

## V12C-0610 1330h POSTER

## Melt Evolution Beneath Mid-Ocean Ridges and Mantle Plumes From a Coupled Thermodynamic and Geodynamic Model

Massimiliano Tironi (tironem@fiu.edu)

CeSM/EC, Florida International University University Park Campus, Bldg. VHI150, Miami, FL 33199, United States

We have developed a model that combines a Gibbs free energy minimization routine incorporating the thermodynamic database for melts, pMELTS (Ghiorso et al., G3, 2002) and a geodynamic multiflow 2D numerical model that solves transport equations for mass, heat, momentum and chemical elements. The effects of latent heat, viscous dissipation and adiabatic heating are also included in the model. For brevity only few common features for melting in mid-ocean ridges and plumes are discussed here. Local equilibrium approximation is the main assumption of the model (Knapp, GCA, 1989). From experimental data on diffusion in mantle minerals, the approximation seems reasonable if porous flow is assumed as the mechanism of melt transport within the molten region. Channeling flow, induced by dissolution reactions (melting) (Spiegelman et al., JGR, 2001), is observed through large portions of the mantle. The location of the channels is extremely variable in time and size. Channels are defined here as mantle regions where melt fraction is approximately 2-3 times higher than the surrounding mantle and where melt transport is still controlled by porous flow. Melt far from the plume/ridge axis accumulates at the base of the lithosphere (Sparks and Parmentier, EPSL, 1991) and the residence time in this area determines periodic fluctuations in the melt extraction to the surface. In the plume model, reactivation of the melting process is observed at about 350 km from the plume axis. Petrology and geochemistry of residual solids and melt are the result of a polybaric process with continuous melt mixing. Preliminary comparison with data from lavas, melt inclusions, abyssal peridotites and mantle nodules shows that the model, within the limits of the available thermodynamic database, produces petrological and major elements geochemical variability similar to that observed in natural samples.

## V12C-0611 1330h POSTER

## Mantle Heterogeneity Beneath the Southwest Indian Ridge (9° - 25° E)

Jared Jeffrey Standish<sup>1</sup> (508-289-3539; jstandish@whoi.edu)Stanley R Hart<sup>2</sup> (shart@whoi.edu)Henry JB Dick<sup>2</sup> (hdick@whoi.edu)<sup>1</sup>MIT/WHOI Joint Program, 266 Woods Hole Road MS# 8, Woods Hole, MA 02543, United States<sup>2</sup>Woods Hole Oceanographic Institution, 266 Woods Hole Road, Woods Hole, MA 02543, United States

Recent isotopic measurements of 20 glasses from 9° to 25° E on the Southwest Indian Ridge reveal striking correlations with trace element data. The isotopic variation in Sr, Nd, Hf, and Pb of these lavas confirms that along-axis heterogeneity exists in the MORB source beneath this part of the SWIR. Major and trace element systematics and isotopic compositions indicate that the along-axis variation in basalt chemistry, specifically the contrast between orthogonal supersegment and oblique supersegment lavas, can likely be explained by 1) variable extents of melting of a heterogeneous depleted peridotite lithology, or 2) variable extents of melting of a two component MORB source; a heterogeneous depleted peridotite lithology and a pyroxenite/eclogite lithology of varying proportion. This chemical variation is coupled with distinct tectonic and morphologic differences between the orthogonal supersegment and the oblique supersegment. One of the most noticeable differences between the two segments is the spreading geometry. The orthogonal supersegment spreads nearly perpendicular to the spreading axis, while the oblique supersegment spreads at up to 35° from the axis. This abrupt change in ridge obliquity results in an effective spreading rate or mantle upwelling rate on the oblique supersegment as low as 4.5 mm/yr (half-rate), which may dramatically influence the thermal structure of the melting zone. Systematic enrichment of the mantle source from east to west along the orthogonal supersegment (16° to 25° E) is contrasted with a more variable, but more highly enriched isotopic and trace element composition on the oblique supersegment (9° to 16° E) (Figure 1A; see link below). Present day influence from the Bouvet Hotspot is unlikely, as the oblique supersegment lies nearly 800 km to the east, and the most enriched lavas are found on the eastern end of the oblique supersegment. Interestingly, the two areas of high magmatic flux on the oblique supersegment, Joseph Mayes Seamount, an axial volcano, and Narowgate, a long-lived cross-axis volcanic high, have very different isotopic signatures, further suggesting a difference in the source composition or possibly a difference in the amount of time-integrated depletion of each residual mantle column. Figure 1B (see

