

Experimental constraints on deep CO₂-rich fluid degassing at arc volcanoes

Margaret Mangan¹, Thomas Sisson¹, William Hankins¹, Nobumichi Shimizu², Torsten Vennemann³

¹US Geological Survey, US, ²Woods Hole Oceanographic Institution, US, ³University of Lausanne, CH

E-mail: mmangan@usgs.gov

Several petrologic and geophysical studies suggest that basaltic magmas residing deep in the roots of many volcanic systems are saturated with an exsolved, CO₂-rich vapor. These CO₂-rich fluids help to form magma pathways by penetrating and pressurizing tensile micro-cracks at the tips of propagating dikes and sills in advance of rising magma.

To estimate the pressure (depth) of deep CO₂-rich degassing under arc volcanoes, solubility experiments on basaltic andesite with 2-6 wt% H₂O and 1 wt% CO₂ (from Ag oxalate) were conducted using a piston cylinder apparatus at 1125°C and pressures of 400-1200 MPa. A welded inner AuPd capsule containing hydrated rock powder and Ag oxalate was placed in an outer Pt capsule in which Ni-NiO buffer and oxalic acid plus Ag oxalate were added. Proportions of oxalic acid to Ag oxalate were set to mimic the anticipated composition of the excess fluid in equilibrium with the melt to reduce the diffusion of hydrogen through the inner capsule (mol fractions CO₂ of 0.70-0.95).

Concentrations of dissolved CO₂ and H₂O in the quenched glasses were determined by manometry at the University of Lausanne and by ion microprobe at the Northeast National Ion Microprobe Facility. The experimental uncertainties are $\leq 10\%$ for CO₂ and $\leq 7\%$ for H₂O. In contrast to published experiments at lower pressure (<400 MPa), no systematic dependence of CO₂ on H₂O was noted in glasses over dissolved water concentrations between 2.3-5.3 wt%. Instead, the data demonstrate the over-riding influence of pressure on CO₂ solubility in deep-crustal, moderately-hydrated basaltic magma. A power law decrease in dissolved CO₂ with decreasing pressure given by $\text{CO}_2(\pm 480 \text{ ppm}) = 0.0008(P(\text{MPa}))^{2.36}$ with $r^2 = 0.95$ best describes the relation. This result is consistent with the numerical model of Papale et al. (Chem. Geol. 2006) which predicts flattening of the H₂O-CO₂ isobaric saturation surface for basaltic magma containing ~2-6 wt% H₂O at pressures above 400 MPa. However, the absolute concentrations of dissolved CO₂ in the quenched glasses suggest that the Papale et al. model under-estimates pressures of fluid saturation by ~20%. Solubility data from mixed H₂O-CO₂ experiments of Shishkina et al. (Chem. Geol. 2008) show similar results for tholeiitic basalt at 500 MPa and H₂O ≤ 4.0 wt%.

In broad terms, the results of these experiments imply that 80-90% of the CO₂ initially dissolved in basaltic magma below arc volcanoes can be released by decompression exsolution at levels deeper than ~20 km.

CO₂, SO₂, and H₂S degassing related to the 2009 Redoubt eruption, Alaska

Cynthia Werner¹, Peter J Kelly², William C Evans³, Micheal P Doukas², Robert McGimsey¹, Christina Neal¹

¹US Geological Survey, Alaska Volcano Observatory, USA, ²US Geological Survey, Cascades Volcano Observatory, USA, ³US Geological Survey, Menlo Park, USA

E-mail: cwerner@usgs.gov

Emissions of CO₂, SO₂, and H₂S from the 2009 eruption of Redoubt Volcano, Alaska were well monitored. Elevated CO₂ emissions were measured 5 months prior to the eruption and varied from 3630 to 9020 tonnes per day (t/d) in the 6 weeks prior to the eruption. In contrast, low S emissions were typical during the pre-eruptive period, resulting in molar C/S ratios of 30–60. However, the high C/S ratio dropped to a value typical for Cook Inlet volcanoes (ave. = 2.4) coincident with the first phreatic explosion on March 15, 2009, and remained low throughout all phases of the eruption. Observations of melt water discharge and water chemistry leading up to the eruption suggested that surface waters represented drainage from surficial lenses of condensed magmatic steam and glacial meltwater, and that only a few hundred tonnes/day of SO₂ were reacting to a dissolved component, not the > 2100 t/d SO₂ expected from degassing of magma in the upper crust (3–6.5 km), where petrologic analysis showed that the final magma equilibration occurred. Thus, the high pre-eruptive C/S ratios could reflect bulk degassing of upper-crustal magma followed by nearly complete loss of SO₂ in a magmatic-hydrothermal system deep in the edifice, though no clear hydrothermal component was detected in the analyses of the effluent, even in post-eruption sampling (Oct. 2012). Alternatively, we prefer that the high C/S ratios are attributed to degassing of low silica andesitic (LSA) magma that intruded the mid-crust in the 5 months prior to eruption; modeling suggests that mixing of this LSA magma with a pre-existing high silica andesite magma or mush in the mid-to-upper crust would have resulted in a C/S ratio consistent with that measured during the eruption. Maximum emission rates measured with airborne techniques were 33,110 t/d CO₂, 16,650 t/d SO₂, and 1230 t/d H₂S. Pre-eruptive open system degassing accounted for 14% of the total CO₂ and 4% of total SO₂, whereas post-eruptive degassing was responsible for 27 and 30% of the total CO₂ and SO₂ with measurements extending over one year following the cessation of dome extrusion. The magma degassed primarily as a closed system with approximately 59 and 66% of the total CO₂ and SO₂, respectively, emitted during the explosive and dome growth periods. SO₂ made up on average 92% of the total S throughout the eruption. Primary volatile contents calculated from pairing degassing estimates with the erupted magma volumes over the same time periods range from 0.9–2.1 wt.% CO₂ and 0.27–0.56 wt.% S, with preferred estimates of 1.25 wt.% CO₂ and 0.35 wt.% S. Assuming these values, up to 30% more magma degassed in the year following final dome emplacement.

Magmatic gases of Gorely volcano, Kamchatka: element fluxes and comparison with MultiGas data

Yuri Taran¹, Ilya Chaplygin²

¹Institute of Geophysics, Universidad Nacional Autonoma de Mexico, Mexico, ²Institute of Ore Deposits, Russian Academy of Sciences, Russia

E-mail: yuri.taran@gmail.com

Basaltic Gorely volcano at Southern Kamchatka is characterized by a strong gas emission from its active crater since 1980. The volcano is located within a large caldera, 15 km to the NW from another strong gas emitter, Mutnovsky volcano. Remote measurements in September 2011 revealed the SO₂ flux from Gorely in the range of 400 to 1100 t/day (800 t/day on average). The MultiGas measurements of the plume composition on the crater rim realized at the same time showed that the gas is water and chlorine rich, with C/S ~1 and S/Cl ~ 2 (Aiuppa et al., 2012). Direct sampling of the 850 °C fumarole near the crater floor and the cold acidic crater lake was done two weeks after the DOAS and MultiGas measurements. Isotopic composition of magmatic vapor corresponds to mixing 25% of meteoric water with typical "andesitic water". Trace element composition of the volcanic gas condensates are compared with the available data from other high temperature volcanic gas emissions, in particular, with the chemistry of fumarolic condensates of Kudryavy volcano. Condensate of Gorely shows a similar trace element pattern but with a notable enrichment in chalcophile and depletion in siderophile elements comparing to Kudryavy. Concentrations of Re (up to 20 ppb) is similar for both volcanoes. Concentrations of Au and elements of Pt group are lower than detection limit of ICPMS. REE distribution in the Gorely condensate is parallel to the REE rock pattern with a slight enrichment in both light and heavy REE. Results for main components generally confirm those obtained by the MultiGas technique though there are some differences:

Date of sampling	H ₂ O	CO ₂	SO ₂	HCl	C/S	S/Cl
Direct 20.09.2011	94.9	1.7	1.9	0.83	0.91	2.26
MultiGas 06.09.2011	93.2	2.7	2.3	1.2	1.17	1.92

Emission rates of elements are calculated using their SO₂/E ratios and the average SO₂ flux from Gorely of 800 t/day.

Aiuppa, A., et al. First volatile inventory for Gorely volcano, Kamchatka. Geoph. Res. Lett., 39, L0637, 2012.

The magmatic-hydrothermal transition: Observations from the 2012 eruptions of White Island and Tongariro, New Zealand

Bruce W Christenson¹, Arthur Jolly², Karen Britten², Agnes Mazot²

¹National Isotope Centre, GNS Science, New Zealand, ²Wairaki Research Centre, GNS Science, New Zealand

E-mail: b.christenson@gns.cri.nz

The 4 August 2012 phreatomagmatic eruption of White Island was the first significant activity from this volcano since February 2001. Although small in size and duration, the eruption was followed by the building of a 20 m high tuff cone, and subsequent extrusion of a small lava dome. Some 6 months prior to the eruption, low temperature (100 °C - 200 °C) fumaroles on the main crater floor began to show increasing trends in CO₂/CH₄, CO₂/H₂O, C/S and CO/CO₂ ratios, constituting shifts from hydrothermal to increasingly magmatic signatures. These changes were also accompanied by a progressive isotopic shift in $\delta^{15}\text{N}_2$ from +2.9 ‰ to +5.5 ‰. This is the heaviest $\delta^{15}\text{N}$ signature yet encountered in the Taupo Volcanic Zone, and provides new insights into the TVZ magmatic N₂ end-member composition. These anomalies were coupled to an increase in harmonic and broad spectrum tremor during the same period. Together, these observations provide an unequivocal context for recognising future eruptive activity, but also criteria for constraining hydrothermal system response, and gas-magma transport behaviour in this volcano.

Similarly, and just two days after the White Island eruption, the 6 August 2012 phreatic eruption of Te Mari, Mt Tongariro marked the re-awakening of this volcano which last erupted in 1896. This eruption was accompanied by precursory volcano-tectonic earthquakes, and by marked changes in chemical signatures of gases emitted from the Lower Te Mari fumaroles. Fumarolic gas sampled from the western rim of Lower Te Mari crater on 22 May 2012 showed no significant changes from baseline values. Earthquake activity commenced on 13 July, and intensified over the period of 18-21 July with approximately 120 located hybrid and volcano-tectonic events. Fumarolic gases collected on July 21 revealed significant changes in gas signatures from the Lower Te Mari fumaroles by this time, with key ratios of CO₂/CH₄ and N₂/Ar increasing from 5,400 to 91,200 and 91 to 1,245 respectively, and increasing further to 121,000 and 1,300 respectively by 27 July. During this time there were no significant changes in fumarolic temperatures or pressures, suggesting that permeabilities in the hydrothermal system were low, and were throttling gas transfer from below. Baseline C/S mole ratios for Te Mari fumaroles are close to 5. Immediately prior to the Aug 6 eruption, C/S had fallen to ca. 3, and post eruption fell to < 1, consistent with extensive degassing of a small magma volume. A second, short-lived pulse of CO₂-rich gas was recognised in late September, but this did not lead to further eruption activity. The current model for this activity involves open-system degassing of shallowly emplaced dike intrusion(s) beneath the volcano.

Gas emission measurements of the active lava lake of Niyragongo, DR Congo

Nicole Bobrowski¹, Giovanni Giuffrida², Dario Tedesco³, Mathiew Yalire⁴, Santiago Arellano⁵, Charles Balagizi⁴, Bo Galle⁵

¹Institut fuer Umweltphysik, Universitaet Heidelberg, Germany, ²Institute Nazionale Geofisica e Vulcanologia, Palermo, Italy, ³Universita Napoli, Caserta, Italy, ⁴Observatoire Volcanologique de Goma, D.R. Congo, ⁵Chalmers University of Technology, Goeteborg, Sweden

E-mail: nbobrows@iup.uni-heidelberg.de

Between 2007 and 2011 four measurement campaigns (June 2007, July 2010, June 2011 and December 2011) were carried out at the crater rim of Nyiragongo volcano, DR Congo. Nyiragongo is considered one of the most active volcanoes in Africa. The ground based remote sensing technique Multi Axis Differential Optical Absorption spectroscopy (MAXDOAS) using scattered sunlight and a Multigas instrument have been simultaneously applied during all field trips and among others bromine monoxide/sulphur dioxide (BrO/SO₂) and carbon dioxide/sulphur dioxide (CO₂/SO₂) ratios were determined. At the various field trips lava lake level changes were observed (in the order of minutes up to days and also between the years). The measured gas ratios varied as well for CO₂/SO₂ ratios between 1.2 and 16.2 and between 0.2 and 1.6×10^{-5} for BrO/SO₂ ratios. BrO/SO₂ ratios showed similar behavior as CO₂/SO₂ ratios. Higher CO₂/SO₂ ratios and BrO/SO₂ levels were generally observed at higher lava lake levels and a decrease of the lava lake was accompanied by a decrease in the BrO/SO₂ as well as CO₂/SO₂ ratio. During all campaign also Cl/S ratios have been determined by filterpack sampling. Overall the Cl/S ratio shows an increase with time from earlier literature data of 0.05 to up to 0.55 in 2011, which is accompanied by a decreasing sulfur dioxide flux.

