shapes for the intrusion result in characteristic deformation at the surface that also depends on the topography of the layer overlying the intrusion.

Using this model we look for, detect and characterize shallow magmatic intrusions in the crust of the Moon and Mars. The lunar crust presents many sites and evidences of magmatic intrusions. On Mars, however, shallow intrusions are present, but in the specific context of the presence of ice and water in the subsurface. These results are consistent with the observed crustal density on the Moon and Mars.

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IUGG-4694

Subsurface dynamics and longevity of the Lusi mud eruption, East Java, Indonesia

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The Lusi mud eruption began in May 2006 near Sidoarjo, East Java, Indonesia and continues at present. Lusi is the largest and longest-lived subaerial mud eruption ever witnessed, and has had tremendous social and economic impacts. Hence, understanding the subsurface mechanics of this erupting system remains an important challenge. Gas and fluid chemistry, clay mineralogy, microfossils, water content, and temperature of the erupting mud and fluids all indicate that the erupting mud is drawn from the Upper Kalibeng Formation (1200-1800 m beneath Lusi), and that there is an additional, deeper (>4 km) source of fluids [Mazzini et al. 2012]. However, it is not clear how many additional fluid sources contribute on eruptive timescales and how the contributions of these sources have changed over the course of the eruption.

We use interferometry of L-band SAR images from May 2006-April 2011 to measure ground deformation associated with Lusi. We find evidence for two subsiding regions, one associated with Lusi and the other associated with the Wunut gas field. We use the ground deformation measurements to constrain an inverse model for the spatiotemporal evolution of the mud and fluid sources. Our inverse model indicates the withdrawal of fluids from a shallow (<2000 m) region beneath Lusi as well as a deeper region (>4000 m), consistent with gas and fluid chemistry. Finally, we use principal component analysis to show that both discharge and subsidence rate have been decreasing exponentially since early 2007 and that the discharge from Lusi will likely decrease to <1,000 m^3/day (less than 1% of the peak discharge) within the next 2-3 years, provided that the behavior of the system does not change, and in particular that a caldera does not form.

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IUGG-4788

"Contribution of geodetic observations towards a multi-disciplinary approach for studying the plumbing system feeding the 2014 fissure eruption at Holuhraun"

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Over two weeks propagating seismicity and deformation revealed the onset of a rifting event with the formation of a 45 km-long segmented dyke extending from subglacial Bárðarbunga caldera and towards the Holuhraun plain north of the Vatnajökull ice cap. A major effusive eruption of lava began on 31 August in Holuhraun plain, which is still ongoing at the time of the writing, early February 2014. Open fissures forming a graben developed above the northern end of the dyke. In September, the surface deformation in Holuhraun plain was dominated by the dyke opening and movement along fissures. In October, only minor deformation was detected in the vicinity of the dyke while the eruptive activity was still strong.
In order to better understand the active volcanic plumbing system feeding the eruptive activity at Holuhraun and its space-time evolution, we carry out an integrated study combining geodetic, seismic and gas observations for the first two months of the eruption in order to investigate the link between ground deformation, magma transfer at depth and the eruptive activity. A large data set of synthetic aperture radar (SAR) images, acquired by TerraSAR-X and CosmoSky-Med satellites, has been used to form interferograms. These data are complemented with three dimensional displacements observed by GPS in the area. Using the series of interferograms, we perform a joint inversion of interferometric SAR (InSAR) images and GPS using a Bayesian approach to characterize the time evolution of the dyke opening at depth. We compare the dyke opening, the seismicity and movement extracted along the open fissures in each interferogram to investigate

magmatic processes. We finally consider how these results compare to the gas measurements, used as one proxy of the eruptive activity.

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IUGG-4987

Muon radiography of Stromboli volcano using nuclear emulsions technique

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Muon Radiography (Muography) method developed in the last decade allow to obtain information about the internal structure of a volcanic edifice using the cosmic rays passed through. The particles flow density and direction had to be detected by the special telescopes. Different particle detection techniques may be used for that.
Nuclear emulsions-based tracking detectors has a number of advantages in a field of muon radiography of volcanoes in respect to the electronic ones: easy to install, compact, do not require electricity, have high angular resolution. On the other hand the data acquisition is quite complicated. We used the emulsion scanning technology developed by Italian groups for a large scale accelerator particle physics experiments like OPERA (1.5 Kton of active emulsion-lead target) for analysis of muography data.

Stromboli is one of the most known and well studied active volcanoes in the world. Nevertheless the details of its internal structure are not well defined yet. Resolution of traditional geophysical survey methods (as seismic, etc) of the order of 0.1-1 km does not allow the detection of the possible gas and lava channels under Sciara di Fuoco, the most interesting part of the dome. We applied the muon radiography method for that. A nuclear emulsion detector of about 1 m^2 active surface was installed on the volcano slope in October 2011 and it was kept there for 5 months of exposure, integrating cosmic rays. Details of the detector preparation, exposure, data analysis and results will be reported here.

IAVCEI (Volcanology, Geochemistry)

VS28c - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-0393

Amphibolic perspective of subvolcanic magmatic systems of andesite-dacite volcanoes: case study from the Ciomadul volcano (E-Carpathians)

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Petrological mapping of volcanic plumbing systems (VPS) is essential to reveal pre-eruptive magmatic processes, conditions and to interpret geophysical signals of monitored volcanoes. Amphibole is an ideal mineral in andesite-dacite magmas to determine the conditions and processes of the VPS due to its sensitivity to magmatic variables (p, T, fO_2, fH_2O, X_{melt}). We present detailed textural, geochemical and calculated geothermobarometric data of amphiboles from the youngest dacitic volcano of the Carpathian-Pannonian Region. The amphiboles show large compositional variation (Al2O3: 6-15 wt%, Cr: 10-3000 ppm, Sr: 55-855 ppm, Eu/Eu*: 0.62-1.19) even in a single sample or single crystal and they represent antecryst (reworked) and phenocryst (in situ crystallized) populations. Hornblendes (antecryst1) have low Al, Mg/Fe, Ba, Sr, Zr content and marked Eu/Eu*; they equilibrated with rhyolitic melt at near-solidus temperature during the late stage of their crystallization. Pargasites (phenocrysts) have high Al, Mg/Fe, Ba, Sr, Zr and no Eu/Eu*, crystallized at high T (>900°C) from a more mafic melt. Hornblendes with pargasitic overgrowth are often found (reverse zoned amphiboles) but never the opposite. Antecryst2 is represented by Cr-, Mg-rich amphiboles; they can contain Cr-spinel inclusions suggesting near-liquidus crystallization from primitive melts. Such a large compositional variation of amphiboles is commonly observed at andesite-dacite arc volcanoes. The antecrysts are derived from a stratified (mafic-felsic) crystal mush column representing a main magma capture zone at upper-mid crustal depths (~7-20km). Pre-eruptive

conditions are indicated by the phenocrysts suggesting reheating before eruptions. New intrusions can reactivate these mushes forming the eruptible magma.

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VS28c - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-4355

Longevity of crystal cargo vs. transience of melts in magma systems

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Volcanic plumbing systems, particularly in continental arcs, have long been recognized as sites of open system processes. Disequilibrium textures or zoning in phenocrysts result if growth is coeval with assimilation or mixing. Dating of growth zones measures a crystal’s residence time in the plumbing system, but not necessarily its residence time in the host melt. Indeed, the relative amount of time spent by melts vs. crystals in any particular crustal reservoir may be very different.

At Parinacota Volcano (central Andes), the system transitioned from tapping of a stagnant, silicic, crystal-rich mush to a more dynamic, mafic, crystal-poor system over ca. 30 k.y. Bulk lava chemistry and isotopic composition during initial stages of this transition (47-28 ka) indicate the magmatic system was compartmentalized: one evolved to more silicic compositions consistent with fractional crystallization, whereas the other became slightly more mafic, consistent with recharge. Despite heterogeneity of host melts, their crystal cargoes are homogenous in terms of mineral phases present, their chemistry, age, and recorded P-T conditions.

The bulk composition of lavas varies from eruption to eruption, on timescales of hundreds to thousands of years – evidence that melts reside in the system relatively briefly. In contrast, U-Th dating indicates the crystal cargo is much older (up to 350 k.y.), especially in the case of zircon. Reconciling these two lines of evidence suggests that: (1) the same cohort of crystals remains in the magma reservoir for periods of time much longer than it takes to build a volcano, (2) the presence of any given melt is ephemeral, and (3) the capacity of melts to transport crystals to the surface is limited and varies with recharge rate.

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IUGG-4803

Anatomy of the late Pleistocene Ciomadul volcano (E-Carpathians, eastern-central Europe), a volcano with Potentially Active Magma Storage

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There are a number of long-dormant and seemingly inactive volcanoes in the Earth that could pose a potential threat. The ability of such volcanoes to become reawakened depends primarily on the state of the magmatic plumbing system. Existence of a melt-bearing magma body beneath the volcano and evidence for its prolonged lifetime and intermittent rapid remobilization in the past could mean a potential that the volcano might be active again. Thus, it can be classified as volcano with Potentially Active Magma Storage. We present here an example for such a PAMS volcano from eastern-central Europe. The late Pleistocene dacitic Ciomadul erupted last time 32 ka, but a magnetotelluric survey indicated a low electric resistivity values in the depth interval of 5-25 km, just beneath the volcanic centres. This can be interpreted as implying a partially melted zone, containing about 5-15% melt fraction. This is consistent with the seismic tomography model that indicates a low-velocity zone at the same depth and with CO2-rich gas emanations having elevated He isotope ratio. A detailed petrologic study revealed that in the past a silicic crystal mush body resided at 7-14 km depth and was rapidly reactivated by major reheating (about 200^{o}C temperature increase) due to the arrival of hot mafic magma. The wide range of U-Th model ages of the studied

zircons indicates prolonged existence of the low-temperature silicic crystal mush beneath the volcano. Crystallization of zircons within the crustal magma chamber started >100 ka before the onset of the volcanic activity. The volcanic history suggests that the melt-bearing crystal mush was rapidly remobilized even after a protracted (several 10's of ka) lull in volcanism to trigger successive eruptions in a comparatively short time window.

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IUGG-1971

Evidence for steady-state dynamics of open-vent mafic volcanoes

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Open-vent systems (e.g. Mayon, Arenal, Llaima, Etna), frequently erupt (years to decades for a hundred years or more) compositionally similar magmas, and thus be could be modelled as a quasi-steady state system. Here we investigate this hypothesis with the following questions: (1) is the magma composition and timing of replenishment constant with time, or is there some cyclicity of the parameters? (2) what are the proportions of incoming versus resident magma, and how much of the reservoir is evacuated with each eruption? These are key questions for improving hazard evaluation, and better understanding the unrest associated with these types of volcanoes.

The petrology and geochemistry from several historical eruptions that span over 35 years of activity (1947, 1968, 1978, 1984) of Mayon volcano (Philippines) shows that all lavas are basaltic andesite with phenocrysts of plagioclase + orthopyroxene (Opx) + clinopyroxene. Opx crystals show a variety of compositions and zoning patterns (reverse, normal, or complex) with Mg# (= 100 *Mg/[Mg+Fe]) varying from 67 to 81. The variety of core compositions and patterns can be interpreted simply as mixing and mingling between an evolved resident magma and a more mafic one. There is a general increase in the maximum Mg# of the Opx from 1947 to 1984, indicating a higher proportion or/and more mafic intruding magma. Mg-Fe diffusion modelling of orthopyroxene shows that times since magma injection and eruption are all between 2-4 months. Thus these times appear to be characteristic of Mayon, and should be considered when interpreting monitoring data linked to unrest. Our results also suggest limited crystal recycling between eruptive events, which support the steady state model consisting of a relatively constant amount of volume.

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IUGG-2423

Magma supply processes after a lateral collapse – insights from a major lava flow field on La Palma's Bejenado volcano

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The giant lateral collapse (≈0.53 Ma) of the western half of the Canary Island of La Palma’s most active rift was followed by the brief, rapid growth of the Bejenado volcano. Nested entirely within the resulting collapse structure, Bejenado was La Palma’s primary eruptive center before activity migrated permanently to its south.