link below) illustrates a well-defined linear correlation between 143/144 Nd and La/Sm (normalized to chondrite) for both oblique supersegment (filled) and orthogonal supersegment (open) lavas. This strong coupling of trace element and isotopic ratios supports our interpretation of a heterogeneous mantle source, but also presents the possibility that the observed glass compositions are the result of variable melting parameters (depth, extent, temperature). Isotope ratios are also generally correlated with major element indices, such as K/Ti and Mg#, providing additional constraints on the petrogenetic evolution of these basalts and lithologic character of the depleted upper mantle. Forward modeling of peridotite versus pyroxenite/eclogite melting should provide useful constraints on the source composition, while inverse trace and major element modeling will add additional limits on the amount of melting on each segment.

URL: <http://www.whoi.edu/science/GG/jstandish/Fall03agu.jp>

## V12C-0612 1330h POSTER

## Channelling of Melt Above Plumes and Beneath MORs

Kristian Mueller<sup>1</sup> (kdg@gmx.de)Harro Schmeling<sup>1</sup> (schmeling@geophysik.uni-frankfurt.de)<sup>1</sup>IMGF, Feldbergstrasse 47, Frankfurt 60323, Germany

We investigate melt transportation in partially molten rocks under different stress fields above the head of a mantle plume or beneath a spreading mid-oceanic ridge under hydrous and anhydrous conditions. We model such aggregates with the 2D-FD code FD-CON [1] by means of a porous deformable matrix with melt under the influence of a given stress field to clarify the following key questions: Could channelling occur in a matrix containing a random melt distribution under a given stress field? Which orientation does it take? Is it possible to achieve a focusing of melt towards a MOR (dykes)? Does applying simple or pure shear to the matrix result in a difference in the formation and orientation of channels? How does the channel instability evolve during finite simple shear? In a deforming partially molten aggregate, weakening of the solid matrix due to the presence of melt creates an instability in which melt is localized by the following mechanism: regions of initially high melt fraction are areas of low viscosity and pressure, so that melt is drawn into these regions from higher pressure surroundings. This further enhances the melt weakening, producing a self-excited localization mechanism [2]. The channelling developing in models with a random melt distribution of  $3.5 \pm 0.5\%$  shows that melt is accumulated preferably in inclined channels. For both, simple as well as pure shear, the growth rate is highest for an orientation parallel to the direction of the maximum compressive stress and proportional to applied stress and the reverse of the Melt Retention Number. This also confirms the theoretical growth rate found by Stevenson [2]. In our isothermal models we found that the influence of water reduces the growth rate, in contrast to non-isothermal models of Hall [3]. Under simple shear melt channels evolve from an irregular melt distribution at angles of 45 degrees to the direction of shear. Upon further straining they rotate out of the orientation of maximum growth rate and partly disrupt. At later stages the mean channel orientation deviates from the compressive stress orientation. We further seek to clarify which physical quantities may affect the orientation of channels and their wavelengths. Possible factors are the compaction length and the nature of the stress field. The latter assumption will be tested combining pure and simple shear. References [1] H. Schmeling, Partial melting and melt segregation in a Convecting mantle. Physics and chemistry of partially molten rocks; N. Bagdassarov and D. Laporte and A. B. Thompson, Kluwer Academic Publishers, 141-178, 2000 [2] D.J. Stevenson. Spontaneous small-scale melt segregation in partial melts undergoing deformation. Geophys. Res. Lett., 16(9):1067-1070, 1989 [3] C.E. Hall and E.M. Parmentier. Spontaneous melt localization in a deforming solid with viscosity variations due to water weakening. Geophys. Res. Lett., 27:9-12, 2000