A model is proposed, which assumes various convective magma cells inside the conduit and the possible temporary interruption of part of the cycling. This model is able to explain our data set as a whole.

First measurement of magma degassing processes and co-varying seismic tremor during an eruption of Piton de la Fournaise hot spot basaltic volcano, Reunion island

Patrick Allard¹, Alessandro La Spina², Giancarlo Tamburello³, Alessandro Aiuppa³, Andrea Di Muro⁴, Diego Coppola⁵, Jean Battaglia⁶, Mike Burton⁷, Florent Brenguier⁴, Thomas Staudacher⁴

¹Institut de Physique du Globe de Paris (IPGP), UMR7154 CNRS, Paris, France, ²Istituto Nazionale di Geofisica e Vulcanologia (INGV), Catania, Italy, ³DISTEM, Università di Palermo, Palermo, Italy, ⁴Observatoire Volcanologique du Piton de la Fournaise, IPGP, La Reunion, France, ⁵Dipartimento di Scienze Mineralogiche e Petrologiche, Università di Torino, Italy, ⁶LMV, CNRS-Univ. Blaise Pascal, Clermont-Ferrand, France, ⁷Istituto Nazionale di Geofisica e Vulcanologia (INGV), Pisa, Italy

E-mail: pallard@ipgp.fr

Piton de la Fournaise (PdF), in the western Indian Ocean, is a very active hot spot basaltic volcano whose eruptions (1 to 2 per year on average) are well anticipated by the local geophysical monitoring network but whose magmatic gases had never been measured. Here we report on the first data for magmatic gas composition (OPFTIR absorption spectroscopy, in situ MultiGas analysis plus filterpack sampling) and budget (DOAS), coupled with recording of seismic tremor and the lava extrusion rate (space-borne MODIS sensing), during a fissure eruption of PdF in October 2010. Dyke ascent from about 2 km beneath the summit crater was tracked by a few hours of precursory seismic signals and volcano deformation. After a strong initial burst coinciding with eruptive fissure opening, both the tremor amplitude, lava extrusion rate and SO₂ flux coherently decreased during the first week of eruption. The emitted magmatic gases, whose composition varied slightly over time, were found to be water-rich and to display high S/Cl but low C/S, Cl/F and Cl/Br ratios. These features are consistent with a hydrous hot spot mantle source and previous volatile fractionation during shallow magma storage. Volatile fluxes referred to the magma extrusion rate and available melt inclusion data point to essentially syn-eruptive (closed system) degassing of sulfur, chlorine and fluorine during the first half of the eruption. In contrast, additional inputs of CO₂ and H₂O are required to explain the gas composition. Differential CO₂ bubbling is supported by high-frequency correlations between the FTIR-sensed CO₂/HCl ratio and seismic tremor, while entrainment of hydrothermal steam might have enhanced the H₂O gas content. The second week of the eruption was marked by a spectacular decoupling between declining lava extrusion and reincreasing seismic tremor amplitude (especially in the low-frequency band), indicating a key control of tremor and degassing activity by differential (open system) gas bubbling across the feeder dyke. Finally, the end of the eruption was preceded by a new sharp tremor increase, with remarkable anti-correlated variations of the 1-3 Hz and 3-5 Hz spectral signals, which we attribute to abrupt geometrical changes prior to dyke closure. Combined geochemical and geophysical survey of Piton de la Fournaise volcano in the future should permit a better understanding and forecasting of its eruptive behavior.

Volatile evolution of magma plumbing system of the 2000 eruption at Miyakejima volcano deduced from melt inclusion analyses

Genji Saito, Yuichi Morishita, Hiroshi Shinohara

Geological Survey of Japan, National Institute of Advance Industrial Science and Technology, Japan

E-mail: saito-g@aist.go.jp

The 2000 eruption of Miyakejima volcano, Japan, is characterized by intrusion of a dyke and a submarine eruption in June, subsidence of the summit area with phreatic and phreatomagmatic explosions in July to August, and intense and continuous degassing from the summit after the major eruptions (e.g., Nakada et al., 2005). Geophysical and petrological observations suggested that shallow andesitic and deeper basaltic magma chambers existed beneath the volcano before the 2000 eruption (e.g., Amma-Miyasaka et al., 2005). In this study, petrological and melt inclusion studies were carried out in order to know volatile evolution of the magma plumbing system. We can consider three component magmas, "A" magma in the shallow magma chamber erupted at the submarine eruption, and "B" and "C" magmas erupted at the summit eruptions. The C magma represents the deeper-sourced basaltic magma and the B magma was produced by 40 wt% fractional crystallization of the C magma. The bimodal olivine core composition and diffusion profiles of the olivines in the ejecta of the summit eruptions indicate the mixing of B and C magmas in two months before the eruption. The melt inclusions in Mg-rich olivines derived from the C magma have slightly higher H₂O (1.9-3.5 wt%) and S (0.06-0.21 wt%) contents, and a lower Cl (0.04-0.07 wt%) content than the inclusions in Mg-poor olivines from the B magma, while they have similar CO₂ (0.003-0.025 wt%) contents. The wide range of CO₂ contents can be explained by magma degassing with a decrease in pressure. The initial CO₂ content of the deep basaltic magma (0.15 wt%) was estimated from the H₂O and S contents of the inclusion in the Mg-rich olivine and the volcanic gas composition. Based on the variation in the chemical composition of the melt inclusions, we propose volatile evolution of the magma plumbing system as follows. In the deep magma chamber at depth of about 10 km, 40 wt% fractional crystallization of C magma having initial volatile content of 3 wt% H₂O and 0.15 wt% CO₂ made B magma having bulk volatile content of 5 wt% H₂O and 0.25 wt% CO₂. This B magma ascended from the deep magma chamber to the shallow magma chamber (3-5 km depth), causing degassing of the B magma with pressure decrease. The decompression degassing decreased the volatile content of the B magma to 3.9 wt% H₂O and 0.008 wt% CO₂. Before the 2000 eruption, the addition of CO₂-rich gas to the B magma occurred in the shallow magma chamber and caused a change in the volatile content of the melt to 2.8 wt% H₂O and 0.035 wt% CO₂. In addition, the C magma ascended from the deep magma chamber and was injected into the B magma. The mixture of the B and C magmas ascended to a depth shallower than 3 km, accompanied by magma degassing with the pressure decrease.

The 2011-2012 submarine eruption of volatile-rich magma at El Hierro, Canary Islands

Marc-Antoine Longpré¹, John Stix¹, Nobumichi Shimizu², Andreas Klügel³

¹McGill University, Canada, ²Woods Hole Oceanographic Institution, USA, ³University of Bremen, Germany

E-mail: m-a.longpre@mcgill.ca

From October 2011 to March 2012 a submarine eruption took place 2 km south of El Hierro, the youngest and westernmost of the Canary Islands. The eruption produced buoyant, gas-filled "lava balloons" that sporadically rose from 100-300 m depth below sea level to the ocean surface and were sampled. Here we report ion microprobe measurements of the volatile element concentrations (CO₂, H₂O, S, F, Cl) of basanite matrix glass and basanite to phonotephrite melt inclusions trapped in olivine and Fe-Ti oxide phenocrysts collected from the glassy lava samples. The results reveal the volatile-rich nature and degassing history of the 2011-2012 magma. Whereas matrix glasses contain 70-710 ppm CO₂, 0.4-0.9 wt.% H₂O, 410-1030 ppm S, 1540-1790 ppm F and 850-1010 ppm Cl, melt inclusions show much greater ranges extending to high concentrations. Carbon dioxide concentrations in melt inclusions exhibit extreme variations from <50 to 13700 ppm, with 50% of values above 2000 ppm CO₂. Most melt inclusions have dissolved water contents in the range 0.5-1.5 wt.%, but values of up to 3 wt.% are observed. Sulphur ranges from 320 to 5580 ppm and is positively correlated with H₂O. Fluorine and chlorine vary from 860 to 2110 ppm and 610 to 1370 ppm, respectively. These volatile concentrations are among the highest ever measured for ocean island magmas. The high CO₂ and H₂O contents require high entrapment pressures (>200 MPa) for most melt inclusions, in agreement with fluid inclusion and clinopyroxene-melt barometry as well as with syn-eruptive seismicity. This suggests that the volatile-rich nature of the El Hierro magma was inherited from the mantle source. Intense shallow level degassing probably led to powerful submarine Strombolian explosions at El Hierro, as indicated by strong bubbling at the ocean surface. First-order calculations, using an eruptive volume of 329 million m³ (converted to 160-260 million m³ DRE assuming 20-50% porosity) determined from high-resolution bathymetric surveys (Rivera et al., 2013) and assuming 1 wt.% CO₂ and 5000 ppm S total degassing, indicate that the El Hierro eruption could have released roughly 4-6 Tg CO₂ and 2-3 Tg S to the hydrosphere and atmosphere. However, the formation of abundant sulphide globules associated with magnetite and clinopyroxene phenocrysts may have provided a sink for much of the sulphur. A positive correlation between S⁶⁺/ΣS, as measured by the peak shift method, and S concentration in melt inclusions suggests that a reduction in the oxidation state of the magma during sulphur degassing, possibly aided by extensive magnetite crystallisation, could have caused saturation with a sulphide liquid. Our findings thus have far-reaching implications for the dynamics of the 2011-2012 El Hierro eruption, the volatile-rich nature and degassing of Canarian and other mafic alkaline magmas, and the nature of the mantle source beneath the Canary Islands.

New insights on the dynamics of the most recent Plinian eruptions of Mt. Pelée (Martinique, Lesser Antilles) inferred from noble gases

Lorraine Ruzié¹, Guillaume Carazzo³, Manuel Moreira², Steve Tait³, Edouard Kaminski³

¹Department of Earth Sciences University of Manchester, United-Kingdom, ²Géochimie et Cosmochimie, IPGP, Sorbonne Paris Cité, Univ. Paris Diderot, France, ³Dynamique des Fluides Géologiques, IPGP, Sorbonne Paris Cité, Univ. Paris Diderot, France

E-mail: lorraine.ruzie@manchester.ac.uk

Mt. Pelée in Martinique is one of the most dangerous volcanoes of the Lesser Antilles arc. The May 8th, 1902 eruption that destroyed the town of St Pierre and killed 28,000 inhabitants is a famous example of its hazardous explosive activity. Lacroix (1904) first defined the Pelean style as dome emplacement associated with lateral blast explosions based on his pioneering description of this eruption. Among the 22 magmatic events recorded at Mt Pelée over the last 5000 years, 6 were (Merapi-type) dome collapse eruptions and 10 were (Pelean-type) lateral blast eruptions. Furthermore, 6 eruptions were Plinian eruptions, which produced both pyroclastic flows and Plinian columns. Such a variability of eruptive regimes is a serious challenge for the management of volcanic hazards at Mt. Pelée, and past eruption deposits are a crucial insight to understand the complex dynamics of this volcano.

Here we use the information recorded by the noble gases trapped inside the vesicles of pumices to study the last three Plinian eruptions of Mt. Pelée (P1, P2, P3). During magma decompression and bubble growth, varying degrees of fractionation between the noble gases can occur because of differing diffusion coefficients and depending on the time-scale involved. A noble gas measurement in a pumice sample thus enables us to quantify the time elapsed between the onset of degassing and quenching due to fragmentation, for example. Type-1 eruptions (P1 and P3-1) are characterized by pumice vesicles with a low enrichment in neon compared to argon ($F^{22}\text{Ne} < 400$) and $^{38}\text{Ar}/^{36}\text{Ar}$ ratio close to its initial value (~ 0.1880). On the other hand, type-2 eruptions (P2, P3-3 and P3-2) are characterized by pumice vesicles with a high enrichment in neon compared to argon ($F^{22}\text{Ne} > 1000$) and a strongly fractionated $^{38}\text{Ar}/^{36}\text{Ar}$ ratio (< 0.1860), rarely observed on Earth.

We interpret these fractionations as the result of two different durations for the dynamics of magma degassing. The strong elemental and isotopic fractionations in type-2 eruptions correspond to a short time scale of degassing, and suggest that fragmentation processes occurred shortly after the onset of degassing in the conduit. Such a rapid evolution may occur where the magma is abruptly depressurized by the collapse of a pre-existing dome, or by a sudden drop of the fragmentation level in the conduit. In type-1 eruptions, fractionations can be explained by slower degassing such that a closer approach to equilibrium between melt and bubble is achieved before quenching.

The noble gas pattern produced during magma degassing with variable time-scales can then be used as a stratigraphic marker of different Plinian eruptions. This represents a new tool for the identification and mapping of old fallout deposits imperfectly preserved in the field.