Our field studies of this volcano have identified a major lava flow field: the Bejenado Effusive Phase (BEP) unit. This superbly exposed 100m thick field exhibits considerable compositional complexity and provides an excellent case study on which to investigate the coupling between eruptive processes and those in the magma supply system. Furthermore, it provides a petrological record of the onset of volcanism after a major lateral collapse.

Early effusive products were primitive, highly porphyritic (>40% crystals) ankaramites. These transitioned into progressively more evolved plagioclase-rich basalts that became highly trachytic in the uppermost part of the sequence. The petrographic textures of the ankaramites are consistent with a clinopyroxene, olivine cumulate disrupted in the late stages of crystallisation by a fresh pulse of more primitive magma. These contrast with the later products which are the only known plagioclase-phyric rocks on northern La Palma, suggesting that crystallisation conditions were unusual. Cpx-melt thermobarometry[1] indicates that all crystallisation took place at mantle depths.

It is likely that this complex story of magma reservoirs and crystallisation processes is related to post-collapse rejuvenation of the island’s magma supply, but the mechanism linking these processes is at present unclear.

1. Galipp, K., Klügel, A. & Hansteen, T. H. (2006), JVGR.,**155,** 285–306

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IUGG-2562

Insights into magmatic process below open vent volcanoes using crystal pattern recognition techniques

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The understanding of the plumbing system and processes below open vent volcanoes crucially depends on the interpretation of chemical and textural information recorded by their crystals. Many mafic open vent volcanoes (e.g. Mayon, Stromboli, Etna, Llaima) show a large variety of phenocryst textures; in particular plagioclase shows a complex textural and chemical record that defies interpretation. Thus, despite the abundance of plagioclase and the easy extraction of textural and chemical data (e.g. electron backscattered images), we are left wondering what it may mean. To alleviate this problem we have started a numerical and natural study of plagioclase crystals. A 3D numerical crystal model of varying aspect ratios and with multiple chemical zones was produced and cut at random orientations to simulate the typical thin sectioning. Simulations show that only 2D sections with the largest number of zoning patterns, particular crystallographic orientations, and the largest number of outer faces really reflect the true zoning pattern. Thus, a good part of the variety of the textural and chemical features of plagioclase phenocrysts may simply be explained by the effect of random 2D cutting of 3D zoned crystals, and does not necessary imply complex magmatic processes. Different 1D traverses along 2D sections also show complex relations, thus making 1D data comparison within and between crystals challenging. We have started to work on the (mostly automatic) extraction of features from images that maximize invariance within the 1D traverses of a single crystal, as a first step towards the application of pattern recognition methods such as the self-organizing maps. This should lead to a more realistic record of magmatic processes from complexly zoned plagioclase crystals.

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IUGG-3169

Magma chamber dynamics prior to the 1400BP eruption of Rabaul, Papua New Guinea

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The 1400BP eruption of Rabaul erupted >11km^3 of mainly crystal-poor dacitic magma, and lead to caldera collapse. Following an initial Plinian phase, multiple pyroclastic flows were then emplaced. In order to identify any pre-eruptive reservoir stratigraphy, we have sampled throughout the eruptive sequence: the Plinian fall deposit, the basal surge unit, the base and top of the massive ignimbrite, and in the uppermost ignimbrite veneer deposit. The presence of mafic xenocrysts (e.g. olivine) suggests mixing between basaltic and silicic magma, however there is also evidence for mixing between two dacitic magmas. EMPA analyses of matrix glass lie on two distinct linear trends on plots of K_2O against SiO_2. Most analyses lie on the trend defined by the whole rock chemistry of almost all eruptive products from Rabaul. X-ray maps show that another, microlite-rich magma with low K_2O glass is mingled with the high K_2O glass. This low K_2O glass resembles magma erupted during a previous caldera-forming eruption, and may represent remnant magma that was remobilised during the 1400BP eruption. Melt inclusions in plagioclase (An_{35-55}), clinopyroxene (Wo_{35-45}, En_{40-50}) and orthopyroxene (En_{70-75}) phenocrysts also fall on the low K_2O trend. LA ICP-MS analyses of these glasses and the host minerals provide trace element data that, along with petrological modelling, help to pinpoint the sources of these two melts. Volatile contents of the melt inclusions have also been measured. Preliminary SIMS data from the Plinian phase shows that the magma initially held up to 6-7wt% H_2O and 1100 ppm CO_2. However, most melt inclusions have lower volatile contents and suggest storage at about 200MPa (~7km).

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IUGG-3445

Decadal timescales of magma mixing at a steady-state volcano: the case of Stromboli Volcano, Italy.

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The present-day persistent activity of Stromboli, usually characterized by strombolian explosions ejecting black scoriae lapilli and ash, is interrupted by effusive eruptions and paroxsyms which also discharge a few amount of gold pumices from a deeper reservoir.The entire system is in steady-state conditions whose driving forces are still not completely understood. Investigating the evolution of the plumbing system toward the present-day condition is crucial to better constrain and understand the dynamics of the Stromboli volcano.

We studied the transitional eruptive phase from the pre-Sciara period to the present-day: (i) the Post-Pizzo pyroclastic succession emplaced prior to the beginning of the present-day activity; (ii) a scoriaceous spatter ejected during one of the early paroxysms of the present-day activity. Multiple banded clinopyroxene with evident resorption features characterizes the older Post-Pizzo products, recording several pulsatory intrusions of new mafic magmas into the system and pointing to the establishment of steady-state condition. Contrarily, single diffused band and/or patchy cores are found in the Present-day spatter. We applied the new NIDIS (non-isothermal diffusion step incremental model, Petrone et al., this session) chronometry to suitable clinopyroxene crystals to constrain the timescales of these refilling events. Decadal timescales (up to 40 yrs) characterise the shallow magma reservoir from the post-Pizzo period, whilst the Present-day activity is characterized by shorter residence time (20-3 yrs). Our results point to a progressive transition from the Post-Pizzo toward the present-day conditions and to consider the dynamics of the Present-day activity as linked to very short timescales of magma interaction.

IAVCEI (Volcanology, Geochemistry)

VS28d - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

IUGG-3706

The plumbing system beneath Quizapu volcano, Chile

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Quizapu is part of a linear system of active volcanos in central Chile. The volcanic petrology and geology have been used to infer the plumbing system beneath the volcano. The 1846-7 eruption (5 km3) started with small flows of dacite, then changed to a range of andesite-dacite compositions and finally terminated with large flows of dacite. Andesitic enclaves occur in some of these flows. Activity restarted explosively in 1932 (5 km3) with an initial andesite-dacite ash, followed by uniform dacite ash and then a terminal andesite ash. All samples, including the enclaves, have compositions that lie on an almost perfect mixing line. The abundant plagioclase macrocrysts were divided into five petrographic groups. Two groups can be ascribed to growth in andesite and dacite magmas, but the 3 other groups are associated with particular magma batches. Initially, andesite magma ponded and differentiated to produce a dacite magma, most of which probably solidified to make a granodiorite batholith. Activation of a N-S fault enabled volcanism: Andesite magma traversed the dacite-filled chamber, heating and raising it up into storage areas hosted by the fault. Here, bubble growth on plagioclase promoted mixing. In 1846 more andesite magma was injected into the shallow part of the system and a vent opened at Quizapu. The first magma was a dacite, but soon other storage areas along the fault started to feed the system - first mixed magmas, then back to dacites. The eruption then terminated until 1932 when renewed injection of andesite into the system created a conduit that tapped a deeper, undegassed dacite chamber and resulted in a strong explosive eruption. The whole story is one of continual andesite magmatism, modulated by storage, degassing and mixing.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-477

Integration of geochemical, petrological and seismic data for the study of volcanic plumbing system of the 1975-76 Tolbachik fissure eruption

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The 1975-76 Tolbachik fissure eruption, Kamchatka is a multicentre basaltic eruption with the volume of erupted material about 2 km^3. One of the main features of this eruption is a sharp change in the rocks composition from high-Mg medium-K basalts to high-Al sub-alkaline basalts and basaltic trachyandesites with the basalts of the intermediate composition erupted during a short period when the activity center migrated. Conceptual model of this eruption, based mainly on the petrological observations, supposes mixing of magmas, rising from different depths, and complex system of coupled vertical and sublateral conduits and magma storage zones, well correlated with shallow seismicity. To obtain additional data on VIPS we use new technique of passive seismics – microseismic sounding method (MSM), based on the fact that heterogeneities of the Earth's crust disturb the spectrum of the low-frequency microseisms in their vicinity (that means amplitude increasing above the low-velocity heterogeneities and decreasing above the high-velocity ones). Using MSM we detected spacious low-velocity area, interpreted as trans-crust zone of magma conductivity. Here we present the images of subvertical conduits with a set of shallow magma chambers and a sublateral conduit on the depth 4-8 km, marked by seismicity, and compare them with the petrological models. It is important, that magma conduits are space-independent, so imaging demonstrates possibility of magma uprise from different storages. At the current stage of our research MSM-based images of the subsurface heterogeneities and seismicity confirm the petrological model of the eruption. Multidisciplinary approach allows us to pass from conceptual scheme to the integrated model of the 1975-76 Tolbachik fissure eruption.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-478

Investigating magma flow within intrusions: Insights from magnetic anisotropy

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

Fieldwork was conducted in a disused quarry near Invertote, Isle of Skye, Scotland, to study how magma flow is preserved within intrusions. At this location a series of five stacked olivine dolerite sills from the Little Minch Sill Complex (c.60 Ma) intruded into Jurassic sediments. The sills are 0.5 to 8 m thick, their contacts defined by contrasts in jointing frequency, crystal layering, occurrence of gabbro lenses and variations in mineral proportion, size and composition. Two dykes cross-cut the site striking approximately 170º. Pahoehoe ropes were found preserved on the exposed margin of one dyke, indicating local lateral magma flow to the north.

Closely-spaced sampling was carried out on a selected sill and dyke to analyse their magnetic fabrics using Anisotropy of Magnetic Susceptibility (AMS) and Anisotropy of Anhysteric Remenant Magnetisation (AARM) techniques. Preliminary results from the sill suggest that susceptibility anisotropy tensors have a K_1 axis parallel to the sill plane, originating from multi- to pseudo-single domain titanomagnetite sources. Within the dyke, K_1 transitions from parallel to oblique to the dyke contacts with increased distance from the contacts, and the signal originates from both paramagnetic and ferromagnetic sources. These results are combined with a petrographic study of the same samples to provide an independent quantification of small scale magma flow trajectories.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-479

Magma mixing and mingling in Iceland: A case study of the Streitishvarf composite dyke, Eastern Iceland

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We present a study carried out on the 10.7(±0.2) My old Streitishvarf composite dyke in East Iceland. The 26m wide dyke features ~5m thick dolerite margins and a 7.5m thick felsic core, separated by distinct hybrid zones (3m-thick). The dyke margins exhibit the most primitive composition: 50.7% SiO_2 and 6.1% MgO. It is a dolerite containing <10 modal% of plagioclase and clinopyroxene phenocrysts in a sub-ophitic groundmass of plagioclase, clinopyroxene, magnetite and interstitial glass. The inner dolerite has a basaltic icelandite composition and contains resorbed quartz xenocrysts. The felsic core contains <15 modal% of phenocrysts of sanidine and quartz which sit in a holocrystalline groundmass of quartz and feldspar. Compositionally the rhyolite is borderline sub-calcic: 73-76% SiO_2 and 0.1-0.5% MgO. It contains 10-15 modal% of up to 30cm-long enclaves of icelandite composition. The hybrid zones contain inversely zoned and embayed macrocrysts of plagioclase and quartz within a devitrified groundmass. The outermost part of the hybrid zone is icelandite: 61.5% SiO_2 and 3.6% MgO. Inward it becomes progressively more silicic, where the innermost zone is dacite: 67.6% SiO2 and 1.87% MgO.