## V12D MCC: Level 1 Monday 1330h

## Igneous Differentiation Posters

Presiding: F J Spera, University of California, Santa Barbara

## V12D-0613 1330h POSTER

Open-System Magma Chamber Evolution: an Energy-Constrained Geochemical Model Incorporating the Effects of Concurrent Eruption, Recharge, Imperfect Assimilation and Fractional Crystallization (EC-E'RA $\chi$ FC)Frank J Spera<sup>1</sup> (805 6833446; spera@geol.ucsb.edu)Wendy Anne Bohrsen<sup>2</sup> (5099632835; bohrsen@caliente.geology.cwu.edu)<sup>1</sup>Dept of Earth Sciences and Institute for Crustal Studies, University of California, Santa Barbara, CA 93106<sup>2</sup>Dept of Geology, Central Washington University, Ellensburg, WA 98926

Geochemical data for many plutonic and volcanic cognetic suites provide overwhelming evidence for open system behavior. Significant petrogenetic processes influencing the geochemical evolution of magma bodies include magma Recharge, heating and partial melting (Assimilation) of country rock, formation and separation of cumulates by Fractional Crystallization and the formation of enclaves by rapid chilling of newly-intruded recharge magma. We have extended the EC-RAFC trace element and isotopic geochemical model (Spera and Bohrsen, 2002; Bohrsen and Spera, 2002) to include the effects of magma Eruption and variable amounts of assimilation,  $A_{\chi}$ . The EC-E'RA $\chi$ FC model tracks the geochemical path (trace element and isotopic composition) of magma body melt (host melt), eruptive magma, cumulates and enclaves for magma undergoing simultaneous eruption, recharge, assimilation and fractional crystallization as a function of magma temperature. EC-E'RA $\chi$ FC is formulated as a set of  $4 + t + i + s$  coupled nonlinear ordinary differential equations, where the number of trace elements, radiogenic and stable isotope ratios simultaneously modeled are  $t$ ,  $i$  and  $s$ , respectively. There are no limitations on the values of  $t$ ,  $i$  or  $s$ . Solution of the EC-E'RA $\chi$ FC equations provides values for the average temperature of wall rock ( $T_a$ ), mass of host melt within the magma body ( $M_m$ ), masses of cumulates ( $M_{ct}$ ), enclaves ( $M_{en}$ ) and wall rock involved in the thermal interaction ( $M_{ao}$ ) and assimilated ( $\chi M_{a*}$ ), the concentration of  $t$  trace elements and  $i$  isotopic ratios in host melt ( $C_m$ ), eruptive magma, cumulates ( $C_{ct}$ ), enclaves ( $C_{en}$ ) and anatectic melt ( $C_a$ ) as a function of magma temperature ( $T_m$ ). Input parameters include the (user-defined) equilibration temperature ( $T_{eq}$ ), the efficiency of mixing of anatectic melt factor ( $\chi$ ), the initial temperature and composition of pristine host melt ( $T_{mo}$ ,  $C_{mo}$ ,  $e_{mo}$ ), recharge melt ( $T_{ro}$ ,  $C_{ro}$ ) and wall rock ( $T_{ao}$ ,  $C_{ao}$ ), distribution coefficients ( $D_m$ ,  $D_r$ ,  $D_a$ ) and their temperature dependencies ( $\Delta H_m$ ,  $\Delta H_r$ ,  $\Delta H_a$ ), heat of transition for wall rock ( $\Delta h_a$ ), pristine ( $\Delta h_m$ ) and recharge ( $\Delta h_r$ ) and the isobaric specific heat capacity of assimilant ( $C_{p,a}$ ), pristine ( $C_{p,m}$ ) and recharge melt ( $C_{p,r}$ ). The magma recharge mass and eruptive magma mass functions  $Mr(T_m)$  and  $Me(T_m)$ , respectively, are specified a priori and allow one to predict the effects of recharge and magma eruption on the geochemical evolution of the system. Melt productivity functions, which prescribe the relationship between melt mass fraction and temperature, are defined for end-member bulk compositions characterizing the local geologic site. EC-E'RA $\chi$ FC makes testable quantitative predictions for relative masses and compositions for volcanic and plutonic products of magma system evolution which can be compared to information gathered from field studies to critically test petrogenetic hypotheses. The 'systems' approach to understanding magma chamber evolution promises to enhance the ability to describe the efficacy of petrologic processes in various tectonic settings. Illustrative examples of complex EC-E'RA $\chi$ FC simulations are presented to highlight the salient features of the model.