Gas geochemistry of the Copahue-Caviahue Volcanic Complex (Argentina).

Mariano Augusto¹, Franco Tassi², Alberto Caselli¹, Orlando Vaselli³, Dmitri Rouwet⁴, Bruno Capaccioni⁵, S Caliro⁶, Giovanni Chiodini⁶, T Darrah⁷

¹GESVA-IDEAN, Dpto. Cs. Geologicas, FCEN, Universidad de Buenos Aires. Buenos Aires, Argentina, ²Department of Earth Sciences, University of Florence, Florence, Italy, ³Institute of Geosciences and Earth Resources of the National Research Council (CNR-IGG), Florence, Italy, ⁴Istituto Nazionale Geofisica e Vulcanologia, Sezione di Bologna, Bologna, Italy, ⁵Department of Earth and Geological-Environmental Sciences, Bologna, Italy, ⁶Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, Naples, Italy, ⁷Division of Earth and Ocean Sciences, Nicholas School of the Environment, Durham, USA

E-mail: magusto@gl.fcen.uba.ar

Copahue volcano is part of the Caviahue-Copahue Volcanic Complex (CCVC), which is located in the Caviahue volcano-tectonic caldera (Argentina-Chile), a pull-apart basin between a southern strike slip and a northern compressive fault system, in the Southern Andean Volcanic Zone. During the last 250 years, at least 12 low-magnitude phreatic and phreatomagmatic eruptions occurred. In 2000 a phreatomagmatic event (VEI 1-2) caused ash fall that affected the nearby villages. Since November-December 2011 the discharge rate of fluids from the Copahue summit has significantly increased up to December 22nd 2012, when a new phreatomagmatic eruption occurred. In this study, the chemical and isotopic ($\delta^{13}\text{C}$ of CO_2 and CH_4 , δD of CH_4 and H_2O , $\delta^{18}\text{O}$ of H_2O , $\delta^{15}\text{N}$, $3\text{He}/4\text{He}$ and $40\text{Ar}/36\text{Ar}$) compositions of fumaroles and bubbling gases collected in 2006, 2007 and 2012, i.e. prior and during the last volcanic crisis, from five thermal areas surrounding the Copahue volcanic edifice are presented and discussed. The main aims are to i) investigate the origin of fluids and their relationship with the tectonic setting, and ii) describe the evolution in fumarolic fluids chemistry and relate it to the changing volcanic activity.

The He isotopic ratios, the highest observed for a Southern American volcano (R/R_a up to 7.94), and $\text{CO}_2/3\text{He}$ ratios (from 1.4 to $8.8 \cdot 10^9$) suggest a non-classic arc-like setting, but rather an extensional regime due to asthenospheric thinning. $\delta^{15}\text{N}$ values (+5.3 to +5.5 ‰vs ATM) point to a source of N_2 mainly from subducted sediments. Although these gases show a clear mantle isotopic signature, magmatic gases, such as SO_2 , HCl and HF are not detected, suggesting gas scrubbing by the hydrothermal reservoir that feed CCVC. Gas geothermometry in the $\text{H}_2\text{O}-\text{CO}_2-\text{CH}_4-\text{CO}-\text{H}_2$ system suggests that CO and H_2 re-equilibrate in a vapor phase at 200-220 °C. On the contrary, rock-fluid interactions controlling CO_2 , CH_4 production from Sabatier reaction and C_3H_8 dehydrogenation seem to occur within the hydrothermal reservoir at temperatures ranging from 250 to 300 °C. Fumarole gases sampled in 2006-2007 show relatively low N_2/He ratios and high R/R_a values with respect to those measured in 2012 and prior to the 2000 eruption. Such compositional and isotopic variations were likely caused by an injection of fresh He-rich magma that likely triggered the 2000 eruption. Presently it is difficult to assess the effects caused to the hydrothermal system by the current phreatomagmatic activity. A high-frequency geochemical monitoring in the thermal areas located at the foothills of Copahue is necessary to identify possible magmatic signals.

The origin of fumarolic fluids from Tupungatito Volcano (Central Chile): new insights from volatile compositions

Oscar Benavente¹, Franco Tassi², Francisco Gutiérrez¹, Orlando Vaselli², Felipe Aguilera³

¹Centro de Excelencia en Geotermia de los Andes, Universidad de Chile, Plaza Ercilla, 803, Chile,
²CNR-IGG, Istituto di Geoscienze e Georisorse Via G. La Pira, 4, Firenze, Italy, ³Departamento de Geología, Universidad de Atacama, Copayapu 485, Copiapo, Chile

E-mail: oscar.benavente.zolezzi@gmail.com

Tupungatito is an early Pleistocene – Holocene volcano located 100 km east of Santiago, in the northernmost sector of the South Volcanic Zone (SVZ) in Central Chile. Permanent fumarolic activity occurs at the Tupungatito summit (González – Ferrón 1995) where three crater lakes are hosted. In this study we present and discuss the very first chemical and isotopic ($\delta^{13}\text{C}$ – CO_2 , R/Ra , and $40\text{Ar}/36\text{Ar}$) composition of fumarolic gases and steam ($\delta^{18}\text{O}$ and δ^{D}) collected from this volcano during two sampling campaigns carried out in February 2011 and 2012. The main aims are to investigate the different fluid source regions and the chemical-physical processes controlling fluid chemistry.

The chemical and isotopic data indicate that the discharged gas species and steam are likely produced by mixing processes of fluids between a magmatic source rich in acidic gases (SO_2 , HCl and HF) and a meteoric – recharged hydrothermal reservoir. The magmatic – hydrothermal fluids at the surface are affected by steam condensation that controls the outlet fumarolic temperatures ($<84^\circ\text{C}$) favoring the dissolution of high soluble magmatic gases. The origin of CO_2 seems to be mainly related to devolatilization of the subduction carbonates, with a limited contribution from the overlying organic – rich sediments, suggesting that the mantle source is strongly contaminated by the slab sediments. Gas geothermometry based on the kinetically rapid H_2 – H_2O – CO – CO_2 system indicates equilibrium temperatures $>200^\circ\text{C}$ at redox conditions more oxidizing than those commonly characterizing hydrothermal reservoirs. Reactions involving CH_4 and C_2 – C_3 alkenes/alkanes pairs, having a relatively slow kinetics, seem to equilibrate at greater depth where temperatures are $>200^\circ\text{C}$ and redox conditions consistent with those inferred by the presence SO_2 – H_2S redox pair, typical of a magmatic fluid environment. A comprehensive conceptual geochemical model describing the circulation pattern of the Tupungatito hydrothermal – magmatic fluids is proposed to show fluid source regions and re – equilibration processes affecting the different gas species occurring at changing chemical – physical conditions as the magmatic – hydrothermal fluids rise up toward the surface.

By comparing the Tupungatito gas geochemical data with those discharging from other volcanic systems located in the northernmost sector of the Chilean Andes, it is possible to assess that i) different climate, ii) amount and composition of the subducted sediment, iii) slab thermal state, and iv) crustal thickness and lithology do not apparently play a significant influence on the gas chemistry.

The current degassing state of Hekla volcano, Iceland

Evgenia Ilyinskaya¹, Alessandro Aiuppa², Baldur Bergsson³, Thrainn Fridriksson⁴, Katharina Lechner³,
Audur Oladottir⁴, Richard Yeo², Gaetano Giudice⁵

¹British Geological Survey, United Kingdom, ²Universita di Palermo, Italy, ³Icelandic Meteorological Office, Iceland, ⁴Iceland GeoSurvey, Iceland, ⁵Istituto Nazionale di Geofisica e Vulcanologia, Italy

E-mail: evgenia@bgs.ac.uk

Hekla volcano is one of the most active and also most unpredictable volcanoes in Europe, as a precursory seismic swarm tends to precede its eruptions by <1 hour. Since 1970, Hekla has erupted every 10 years, and is now inflated to same level as prior to the last eruption in 2000.

There is a significant uncertainty about the depth of the magma source^{1,2,3,4,5} (<9 to >25 km) and the total output of gaseous emissions both during eruptions and the quiescent intervals. It is also unknown whether the frequent activity of Hekla during the past century is a beginning of a new eruptive trend.

In the summer of 2012 we examined gas emissions from Hekla during a quiescent interval. This was the first time that continuous and near real-time gas measurements were set up at an Icelandic volcano. The aims were twofold: Firstly, to quantify the current gas release and investigate the gas source (magmatic vs hydrothermal components); secondly to evaluate a 'proof-of-concept' methodology for volcanic gas measurements in Iceland and thus contribute to volcanic monitoring.

Our findings showed that Hekla's gas emissions are dominated by CO₂ (flux 14 T d⁻¹) which is consistent with a deep-lying magma source. Hekla's gas emissions are proportionally significantly more CO₂ rich than other known volcanic gas sources in Iceland. Gas is only emitted from Hekla's top crater (last active 1980), while more recently active craters (1991 and 2000) have higher ground temperatures, but no detectable degassing. The isotopic signature of CO₂ is magmatic, while H₂O isotopes have a more complicated behaviour and may indicate a hydrothermal component. We believe that the elevated ground temperature at the younger craters are caused by residual heat in the erupted material from 1991 and 2000, while the gas flux in the summit crater is driven by ongoing degassing of magma at depth.

The project is ongoing and now forms a part of the FUTUREVOLC, a newly commenced EU FP7 supersite project.

References: 1. Geirsson et al. 2012 JGR; 2. Ofeigsson et al. 2011. JGR 116(B5); 3. Sigmundsson et al. 1992. Geophys. Res. Lett. 19(14); 4. Soosalu and Einarsson 2004 . Bull. Volc. 66(3); 5. Sturkell et al. 2005. EOS 86(52)

Increasing activity of Ijen Crater Lake Indonesia In 2011-2012

Sofyan Primulyana¹, Syegi Lenarahmi Kunrat², Ugan Boyson Saing³

¹CVGHM (Center for Volcanology and Geological Hazard Mitigation), Indonesia, ²CVGHM (Center for Volcanology and Geological Hazard Mitigation), Indonesia, ³CVGHM (Center for Volcanology and Geological Hazard Mitigation), Indonesia

E-mail: sofyan@vsi.esdm.go.id

Ijen Crater Lake is located on the eastern border of Java island, Indonesia. Monitoring of volcanic activity of Ijen Crater Lake has been done using visual observation, temperature measurement, seismicity, and changes in chemical composition. Since October 2011, the activity of Ijen Crater Lake has increase which were marked by the increasing of seismicity. Water lake temperature increased from 27 °C up to 45 °C on March 2012. Water lake color changes from dark green to whitish green observed in October to December 2011. On January 2012 gas bubble observed on the surface of the lake. From January to March 2012, Chloride concentration increased from 20,934 mg/liter to 45,629 mg/liter, Sulfate concentration increased from 30,078 ppm to 57,017 ppm, the ratio of Cl/SO₄ increased from 0.70 to 0.80.

The end of March 2012, activity of Ijen Crater Lake begins to decline which were characterized by the decreasing of water lake temperature into relatively stable about 35-36 °C. Gas bubble was not visible on the surface of the lake since mid-March 2012. Chloride concentration decreased from 45,629 mg/liter to 25,250 mg/liter, the ratio of Cl/SO₄ decreased from 0.80 to 0.32, whereas sulfate is still an increase up to 79,435 ppm. From May to August 2012, chloride and sulfate concentration showed a pattern indicating magmatic gasses supply is relatively stable.

Isobaric bubble growth and collapse in magma

Felix W von Aulock, Ben Kennedy, Christopher Oze, Paul A Ashwell

University of Canterbury, Christchurch, New Zealand

E-mail: felixv.aulock@gmail.com

Bubble growth forces magma to rise in volcanic conduits, produces overpressure within the conduit and leads to fragmentation of the melt during explosive eruptions. The three main mechanisms controlling the growth of bubbles in melts are: (1) decompressive expansion, (2) water diffusion/exsolution related to oversaturation and (3) bubble coalescence. Magma can experience isobaric conditions as it stagnates in a magma chamber, lava dome or post-eruptive pyroclast. In all these instances, water may diffuse in and out of bubbles despite negligible decompression. After the melt solidifies, water gradients related to bubbles formed by dissolution and/or resorption, are capable of preserving these periods of magma stagnation.

Here we present high-resolution water distribution data of isobaric bubble growth experiments in natural rhyolitic samples. Bubble free aphanitic rhyolite was heated to 950°C and volume changes were visually tracked. The samples were either just kept at 950°C for 3-24 h or were subsequently cooled to 850°C and kept for an equal amount of time before they were cooled to room temperature.