The hybrid zones were produced by mixing of the end members, as indicated by linear mixing trends on bivariate plots. Hence the formation of the hybrid zone is best described as a sequential in situ mixing, starting with the basalt and rhyolite. This was followed by mixing of the newly formed hybrid with the rhyolite, this was repeated in succession making each hybrid segment more silicic with time.

Our observations imply that the production of icelandite by mixing of basalt and rhyolite magmas is confined to segments of flow-induced shear and is an energy consuming process.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-480

Petrological and experimental modelling of cooling histories in magma bodies

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The extent and consequences of convection in crustal magma chambers has been the subject of debate for decades. Particular issues concern the extent to which solid particles may be redistributed by convective flow in the bulk magma, and the extent to which liquid may convect within the crystal pile on the chamber floor.

We have derived a theoretical model of the different convective regimes possible in a non-crystallising system in which convection in the mush pile and overlying fluid is thermally driven. The model has been verified by low-temperature analogue tank experiments. These experiments are heated from below and cooled from above and incorporate a permeable layer of inert particles and an overlying fluid. Several modes of behaviour are observed at various Rayleigh numbers. These modes evolve from suppressed mush convection (at low Rayleigh numbers), through to the eruption of crystal fountains, to the entire mush pile becoming entrained into the convecting fluid.

Quantitative microstructural textural analysis of mafic intrusions can be used to describe whether these conditions occur in igneous intrusions. Studies have shown that the average apparent aspect ratio of plagioclase observed in thin sections from basaltic sills correlates with the time taken to crystallise, assuming conductive cooling. This relationship does not extend to dykes, with generally higher values than expected for any given intrusion thickness. These observations could be due to vigorous convective scouring in dykes resulting in removal of the sidewall mush and entrainment into the interior. In contrast, convection is insufficiently vigorous/long-lived in sills, preventing scouring and disaggregation of the floor mush which therefore records in situ crystallisation during conductive cooling.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-482

The Nealticán fissure eruption, Popocatépetl, Mexico: From magma mixing to eruption within days

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Magma mingling and mixing are dominant processes at Popocatépetl volcano, Mexico, and are generally believed to be common causes for eruptions. However, the (potential) correlation of the eruptive style with frequencies of magma mixing and the speed of ascent after mixing remains largely unknown for Popocatépetl. We present whole-rock and mineral compositions for the Nealticán lava flow, which originated from a fissure on the NW flank of Popocatépetl before the latest Plinian eruption at ca. 1100 y BP. Nealticán rocks are andesites with varying vesicularity and a phenocryst assemblage dominated by plagioclase (An_{29-62}) and pyroxene in a cryptocrystalline matrix. Pyroxenes are clinoenstatites (Wo_{2-5}) and can be subdivided into a low-Mg (Mg# = 59-67) and a high-Mg (Mg# = 76-86) group as well as a hybrid, zoned population, typified by low-Mg cores and high-Mg rims. Mineral compositions, combined with the presence of evolved glomerocrysts suggest the injection of a mafic endmember melt into a partly crystallised, more evolved magma body, and subsequent magma mixing. Numerical modelling of Fe-Mg diffusion in the zoned pyroxenes suggests magma mobilisation, ascent and eruption within hours to days after the mixing event. Similar, comprehensive studies of both Plinian and low- to moderately explosive eruptions at Popocatépetl will be collated to create a differential model of pre-eruptive conditions in the plumbing system.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-483

Sill geometry and distribution in tectonically inert settings: The san rafael sub-volcanic field, Utah, USA

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Complex sill-network intrusions in basin settings can have significant impact on subsurface fluid flow (e.g., acting as aquitards or aquicludes to water aquifer and hydrocarbon systems), geothermal systems, and the maturation of hydrocarbons. Models for these effects are critically dependent on the models for sill emplacement, and the resulting geometry and distribution of the sill network. Here we present preliminary field observations from the San Rafael Sub-Volcanic Field (SRSVF); the subsurface plumbing system of a monogenetic basaltic volcanic field, which was emplaced during a period of tectonic quiescence. The SRSVF hosts dykes, sills, and volcanic breccia bodies, which were intruded into Jurassic strata of the San Rafael Group between 3.7 to 4.6 Ma, and covers an area of about 1200 km^2, occupying an elevation range of ~500 m. Emplacement depth is estimated to be within the upper 1 km of the crust. Sill scale ranges from 50 m thick tabular units that are laterally continuous for the extent of exposure (~1-2 km), and down to cm-thick sills with lateral extents on the order of tens of metres. Thick tabular sills show vertical steps indicating progressive propagation, inflation, and linkage. Small sills form horizontal extension and extensional-shear type networks and are typically found in close spatial association with the thicker sills. On-going work aims to constrain the relative timing of thin versus thick sills, and the influence of sill emplacement on the physical and fluid flow properties of host rocks.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-484

NIDIS: The non-isothermal diffusion incremental step model. A new approach to elemental diffusion in volcanic rocks.

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Volcanic systems are normally considered as isothermal diffusing systems in which the diffusion temperature is treated as "constant" for the duration of the pre-eruptive processes. Diffusion coefficient depends exponentially on temperature and on other intensive thermodynamic variables. However, temperature is the main critical parameter. In cases were the chemical zoning pattern of minerals indicates a substantial difference (~ 50 °C) in the equilibrium temperature of the different zoned portions, we found that this produces a bias in the estimated timescales of a factor of 3 to 5. This is a significant difference and cannot be ignored.

We propose a new approach to take into account a diffusion coefficient for each compositional band in order to match the specific equilibrium temperature of the band. A mineral showing multiple bands of different composition, testifying the arrival of hotter and more mafic magma, will show multiple diffusion profiles which are the results of diffusion at different temperatures for different timescales. It is thus possible to deconstruct the main core-rim diffusion profile into different isothermal steps with its own diffusion coefficient. Each step takes into account the diffusion timescale of the previous step. The final diffusion profile is thus the result of different isothermal steps at different temperatures. We propose to call this approach the non-isothermal diffusion incremental step (NIDIS) model. This novel approach considers the so-far-ignored importance of changes in temperature, and consequently in the diffusion coefficient, also in volcanic systems. This model can also have important implications in reconsidering the meaning of crystal residence time in fast cooling systems.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-485

Potential for vanadium–titanium–iron mineralization in the 1.79 Ga Carson–Hart Large Igneous Province intrusive complex, north Western Australia

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The Hart Dolerite is the intrusive portion of the Carson–Hart Large Igneous Province in the Kimberley region of northern Western Australia. It forms a series of sills that intrude some 2-3 km beneath the eruptive surface marked by basalt lava of the Carson Volcanics. The sills are well exposed for several hundred kilometres around the upturned and folded margins of the hosting basins. The mean U–Pb crystallization ages of zircon and baddeleyite obtained from the granophyre and upper mafic sills in the Hart Dolerite is 1797 ± 11 Ma. A vanadium–titanium deposit with a measured resource of 322 Mt at 0.32% V_2O_5 and 2% Ti (King River Copper Ltd, 2014) is hosted in Hart Dolerite at Speewah Dome. One unit within the compound lower sill contains the mineralization. Abundant magnetite with elevated Ti, Fe and V cause the characteristic elevated magnetic susceptibility of the unit. Study of the sill complex regionally indicate several other areas where parts of the sill display the same architecture within the sill complex and the same set of characteristic as the vanadium-titanium hosting unit at Speewah Dome. This discovery increases the potential to target Speewah-style vanadium-titanium mineralisation elsewhere in the Carson–Hart Large Igneous Province.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-486

Assessing the ambiguity and variability of potential field models of volcanic plumbing systems. Examples of maar-diatremes from south-eastern Australia.

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Two and three-dimensional potential field modelling techniques are being increasing applied to understand volcanic plumbing systems. However, potential field models are inherently non-unique, and it is essential to analyse the robustness of the models to ensure the range of both geologically and geophysically acceptable models are understood. This process is a neglected issue when it comes to potential field modelling.

We present a method and results for a sensitivity analysis of geophysical models of maar-diatremes in order to better constrain the geometry of the diatreme, location of vents, and presence of dykes and buried lava flows. We test how the maar-diatreme models would be affected if the input variables (e.g., density, magnetic susceptibility, geometry) deviate from the apriori model. This helped identify which structures in the models were well constrained in terms of their geometry and petrophysical properties, and delineated a range of end-member models that satisfied the geophysical and geologic data.

Results of the sensitivity analyses support previous interpretations of the data, but highlight where the models are more ambiguous, and how their geometry could vary within the bounds of the property constraints. 2D petrophysical analysis suggests that the range of allowable petrophysical properties for a fixed model geometry is relatively small, indicating that the models are well constrained for the given geometry. 3D geometric analysis can determine the range of variability in the diatreme geometries due to uncertainties in their petrophysical properties. Results support the initial model geometries, but indicate that the maximum diatreme depth might be shallower if they are less dense than the reference model, and deeper if they are more dense.

IAVCEI (Volcanology, Geochemistry)

VS28p - VS28 Understanding VIPS (Volcanic and Igneous Plumbing Systems) through Multidisciplinary Research

VS28p-487

Geology, petrology and geochemistry of the tolbachik volcanic massif, Kamchatka, Russia

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Data on the geology, petrography, and geochemistry of previously geochemically unstudied Middle-Late-Pleistocene rocks from Tolbachik volcanic massif (Central Kamchatka Depression, CKD) are presented. Two volcanic series - middle-K and high-K were erupted. The geochemical history of the massif was started earlier 86 ka (K-Ar dating) with the formation of the Tolbachik pedestal presented by middle-K series. During stratovolcanoes formation both series occur and the role of high-K melts was increasing with time. In Holocene high-K rocks are dominated but some cinder cone lavas are presented by middle-K high-Mg melts which suggest that both volcanic series are still exists. The computer modeling show that both series can be explained by the process of crystal fractionation at different water content from nearly or the same mantle source similar to high-Mg basalts of 1975 Northern Breakthrough. Middle-K rocks could crystallize at water-rich conditions (more than 2% of H_2O) while the high-K rock could crystallize at dry conditions at the same pressure. However the existence of different mantle sources and possible magma mixing cannot be excluded. Our data show that fractional crystallization at different P-T-H_2O-fO_2 conditions can be one of the main processes responsible for rock variations at CKD. Sr-Nd-Pb isotopes suggest 2-4% of crustal assimilation to the magma chamber during pedestal and stratovolcanoes formation while lava-cinder

cones are not show evidences of crustal assimilation. Major and trace element data coupled with K-Ar dating provide strong evidence that Povorotnaya mount located in 8 km NE of Plosky Tolbachik is the old block of the Tolbachik massif pedestal and for the moment the oldest known object (306 ka by K-Ar dating) in Klyuchevskaya group.

IAVCEI (Volcanology, Geochemistry)

VS32a - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-1213

How will climate change impact future explosive eruptions dynamics?

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Climate models commonly assume that the average volcanic forcing is steady because of difficulties in assessing the magnitude and frequency of future volcanic eruptions. However, temperature and wind profiles also govern plume stability and height, which control the longevity of volcanic aerosols in the atmosphere, in turn. A major effect of human-induced climate change is greater variability. In the future, what will be its impact on the structure and radiative properties of eruption clouds, the likelihood of pyroclastic flows and environmental risks related to ash dispersal and sedimentation?

To investigate how changing atmospheric conditions could impact explosive eruptions we use a one-dimensional plume model applied to eruptions from various regions. We constrain the atmospheric conditions (wind and temperature profiles) using CMIP5 global climate models simulations. For each location, we carry out calculations for 4 periods with differing greenhouse forcing, between 1900 and 2100. We also constrain the eruption source conditions for each region using the data available through the global volcanism program database, and assume that they are not changing over time. Our results permit us to estimate changes in eruption plume height and stability driven by anthropogenic greenhouse gas emissions. We analyze the independent and combined effects of wind and temperature variations, as well as the sensitivity of our results regarding the region, the chosen global circulation model, and the forcing scenario. Finally, we compare the changes predicted by the one-dimensional model with popular scalings for volcanic plume height, which can be easily parameterized in a global circulation model.