URL: <http://magma.geol.ucsb.edu/>

## V12D-0614 1330h POSTER

## Closed System Behavior of Trace Elements During Basalt Crystallization in the Makaopuhi Lava Lake, Hawaii.

Justin J. Hagerty<sup>1</sup> (jh2713@unm.edu)

Charles K. Shearer<sup>1</sup> (cshearer@unm.edu)<sup>1</sup>Institute of Meteoritics, 1-University of New Mexico MSC03 2050, Albuquerque, NM 87131, United States

The Makaopuhi Lava Lake formed during an eruption of the Kilauea volcano in March 1965. During a U.S.G.S. study of the lava lake (Wright and Okamura, 1977), direct measurements were made of the thermal history, oxygen fugacity, volatile content, petrography-chemistry, viscosity, and density. These observations provide a unique opportunity to place trace element behavior into the context of a well-defined, natural magmatic system. Samples used in this study were collected at temperatures between 1160 and 990°C and at an approximate fO<sub>2</sub> equal to the NiNiO buffer. All samples represent coexisting crystals and glass. The crystallization sequence within the lake was: olivine, augite, plagioclase, ilmenite, pigeonite, magnetite, apatite. During crystallization the olivine composition ranges from Fo85 to Fo50 and the MgO of the melt ranges from 3 to 9 wt.%. Trace element measurement (K, V, Cr, Mn, Co, Ni, Y, Sm, and Th) on individual phases were made using secondary ion mass spectrometry. Absolute concentrations of each element for each phase were calculated using empirical relationships of Trace Element/30Si<sup>+</sup> ratios, which were normalized to known SiO<sub>2</sub> content. Our initial results show that as the temperature decreases, the melt composition exhibits a predictable decrease in Ni, Co, and Cr, a minor increase in Mn and V, and substantial increases in K, Y, Sm, and Th. Nickel and Cr decrease from olivine core to rim, whereas Mn, Co, and V exhibit limited variation from core to rim. The behavior of trace elements between olivine and melt changes systematically with decreasing temperature. The distribution coefficients (D<sub>ol/melt</sub>) for highly incompatible elements such as K, Y, Sm, Th decrease with decreasing temperature. The D<sub>ol/melt</sub> for Ni remains the same over much of the temperature range (15), but increases dramatically at very low temperatures. The D<sub>ol/melt</sub> for Cr, V, Mn, and Co systematically increase with decreasing temperature.

## V12D-0615 1330h POSTER

### Extreme Magma Differentiation in a Hawaiian Magma Chamber: An Analysis of Gabbro and Syenite Xenoliths From Hualalai Volcano

Patrick J Shamberger<sup>1</sup> (808-956-8558; shamberg@hawaii.edu)Julia E Hammer<sup>1</sup> (808-956-5996; jhammer@soest.hawaii.edu)<sup>1</sup>University of Hawaii - Manoa, 1680 East West Rd., Honolulu, HI 96822, United States

Large volumes of highly differentiated trachyte magma erupted from Hualalai Volcano 103±11 k.y.a. as a >275m thick flow on the north flank, a large pumice and obsidian cone, lavas at the NW tip of the main rift zone, and as blocks in a maar deposit. The principle flow is recognized as the largest single eruptive event on the island of Hawaii (Moore, et al., 1987). This episode contradicts previous notions of Hawaiian evolution, which generally associate highly evolved magmas with the conclusion of the post-shield alkalic stage (e.g., West Maui volcano). Hualalai differs from this pattern in that the evolved magmas appeared at the beginning of the post-shield alkalic stage and were erupted over a relatively narrow time interval. These distinctions have significant implications for our understanding of Hawaiian volcanoes' magmatic plumbing systems, including the depths, magma replenishment and extraction frequencies, and longevity of the reservoirs that feed eruptions, especially in the transitory interval between the tholeiitic shield and alkalic post-shield stages. Gabbro and syenite nodules erupted <10 k.y.a. from Hualalai's summit vents may represent cumulates, residual liquids, and/or crystallized magmas associated with trachyte differentiation, and thus provide insight into the processes leading to extreme fractionation. Because they contain a large number of phases and preserve reaction relationships in the form of mineral textures, the crystalline nodules may incorporate more information about magma differentiation conditions than can be extracted from the relatively homogeneous and micro-crystalline trachyte itself. The nodules were transported to the surface in alkali basalt at numerous vents and were found distributed in spatter and tephra deposits near the summit of the volcano over a region several km in diameter. They span broad compositional and textural spectra. Modes range from 58-93 vol% felsic minerals, dominantly plagioclase, with augite and Ca-poor pyroxene comprising most of the balance. Several nodules contain the hydrous minerals biotite and calcic amphibole. Accessory phases include ilmenite, magnetite, apatite, zircon, ± olivine or quartz. In many instances, the major minerals are clearly in reaction relationship with their surroundings. E.g., blebs of alkali feldspar dispersed throughout large plagioclase phenocrysts suggest the existence of precursor ternary feldspar; crystallographically-controlled oxide stringers along pyroxene planes suggest oxidation. We are considering deposit characteristics, mineral assemblages, and phase compositions of the basalt-hosted xenoliths