Samples show an initial volume increase of 140% - 450%, and later deflate by about 5% of the maximum volume. Bubble sizes in the samples range between 10 μm to 1 mm. The surface of the sample consists of a thin skin of bubble-free glass that prevents the sample from deflating through a permeable network. Water gradients show a decrease of water content across this rim to the outer surface of the sample. The background water content of the glass ranges between 0.1-0.5 wt. %. Water content either increases or decreases around bubbles. If the samples are heated to 950°C for only short timescales of 2-3h, water contents decrease towards the surface of the bubble. No systematic gradients develop around bubbles in samples that were held for 24h at 950°C. Many bubbles in samples that were cooled by 100°C and kept at this lower temperature show an increase of water in the glass towards the surface of the bubbles.

This shows that water diffuses into vesicles during growth until equilibrium bubble size is reached when volatiles neither exsolve nor resolve around individual bubbles. Equilibrium bubble size, however, can vary depending on local quantities of water. The equilibrium is reached after ≤ 24 h at temperatures of 950°C and diffusion homogenizes water contents and any gradients that remain from stages of bubble growth. If the glass is subsequently cooled, the solubility of water increases and it can get resorbed into the glass.

Our experiments allow us to track the volatile diffusion around bubbles, showing the thermal history and degassing patterns in almost completely degassed samples. This approach will serve as an important tool for the estimation of timescales and processes that control effusive and explosive volcanic eruptions.

Modelling gas transfer, storage and resulting displacement in a 3d permeable volcanic edifice

Amy S.D. Collinson, Jurgen W. Neuberg

University of Leeds, UK

E-mail: ee07asdc@leeds.ac.uk

We use previous experimental data on permeabilities to create 3D numerical models to investigate gas transport and storage in a permeable volcanic edifice. We combine the continuity equation, Darcy's law and the ideal gas law to derive a partial differential equation which is solved using a finite element method to obtain the gas pressure. The associated pressure gradient is then used within Darcy's law to calculate the gas flux. Additionally, we investigate how the presence of gas and variations in permeability influence the rate and degree of deformation in the volcanic edifice.

This method allows the modelling of two and three dimensional structures, both in stationary and time-dependent evolution. Different geometries are created and the pressure and permeabilities incorporated into the model as boundary and domain conditions respectively.

We present two case studies in order to illustrate how variable permeability and pressure gradients influence the gas flux. Firstly we investigate an event at Soufriere Hills Volcano during March 2012 which culminated in significant ash venting. Secondly we attempt to model degassing rings on volcanoes such as Santiaguito and Colima.

Our model is highly versatile and aims to shed new light on the understanding of gas storage and transport in a permeable volcanic edifice.

New approach to evaluating the mass flux of volcanic fluids using the electrical conductivity structure of a volcano: application to Unzen volcano, SW Japan

Shogo Komori¹, Tsuneomi Kagiya², Jerry P Fairley³

¹Institute of Earth Sciences, Academia Sinica, Taiwan, ²Aso Volcanological Laboratory, Kyoto University, Japan, ³Department of Geological Sciences, University of Idaho, USA

E-mail: komori@earth.sinica.edu.tw

The efficiency of degassing of volcanic fluids in magma is one of the key parameters controlling the explosive potentiality of the eruption and the diversity of the volcanic activity. Therefore, to evaluate the mass flux of volcanic fluids is important in considering the constraint conditions of these phenomena. When volcanic fluids are dissolved into the pore water of the aquifer, the aquifer has a high electrical conductivity; this is because that the pore water conductivity is increased due to the high- salinity and temperature, and that the surface conductivity of matrix is also increased due to hydrothermal alteration. The spatial extent of the high conductivity region could be related to the abundance of the flux of volcanic fluids. Therefore, the electrical conductivity structure of a volcano has a potentiality for estimating the volcanic fluid mass flux by groundwater flow.

The authors developed the simple steady state model of volcanic fluids dissipation inside the aquifer, to investigate the factors controlling the spatial extent of the high electrical conductivity region. Firstly, the model of the groundwater flow was developed, to estimate the salinity and temperature distributions of the aquifer. Some simplification were used with respect to the groundwater flow; a simple geometry and physical properties of the aquifer, and relatively little contribution of the groundwater flow from the buoyancy force. Secondly, the simple model of the electrical conductivity was developed, to estimate the bulk electrical conductivity distribution using the temperature and salinity distributions. This model assumes that the pore water conductivity and the surface conductivity of matrix can be represented simply as a function of temperature and salinity of pore water.

Results showed that the spatial extent of the high electrical conductivity region is essentially controlled by the volcanic fluids flux, rainfall recharge and aspect ratio of the aquifer, regardless of the many uncertainties of the parameters used. The above results were applied to the electrical conductivity structure at Unzen volcano, SW Japan, obtained from TDEM surveys. The estimated volcanic fluids flux from magma by groundwater flow was $10^{5.3 \pm 0.5}$ t/yr. This value is quantitatively consistent with the other petrology, geochemical and geophysical evidences; which are the spatial change of water content of magma by melt inclusion analysis, CO₂ flux by groundwater and soil analysis, and magma input rate by GPS and leveling surveys.

Recent Unzen volcano (150Ka-present) has the dome-forming eruptions; that means non-explosive activities are dominant during recent Unzen. Our result suggests that the magma is steadily releasing the volcanic fluids at the underground prior to eruptions. This effective degassing might lead to the decrease of water content of magma, and be one of the reason of the non-explosive volcanism.

The redox state of volcanic gases: a reflection of magma depth.

Yves Moussallam¹, Clive Oppenheimer¹, Bruno Scaillet², Phil Kyle³, Fabrice Gaillard², Nial Peters¹, Margaret Hartley⁴

¹Department of Geography, University of Cambridge, Downing Place, Cambridge, CB2 3EN, UK,

²ISTO, UMR 6113 Université d'Orléans-CNRS, 1A rue de la Ferrollerie, 45071 Orléans cedex 2, France,

³Department of Earth and Environmental Science, New Mexico Institute of Mining and Technology, USA,

⁴Department of Earth Sciences, University of Cambridge, Downing Place, Cambridge, CB2 3EQ, UK

E-mail: ym286@cam.ac.uk

The combination of "Multi-gas" electrochemical sensors and open-path Fourier transform infrared spectroscopy has made it possible to record continuous measurements of redox couples such as H₂O/H₂, SO₂/H₂S and CO₂/CO in volcanic plumes. While variations through time in these ratios have been observed at volcanoes such as Erebus (Antarctica), the cause of these variations has remained uncertain. We applied Fe and S K-edge x-ray absorption near-edge structure spectroscopy (XANES) to investigate a suite of melt inclusions in lavas belonging to the Erebus lineage (basanite through phonolite) with entrapment depth spanning the entire lithosphere. We found that a strong reduction of both Fe and S is associated with magma ascent and that the fO_2 of the magma reduces by more than two log units with decreasing pressure. Although the driving force behind this process cannot be unambiguously identified, we propose that sulfur degassing is a likely explanation. This redox-depth relationship allows us to examine the redox state of volcanic gas emissions at Erebus in terms of their last equilibration depth. In this way, we can explain oscillatory variations in CO₂/CO and H₂O/H₂ observed for the plume emitted from the Erebus lava lake as a reflection of episodic input of magma into the lake from the underlying conduit.

Magma degassing, oxidation, and gas adsorption processes during a series of ash eruptions in progress at the Sakurajima volcano, Kagoshima, Japan

Isoji MIYAGI, Hiroshi SHINOHARA, Jun'ichi ITOH

Geological Survey of Japan, Japan

E-mail: miyagi.iso14000@aist.go.jp

In order to understand magmatic processes near the top of a volcanic conduit, we examined more than 100 ash samples from the Sakurajima volcano erupted during 1981 to 2012. We describe variations in the color and the amount of leachates for ash samples that were collected shortly after an eruption without having been exposed to rain. Chemical analysis of ash leachates (Cl, F, and SO₄ contents) was performed using an ion chromatograph on aqueous solutions prepared from the ash and deionized water. The color analysis was performed using a colorimeter on bulk ash, on separated finer ash fractions, and on finely ground coarser ash fractions. We also obtained SEM images, XRD on finer fractions, and EPMA data on polished ash sections, as well as time and date of each eruption.

The amount of leachates extracted from ash sample varies by nearly three orders of magnitude over the entire range of sampled eruptions through time and exceeds, especially the sulfur, range of the same chemical compounds dissolved within the original melt. The long-term temporal change was observed as follows. Based on the amount of leachates present, ash samples are classified into two major groups: one is with a molar S/Cl ratio of ~ 10 , and the other with S/Cl of ~ 1 and that is relatively depleted in S. Ash samples erupted during 1981-1991 from the Minami-dake summit crater belong to the latter group. Ashes erupted from the Showa crater in early 2008 belong the former group, of which the S content was found to decrease systematically through time, and in 2011, ashes of the latter group erupted for the first time from this crater. Based on the coloration, ash samples in this study are classified into two groups: one is yellowish color, the other is less yellowish. The coloration of the former group can be explained by the existence of yellowish native sulfur as well as other hydrothermally altered minerals that were subsequently confirmed using X-ray diffractometer. Short-term temporal change was also defined based on the following observations: (1) positive correlations between the interval of successive eruptions and both the yellowness and the amount of ash leachates were observed; (2) the lower the total amount of ash leachates present and the lower the yellowness of the ash; and (3) the ratio of altered to the unaltered ash particles is higher in cases where the ash deposits resided for a longer repose time before the eruption, and this ratio drops correspondingly (and rapidly) with a drop in the repose time.

Our interpretation is that the observed temporal changes in volcanic ash result from a transition in the amount of fumarolic sulfur accumulation in partly solidified magma near the top of volcanic conduit, which may reflect the mean residence time of the magma. The magma probably periodically renewed in response to ash eruption and/or magma convection near the top of the volcanic conduit.

Remote temperature sensing of volcanic fumaroles using hydrogen isotopes of excess molecular hydrogen in plumes

Urumu Tsunogai¹, Daisuke D Komatsu¹, Fumiko Nakagawa²

¹Nagoya University, Japan, ²Hokkaido University, Japan

E-mail: urumu@nagoya-u.jp

The temperature of fumarolic gases provides important information about the magmatic/hydrothermal systems under the volcanoes. Direct measurements on fumaroles, however, are often neither practical nor safe in most of the active volcanoes. Remote sensing using infra-red (IR) wavelengths of surface temperatures offers an alternative to direct measurement since the early 1960s. The IR remote sensing, however, have several problems when applied to determine the outlet temperature of volcanic fumaroles.

In high-temperature volcanic fumaroles (>400°C), the isotopic composition (δD value) of molecular hydrogen (H_2) reaches equilibrium with that of the fumarolic H_2O under the outlet temperature so that the δD value of fumarolic H_2 is a function of fumarolic temperature. Combining this temperature-dependent variation in δD value of fumarolic H_2 with our high-sensitivity mass spectrometric technique which enable us to deduce the δD value of fumarolic H_2 from trace H_2 in the volcanic plume, we can determine the temperature at volcanic fumaroles remotely. To ascertain that we can estimate the δD value of fumarolic H_2 from those in a volcanic plume, we estimated the values in three fumaroles with outlet temperatures of 630°C (Tarumae), 203°C (Kuju), and 107°C (E-san). For this we measured the concentration and δD value of H_2 in each volcanic plume, along with those determined directly at each fumarole and found a linear relationship between the depletion in the δD values of H_2 in each volcanic plume, with the reciprocal of H_2 concentration. Furthermore, the estimated endmember δD value for each H_2 -enriched component ($-260 \pm 30\%$ vs. VSMOW in Tarumae, $-509 \pm 23\%$ in Kuju, and $-437 \pm 14\%$ in E-san) coincided well with those observed at each fumarole ($-247.0 \pm 0.6\%$ in Tarumae, $-527.7 \pm 10.1\%$ in Kuju, and $-432.1 \pm 2.5\%$ in E-san). Moreover, the calculated isotopic temperatures at the fumaroles agreed to within 20°C with the observed outlet temperature at Tarumae and Kuju. We concluded that the δD value of the fumarolic H_2 was quenched within the volcanic plume. This enabled us to remotely estimate these in the fumarole, and thus the outlet temperature of fumaroles, at least for those having the outlet temperatures more than 400°C. The remote temperature sensing using hydrogen isotopes (HIReTS) developed in this study is widely applicable to many volcanic systems.

Petro-geochemical evidence for vapour transport in andesite shear fractures

Melissa Plail¹, Marie Edmonds², Jenni Barclay¹, Madeleine C.S. Humphreys³, Richard A Herd¹

¹University of East Anglia, UK, ²University of Cambridge, UK, ³University of Oxford, UK

E-mail: m.plail@uea.ac.uk

The andesitic Soufrière Hills Volcano (SHV), active since 1995, emits large fluxes of volcanic gases (dominantly H₂O, CO₂, SO₂, HCl), even during eruptive pauses. Effective open-system degassing at dome forming eruptions may control eruption style. It has been observed that the flux of gas is largely decoupled from the flux of magma to the surface, indicating efficient magma-vapour segregation. Evidence for vapour transport through magma is not often preserved in the erupted rocks, perhaps due to overprinting during eruption, or because the transport zones themselves are not usually erupted. We present petro-geochemical evidence for vapour transport through shear fractures in andesite at SHV and a model for their formation.