IAVCEI (Volcanology, Geochemistry)

VS32a - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-1937

Observed multivariable signals of late 20th and early 21st century volcanic activity

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The relatively muted warming of the surface and lower troposphere since 1998 has attracted

considerable attention. One contributory factor to this “warming hiatus” is an increase in volcanically

induced cooling over the early 21st century. Here we identify the signals of late 20th and early 21st century

volcanic activity in multiple observed climate variables. Volcanic signals are statistically discernible in spatial

averages of tropical and near-global SST, tropospheric temperature, net clear-sky short-wave radiation, and

atmospheric water vapor. Signals of late 20th and early 21st century volcanic eruptions are also detectable

in near-global averages of rainfall. In tropical average rainfall, however, only a Pinatubo-caused drying signal

is identifiable. Successful volcanic signal detection is critically dependent on removal of variability induced

by the El Nino–Southern Oscillation.

IAVCEI (Volcanology, Geochemistry)

VS32a - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-2327

Late-Plestocene glacier melting during lava dome growth at Nevado de Toluca volcano (México): hazard implication at active, ice-capped volcanoes.20

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Nevado de Toluca volcano is one of the largest stratovolcanoes in the Trans-Mexican Volcanic Belt. During Late Pleistocene its activity was characterized by large domes grow and subsequent collapse emplacing large block and ash flow deposits, intercalated by Plinian eruptions. Morphological and paleoclimate studies at Nevado de Toluca and surrounding area evidenced that the volcano was affected by extensive glaciation during Late Pleistocene and Holocene. During the older recognized glacial period (27-60 ka, MIS 3), the glacier was disturbed by the intense magmatic and hydrothermal activity related to two dome extrusion episodes (at 37 ka and 28 ka). Glacier reconstruction indicates maximum ice thickness of 90 m along main valleys, as at the Cano ravines, the mayor glacial valley on the northern slope of the volcano. Along this ravine, both 37 and 28 ka block-and-ash deposits are exposed, and they directly overlay a fluviatile sequences, up to 40 m-thick, which ^{14}C ages clearly indicate that their emplacement occurred just before the dome collapse. These evidences point to a clear interaction between the growing dome and its hydrothermal system with the glacier. During dome growth, a large amount of melting water was released along major glacial valleys forming thick fluvioglacial sequences that were subsequently covered by the block-and-ash flow deposits generated by the collapse of the growing dome. Even though this scenario is no longer possible at the Nevado de Toluca volcano, data here presented indicate that special attention should be paid to the possible inundation areas from fluviatile/lahar activity prior to the main magmatic eruption at ice-capped volcanoes.

IAVCEI (Volcanology, Geochemistry)

VS32a - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-4356

The climate impacts of volcanic "double events"

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The major eruptions of 1808/1809 (Unknown) and 1815 (Tambora) constitute an example of a volcanic "double event", wherein the close temporal proximity of two eruptions creates the potential for climate impacts of the two eruptions to superimpose. Ice core records provide evidence of other such double events, and climate proxy records (particularly tree ring records) are used to assess the climate impact of double events compared to single events. We perform climate model simulations to investigate specific events within the last 2000 years, and assess the potential for additive climate impacts. In particular, simulations are used to investigate the impact of decadal scale volcanic radiative and dynamical anomalies on high latitude processes such as sea ice growth and ocean circulation. Our model results show that given certain conditions, two closely spaced eruptions of Tambora magnitude could have a larger cumulative climate impact than a single eruption of much greater magnitude. Based on the observational records and model results, we propose that volcanic double events are a more probable agent for abrupt climate change than very large single eruptions.

IAVCEI (Volcanology, Geochemistry)

VS32a - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-4771

Toward a more realistic assessment of the climatic impacts of the 1257 eruption based on medieval sources,tree-rings and climate models.

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Polar ice cores attest to a colossal volcanic eruption that occurred in 1257 to leave the largest sulphur signal of the past millennium and possibly the last 7000 years. Paradoxically, while climate models suggest a global surface cooling of about 2°C after the Samalas eruption, proxy-based records largely lack evidence for significant climate cooling. This stunning discrepancy has hampered the understanding of the contribution of historical volcanic eruptions to past climate changes and precluded conclusions about potential consequences of future eruptions on climate. Drawing on a compelling body of evidence from newly exhumed contemporary historical sources, tree-ring reconstructions, and a general circulation model (GCM) incorporating microphysical aerosol processes as well as information about the eruption location, season and height of SO_2 injection, we demonstrate that a persistent dry veil started to install in Europe in October 1257 to cause an average surface cooling of 1.1°C over the northern hemisphere in 1258. Converging proxy and climate model data also attest to the persistence of volcanic cooling until 1261, but point to significant regional differences of impacts. We conclude that single colossal volcanic eruptions may effectively perturb climate at local and regional scales, but that their impact is neither sustained in time nor spatially generalized.

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VS32a - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-5437

Volcanism and glacial-interglacial cycles in Iceland

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The effects of volcano-ice interaction on eruption style are well known, and volcanic successions from ice covered areas have been described for several areas. A theory relating the rate of de-compressional melting to loading/unloading effects of ice sheets also exists. Variations in the rate of magma production in the volcanic zones of Iceland have been proposed and supported by data for some regions. The relatively large lava shields that are widely found in the West and North Volcanic Zones of Iceland have been considered to indicate an early Holocene peak in volcanic production rate. Similarly, the large effusive fissure eruptions that occurred in a section of the East Volcanic Zone during the first half of the Holocene also indicate such a peak. A gravity study of a section of the West Volcanic Zone and the eastern part of the Reykjanes Peninsula has been used to estimate the volumes of the Holocene lava pile. These studies, constrained by published information on lava flow ages and drill-hole data, provide evidence for lava production of few tens of km^3 in the region between Þingvallavatn and the glacier Langjökull, with the eruptions mainly occurring in early Holocene. For the Brennisteinsfjöll volcanic system, eastern part of the Reykjanes Peninsula, Holocene lava is estimated as 15 km^3. Production during the last glaciation, based on the volume of hyaloclastites in the same area, indicates a rate that may have been several times lower during the glacial period. Thus, the indications are for a sizeable peak in activity following deglaciation for both areas studied. Large explosive eruptions also occurred near the end of the last glaciation in Iceland, possibly sparked off by de-loading of central volcanoes with shallow magma chambers.

IAVCEI (Volcanology, Geochemistry)

VS32b - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-0898

Towards a coordinated modeling assessment of the climate response to strong volcanic eruptions

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Our understanding of volcanic impacts on the global climate is limited by observational uncertainties and by non-robust dynamical responses simulated by climate models. The lack of agreement between model results is crucially determined by the different model characteristics, including the implementation strategy of the forcing, and by uncertainties related to eruption details and background climate. To separate the individual effects of these factors it is necessary to coordinate modeling activities and to separately focus on the two main steps linking volcanoes and climate: first, dynamics of the stratospheric volcanic cloud and chemical and microphysical transformations occurring within it; then, aerosol direct radiative effects and associated feedback mechanisms activated in the climate system.

The Stratospheric Sulfur and its Role in Climate Initiative (SSiRC) model intercomparison uses global aerosol models to understand the radiative forcing of stratospheric aerosols and to assess related parameter uncertainties. The Model Intercomparison Project on the climatic response to Volcanic forcing (VolMIP) focuses on the response of the coupled ocean-atmosphere system to strong volcanic forcing. By subjecting climate models to the same volcanic forcing and under a similar range of background climate conditions, VolMIP aims at identifying the causes that limit robust simulated behavior, especially as far as different treatment of physical processes is concerned.

We will present ongoing activities and research highlights achieved within VolMIP and SSiRC, and illustrate how they are contributing to constrain uncertainties in the

climate response to volcanic forcing, improve the evaluation of climate models, and advance our understanding of past, current and future climates.

IAVCEI (Volcanology, Geochemistry)

VS32b - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-1395

Stratospheric sulfate aerosol loading, timing, and climate impact of volcanic eruptions during the Common Era

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Simulations of past climate conditions depend critically on accurate records of past aerosol forcing from volcanic eruptions, reconstructed from measurements of sulphate deposition in ice cores. Non-uniform transport and deposition of volcanic fallout mean that multiple records from a wide array of ice cores must be combined to create accurate reconstructions. Here we re-evaluated the record of volcanic sulphate deposition using a much more extensive array of Antarctic and Greenland ice cores. In our new reconstruction, many additional records have been added and dating of previously published records corrected, improving and extending the record throughout the Common Era. Whereas agreement with existing reconstructions is excellent after 1500, we found a substantially different history of volcanic aerosol deposition before 1500; for example, global aerosol forcing values from some of the largest eruptions (for example, 1257 and 1458) previously were overestimated by 20–30% and others underestimated by 20–50%. Our study of climate response following major volcanic eruptions reveals synchronicity of major volcanic eruption dates to historical documentary records and tree-ring reconstructed cooling extremes occurring in the immediate aftermath of large volcanic eruptions throughout the past 2,000 years. Strong post-volcanic summer cooling is not restricted to tropical eruptions, but is also observed after many eruptions located in the high latitudes of the Northern Hemisphere.

IAVCEI (Volcanology, Geochemistry)

VS32b - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-3174

Long-range transport, air quality effects and regional climate impacts of volcanic sulfur emitted at Nornahraun (Bár*arbunga, Iceland)

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On 31st August 2014, a large, lava-producing fissure eruption began in Iceland about 45 km from Bárðarbunga volcano. The 'Nornahraun' eruption is the first flood lava eruption since the Laki eruption in 1783 in Iceland. For more than 150 days the eruption has emitted on average 35 kilotons of sulfur dioxide (SO_2) per day into the atmosphere; almost three times the total daily anthropogenic SO_2 emissions from the European Union.

We present air quality measurements from Ireland and the UK, which represent the highest measured SO_2 concentrations since the late 1980s recorded on two occasions in September 2014. Measured peak SO_2 concentrations at the surface were short lived, 6-12 hours, and below the World Health Organisation's 10-minute air quality standard for SO_2 of 500 μg/m^3. These two pollution events demonstrate, however, that gas from relatively low altitude volcanic emissions in Iceland can be dispersed over distances >2000 km and potentially pose a hazard to northwest Europe if the emission strength increased.

The air quality measurements made in the near-field (<100 km from eruption source) and the far-field (>100 km from the source) provide us with a unique dataset for the verification of atmospheric dispersion models. We use the NAME

model to simulate the long-range transport, removal and chemical conversion of the volcanic SO_2 during Sep 2014. We evaluate a range of model simulations, using varying model input and physical parameters, against ground based measurements and satellite retrievals of SO_2. In addition, we perform global climate model simulations, which show that the sulfur emissions from the eruption may result in a significant radiative forcing of climate by brightening low-level liquid clouds on a regional scale.

IAVCEI (Volcanology, Geochemistry)

VS32b - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-3528

Investigating stratospheric warming due to the Nabro eruption with GPS radio occultation

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The eruption of the Nabro volcano in June 2011 has been recognized as the largest volcanic eruption since Pinatubo 1991, ejecting ash and sulfur dioxide (SO_2) into the atmosphere. The cloud was spread over more than 60 degrees in latitude and more than 100 degrees in longitude within a few days and lasted for more than 15 days. In the Nabro area there are no in-situ measurements such as radiosondes for evaluating the tropopause altitude and for studying the atmospheric thermal structure.

The Global Positioning System (GPS) Radio Occultation (RO) technique enables measurements of atmospheric parameters in nearly any meteorological condition, with global coverage, high vertical resolution and high accuracy, making RO data well suited to study the thermodynamic structure of volcanic clouds and their impact on climate. By analyzing RO temperature profiles in the volcanic cloud area, we evaluated the cloud top altitude and the tropopause altitude. We furthermore investigated the vertical temperature structure before and after the eruption. Our results show that the volcanic cloud was directly overshooting the tropopause, which led to the injection of SO_2 and warming of the lower stratosphere for about 6 months.