Andesite blocks in deposits from two recent eruptive events from SHV contain narrow shear zones, up to 2 m in length and 2-10 cm in width, with alternating darker fine-grained and lighter coarser-grained bands. Analysis has shown that the dark, fine-grained bands (grain size ~30-70 µm) have low porosity (~1%), oxides (<8% vol), orthopyroxene, cordierite microlites (Mg_{1.3-1.7}Fe_{0.4-0.8}Al_{3.7-4.04.9-5.2}O₁₈), groundmass cristobalite, quartz and sieve-textured plagioclase. The light, coarse bands (grain size ~100-350 µm) has higher porosity (7-19 vol %) and consists of broken plagioclase, orthopyroxene, clinopyroxene and sparse large amphibole crystals, and a reduced abundance of oxides (<2.4% vol). Glass is rare to absent in both types of band. Mineral compositions in the shear zones are identical to those established in the SHV andesite. However, bulk ICP-MS analyses indicate that some metal concentrations (Cu, Ni, Pb, Au and Zn) are greatly enhanced relative to the surrounding andesite. For example, Cu and Au concentrations are up to and over ten times higher than in the andesite host. Cu is present as copper sulphide inclusions in Ti-magnetites and plagioclase phenocrysts.

We hypothesise that the elevated metal concentrations and presence of abundant, disseminated metal-bearing grains are evidence that these zones are relict vapour transport pathways in the shallow volcanic system. Rapid shear of andesitic material formed brittle fractures either at the conduit wall or in the shallow dome, along which metal-bearing vapour or fluid was transported. Partial melting occurred as a result of frictional heating during shearing, and volatile resorption occurred as the melt cooled. The unusual presence of volcanic cordierite is likely to have crystallised from a peraluminous partial melt that formed by preferential melting of plagioclase at elevated temperatures. These sheared zones provide the first petrological evidence for vapour transport at SHV, and a window onto the early stages of mineralization at island arc volcanoes.

Chemical heterogeneity in rhyolite caused by magma degassing

Kim Berlo¹, Hugh Tuffen², Victoria Smith³, Jonathan Castro⁴, David M Pyle¹, Tamsin A Mather¹, Tina Geraki⁵

¹Department of Earth Sciences, University of Oxford, UK, ²Lancaster Environment Centre, Lancaster University, UK, ³Research Laboratory for Archaeology and the History of Art, University of Oxford, UK, ⁴Institute of Geosciences, Johannes Gutenberg University Mainz, Germany, ⁵Diamond Light Source, Harwell Science and Innovation Campus, UK

E-mail: kim_berlo@inbox.com

Gas moves through magma via bubbles and fractures. During this transport (open system degassing, gas fluxing or streaming), elements are continually redistributed between melt and gas phase. However, this redistribution takes time and not all elements can keep up. Hence, magma is likely to be heterogeneous with respect to volatile elements. The extent of this heterogeneity is determined by the volatilities and the diffusivities of the elements, and time. Maps of the chemical heterogeneity of magma can therefore provide an insight into the flux of gases through magma directly preceding an eruption.

In this contribution we show that tuffisite veins, glass-filled fractures formed when magma fragments during deformation and degassing within the conduit, are associated with both enrichments and depletions of volatile elements. A rhyolitic tuffisite vein within an obsidian-rimmed bomb erupted from Chait n volcano (Chile) in 2008 is enriched in As, Pb, Zn, Sb and Mo and depleted in Li. In contrast, a tuffisite vein from Torfaj kull (Iceland), from a shallow dissected lava-filled conduit, is depleted in all measured elements. Both veins locally contain vesiculated clasts, which are enriched in volatile elements compared to the host glass.

From the spatial distribution of the chemical variations we were able to estimate a total gas flux through the veins showing that tuffisite veins form highly efficient gas pathways, which channel pre-exsolved volatiles to the surface. We also infer significant vertical transport of clasts within interconnected tuffisite vein networks, indicating that degassing pathways may extend hundreds of metres below the surface.

The surface tension of rhyolite from combined experiments and numerical modeling

Helge M Gonnermann¹, James E Gardner²

¹Rice University, USA, ²University of Texas, USA

E-mail: helge@rice.edu

Bubbles provide the driving force for volcanic eruptions. Consequently, it is critical to understand their nucleation, which strongly depends on volatile supersaturation in the melt and is even more sensitive to surface tension. The latter can be constrained from experiments, wherein small volumes of volatile-saturated melt, typically of the order of 0.01-0.1 cubic centimeter, are rapidly decompressed. Here, we present the results of such bubble nucleation experiments in hydrated rhyolite, together with numerical modeling of the experiments. The numerical model combines classical nucleation theory with diffusive bubble growth and is constrained by the bubble number densities and size distributions measured in the experimental charges after quenching.

From the integrated bubble nucleation and growth modeling we find that surface tension may not be constant during the experiments, but instead increases as water diffuses from the melt into existing bubbles. This is consistent with previous results and indicates that surface tension decreases with water content. The resultant estimates of surface tension range between approximately 65 and 85 mN/m and are remarkably consistent across a wide range of water saturations and melt temperatures. Bubble nucleation in experiments with high decompression rates and low final pressures peaks, at some time during the experiment. Subsequently nucleation rates decrease rapidly and nucleation ends before the experimental charge is quenched. This is a consequence of high nucleation rates and efficient water diffusion from melt into numerous existing bubbles. Once supersaturation starts to diminish for the entire melt volume, nucleation rates plummet and nucleation ceases. In contrast, during experiments with a high final pressure, nucleation rates and bubble number density remain sufficiently low for most of the melt to remain fully supersaturated and bubble nucleation to continue at an almost constant rate, until the sample is quenched. It is therefore important that the estimation of surface tension from nucleation experiments is based on the actual time interval during which bubble nucleation takes place, and that it accounts for possible changes in surface tension during the experiment.

A condition of degassing magma deduced by the chemical and isotopic ratio of fumarolic gas

Takeshi OHBA

Tokai University, Japan

E-mail: takeshi_ohba@tokai-u.jp

The inside of active volcano is a complex system. The chemical constituent and enthalpy are provided by a degassing magma. The degassed volatile species inevitably encounter the groundwater, resulting in the formation of magmatic-hydrothermal system. The vapor and the conjugated liquid phases co-exist in the hydrothermal system. A part of vapor phase is discharged and noticed as fumarolic gas at surface of geothermal area. The importance of fumarolic gas depends on the fact that fumarolic gas carries the information on degassing magma and hydrothermal system. Among the components of volatile, SO₂, H₂S, HCl interact with groundwater and are modified significantly in terms of their contents. The CO₂ is expected to be less modified because CO₂ is less soluble in water and cannot be removed as mineral deposit in acidic environment which is typical to magmatic-hydrothermal system. As the most abundant specie, H₂O is contaminated by groundwater, however, the degree of contamination could be evaluated based on the D/H and 18O/16O ratios.

In the hydrothermal system, the dominant interactions of volatile are, the mixing with groundwater and the separation of vapor and liquid phases. Based on the CO₂/H₂O ratio and isotopic ratio of H₂O of fumarolic gas, the CO₂/H₂O ratio of degassed volatile can be evaluated assuming the following conditions: the conservation of enthalpy, the conservation of amount and isotope for CO₂ and H₂O, and the equilibrated distribution of CO₂ and isotope between vapor and liquid phase. The above evaluation was applied to the fumarolic gases of active volcanoes in Japan. The CO₂/H₂O molar ratio was 0.03 in 1994 for the gases at Shinmoedake volcano at Kirishima, which has erupted in 2012. The fumarolic gases at Kusatsu-Shirane and Atosanupuri results in low value as much as 0.06. Those volcano has been dormant with persistent discharge of fumarolic gas. At Hakoke volcano, a temporal variation in the evaluated CO₂/H₂O ratio has been observed. In 2001, the ratio increased to 0.021 but decreased to 0.004 in 2005. In 2001, volcanic earthquakes were observed at Hakone volcano the number of which was significant relative to quiescent period.

The CO₂/H₂O molar ratio evaluated from the composition of fumarolic gas provides a useful information for a degassing magma. The high CO₂/H₂O ratio of degassed gas suggests the high CO₂ content in magma chamber. As the CO₂ is less soluble component in silicate melt, CO₂ preferentially leaves the magma chamber through degassing. The increase in CO₂ content in magma chamber suggest two possibilities. One is the replenishment of new magma enriched in CO₂ gas provided by a source connected to the magma chamber. Another is the accumulation of bubbles in the roof magma chamber. In the gas phase of bubbles, CO₂ is enriched relative to H₂O. The degassed gas phase contributed by the bubbles should be enriched in CO₂ gas.

Diffusive Helium Emissions as a Precursory Sign of Volcanic Unrest at El Hierro Island, Canary Islands, Spain

Eleazar Padron¹, Nemesio M Perez¹, Pedro A Hernandez¹, Hirochika Sumino³, Gladys Melian¹, Jose Barrancos¹, Dacil Nolasco¹, German Padilla¹, Samara Dionis², Fatima Rodriguez², Inigo Hernandez², David Calvo², Keisuke Nagao³

¹Environmental Research Division, ITER, Spain, ²Instituto Volcanológico de Canarias, Spain, ³Geochemical Research Center, University of Tokyo, Tokyo, Japan

E-mail: eleazar@iter.es

Since July 16, 2011, an anomalous seismicity at El Hierro island, the youngest and smallest of the Canary Islands, was recorded by IGN seismic network. After the occurrence of more than 10,000 seismic events, a submarine eruption took place 2 km off the southern coast of El Hierro Island on October 12, 2011. Frequent episodes of turbulent gas emission and foaming, and the appearance of steamy lava fragments were observed on the sea surface. As part of the volcanic surveillance of the island, the Instituto Volcanológico de Canarias (INVOLCAN) geochemical monitoring program is carrying out diffuse helium surveys on the surface environment of El Hierro (soil atmosphere). This noble gas has been investigated because it has been considered an almost ideal geochemical indicator because it is chemically inert, physically stable, nonbiogenic, sparingly soluble in water under ambient conditions and almost non-adsorbable. The helium concentration gradients with respect to its value on air measured at 600 sampling sites allow us to estimate a pure diffusive emission rate of helium throughout the island. Since the beginning of the volcano-seismic unrest, 19 helium emission surveys have been carried out. The helium emission rate has shown an excellent agreement with the evolution of the volcanic crisis of the island, reaching 30 kg/d on October 6, several days before the occurrence of the submarine eruption. A significant decrease to 13 kg/d was estimated almost 10 days after the beginning of the eruption, followed by a sudden increase to 38 kg/d several days before the largest seismic event of the volcanic crisis ($M = 4.6$) occurred on November 11. On 5 March, the submarine eruption was over, but the volcanic process that started in mid-July 2011 had not finished. By the end of June 2012, a new seismic unrest episode occurred, accompanied by the highest deformation rate measured in the island during the unrest period. Within this phase, a new increase on the diffusive helium emission (up to 20 kg/d) was observed.

Helium emission data measured in El Hierro 2011-2012 volcano-seismic unrest demonstrate that diffuse helium surveys is a powerful tool for volcano monitoring. The geochemical parameters presented here are extremely important for forecasting the onset of volcanic unrest and subsequent volcanic eruptions, mainly when magma migrates aseismically, i.e., silently, toward the surface.

Helium isotope geochemistry of thermal springs and volcanic gases from Guadeloupe, Lesser Antilles

Philippe Jean-Baptiste¹, Patrick Allard², Elise Fourre¹, Lorraine Ruzie², Alessandro Aiuppa³, Francesco Parello³

¹LSCE CEA-CNRS-UVSQ/IPSL, France, ²IPGP-CNRS, France, ³CFTA Palermo University, Italy

E-mail: Philippe.Jean-Baptiste@cea.fr

The island of Guadeloupe is located in the middle of the 850 km long Lesser Antilles island arc. Volcanic activity is concentrated in the southwestern part of the island (Basse Terre), with the active system of La Soufriere volcano. Most of the thermal manifestations are located around La Soufriere dome and in the Bouillante geothermal area. Since the last magmatic eruption in 1530, several phreatic eruptions have been recorded, with one of the most violent episode in 1976-1977. The Bouillante system, where a geothermal plant generates 15 MW of electrical power, is located a few kilometers to the northwest. Between 1995 and 2012, twenty sites, including fumaroles, bubbling gas, hot springs and production wells, were sampled on five occasions (1995 / 1996 / 1999 / 2006 / 2012) for helium isotope geochemistry in order to map their spatial distribution and temporal trends in mantle-derived ³He inputs across the region. The data set reveals helium (⁴He) concentrations in the water samples ranging from 5 to 30 (10⁻⁸ cm³ STP/g) for La Soufriere volcanic system, and up to 7300 for a submarine hot spring (- 23 m) located in the Bouillante area (Ilet Pigeon). Helium concentration in volcanic gases (fumaroles and bubbles) varies between 5.3 and 10.5 ppmv around La Soufriere, with air-corrected ³He/⁴He ratios in the range 7.9 - 8.4 Ra, coincident with the MORB ratio (³He/⁴He = 8 Ra, where Ra = air ³He/⁴He ratio). In contrast, the nearby Bouillante system is characterized by higher helium gas contents (up to 494 ppm) and much lower ³He/⁴He values (between 3.3 Ra and 4.5 Ra), indicating a substantial crustal contribution to the volatile budget of the geothermal system. No temporal change in the ³He/⁴He ratios over the last 16 years evidences a steady feeding source for both systems. A detailed discussion of the helium data set will be presented and the results will be examined in relation to the geological and tectonic framework of the island of Guadeloupe.

Methane efflux from the soil and methanotrophic activity in volcanic-geothermal areas: Examples from Italy and Greece

Antonina Lisa Gagliano¹, Walter D'Alessandro², Francesco Parello¹, Paola Quatrini³

¹University of Palermo, Dpt. DISTEM, Italy, ²Istituto Nazionale di Geofisica e Vulcanologia, Italy, ³University of Palermo, Dpt. STEM BIO, Italy

E-mail: w.dalessandro@pa.ingv.it

Methane plays an important role in the Earth's atmospheric chemistry and radiative balance being the most important greenhouse gas after carbon dioxide. It is released to the atmosphere by a wide number of sources, both natural and anthropogenic, with the latter being twice as large as the former. It has recently been established that significant amounts of geological methane, produced within the Earth's crust, are currently released naturally into the atmosphere. Active or recent volcanic-geothermal areas represent one of these sources of geological methane. Due to the fact that methane flux measurements are laboratory intensive, very few data have been collected until now and the contribution of this source has been often indirectly estimated. Both the Italian and the Hellenic territories are geodynamically very active with many volcanic and geothermal areas. Here we report on methane flux measurements made at Pantelleria (Italy), Sousaki and Nisyros (Greece). The total outputs of these three systems are about 10, 19 and 2 t a⁻¹ respectively. These figures are up to one order of magnitude lower than those obtained through indirect estimations.

At the global scale, microbial oxidation in soils contributes to the total removal of methane from the atmosphere. Environmental conditions in the soils of volcanic/geothermal areas (i.e. low pH, high temperature, etc.) have been considered inadequate for methanotrophic microorganisms. But recently, it has been demonstrated that methanotrophic consumption in soils occurs also under such harsh conditions due to the presence of thermo-acidophilic Verrucomicrobia.

Here we present the results of laboratory incubation experiments on soil samples collected at the main exhalative areas that highlighted methanotrophic activity also at Pantelleria and Sousaki.

Soil metagenomic DNA was extracted from some of the Pantelleria samples and analysed using Temporal Temperature Gradient Electrophoresis (TTGE) of the amplified Bacterial 16S rRNA gene in order to evaluate the total bacterial diversity. Soil DNA amplification with primers targeting Proteobacterial and Verrucomicrobial methane monooxygenase genes (*pmmo*) revealed the presence of methanotrophs affiliated to both phyla up to a depth of 11 cm and a temperature of 80°C. The diversity of proteobacterial methanotrophs was investigated by creating a clone library of the amplified methane mono-oxygenase encoding gene, *pmmoA*. The clone sequences are close to those of uncultured type I methanotrophic proteobacteria.

An attempt to isolate methanotrophs was carried out on soils from Pantelleria, sampled at different depths, by enrichment cultures on a mineral medium in a methane-enriched atmosphere. No isolates were obtained from enrichments carried out at 65°C while incubation at 37°C allowed to isolate a few methanotrophic strains that were identified as *Methylocystis* spp.

Vesicle evolution in magma conduits - implications for the processes of silicic magma ascent

Antonio M. Alvarez-Valero¹, Juan Gomez-Barreiro¹, Javier Borrajo², Carlos Montes³, Nuria Gomez-Gonzalez³, Juan C. Gonzalo¹, Piedad Franco¹, Clemente Recio¹, Francisco Pla⁴, Leo M. Kriegsman⁵, Asuncion Carnicero¹, Jose M. Ugidos¹

¹Department of Geology, University of Salamanca, Spain, ²Department of Physics, Engineering and Medical Radiology, University of Salamanca, Spain, ³Department of Medical Physics, University Hospital of Salamanca, Spain, ⁴Department of Mathematics, University of Castilla-La Mancha, Spain, ⁵Department of Geology, Naturalis Biodiversity Center, Netherlands

E-mail: aav@usal.es

Volcanoes commonly show two active processes, namely: (i) those occurring at depth, in mid-crustal level magma storage zones that represent the initial state before eruption; and (ii) those occurring during ascent to the surface which either may alter the course of an eruption already in progress or promote its triggering. The distinction between both processes is essential to advance the knowledge on priming of a magmatic body and on how silicic magmas evolve. As such, the role of gases and fluids is decisive.

Our knowledge of how gases behave and influence the eruptive style of magmas has greatly advanced from sampling and observations of volcanic products; lab experiments; and numerical models. However the state of magmatic gases and fluids just before the critical importance of the inception of the eruptive decompression is still poorly understood and difficult to assess.

For this purpose, we present an integration of (i) direct sample observations from different depths under a volcano; (ii) microtomographic analysis (last generation of clinical TAC and micro-CT); and (iii) numerical simulations of vesicle evolution in the magma conduit by utilizing -as input- the previous observed parameters.

Volatile and light lithophile trace element geochemistry of the 2010 eruption of Merapi volcano revealed by melt inclusions

Katie Preece¹, Ralf Gertisser², Kim Berlo³, Jenni Barclay¹, Richard Herd¹

¹School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK, ²School of Physical and Geographical Sciences, Keele University, Keele, Staffordshire, ST5 5BG, UK, ³Department of Earth Sciences, University of Oxford, Oxford, OX1 3AN, UK

E-mail: K.Preece@uea.ac.uk

The 2010 eruption of Merapi (VEI 4) was the volcano's largest since 1872. In contrast to recent prolonged and effusive dome-forming eruptions at Merapi, such as the previous eruption in 2006, the 2010 eruption began explosively, before a new dome was rapidly emplaced between 30 October and 4 November 2010. On 5 November, this new dome was destroyed by explosions, generating pyroclastic density currents (PDCs), predominantly consisting of dark-coloured, glass-rich, dense blocks of basaltic andesite dome lava, which travelled ~16 km from the summit, immediately followed by PDCs characterised by scoriaceous and pumiceous clasts.

In this paper, we present volatile and light lithophile element data of clinopyroxene-hosted melt inclusions from samples of the dense dome lava, scoria and pumice from the PDCs generated during the peak of the 2010 eruption. SIMS analysis of volatiles (H₂O and CO₂) and light lithophile elements (Li, B, Be) are augmented by electron microprobe analysis of major elements and volatiles (Cl, S) in the same melt inclusions and groundmass glass.

The melt inclusions are dacitic to rhyolitic in composition (63.3-71.8 wt.% SiO₂) and have variable contents of H₂O and CO₂, ranging between 0.1-3.8 wt.% and up to ~2500 ppm, respectively. The highest H₂O contents are preserved in melt inclusions from scoriaceous and pumiceous clasts. Some melt inclusions from the pumice preserve evidence of relatively high CO₂ contents at medium (~2 wt.%) H₂O contents. Chlorine contents range from 2000-5000 ppm and S is present in quantities up to 500 ppm in the melt inclusions, with the groundmass glass of pumice characterised by higher volatile concentrations than the groundmass of the dense dome. Light lithophile element analyses show a moderate range in concentration in the melt inclusions of Li (15-68 ppm) and B (25-84 ppm) and uniform Be concentrations (1-2 ppm).

Our data suggest that a simple model of equilibrium decompression-driven degassing cannot explain the H₂O and CO₂ concentrations in the analysed melt inclusions. Instead, melt inclusion data record a complex pre-eruptive storage and ascent history of the 2010 magma, highlighting open-system processes, including entrapment of melt at multiple levels within the crust, enrichment of CO₂ in some inclusions, and the influx and exsolution of Li-rich vapours at shallow depths. Despite the more explosive nature of the 2010 eruption, melt inclusions reveal a similar pre-eruptive volatile content to the 2006 eruption, suggesting that degassing behaviour rather than higher initial volatiles contents, contributed to the paroxysmal 2010 eruption.

Volcanic gases as precursor of the 2010 Merapi explosive eruption

Hanik Humaida, Euis Sutaningsih, Kurniadi Rinekso, Yulianto Yulianto, Sri Hartiyatun, Elisabeth Sartini,
Rachmad Widyo Laksono

Geological Agency of Indonesia, Indonesia

E-mail: hanikhumaida@gmail.com

The 2010 Merapi explosive eruption, bearing a VEI 4, was not preceded by the formation of a lava dome. This phenomenon was contrary to what had normally been expected. The precursors of volcanic activity occurred in a short time. On October 26, 2010, Merapi erupted for the first time. The raising of its activity status prior to the eruption was determined according to the increase in the seismicity, deformation, as well as in the amount of the volcanic gas emission. Pre-eruptive volcanic gas emission began to significantly changes in August, 2010, in which the H₂O concentration decreased from its normal condition, 90 % mol, down to 80 % mol. Such other gases as CO₂, H₂S, SO₂, and HCl, also underwent a remarkable change of concentration. The HCl and SO₂ ratio was used as an initial indicator of increasing activity before eruption. It turns out that there occurred an increase in concentration ratio of those two gases when compared with their normal condition, May 2010. The ratio of CO₂ and SO₂, CO₂ and HCl, and CO₂ and H₂O also increased, serving as indicator that the source location of those volcanic gases had with the passage of time moved even deeper down, up to the moments when the volcano was about to erupt. The decreasing CO₂ and H₂S ratio also indicated that, considering the fact that despite an increasing pressure H₂S is a stable sulphuric compound, a deeper source location was to be found. The CO₂ gas changed very significantly, and as it is characteristically magmatic with low solubility when compared with any other volcanic gases, it was the first to be emitted. The CO₂ gas concentration went up to 34 % mol and 62 % mol on 20 October 2010, higher when compared with its concentration in its normal condition, which was less than 10 % mol. The flux of SO₂ gas seems to give indication of the explosive eruption. From the long term monitoring, 1992-2009, it had different indicators between 1992-1998 and 1999-2009. It has slightly decreasing and increasing with the slope value -0.017 and 0.032 trend line of SO₂ gas flux respectively. Given the description as such, it becomes clear that the emission of volcanic gases was a clear early indication of Merapi eruption on October - November 2010.

Quantitative analysis of water concentration in melt inclusions by reflectance micro-FTIR spectroscopy

Atsushi Yasuda

Earthquake Research Institute, Univ. Tokyo, Japan

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

A technique based on micro reflectance spectroscopy using a vacuum Fourier Transform infrared (FTIR) spectrometer has been developed for the quantitative measurement of water content in melt inclusions in phenocrysts. Water in magma strongly affects how a volcano erupts. Thus it is important to determine the amount of water dissolved in the magma in order to predict how the eruption develops. Previously, a FTIR micro reflectance measurement was proposed to be a promising method to determine the concentration of water in volcanic glasses rapidly because of its great advantage in sample preparation. It requires neither doubly polished wafers nor measurement of sample thickness. However, application of the method to natural samples has been limited so far because the resonance due to the O-H stretching vibration of dissolved water in the glass observed around 3650cm^{-1} is weak. Moreover, requirement of smaller apertures for measurement of melt inclusions with several tens micron in diameter significantly decreases the signal-to-noise ratio. Consequently quantitative analysis of water in such a small melt inclusion was considered to be difficult. We overcome the difficulty by two improvements.

Firstly a vacuum FTIR apparatus was introduced. Evacuation the whole light path by a vacuum pump (<100 Pa) can reduce more efficiently noisy absorption around 3650cm^{-1} due to water vapor than purging dry N_2 gas. Thirty-one glasses with various water content ranging from basaltic to rhyolitic composition were synthesized by an internal heated pressure vessel. Reflectance IR spectra were taken between $650\text{-}7000\text{cm}^{-1}$ on singly polished glass samples. The maximum amplitude of the signal at around 3650 cm^{-1} resonance normalized to a baseline of reflectivity was plotted against water contents of the samples determined by Karl-Fischer titration (ranging from 0.1 to 5.1 wt%), and a linear correlation was obtained. It appears that the slope of the correlation line slightly depends on the bulk composition. When a reflectance spectrum is taken with a microscope aperture of 20×20 micron and 1024 scans, the intensity of noise around 3650cm^{-1} is 0.02 (1σ), corresponding to approximately 0.2 wt% H_2O .