This study shows the capability of GPS RO data for improving the detection and monitoring of volcanic clouds. The global coverage allows monitoring any volcano of the Earth and determining the tropopause altitude with high accuracy at any latitude. The reliable performance under essentially all weather conditions and the high vertical resolution help to understand whether the eruptions overshoot into the stratosphere and contribute to atmospheric climate variability.

IAVCEI (Volcanology, Geochemistry)

VS32b - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

IUGG-3813

Volcanic eruptions as an analog for stratospheric geoengineering: Are we prepared for the next large volcanic eruption?

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In response to the global warming problem, there has been a recent renewed interest in geoengineering “solutions” involving “solar radiation management” by injecting particles into the stratosphere. It may be very difficult to create stratospheric sulfate particles with a desirable size distribution. Observations of the next large volcanic eruption will help to understand the evolution in stratospheric sulfate aerosol size distribution over the first few months after the eruption. We need to develop a capability for continuous in situ particle sampling and perhaps small-scale sulfur injections to study particle growth on an existing sulfate cloud. While volcanic eruptions have been suggested as innocuous examples of stratospheric aerosols cooling the planet, the volcano analog also argues against geoengineering because of ozone depletion, regional hydrologic responses, and other negative consequences. Volcanic eruptions are an imperfect analog, since solar radiation management proposals involve the production of a permanent stratospheric aerosol layer, while volcanic layers are episodic. Nonetheless, we can learn much from the volcanic example about the microphysics of stratospheric sulfate aerosol particles; changes in atmospheric circulation, producing regional climate responses, such as changes to the summer monsoon; atmospheric chemistry; changes of the partitioning of direct and diffuse insolation; effects on satellite remote sensing and terrestrial-based astronomy; and impacts on the carbon cycle. Much more research is needed before we can quantify the benefits and risks of stratospheric geoengineering, so that policymakers in the future can make informed decisions about whether to ever implement it.

IAVCEI (Volcanology, Geochemistry)

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IUGG-4442

El Niño–Southern Oscillation Response to tropical stratospheric volcanism

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While the El Niño Southern Oscillation (ENSO) is a natural mode of variability of the tropical Pacific, recent studies have explored how it can be impacted by external radiative forcing such as the one associated with tropical volcanism. Though the instrumental record is too brief to fully characterize natural ENSO variability, recent proxy reconstructions covering the last few centuries suggest increased probability of an El Niño event occurring a year after tropical explosive eruptions. Yet, the processes by which volcanic forcing influences ENSO and other ocean-atmosphere modes of variability are neither fully understood nor well reproduced by state-of-the-art ocean-atmosphere coupled models (OAGCMs).

This contribution investigates the links between tropical explosive volcanism and ENSO in a suite of externally forced and unforced ensemble experiments with two coupled OAGCMs (IPSL-CM5A-LR and CNRM-CM5) ensembles using the same volcanic forcing, derived from the Pinatubo eruption. As suggested by observations, both simulations tend to produce an El Niño after the eruption, despite the use of different models and different choices of initial states, suggesting that the increased probability of an El Niño after a strong tropical eruption is robust. We then use a suite of AGCM experiments to understand if the development of ENSO mainly arises from the purely atmospheric or surface (land and/or ocean) response to the eruption radiative forcing.

IAVCEI (Volcanology, Geochemistry)

VS32p - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

VS32p-120

Mechanism of stratospheric decadal abrupt cooling in the Early 1990s as influenced by the Pinatubo eruption

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Studies have suggested that one volcanic eruption can influence seasonal to inter-annual climate variations. This study indicates that the Pinatubo eruption in 1991 may have actually induced the stratospheric decadal cooling recorded in the early 1990s. Using the NCEP/NCAR reanalysis and TOMS/SBUV satellite data, a decadal abrupt cooling of stratospheric tropical air temperature was found to have occurred in the early 1990s during a long-term descending trend. We generated the spatio-temporal structures of the decadal abrupt changes (DACs) for the stratosphere, and explored the relationship between the Pinatubo volcano eruption in 1991 and stratospheric DACs in the early 1990s. Our results suggest that the eruption of Pinatubo prompted a decadal decrease of ozone by the activation of nitrate and sulfate volcanic aerosols on ClO free radicals. The stratospheric heat absorbed by ozone decreased over a decadal time scale. As a result, decadal abrupt cooling of stratospheric tropical air temperatures occurred in the early 1990s, and may be attributed to the Pinatubo eruption. The results therefore indicate that one strong volcanic eruption can induce stratospheric decadal climate variation.

IAVCEI (Volcanology, Geochemistry)

VS32p - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

VS32p-121

Disentangling the eruption source parameters that control the climate effects of volcanic eruptions

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Climatic cooling associated with volcanic eruptions does not scale linearly with the mass of SO_2 emitted into the atmosphere. Many other parameters such as the injection height, latitude, season, and atmospheric circulation such as the Quasi-Biennial Oscillation phase, can affect the magnitude of the climatic impact of an eruption. However, a fundamental understanding of the importance of each of these parameters and the magnitude of the climatic response has yet to be elucidated. Furthermore, there has been no comprehensive assessment of these relationships when considering aerosol microphysical processes. Model simulations are conducted using the UM-UKCA model to investigate the effect of eruption source parameters on aerosol properties and consequent climatic cooling. The 1991 Mt. Pinatubo eruption is used as the baseline experiment and parameters such as the SO_2 mass emission rate, injection height, latitude, and season are subsequently systematically varied. Results will be initially used to assess each parameter's contribution to climatic cooling. This will aid with the development of a Volcanic Climate Index to primarily predict global climatic cooling in the years following an eruption. Further exploration may consider other climatic and regional impacts such as precipitation changes, to gain a detailed understanding of the impact of past, present and future volcanism, as well as considering the feasibility of geoengineering techniques using SO_2.

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VS32p - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

VS32p-122

Seasonally modulated geothermal meltwater release from the Katla volcanic system, Iceland

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Katla is a large, restless Icelandic volcanic system, whose 100 km^2 caldera with strong geothermal flux is covered by the ≤740 m-thick Mýrdalsjökull ice cap. Historical eruptions predominantly occur in summer/late summer months, attributed to stress readjustments during seasonal snowpack thickness variations. Similarly, seasonal seismicity may reflect modulation of glacial movements by shifting meltwater supply to the glacier base. To probe geothermal-hydrological coupling, we have determined the sulphate isotopic composition of a 2009-2012 series of glacial meltwater samples discharged from Sólheimajökull, a valley glacier of Mýrdalsjökull. Dual isotopic analysis of δ34S and δ18O in dissolved sulphate allows fingerprinting of sources, mixing and chemical evolution during subglacial meltwater transport.

Strikingly, meltwater $\delta^{18}O_{SO4}$ signatures indicate inverse redox conditions at the glacier bed to those normally encountered at Arctic/Alpine glaciers, with seasonal release of geothermally-derived volatile gases leading to discharge of reduced, anoxic meltwater in summer, rather than winter. This reflects headward expansion of the channelized subglacial drainage system during the summer melt season, accessing key geothermal loci within the caldera. Summer volatile release may be further enhanced by unloading due to snowpack melting, but steady ice cauldron volumes indicate a seasonally-invariant geothermal heat output. In winter, restriction of subglacial channels to lower elevations seals geothermal fluids and dissolved gases beneath the ice cap, with only sporadic release permitted by periodic subglacial water pressure increase. Sulphate isotopic signatures are therefore sensitive indicators of hydrologically-modulated geothermal volatile fluxes.

IAVCEI (Volcanology, Geochemistry)

VS32p - VS32/VS33 Weather and Climate Effects of Volcanic Eruptions / VS33 Understanding Volcano-Climate Feedbacks

VS32p-123

On the fertilization of the surface ocean by volcanic ash remobilization from its deposits on land

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The climate effect of surface ocean iron fertilization and the activation of the biological CO2 pump have been mainly addressed for mineral dust (Langmann, 2013, doi:10.1155/2013/245076). Recent studies considering volcanic ash as an iron carrier focus on the immediate time after a volcanic eruption. However, volcanic ash may fertilize the surface ocean during periods of months to years if it is remobilized into the atmosphere from its ash deposits on land by wind. This has been observed e.g. after the eruption of Katmai, Alaska (1912), Mt. Hudson, Chile (1991) and Eyjafjallajoekull, Iceland (2010), with indications that such events occur until today. Here we report model simulation results on the remobilization of volcanic ash after the eruption of Mt. Hudson, Chile (1991) and the subsequent deposition of volcanic ash into the Atlantic sector of the Antarctic Ocean using the climate model REMOTE. We will show the sensitivity of the model results on various input parameters (e.g. friction velocity, sea spray, precipitation) and provide estimates on iron-fertilization of the surface ocean.

IAVCEI (Volcanology, Geochemistry)

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VS32p-124

Volcanic eruptions and the polar vortex: mechanisms and sensitivity to forcing structure

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Climate models forced by prescribed volcanic aerosol fields fail to reproduce the strengthened Northern Hemisphere stratospheric winter polar vortex expected from observations. We investigate the impact of volcanic aerosol forcing on stratospheric dynamics in ensemble simulations with the Max Planck Institute Earth System Model. The model is forced by four different prescribed forcing sets representing the radiative properties of stratospheric aerosol following the 1991 eruption of Mt. Pinatubo: two forcing sets are based on observations, and are commonly used in climate model simulations, and two forcing sets are constructed based on coupled aerosol-climate model simulations. For all forcings, we find that temperature and zonal wind anomalies in the Northern Hemisphere high latitudes are not directly impacted by anomalous volcanic aerosol heating. Instead, high latitude effects result from enhancements in stratospheric residual circulation, which in turn result, at least in part, from enhanced stratospheric wave activity. High latitude effects are therefore much less robust than would be expected if they were the direct result of aerosol heating. Differences in the dynamical response to the different forcing sets imply that reproducing the polar vortex responses to past eruptions, or predicting the response to future eruptions, depends on accurate representation of the space-time structure of the volcanic aerosol forcing.

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VS32p-125

Simulating the climate responses induced volcanic eruptions using a global aerosol model.

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It is now generally recognised that volcanic eruptions have an important effect on climate variability from inter-annual to decadal timescales. Several outstanding questions remain and concern the behaviour of various SO2 emission rate into the stratosphere after eruptions such as those that did occur during the last centuries. To contribute to the on-going effort to reduce the large uncertainties regarding the climatic responses to large volcanic eruptions we discuss results from process-oriented sensitivity experiments using the state-of-the-art IPSL global climate model forced with a well-established global aerosol process model containing a fully explicit size-resolving aerosol microphysical module. The effects of the eruption season are also evaluated. Climate simulations reveal that there is no canonical linear relationship between the global cooling and the magnitude of the eruptions, due notably to self-limiting microphysical aerosol processes. These processes explain the relatively weak global cooling that never exceeds 2.5°C in our model for the very large eruptions. For comparable latitude, the aerosol microphysical processes and evolution differ significantly depending on the eruption season and strength. The implication of these results for the climate variability following volcanic eruptions will be discussed.

IAVCEI (Volcanology, Geochemistry)

VW01a - VW01 2nd Workshop on Volcano Geology

IUGG-4559

"Role of fundamental volcanic geology in hazard assessment"

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Volcanic hazard is defined as the probability of any particular area being affected by a destructive volcanic event within a given period of time. At present, volcanic hazard is usually assessed in the form of event tree structures containing possible eruptive scenarios and probabilistic methods are applied to these structures to estimate the long-term and short-term probabilities for each scenario. Consequently, long-term forecasting is based on historical and geological data and theoretical models, while short-term forecasting is complemented with continuous monitoring data when an unrest episode has started. The complexity of any volcanic system and its associated eruptive processes, together with the lack of data that characterise many active volcanoes, particularly those with long recurrences, make volcanic hazard quantification very challenging, as there is often not enough observational data to build a robust statistical model. A detailed knowledge of the past eruptive record (i.e. volcanic stratigraphy), the internal structure of the volcanic system, and of its tectonic controls, is fundamental to the establish reliable basis on which to built the hazard assessment structure, to determine the time constraints of the volcanic processes, and to correctly interpret volcanic unrest and precursory signals of future eruptive events.