As the second improvement, we devised a correction method for spectrum interference by host crystal. When a small melt inclusion is analyzed, some signal from host crystal may overlap the spectra of melt inclusion, resulting in underestimation of water content in the melt inclusion. However, fortunately enough, most silicate crystals have distinct reflection peaks in the region $800\text{-}1200\text{cm}^{-1}$. Using those peaks, the contribution of host crystal to the measured reflective spectra can be estimated within a precision of 10% relative.

Olivine-hosted melt inclusions collected from 2011 Shinmoe-dake eruption were studied as a practical application of the new technique.

Investigating pore-scale processes controlling the volatile transport in silicic magma reservoirs.

Andrea Parmigiani¹, Christian Huber¹, Olivier Bachmann²

¹Georgia Institute of Technology, US, ²ETH Zurich, Switzerland

E-mail: aparmigiani3@mail.gatech.edu

Our limited understanding of exsolved magmatic volatile phase (MVP) transport in magma reservoirs with variable crystallinities does not allow us to constrain important concepts such as (1) how fast volatiles move in reservoirs, and (2) when and where they can accumulate. Consequently, we need more sophisticated physical models to shed light on the non-linear interactions between the exsolved MVP, silicate melts, and the crystal matrix. The study reports the use of multiphase numerical modeling to calculate the mass transport of the MVP in a crystalline skeleton that is initially saturated with a silicate melt. We focus on capillary channels formation of the MVP, as these channels represent paths of low resistivity for rapid volatile transport in magmatic environment. The host medium (crystalline matrix) can be homogeneous or display sudden transitions in crystallinity, in order to test two potential configurations that are thought to be important in magma reservoirs: (1) high crystal content magmas (homogeneous crystal mushes) and (2) regions of transition between high crystal content magmas and a melt-rich layer (crystal-poor silicic cap overlying a mush zone).

The stability of these channels are studied in two different physical contexts, In the first experiment, we studied the thermal reactive transport associated with the percolation of a hot buoyant volatile phase in an homogeneous crystal-rich mush zone. In such a situation, we observe that an increase in porosity due to thermal dissolution of the crystalline network can lead to a break-up of the volatiles capillary channels with a consequent decrease in volatile and heat flux through the system. Similar concepts can be applied to chemically reactive systems important for ore deposit formations. In the second experiment, the MVP transport behavior at the transition from a high crystallinity medium (crystallinity >0.5 where the volatiles mainly ascend buoyantly through the capillary channels) and a low crystallinity medium (crystallinity ≈ 0.2) was studied. We find that capillary channels break as they penetrate into the crystal-poor layer (capillary pinch-off). Moreover, the viscosity contrast between the MVP and the melt causes a sudden increase in viscous dissipation as the transport regime of the MVP shifts from capillary channels to disconnected bubbles/slugs in the melt-rich layer. As a result, the MVP tends to accumulate in the melt-rich layer. The accumulation of MVP in the crystal-poor layer can affect the physical properties of the latter, and greatly impact the eruptibility of the system.

Automatic continuous observations of SO₂ flux at Suwanose-jima volcano, Southwest Japan

Masaaki Morita, Toshiya Mori

Geochemical Research Center, Graduate School of Science, The University of Tokyo, Japan

E-mail: morita@eqchem.s.u-tokyo.ac.jp

Suwanose-jima is a remote volcanic island (about 27 km² in area) located about 200 km southwest of Kyushu island, Japan. It is an andesitic volcano and, since 1950s, there has been intermittent Strombolian and Vulcanian eruptions. It is still one of the most active volcanoes in Japan that emits volcanic gas continuously. Sulfur dioxide flux data of this volcano is rare because measurements have only been carried out once every few years for the last 10 years. Previous studies revealed that the average SO₂ flux of the volcano was 500–1000 ton/day with typical daily variations ranging from 100 to 2000 ton/day [Mori et al., 2004; Oikawa et al., 2004].

Existing scanning DOAS systems have an outer cylinder with a window and a mirror/prism both rotating with a stepper motor [Edmonds et al., 2003; Galle et al., 2010]. In this study, we made a small DOAS scanner replacing the outer cylinder with a cylindrical quartz glass window. The advantage of this scanner is that it reduces power consumption by using a relatively small stepper motor that only rotates the mirror.

The new device with a USB2000+ spectrometer (Ocean Optics, Inc.) was set about 4 km south-southwest of the volcano on 20th January, 2013. It was powered by a solar panel and observed data were transmitted via cellular phone networks. The measurements were carried out from 8 am to 5 pm everyday and each scan took about 10 to 15 minutes. An integrated SO₂ column amount of each scan was multiplied by a wind velocity value from weather GPV data by Japan Meteorological Agency. Preliminary results showed that average SO₂ emission rates were about 500–1000 ton/day with the maximum of 2000 ton/day. These values were comparable to those of other recent observations. Acquired time-series data of SO₂ flux will be discussed with volcanic activities of the volcano.

References

- Edmonds et al. (2003) Bull. Volcanol., 65(8), 578–586.
- Galle et al. (2010) J. Geophys. Res., 115, D05304.
- Mori et al. (2004) Annuals Disas. Prev. Res. Inst., Kyoto Univ, 47(C), 157–162.
- Oikawa et al. (2004) Programme and Abstracts Volcanol. Soc. Japan, 66 (conference proceedings in Japanese).

Comparison of seismo-acoustic and SO₂ measurement at Tungurahua volcano (Ecuador) between 2010 and 2012

Jean Battaglia¹, Silvana Hidalgo², Alexander L. Steele², Santiago Arellano³, Mario Ruiz², Bo Galle³

¹Laboratoire Magmas et Volcans, CNRS UMR 6524, Univ. B. Pascal, IRD, Clermont-Ferrand, France,

²Instituto Geofísico Escuela Politécnica Nacional, Ladron de Guevara E11-253 y Andalucía, Quito, Ecuador, ³Chalmers University of Technology, Gothenburg, Sweden

E-mail: battag@opgc.univ-bpclermont.fr

Tungurahua is an andesitic volcano located in Central Ecuador that has been erupting since 1999, with repeated phases of enhanced activity during which explosions, ash emissions and occasional pyroclastic flows have occurred. Related to this activity the volcano emits SO₂ gas plumes and various seismic signals like tremors and explosion quakes. It is monitored by a network including up to 4 DOAS permanent NOVAC-1 type instruments, 5 broadband seismic stations coupled with infrasound sensors and 6 short period seismometers. We examined the data from these instruments for the period 2010-2012 with the aim of looking for a possible relation between seismic and acoustic recordings and the amounts of SO₂ emitted by the volcano.

NOVAC instruments only provide valid measurements under good weather and daylight conditions, leading to intermittent and sometimes sparse time series. Daily average mass fluxes of SO₂ have been extrapolated from the available measurements. Alternately, we determined the daily observed SO₂ masses by summing all valid recordings during the 10 hours of daily measurement. This approach strongly reduces SO₂ measured emissions during quiescence periods and provides time series having an improved correlation on a long time scale with the eruptive phases of the volcano. To complete the characterization of degassing we proceeded in two ways. We first established the acoustic and seismic energies of individual explosions and calculated cumulative daily values. Secondly, to quantify amplitudes of background tremor we calculated median amplitudes over sliding 10-minute windows in different frequency bands.

We compared the temporal evolutions of the different seismic and acoustic parameters with the observed SO₂ emission estimates for 4 periods of enhanced activity starting in January, May and November 2010 and May 2011. Since November 2011 until September 2012, the volcano presented an activity characterized by more frequent and shorter periods of explosive activity. In general irregular correlations are found between seismicity and degassing. Often temporal variations in SO₂ emissions are poorly reproduced by both tremor and explosion amplitudes, especially in terms of intensity. Large increases in explosive activity are rarely accompanied by large increases in SO₂ observed masses (January and May 2010). Degassing may persist despite significant drops in seismicity, including background tremor (May 2010). On the other hand, rough qualitative correlations are sometimes observed between SO₂ emissions and explosive activity (November 2010), tremor (November 2011) and sometimes with both tremor and explosions (May 2011). No better correlations are obtained when looking at higher frequency tremor (above 5 Hz) as compared to the dominant 1-5 Hz band. Our results suggest that the relation between seismic activity and SO₂ degassing may be strongly controlled by the conditions at the vent.

Gas geochemistry of geothermal fluids from the Copahue Caviahue Volcanic Complex (Argentina)

Mariano Augusto¹, Franco Tassi², Alberto Caselli¹, Orlando Vaselli³, Dmitri Rouwet⁴, Bruno Capaccioni⁵, Stefano Caliro⁶, Giovanni Chiodini⁶, Tom Darrah⁷

¹GESVA IDEAN, Dpto. Cs. Geológicas, FCEN, Universidad de Buenos, Argentina, ²Department of Earth Sciences, University of Florence, Italy, ³Institute of Geosciences and Earth Resources of the National Research Council (CNR IGG), Italy, ⁴Istituto Nazionale Geofisica e Vulcanologia, Sezione di Bologna, Italy, ⁵Department of Earth and Geological Environmental Sciences, Bologna, Italy, ⁶Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, Naples, Italy, ⁷Division of Earth and Ocean Sciences, Duke University, Durham, USA

E-mail: franco.tassi@unifi.it

Copahue volcano is part of the Caviahue Copahue Volcanic Complex (CCVC) which is located in the southwestern sector of the Caviahue volcano tectonic depression. This depression is a basin accommodating stresses between the southern Liquine Ofqui strike slip and northern Copahue Antinir compressive fault systems in a back arc setting with respect to the Southern Andean Volcanic Zone.

During the last 250 years at least 12 phreatic and phreatomagmatic eruptions occurred. In 2000 a phreatomagmatic event caused ash falling that affected the nearby villages.

Since November 2011 the discharge rate of fluids from the Copahue summit has significantly increased up to December 2012 when a new phreatomagmatic eruption occurred. In this study the chemical and isotopic compositions of fumaroles and bubbling gases collected in 2006 and 2007 and 2012 prior and during the last volcanic crisis from five thermal areas surrounding the Copahue volcanic edifice are presented and discussed. The main aims are to i) investigate the fluid source regions and their relationship with the peculiar tectonic assessment of this volcano and ii) describe the chemical evolution of the fumarolic fluids caused by the ongoing activity. The He isotopic ratios are the highest observed for a Southern American volcano (R/Ra up to 7.94). Nitrogen isotope values (+5.3 to +5.5 ‰ vs. ATM) point to a source of nitrogen mainly from subducted sediments.

Despite these gases show a clear mantle isotopic signature magmatic gases are below the instrumental detection limit being likely affected by scrubbing processes within a hydrothermal reservoir constituting the main source feeding the CCVC gas discharges.

Gas geothermometry suggests that CO and hydrogen equilibrate in a vapor phase at 220 celsius degrees. Rock fluid interactions controlling carbon dioxide and methane production from Sabatier reaction and propane dehydrogenation seem to occur within the hydrothermal reservoir at temperatures ranging from 250 to 300 celsius degrees. Fumarole gases sampled in 2006 and 2007 show relatively low nitrogen/He ratios and high R/Ra values with respect to those measured in 2012 and prior to the 2000 phreatomagmatic eruption. Such compositional and isotopic variations were likely caused by an injection of fresh magma that likely triggered the 2000 eruption.

Presently it is difficult to assess the effects caused to the hydrothermal system by the current phreatomagmatic activity. This can likely be evaluated by intensifying the geochemical monitoring in the thermal areas located at the foothills of Copahue to verify the presence of possible magmatic signals.

Volatile leakage from the crater bottom of Teishi Knoll of Izu-Tobu Volcanoes, Japan, 23 years after the 1989 submarine eruption

Kenji Notsu¹, Rumi Sohrin², Hideki Wada², Tatsuya Tsuboi², Hirochika Sumino³, Toshiya Mori³, Urumu Tsunogai⁴, Pedro Antonio Hernandez⁵, Yusuke Suzuki⁶, Ryoya Ikuta², Kohei Oorui¹, Masato Koyama⁷, Toshiaki Masuda², Naoyuki Fujii¹

¹Center for Integrated Research and Education of Natural Hazards, Shizuoka University, Japan, ²Institute of Geosciences, Faculty of Science, Shizuoka University, Japan, ³Geochemical Research Center, Grad. School Sci., The University of Tokyo, Japan, ⁴Graduate School of Environmental Studies, Nagoya University, Japan, ⁵Environmental Research Division, ITER, Spain, ⁶Izu Peninsula Geopark Promotion Council, Japan, ⁷Faculty of Education, Shizuoka University, Japan

E-mail: k.notsu@nifty.com

A submarine eruption occurred off the Izu Peninsula, Japan, at about 18h 33m of 13 July 1989, forming Teishi Knoll (diameter about 450m, height 10m) on the seafloor at a depth of 90-100 m. Since the diameter and depth of Teishi crater are about 200m and 10m respectively, the shallowest point of the crater rim is 81m deep and the deepest point of the crater bottom is 122m deep. Teishi Knoll is the youngest volcano belonging to Izu-Tobu Volcanoes consisting of more than 100 monogenetic volcanoes both on land and seafloor. The eruption was associated with intense gas emission. The released bubbles were collected from the crater bottom using an unmanned probe boat, Dolphin 3K, on 27 Sep. 1989, and their chemical composition (volume per cent) was measured to be CO₂ (23.8), H₂ (14.0), N₂ (49.0), O₂ (10.6) and CH₄ (1.8) (Ossaka et al, Fall Meeting of Vol. Soc. Japan, Abstract No.50, 1992). Soon after the eruption, the bubbling activity has decreased and disappeared until the end of 1991. To monitor the volcanic activity of Teishi Knoll, seismic and geodesic observations and observation of colour of surface seawater have been continued, but no survey has been carried out to examine volatile release from the crater bottom until now.

In this work, we tried to detect volatile components of magmatic origin in seawater inside the Teishi crater bottom. A plastic tube with an inner diameter of 12mm (TOYOX TG12) attached with stainless wire was thrown down from the deck of a small fishing boat (9-ton) to the depth at which seawater samples were collected. A CTD sensor and metallic drag were connected to the lower end of the stainless wire. The seawater was continuously pumped out using a tubing pump, introducing into several sample bottles. Inside the crater of Teishi Knoll, seawater samples were collected at 3 different points just above the crater bottom (A:116-117m, B:114-115m, C:107-108m deep). Shallower seawater samples were also collected above the crater (D:100m, E: 80m, F: 50m deep) for comparison. For each seawater sample, dissolved CH₄ content with its ¹³C/¹²C ratio, dissolved TIC (total inorganic carbon) content with ¹⁴C content and ¹³C/¹²C ratio, dissolved organic carbon content, dissolved inorganic gases contents, and dissolved rare gases contents with ³He/⁴He ratio, were measured. The CH₄ contents of crater bottom samples (A-C) are 10-30 per cent higher than shallower samples (D-F), and ¹³C/¹²C ratios of CH₄ in A-C samples seem to be higher than D-F ones, suggesting the addition of CH₄ originated from magmatic fluid through the crater bottom. The ¹⁴C content and ³He/⁴He ratio of the bottom samples also show the magmatic fluid contribution through the crater bottom. Considering that leaked contents of CH₄ or CO₂ through the crater bottom are very few, volatile emission from the Teishi magma has become extremely weak, 23 years after the eruption.

1. An increasing trend of diffuse CO₂ emission from Teide volcano (Tenerife, Canary Islands): geochemical evidence of magma degassing episodes

German D. Padilla¹, Nemesio M. Perez¹, Pedro A. Hernandez¹, Eleazar Padron¹, Gladys Melian¹, Dacil Nolasco¹, Jose Barrancos¹, David Calvo², Fatima Rodriguez², Samara Dionis², Inigo Hernandez², Giovanni Chiodini³

¹Environmental Research Division, ITER, Tenerife, Spain, ²Volcanological Institute of the Canary Islands (INVOLCAN), Tenerife, Spain, ³Instituto Nazionale di Geofisica e Vulcanologia, Observatorio Vesuviano, Naples, Italy

E-mail: german@iter.es

Multiple soil CO₂ efflux surveys have been undertaken at the summit cone of Teide volcano, Tenerife, from 1997 to 2011, to determine the total CO₂ emissions from the summit cone and to evaluate the temporal variations of CO₂ efflux and their relationships with volcano-seismic activity. Our results reveal significant fluctuations in degassing rate, which do not seem to be masked by atmospheric variations. These geochemical observations provide evidence for the unrest of the volcanic system, as has been suggested previously by anomalous seismic activity recorded in Tenerife during April 22-29, 2004. A new trend of increasing CO₂ efflux and CO₂/CH₄ ratio in fumarolic gas discharges was observed from 2006 to 2009, suggesting that subsurface magma movement is the cause for the observed changes in the total output of diffuse CO₂ emission at summit cone of Teide.

Diffuse CO₂ Monitoring at Cerro Negro Volcano, Nicaragua

BARRANCOS Jose¹, IBARRA Martha², MELIAN Gladys¹, ALVAREZ Julio², RODRIGUEZ Fatima³,
NOLASCO Dacil¹, PADILLA German¹, CALVO David³, DIONIS Samara³, PADRON Eleazar³,
HERNANDEZ Pedro A.³, PEREZ Nemesio³, MUNOZ Angelica²

¹Environmental Research Division, ITER, Tenerife/Spain, ²Instituto Nicaraguense de Estudios Territoriales, INETER, Managua/Nicaragua, ³Volcanological Institute of the Canary Islands, INVOLCAN, Tenerife/Spain

E-mail: jbarrancos@iter.es

Cerro Negro is an active basaltic volcano belonging to the active Central American Volcanic Arc which includes a 1,100 Km long chain of 41 active volcanoes from Guatemala to Panama. Cerro Negro first erupted in 1850 and has experienced 21 eruptive eruptions with inter eruptive average periods between 7 and 9 years. Since the last eruption occurred on 5 August 1999, with erupted lava flows and ash clouds together with gas emissions, a collaborative research program between INETER and ITER was established for monitoring diffuse CO₂ emissions from this volcano. Until 2012, twelve soil CO₂ emission surveys covering an area of 0.6 km² have been performed by means of the accumulation chamber method to evaluate the spatial and temporal variations of CO₂ degassing rate in relation to the eruptive cycle of Cerro Negro. A total diffuse CO₂ emission output of 1,869 t/d was estimated for the 1999 survey; just 3 months after the 1999 eruption which can be considered within the post-eruptive phase. For the April, 2002 and March, 2008 surveys, considered within the inter-eruptive phase, a clear decreasing tendency on the total diffuse CO₂ output was observed, with estimates of 431 and 10 t/d, respectively, except a small increment in 2004, to 256 t/d, associated with an anomalous seismic activity. The higher anomalies are located around the crater of 1995 and 1999. An increasing on the total CO₂ emission has been observed, from December 2008 to February 2011, with total diffuse CO₂ output estimates from 12 t/d to 43 t/d, respectively. These temporal variations show a close relationship between diffuse CO₂ emission and the eruptive cycle at Cerro Negro. This relationship indicates that monitoring CO₂ emission is an important geochemical tool for the volcanic surveillance at Cerro Negro.

Mixing and degassing processes in the Skuggafjöll eruption, Iceland: Insights from coincident volatile and trace element melt inclusion analyses.

David A Neave¹, John Maclennan¹, Marie Edmonds¹, Thor Thordarson²

¹University of Cambridge, United Kingdom, ²University of Iceland, Iceland

E-mail: dan27@cam.ac.uk

In recent years the original, pre-eruptive CO₂ contents of magmas have been calculated using CO₂/Nb ratios from mid-ocean ridge and ocean island lavas and melt inclusions which are believed to be un-degassed. While this technique has the potential to be powerful for estimating volcanic CO₂ fluxes from the solid earth to the atmosphere, very few studies currently exist with coincident measurement of volatile and trace elements in basaltic melt inclusions. Flux calculations are based on the assumption that the CO₂ and Nb contents of melt inclusions are only controlled by varying amounts of fractionation and degassing. Here we present recently acquired SIMS data obtained from a suite of olivine-hosted melt inclusions from the sub-glacial Skuggafjöll eruption in the Eastern Volcanic Zone of Iceland, that indicate that the above mentioned assumption may not be valid. The Skuggafjöll melt inclusions show strong correlations between trace element (e.g. Zr, Nb, La, Ce) concentrations and trace element ratios (e.g. La/Yb) indicating variability in the composition of mantle melts supplied to the magmatic system feeding the Skuggafjöll eruption. Both melt inclusions and matrix glasses contain ~0.38 wt.% H₂O, consistent with rapid diffusive re-equilibration of H₂O and eruption under ice. However, the CO₂ concentration of melt inclusions ranges from 200 to 1200 ppm with CO₂/Nb values up to 410. CO₂ concentrations correlate negatively with trace element concentrations, linear regression of CO₂ on Nb yields $r = -0.76$, in stark contrast with trends obtained from existing 'un-degassed' datasets. At face value this anti-correlation could be interpreted as a record of concurrent crystallisation and degassing. However negative correlations are also observed between CO₂ and trace element ratios such as La/Yb. The most depleted, low La/Yb inclusions have the highest CO₂ and the most enriched, high La/Yb inclusions the lowest, suggesting that CO₂ behaved differently in parental melts of different composition during the formation of the Skuggafjöll magma. These observations may be accounted for by mixing of variably degassed melts shortly prior to eruption. The most depleted inclusions record entrapment pressures of 2 kbar using H₂O-CO₂ equilibrium. These melt inclusions are taken here to represent un-degassed melts on the basis of their high CO₂/Nb (>350). Consequently, they can be used to estimate total pre- and syn-eruptive CO₂ emission from the eruption. The low CO₂ in enriched melt inclusions suggests that degassing has taken place to lower their CO₂/Nb. This implies that the depleted and enriched components of the Skuggafjöll magma have been stored different pressures, and hence depths, in the crust. These observations have important implications for the interpretation of melt inclusion data and suggest that magma mixing, as well as degassing, may be important in controlling the volatile content of erupted melts.

Magma reservoir-vent system within Miyake-jima volcano revealed by GPS observations of crustal deformation associated with the emission of volcanic gas

Jun Oikawa¹, Shigeru Nakao², Takeshi Matsushima³

¹University of Tokuo, Japan, ²Kagoshima University, Japan, ³Kyushyu University, Japan

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

Analysis of GPS data during the degassing stage of volcanic activity at Miyake-jima volcano, Japan, in 2000 indicates a source of crustal deformation on the south side of the summit crater wall at a depth of 5.2 km. The rate of volume fluctuation was $-3.8 \times 10^5 \text{m}^3/\text{month}$ from September 2000 to January 2001 and $-0.8 \times 10^5 \text{m}^3/\text{month}$ from February to June 2001. As the volume is equivalent to the volume occupied by the volatile components dissolved in the magma, it is proposed that contraction of the magma reservoir reflects degassing of its volatile components. The observations indicate that the magma reservoir is connected to the summit crater by a magma-filled vent. Convection within the vent carries volatile-rich magma upward to the crater, where volcanic gas is released by degassing. The depleted magma is then carried into the magma reservoir, which contracts due to the loss of volume originally occupied by the volcanic gas.

Research on mud volcano in northern tianshan based on geochemistry causes

Xiaoqi Gao

Earthquake Administrator of Xinjiang Uygur Autonomous Region, China

E-mail: Gaoxq06@126.com

Mud volcano is a kind of structural geology phenomena under certain hydrogeology environment. Appearance of mud volcano related to oil-gas belt. Gas and groundwater close to surface in some region, under pressure from underground, bring sediment to surface along crack. This is the forming process of mud volcano. According to mud volcano brought plenty of valuable information to the ground, therefore, many researchers called it "Heaven granted well".

The consistency of mud is related to distribution of underground water. There are different kinds of mud volcano such as: mud cone, mud shield, mud basin, mud pool and mud hole according to different mud consistency.

Mud volcano in China mainly located in Xinjiang and Taiwan. Moreover, there are some small mud volcanoes in Tata River near Chaidamu basin margin in Qinghai province, Qu river in Sichuan basin and southern region of Jiangsu province. Most diameter of these mud volcano pretty small.

Mud volcano in Xinjiang located in the Midwest region of Northern Tianshan, five of them were representative such as: Horgos, Dushanzi, Wenquan, Poplar valley and Saitetike. Poplar valley and Saitetike mud volcano are the largest mud volcanic cluster in Asia. These mud volcanoes located in axis of Northern Tianshan piedmont depression anticline structure and exposure strata is mainly sandstone which full of underground water. The features of these underground water are as follow: high depression, high salinity and rich in petroleum and gas.

Mud volcanoes in Taiwan are more than twenty and mainly located in Gaoxiong and Hengchun, what's more, seventeen of these are in activating stage. The geological feature of these mud volcanoes are very typical and show brilliant scenery such as flaming.

The author tested gas, fluid and solid components of mud volcanoes in the Midwest region of Northern Tianshan from 2006 to 2012, and found geochemistry features of these mud volcanoes:

1. Mud volcanoes in Horgos, Dushanzi, Poplar valley and Saitetike have similar geochemistry features while in Dushanzi showed some significant differences in Dushanzi.
2. The gas component of mud volcano mainly is alkane gas with about 35.6%-72.0% except mud volcano in Wenquan.
3. The gas of mud volcanoes showed typical crust-derived helium with low $^3\text{He}/^4\text{He}$ and R/Ra value about 0.09-0.049.