IAVCEI (Volcanology, Geochemistry)

VW02a - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-2213

TError: a systematic approach for the quantification of the uncertainty propagated during the characterization of tephra deposits

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The characterization of tephra deposit is associated with large uncertainties that are rarely quantified. From field mapping to the estimation of physical Eruption Source Parameters (ESP), uncertainties related to natural processes, measurement techniques and subjective choices interact and propagate in a non-linear way, resulting in a distribution of noise around the final value. More than achieving an unnecessary degree of precision, today's challenge in tephra-related sciences is the ability to quantify the uncertainty related to field-derived ESP.

For this reason, we developed a package named TError, which contains the implementation of the most commonly used methods to quantify ESPs and can be used as a framework to quantify the degree of uncertainty of final values. Inputs to the code are a range of field-based, model-based and empirical parameters. Two main functions are available in the code. Firstly, a sensitivity analysis function allows systematically and deterministically adding an uncertainty to one input parameter at the time and assessing the impact on the final ESPs. Secondly, a propagation function relies on stochastic techniques to construct distributions of noise for each input parameter based on user-defined reference values and maximum error, which are then propagated in order to quantify ESPs as distributions.

Results of each function are compiled in comprehensive sets of tables and figures assisting the interpretation of the results, thus providing a first step to a systematic quantification of the uncertainty related to field derived ESPs.

IAVCEI (Volcanology, Geochemistry)

VW02a - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-5586

Quantifying uncertainties in tephra thickness and volume estimates

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Deposit-based characterisation of eruption processes and related source parameters are key for quantitative modelling of volcanic hazard and risk. Of particular importance is estimation of eruption size, determined from tephra fall deposits, for which uncertainties are rarely presented. We investigate the main sources of uncertainty in tephra volume estimation by detailed analysis of the Fogo Member A deposit, Sao Miguel, Azores. Results show field measurement uncertainties are typically about 9% of measured thickness while uncertainty associated with natural deposit variability ranges between 10% and 40% of average thickness, with a mean deviation of 30%. Uncertainties also arise in isopach map production where personalistic contours are drawn to encompass measurements of a given thickness, generally by eye. Uncertainties in calculated tephra volumes were investigated by fitting a numerical model to thickness data using cubic B-splines under tension, allowing isopachs to be objectively determined in relation to the original data, its quantity and quality. This enables us to formally assess limitations in volume estimates within the tephra record associated with previously published maps. Using this method, volume uncertainties are correlated with number of data points and decrease from as much as 40% relative to the mean volume for 30 measurements to 10% for 120 measurements. Thus, while the accuracy of this method depends on the number of data points, their spatial distribution and their associated measurement uncertainties, its reliability can be fully quantified on these terms. This said, comprehensive uncertainty assessment is not feasible for tephra volume estimates from most conventional field studies, and improved measurement regimes are desirable.

IAVCEI (Volcanology, Geochemistry)

VW02b - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-2253

Reconstructing the large, plinian Hekla 3 and Hekla 4 eruptions: field, lab and software strategies

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Hekla is the third most active volcano in Iceland, with 18 eruptions since the island was settled around 871 AD. Explosive eruptions produced at least 9 of the 22 most prominent and widely-distributed ash marker layers found in European soils and lakes. The Hekla 3 (2879+/-34 14C BP) and Hekla 4 (3826+/-12 14C BP) are the two largest of the Holocene. Both erupted over 10 km3 of tephra and are important teprochronological markers in Europe.

Undertaking a modern re-evaluation of the eruptions has been a four-year project with significant logistical challenges. Data from 300 field sites includes stratigraphic logs, photographs (over 3,000), thicknesses measurements (over 650), max pumice/lithic sizes, bulk densities and grainsize distributions derived from sieving (over 220) and laser particle size analysis (over 350). All field observations are timestamped and associated with a GPS location. Photographs are geotagged, as are photographs of notebook pages taken as backups. Measurements and samples are associated with an eruption (H3, H4) and a phase (A-D), although these can be revised on later consideration of data. 'Raw' notebook data (e.g. 3 x maximum clast diameter for 5 clasts) and laboratory data (sieve mass fractions) are stored in plain text files. These are processed by Python scripts with results (e.g. max lithic or Md-phi values) written to other text files. In turn, these can linked to locations or eruption phases using database methods such as JOINs. Further scripts allow loading of data into GIS (GRASS and QGIS) and calculation of parameters such as isopach areas and volumes.

Erupted volumes, plume heights, mass discharge rates and total grain size distributions calculated by a number of different methods will be presented and compared.

IAVCEI (Volcanology, Geochemistry)

VW02b - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-3632

Lava fountains producing unexpected tephra fallouts at Mt Etna: The 23 November 2013 case

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Hundreds of paroxysmal episodes and a few explosive eruptions characterized by prolonged (weeks to months) ash-emissions make Mt. Etna, in Italy, one of the most fruitful basaltic volcanoes in the world over recent years. Within this explosive activity, lava fountains are the most common eruptions. However, ground-based observations on a number of eruption plumes and fallout deposits show that these episodes, although sharing the same eruptive style, are characterized by significantly dissimilar energy. The 23 November 2013 lava fountain from the New South-East Crater was exceptionally intense although the short duration of the paroxysmal phase (<1 hour). Surveys to map and sample the tephra fallout showed abundant decimetric-sized bombs felt within the first 5-6 km from the vent, and a distal (between 5 and 25 km) deposit macroscopically thicker and coarser than usual; in addition, ash was reported to fall up to distances of 400 km. The total erupted mass was estimated $1.85 \pm 0.8 \times 10^9$ kg by the analysis of tephra deposit, in agreement with the value of 2.4×10^9 kg estimated by modelling. The estimated mass eruption rate was $6.2 \pm 2.5 \times 10^5$ kg/s. Grain-size distribution of samples become classed at about 20 km from the vent. By comparing dispersal and sedimentological features and physical parameters of the fallout deposit with other lava fountains of Etna, the 23 November 2013 episode may be considered one of the most explosive events of the 21th Century, allowing us to improve the classification of the "lava fountains" at Etna and the assessment of the associated volcanic hazard.

IAVCEI (Volcanology, Geochemistry)

VW02b - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-5517

Reconstructing eruptive source parameters from tephra deposit: a numerical approach to medium-sized explosive eruptions

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Reconstructing eruptive parameters using information contained in the ground deposits is still very challenging. Often the quality and the quantity of the deposit samplings significantly affect our capability in constraining the main features of explosive eruptions. In addition, the techniques used for integrating and interpolating the data can add errors and uncertainty on the final estimates.

Here we focus on the problem of reconstructing the total grain size distribution (TGSD) and the erupted mass in medium-sized explosive eruptions using a new approach.

We simulate with a dispersal model two fictitious events at Mt. Etna, characterized by realistic eruptive input parameters known a-priori, and we compute the resulting synthetic deposits.

Then, pretending to be volcanologists in the field, we sample these deposits for producing 2000 different sets of 100 samplings for each eruptive event.

Using standard reconstruction techniques - like Pyle, Power law and Weibull, we estimate the erupted mass for each of the 2000 sets. Voronoi’s tessellation is also used for reconstructing the TGSD. The results obtained using the different techniques are then compared with the known initial parameters and a statistical analysis is performed.

The study allows to estimate the mass distribution within the deposit and, in such a way, the amount of mass “lost” during the dispersal process. The statistical analysis shows that, on average, the values of deposited mass, emitted mass and TGSD, obtained using different reconstructing techniques, is strongly deteriorated by the extrapolation process.

The results indicate a method to identify the distances where ground loading peaks of individual grain-sizes falls on the deposit helping to build new sampling strategy.

IAVCEI (Volcanology, Geochemistry)

VW02c - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-2854

Tephra dispersal modelling: The role of field measurements in model forecasts and hazard assessments

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Tephra Transport and Dispersal Models (TTDMs) simulate atmospheric dispersion and sedimentation of tephra depending on meteorological fields and eruption characteristics, defined by the so-called Eruption Source Parameters (column height, eruption rate and vertical distribution of mass) and particle properties (grain size distribution, density, shape). TTDMs are used for multiple purposes, including forecasting of ash clouds for civil aviation purposes, forecasting of tephra fallout at proximal populated areas, long-term hazard assessment, or characterization of past eruptions. A key aspect for model accuracy is to constrain volcanological inputs trough data assimilation (in the case of forecasts) or trough the definition of realistic scenarios and associated probability density functions (in the case of hazard assessments). We review which parameters derived from studying tephra fallout deposits are more relevant for TTDMs and how the accuracy and uncertainties related to measurements transmit into models.

IAVCEI (Volcanology, Geochemistry)

VW02c - VW02 Best Practices and Recommendations for Tephra Measurements

IUGG-4641

Insights from new methods of determining grainsize, total grainsize and mass distribution of tephra fall deposits

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Recent advances have shown that tephra fall deposits have a complex architecture leading to spatial heterogeneities of grain-size, density and componentry which impede the determination of the eruptive parameters (volume and mass of magma erupted, fragmentation efficiency, etc.). We propose a set of new methods to infer some characteristics of tephra fall deposits while accounting for their heterogeneities, and demonstrate their efficiency using the case of the May 18, 1980 Mount St. Helens, and August 2006 Tungurahua eruptions.

We developed methods to accurately and efficiently describe spatially heterogeneous grain size distributions that depart from a lognormal shape by creating a deconvolution algorithm for polymodal and strongly asymmetric unimodal distributions using a Weibull function. We also propose to assess the Total Grain Size Distributions of tephra fall deposits by interpolating spatially mass distributions separately for each grain size fraction, in order to address one shortcoming of the commonly used Voronoi tessellation method which assumes a constant grain size distribution in each cell regardless of cell size, thus making the technique inherently dependent on sampling density. Finally, we show that the density of tephra fall deposits varies strongly laterally, along with the mean density of the particles, leading to uneven packing and suggesting that volume-to-mass conversion protocols generally used for eruption size determination are highly inaccurate. We demonstrate that the density distributions of the different components constituting fallout deposits can be described by a sigmoidal law, and lateral mass variations in tephra layers are controlled by the proportion of the grain components, which can be predicted from empirical laws.

IAVCEI (Volcanology, Geochemistry)

VW02p - VW02 Best Practices and Recommendations for Tephra Measurements

VW02p-607

Tefranet: a collaborative system for tephra fallouts from Etna using mobile and web-based apps

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In the last 20 years, Mt Etna (Italy) produced more than 200 paroxysmal episodes from one of its 5 summit craters, and two prolonged tephra emissions during the 2001 and 2002-03 flank eruptions. Such a frequent explosive activity posed the need, for surveillance and research purposes, to map the fallout deposits and collect tephra samples with accuracy and rapidity, especially in case of paroxysmal episodes lasting tens of minutes to 1-2 days. Due to the low load per square meter, rapidly decreasing away from the upper volcanic slopes, the original amounts of tephra in the ground may be easily modified or significantly removed by anthropic (e.g. car traffic) and atmospheric (wind and rain) factors.

Tefranet is a collaborative system designed to recover quickly, possibly in real time, georeferenced information on tephra fallouts. The system provides a mobile application and a web site, with particular attention to an administration backend tool. Tefranet makes us of owners of smartphones or other mobile devices living in the east Sicily. Users will alert, in case of tephra fallout, the INGV specialists but also the Tefranet community, being all the users able to visualize real time all the signals on a map. Afterward, users may signal other information (e.g. start/end of the tephra fallout, estimation of the clast size, thickness of the deposit, level of tephra cover on the ground) and send photos of deposit and (possibly) eruption plume. All this information will make the survey at Etna more effective, allowing to map more rapidly and extensively the fallout deposits and to plan accurately the collection of tephra samples. Accordingly, the use of Tefranet may really help to improve the study of short-lived fallout deposits like those erupted from Etna.

IAVCEI (Volcanology, Geochemistry)

VW03a - VW03 Effective Communication Tools: What Can Volcanology Learn from Other Hazards?

IUGG-1338

Inconsistency in the use of Volcanic Alert Level in small oceanic islands

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The recent volcanic crisis in the El Hierro Island (2011-2014) was more complex than expected in such a small island, not because the submarine eruption itself, but because the numerous seismic episodes that culminating with earthquakes severe enough to be felt in the whole island (M > 4, Mmax=5.4) which also triggered many landslides. The abrupt orography, specially en in the north, El Golfo Valley, made necessary the evacuation of some local residents in the areas threatened by landslides. But the emergency plan was developed to deal with volcanic eruptions, so the landslide hazard was not considered initially in the communication strategy followed at that time.
While a possible basaltic volcanic eruption was expected to be happen during each seismic episode and over a relative small area, the seismic activity and the triggered landslides affected a wider area. So the restricted area defined initially in the Volcano Traffic Light (VTL) was conflicting with the level of hazard poses by the landslides.
The combination of natural phenomena in time but at different impact scales in small islands might be communicated following two approaches. In the first, adding a new warning tool to be used simultaneously with the VTL or Volcanic Alert Level (VAL), but making more complex the understanding of the warning message. We propose a different approach, using only a global warning tool namely Geologic Hazards Traffic Light (GHTL) (including for example, earthquakes, eruptions, lahars and others), and addressing the level of alert of population, not of the natural phenomena.

IAVCEI (Volcanology, Geochemistry)

VW03a - VW03 Effective Communication Tools: What Can Volcanology Learn from Other Hazards?

IUGG-3190

KAZAN: Will you survive the next disaster? - An educational game to raise awareness about hazards and disaster risk reduction

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Geological hazards are usually not the first concern in the daily life of an exposed population. It is important however to establish a continuous communication between population, policymakers and scientists to raise awareness and favor the implementation of basic risk reduction strategies.

KAZAN is an educational board game that raises awareness about geological hazards. The game has been developed for students, citizens and stakeholders with the aim to let them discover key information about hazards and their spatial variability; to increase awareness about the impacts of the hazards for different intensities and the importance of resources accessibility; and to let them experience different risk reduction strategies. During the game, the players embody a character living on an island. Each year, they receive their salary used to meet their basic needs and to develop their community. Huts, houses and roads can be constructed but as the island is randomly threatened by geological hazards (earthquake, tsunami, lava flow and volcanic ash fall), players can also invest in protection measures. In this context, players virtually experience the hazards impacts and they are directly confronted with the implications of decisions taken during the game. Moreover, players come to realize that what they lived in the game reflects situations in real life and that prevention measures are important to take both at a personal and at a community level.

KAZAN was tested on different groups of students, geologists and hazard managers in Europe and in Africa. In this contribution, we will analyze the game strategies, the players' opinions about the usefulness of the game and the game impact on the players understanding of the hazards.

IAVCEI (Volcanology, Geochemistry)

VW03b - VW03 Effective Communication Tools: What Can Volcanology Learn from Other Hazards?

IUGG-2385

The Science of Natural Hazards: Visual Communication Using Infographics

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As disasters are mostly felt at local levels, improving communication with the public is an important component of comprehensive disaster resilience strategies. Despite the available information regarding natural hazards and disaster preparedness, studies show that people are not prepared and do not feel informed. This highlights the urgent general requirement for enhanced scientific communication and increased public scientific literacy, specifically in high-risk environments.

In response this project presents infographics that visually communicate the science of natural hazards to the general public. Pedagogical goals are to increase scientific literacy through a more comprehensive understanding of the nature of science, as well as a specific increased understanding of key concepts associated with high-risk environments. We aim to achieve this by representing the scientific method as the iterative and dynamic process it is, rather than the dominant portrayal and perception of science as a series of sequential steps that yield a definite conclusion. This includes an explanation of the concept of uncertainty and the quantification thereof, to aid the reader's understanding of probability-based forecasts. In the presentation of these concepts careful attention has been paid to design factors such as the use of colour, typography, composition, iconography, and more to optimise readers' comprehension and engagement.

These infographics present an initial step of a much broader project whose overall aim is to enhance communication between scientists and the general public by using combined visual and textual representations that allow the public to process and understand complex concepts and information more effectively, efficiently, and accurately.

IAVCEI (Volcanology, Geochemistry)

VW03b - VW03 Effective Communication Tools: What Can Volcanology Learn from Other Hazards?

IUGG-2802

Three examples of how to use social science to develop new warning systems for natural hazards

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As scientists, we sometimes wonder why the warnings that we issue about hazards are not heeded. How can warnings be effectively communicated to stakeholders, the media and the public? How can we strike a balance between being too reassuring (and facing potential liability issues if the event is worse than described) and potentially causing alarm or warning fatigue by telling people the worst case scenario?

I will give three examples of how social science research has been used in New Zealand to help develop better communication tools for warnings of natural hazards. The first example is how I revised the Volcanic Alert Level system between 2010 and 2014, using input from stakeholders and volcanologists. A more useful system was developed and implemented with the Ministry of Civil Defence and Emergency Management in July 2014. The second example learns from the Canterbury Earthquake sequence that struck Christchurch city in 2010-11, killing 185 people. We used focus groups to understand how seismologists can communicate aftershock probabilities more effectively to a range of stakeholders. We applied our preliminary findings during an earthquake sequence near Wellington city in 2014 and used three scenarios, including probabilities and the worst case. The third example outlines current research with the New Zealand MetService to revise the severe weather warning system, and whether the risk matrix, impact-based approach will be effective for New Zealand.

This presentation will provide the opportunity for discussing communication tools used for different hazards. Input from workshop participants on challenges faced, and solutions developed, will be sought.

IAVCEI (Volcanology, Geochemistry)

VW04a - VW04 Remote Sensing and Modelling of Volcanic Ash in Latin America

IUGG-5263

Volcanic ash dispersion modeling and forecasting in Argentina. recent and future developments.

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This is an overview of the activities related to volcanic ash dispersion modeling in Argentina, performed by a multi-disciplinary group of researchers of several institutions from Latin America and Spain. The research of these phenomena by using FALL3D eulerian transport and deposition numerical model was developed. The performance of this model on past eruptions has been investigated; in addition,

volcanic ash dispersion forecasts were produced on a quasi operational basis during Cordón Caulle's eruption to support the Buenos Aires Volcanic Ash Advisory Center (VAAC). Ongoing sensitivity experiments aim to investigate the effects of particle size and density, ash plume height and mass vertical distribution on the model's performance. Volcanic ash re-suspension events, such as the one occurred in Oct-2011 in Argentina has been and are currently being studied by using a specific module recently included in FALL3D and NOAA HYSPLIT trajectory model. We have recently started working on the comparison of model outputs and quantitative satellite retrievals (i.e. mass loadings). This research will lead, eventually, to the development of mixed products (satellite + model) and to the improvement of volcanic ash forecasts (i.e. inverse modeling). Finally, to improve model initialization on real time basis by means of an assessment of pre-eruptive scenarios a database is being developed that includes volcano location and key volcanological attributes inherent to the eruptive history such as column height, mass discharge rate and particle size distribution. The ultimate aim is to develop and implement an operational ensemble dispersion forecasting system using input initial conditions constrained by the combined satellite-model products.

IAVCEI (Volcanology, Geochemistry)

VW04b - VW04 Remote Sensing and Modelling of Volcanic Ash in Latin America

IUGG-3804

A system to forecast ash dispersion and deposition from Tungurahua volcano, Ecuador.

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Tungurahua volcano, located in the central area of the Ecuadorian Sierra, is erupting intermittently since 1999 alternating periods of quiescence with vulcanian explosive activity. To protect public health and improve risk management, regions potentially affected should count on information regarding the possible ash dispersion trajectories and ground deposition patterns. With pre-defined Eruption Source Parameters (ESP) for vulcanian eruptions, we daily forecast ash dispersion and sedimentation from Tungurahua, coupling the meteorological Weather Research Forecasting (WRF V3.2) and the volcanic ash dispersion FALL3D-7.0 numerical models. Codes were compiled with Open Multi-Processing interface, in the High Performance Computing system from the Universidad San Francisco de Quito. The meteorological simulations use a master domain of 80×80 cells (each of 36×36 km) and two nested subdomains, the second of which covers Ecuador with 199×199 cells (4 km horizontal resolution). Meteorological fields are forecasted three days ahead. Results of the inner subdomain are used to simulate ash transport during the second and third days. Ash dispersion and ground deposition results are post-processed and uploaded to the web page of the Research Group of Volcanic Ash in Ecuador (GICVE). (https://www.usfq.edu.ec/programas_academicos/colegios/politecnico/institutos/gicve/Paginas/default.aspx). Today, the dedicated computational resources are 24 cores (2.00 GHz, 24 GB RAM) that require about 25h, 80% corresponding to the meteorological component.

IAVCEI (Volcanology, Geochemistry)

VW04b - VW04 Remote Sensing and Modelling of Volcanic Ash in Latin America

IUGG-4591

Dynamics, sedimentation and impact of the 2011 eruption of Cordón Caulle volcano (Chile)

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The 2011 eruption of Cordón Caulle volcano (Chile) severely impacted the ecosystem, urban areas, various economic sectors (e.g. aviation, tourism, agriculture and fishing industry) and critical infrastructures (e.g. airports, hospitals and roads). During the initial climactic phase (4-5 June), 11-14 km-high plumes dispersed most of the erupted rhyolitic tephra towards Argentina. This first eruptive phase was followed by activity of lower intensity, leading to the development of a complex stratigraphic sequence, mainly due to rapid shifts in wind direction and eruptive style. The resulting tephra deposits consist of 13 main layers grouped into 4 units of VEI 3-4. All layers analysed are mostly characterized by bimodal grain-size distributions, with both the modes and the fraction of the coarse sub-populations decreasing rapidly with distance from vent and those of the fine sub-population being mostly stable. The Total Grain-Size Distribution (TGSD) of the climactic phase is also bimodal, with the coarse sub-population representing 90 wt.% of the whole distribution. Polymodality of individual samples is related to size-selective sedimentation processes, such as particle aggregation and gravitational instabilities, while polymodality of the TGSD is mostly related to the complex internal texture of the most abundant juvenile clasts. Plume dynamics and rise were strongly affected by wind during the whole eruption with negligible up-wind spreading and sedimentation. Nonetheless, cloud spreading during the climactic phase is consistent with a gravitational intrusion. A comprehensive probabilistic hazard assessment considering various eruptive and atmospheric scenarios was also carried out to explore the whole range of potential impact of a future eruption.

IAVCEI (Volcanology, Geochemistry)

VW05a - VW05 Models in Volcanology

IUGG-2800

Colorful images and beyond: Monitoring methods for quantitative analysis of analogue models of lithospheric deformation

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Deformation of the earth's lithosphere takes place over a large range of temporal and spatial scales. In many instances, deformation is either too slow to be measured precisely (tectonic deformation, magma emplacement) or too rare and unexpected (earthquakes, landslides, volcanic eruptions) to fully capture the kinematics – and therewith the dynamics – of the process in nature. Amongst the many existing simulation methods, properly scaled physical analogue models have the potential to bridge this gap in cost-effective and self-consistent way, in particular with the recent developments in real-time monitoring methods, which bring huge advantages compared to the classical post-mortem sectioning of the models.

In this talk I give an overview of current methods for quantitative high resolution monitoring of a variety of deformation processes (characteristics of each method, suitable for which process), and show several examples of post-processing (beyond producing colorful images) and how these observations aid the formulation of empirical laws and validation of analytical models. Established methods for kinematic monitoring range from optical imaging to CT and laser scanning. Digital image correlation (DIC) allows the calculation of displacement fields and topography by means of pattern recognition. A current field of exploration is probing boundary forces, internal stresses and seismic energy with a suite of sensors recently applied in analogue modelling.

IAVCEI (Volcanology, Geochemistry)

VW05c - VW05 Models in Volcanology

IUGG-4431

The three youngest Plinian eruptions of Pelée, Martinique (P1, P2 & P3): Constraining eruptive conditions from field and experimental studies.

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Mt Pelée on Martinique, French West Indies, is infamous for the last big eruption in 1902 AD that destroyed agricultural land and several cities, including the city of Saint Pierre, by pyroclastic density currents. Beside such mostly valley-confined deposits, the geological record shows thick fall deposits of at least three Plinian eruptions during the past 2000 years.

In an attempt to describe and understand the apparent variability of eruptive scenarios, we have investigated approx. 50 outcrops belonging to the P1 (1315 AD), P2 (345 AD) and P3 (4 AD) eruptions and collected bulk samples as well as >100 mm pumiceous clasts. All samples are andesitic, contain plagioclase and pyroxene in a glassy matrix and range in porosity between 55 and 69 vol.% with individual bubbles rarely larger than 1 mm. Our approach was two-fold: 1) Loose bulk samples have been subject to dry mechanical sieving in order to quantify the grain-size distribution and the fractal dimension. 2) From large clasts, 60*25 mm cylinders have been drilled for fragmentation experiments following the sudden decompression of gas in the sample's pore space. The used experimental set-up allowed for precisely controllable and repeatable conditions (5, 10 and 15 MPa, 25 °C) and the complete sampling of the generated pyroclasts. These experimentally generated clasts were analysed for their grain-size distribution and fractal dimension. For both samples, we find values of fractal dimension between 2,5 and 3,7.

Deciphering eruption conditions from deposits alone is challenging because of the complex interplay of dynamic volcanic processes and transport-related sorting. We use the quantified values of fractal dimension for increased interpretability of well-preserved deposits and a critical evaluation of the limits.

IAVCEI (Volcanology, Geochemistry)

VW05c - VW05 Models in Volcanology

IUGG-4460

Dimensional analysis, scaling, and similarity: An overview of the methods and their application to investigate volcanic processes

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Volcanic phenomena are often difficult to observe directly and they are governed by complex physical processes that commonly involve fluid and solid phases with a wide range of physical properties. For these reasons, volcanologists have developed different types of small-scale experiments to investigate volcanic processes and characterize their fundamental parameters. With this approach, a key issue is to scale properly the experiments to insure dynamic similarity with the natural systems, which is achieved through the use of appropriate dimensionless numbers. This presentation is aimed at reviewing the concepts of scaling and dimensional analysis, and the methods used to obtain dimensionless numbers will be also discussed. In particular, we will examine the concept of fundamental and derived units in the context of the Buckingham theorem, and we will describe how dimensionless numbers can be obtained through a matrix of dimensions. Other methods used to obtain dimensionless numbers from sets of non-dimensional equations will also be presented. Finally, limitations of applicability of experimental results to the large-scale natural systems will be discussed.

IAVCEI (Volcanology, Geochemistry)

VW05p - VW05 Models in Volcanology

VW05p-239

Advanced imaging and quantification of volcano deformation in analogue models using computed X-ray micro-tomography

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Analogue models have been used for few decades to study geometric, kinematic and dynamic aspects of volcano deformation processes. These include, but are not limited to, deformation induced by gravitational forces and magma propagation. While analogue sand box models include limited complexities of a natural system that are not represented in most numerical models, visual observation and quantification of the geometric, mechanic and dynamic aspects in the model interior are impossible. Sandboxes with a vertical glass pane have been introduced to overcome this issue. This in turn imposes a debatable and unquantified influence of border effects on the simulated deformation. We report the novel advances on the use of computed X-ray micro-tomography (μCT) techniques to image and quantify the geometry, mechanics and dynamics of deformation in analogue models, which opens a window on the volcanic processes at depth. Examples focus on long-term gravitational deformation and depletion-induced collapse of pit craters and calderas. Even though technical specifications of the available μCT-scanners require a meticulous balance between scanning resolution, signal to noise ratio and X-ray beam energy on one hand and a limited model size and analogue material properties on the other hand, a complete and non-destructive 3D view of the model interior can be obtained. As a result, the innovative use of radiographs or dynamic scanning allows the quantification of deformation parameters during model deformation in 2D or 3D, which can in turn be compared to field and monitoring data from active volcanic systems.

IAVCEI (Volcanology, Geochemistry)

VW05p - VW05 Models in Volcanology

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"Monitoring analogue volcanological models using Kinect v1 and v2 sensors"

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Monitoring vertical deformation in analogue volcanological models is commonly performed with techniques such as photogrammetry or laser scanning. A new methodology for vertical monitoring of the models has been proposed recently, using Microsoft® Kinect sensor. Kinect v1 comprises color (RGB) and infrared (IR) cameras, together with an IR light emitting a structural light pattern (known by the device) used to derive a distance image. Kinect v1 were first used for monitoring vertical deformation in analogue models of caldera collapse, and later in our laboratory for monitoring deformation of volcanoes by processes of spreading and intrusion. Those experiments demonstrated the cost-effectiveness of Kinect for monitoring analogue volcanological models: good spatial resolution, high acquisition rates and easy data post-processing. The main limitations were related to the artifacts detected in the distance images and the low resolution of the RGB images. Additionally, we found some technical problems mainly related to lighting conditions (inducing artifacts in distance data) and computer capacity for data acquisition. At July 2014 Microsoft® released Kinect v2. Main improvements of the new sensor are related to the RGB camera resolution (1920x1080 px.), the distance images resolution (512x424 px.), the acquisition process (IR time-of-flight technique) and data transfer. Kinect v2 can process up to 2 Gb/s and USB 3.0 provides 10x faster data transfer, which allows a very high rate of monitoring. We have developed a software for Kinect v2 which allows us to control acquisition rate during the experiments and output data format. Our first tests show that lighting effects are now strongly reduced, which produces a substantial improvement of distance data using Kinect v2 vs. v1.

IAVCEI (Volcanology, Geochemistry)

VW05p - VW05 Models in Volcanology

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The effect of inertial particles on turbulent entrainment in volcanic plumes

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Explosive volcanic eruptions produce turbulent, buoyant jets/plumes that contain entrained particles. In these flows, turbulent entrainment of ambient air controls the ultimate rise height and spread of the jet. In these dilute particle-gas systems, the particles they contain can strongly control the dynamics of the bulk flow through the coupling between themselves and the surrounding fluid. The metric for the type of particle-fluid coupling is the Stokes number, St, which is a ratio of the time scale for the inertial response of a particle to the overturn time scale for the entraining eddies. Particles with St=O(1) are said to be inertial, critically coupled to the flow and can hence have a significant effect on the overturning motions responsible for entrainment.

The characteristics of turbulent flows can be revealed using spectral methods. This technique can, in particular, reveal how turbulence is modified due to the overturning of density interfaces and the presence of inertial particles. We employ such a method (incorporating novel PIV measurements) to show that inertial particles change the turbulent structure of particle-laden and particle-free flows leading to energy cascades which are anisotropic in the horizontal and vertical directions. Crucially, flows laden with such particles carry considerably more energy in the stream-wise direction than particle-free flows which decreases entrainment. This behaviour suggests that turbulent entrainment can effectively be shut down under the presence of critical St, giving rise to collapsing fountains whereas particle-free flows under the same source conditions would produce buoyant plumes.

IAVCEI (Volcanology, Geochemistry)

VW05p - VW05 Models in Volcanology

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Analog earthquake models: Some scaling and monitoring issues

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Experimental simulation of seismotectonic deformation using laboratory scale analog models is a challenge because of the large range in scales: typical velocities encompass more than 13 orders of magnitude from km/s (rupture velocity) to mm/a (e.g. tectonic uplift). We tackle this issue by introducing a non-linear time scale attributing distinct scaling to short and long term stages of the seismic cycle. Only at short timescales, i.e. during rupturing, inertia has to be considered. In this case, through the Froude and Cauchy numbers, the co-seismic timescale is given as the square root of the length scale. At long time scales where visco-elastic effects dominate, we argue for the negligibility of inertia and re-interpret the conventional tectonic scaling argument (i.e. constancy of the dimensionless ratio of the product of viscosity and strain rate divided by the stresses) by keeping the ratio of viscosity to the product of elasticity times Maxwell relaxation time at unity. This original approach reduces the range of velocities to three orders of magnitude in the analogue model (mm/s to m/s), accessible with state-of-the-art monitoring techniques with a magnitude of completeness that scales typically to M6 events. At the meeting we plan to present first results from such a setup including static and dynamic surface deformation pattern from PIV monitoring and accelerometers (“seismographs”) combined with volumetric strain and stress inversion using elastic dislocation modelling and “in-situ” stress observations exploiting photoelasticity.

IAVCEI (Volcanology, Geochemistry)

VW05p - VW05 Models in Volcanology

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Distinguishing volcano sagging and spreading behaviors by using a Digital Image Correlation approach to quantifying analog models

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Spreading and sagging are two long-recognized modes of basement-controlled deformation at volcanoes. Recent analogue experiments have identified a continuum-like transition between such deformation modes, but exactly how changes in basement properties may control this is still debated. One challenge has been to find objective criteria for distinguishing between the end-member modes of deformation (spreading or sagging) and any transitional modes. To address these issues, we conducted scaled analogue experiments involving a sand-plaster cone emplaced upon a basement that comprised an upper brittle layer and a lower ductile layer. Horizontal deformation and displacement fields were quantified by Digital Image Correlation (DIC) analysis of time-lapse images. We find that cones spread, sag, or display mixed styles, depending on the ratios of ductile (D) or brittle (B) layer thickness to cone height (H). While these behaviors comprise a continuum structurally, there is a clear distinction between end-member and transitional behaviors in terms of horizontal displacement patterns. Spreading and sagging behaviors are characterized by maximum displacement vectors directed radially away from or toward the volcano summit, respectively. The transitional ‘spragging’ phase generally shows both inward and outward directed displacements, but the maximum displacement is always directed outward and located in the basement. These objective criteria for deformation mode classification enable the geometric control from the basement properties to be quantitatively expressed in dimensionless B/H vs. D/H space. Our new, comprehensive quantification of how basement properties may control the structural architecture of volcanoes is validated by data from several cases in nature.

IAVCEI (Volcanology, Geochemistry)

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Using PIV, DIC and rheometry to characterise magma intrusion dynamics in gelatine analogue models

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Gelatine analogue models have been used extensively in volcanology to study the dynamics of magma intrusion in the crust. Careful scaling suggests gelatine can be considered a good crustal analogue, behaving almost ideal-elastically at low concentration (2-5 wt% gelatine concentration) and low temperature (5-10 ºC). Gelatine is transparent and so when injected by fluid it is possible to instantly observe the growth of experimental intrusions, as well as monitoring any surface signals of sub-surface flow. We have applied Particle Image Velocimetry (PIV) and Digital Image Correlation (DIC) to quantify with high accuracy and precision the fluid dynamics and host deformation associated with the development and propagation of dykes and sills. Using a rheometer we have explored the visco-elastic range of gelatine mixtures and consider the application of this material to study the construction of larger igneous bodies, such as magma chambers and plutons.

IAVCEI (Volcanology, Geochemistry)

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"Why geology is important to model volcanic processes"

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Modern volcanology has improved the knowledge on how volcanoes work through the use of experimental and theoretical models that help us to visualise and quantify, for example, the changes occurring at the interior of volcanic systems due to magma movement or the eruption behaviour or some volcanoes. The irruption of simple and sophisticated physical and mathematical modeling has forced a true revolution inside volcanology during last years. However, as it occasionally occurs with new exciting and rapid changes not all contributions are good enough or fully satisfy the created expectancies. Some of the current models explaining volcanological processes have ignored the physical constraints that the geological record imposes on some required assumptions and simplifications used to develop such models. In this contributions I make a reflection on the necessary contribution of geology to experimental and theoretical volcanological modelling in order to validate the new findings and make they really useful to understand how volcanoes work.