to infer the depth and H<sub>2</sub>O content of magma fractionation.

## V12D-0616 1330h POSTER

### Tracking Pyroxenes Through a Magma System Using Trace Elements: an Example From Tenerife, Canary Islands

Paul Olin<sup>1</sup> (509 335 1288; polin@mail.wsu.edu)John Wolff<sup>1</sup> (509 335 2825; jawloff@mail.wsu.edu)Charles Knaack<sup>1</sup> (509 335 6742; knackc@wsu.edu)<sup>1</sup>Department of Geology, Washington State University, Pullman, WA 99164, United States

Although much attention is currently focused on applications of radiogenic isotope microanalysis to petrogenetic problems, many volcanic suites do not exhibit a large enough range in, for example, Sr isotope ratios for the technique to be useful. Advances in LA-ICPMS instrumentation allow rapid and routine trace element microanalysis of minerals and glasses at a spatial resolution approaching that of the electron microprobe, providing a microanalytical complement to isotope studies in igneous petrogenesis. We apply this approach to clinopyroxenes from the basanitic through phonolitic mixed-magma rocks of the bimodal Diego Hernandez Formation (DHF), Tenerife, Canary Islands. Two distinct phonolite types, distinguished on the basis of REE and HFSE abundances, have alternated in volumetric significance during the 180 ky eruptive history of the DHF. Also, there is abundant petrographic evidence for repeated mingling of phonolitic and basanitic magmas prior to explosive eruptions, while whole-rock compositions of several associated mafic lavas are consistent with more complete hybridization of basanitic and phonolitic liquids. Clinopyroxenes from the suite fall into three groups: 1) titanaugites with unremarkable REE patterns; 2) salites with elevated REE contents and negative Eu anomalies; 3) salites with negative Eu anomalies and strong MREE depletion. Type 1 titanaugites crystallized from basanitic liquids, Type 2 salites from tephriphonolitic and phonolitic liquids, and Type 3 from highly-evolved phonolitic melts saturated with titanite. All three types are found, as discrete grains and as zones within complex grains, in the products of the largest explosive eruptions in the DHF, clearly demonstrating repeated crystal transfer between basanite, phonolite, and highly evolved phonolite, prior to the mingling events that triggered the individual eruptions. The ability to fingerprint crystals derived from different phonolite types is an important step in unravelling complex shallow-level magmatic processes on Tenerife. The large gap in REE abundances between Type 2 and 3 pyroxenes is consistent with earlier suggestions that the highly-evolved phonolites may contain a component of strongly differentiated syenite recycled from within the island edifice.

## V12D-0617 1330h POSTER

### Coherent Time-Dependent Variation of <sup>87</sup>Sr/<sup>86</sup>Sr in Clinopyroxene From the Alban Hills Volcanic District (Central Italy): Clues to Source Evolution

Daniel B. Karner<sup>1</sup> (daniel.karner@sonoma.edu); John N. Christensen<sup>2</sup> (jnchristensen@lbl.gov);Carmela Freda<sup>3</sup> (freda@ingv.it); Mario Gaeta<sup>4</sup> (mario.gaeta@uniroma1.it); Fabrizio Marra<sup>3</sup> (marra@ingv.it); Piergiorgio Scarlato<sup>3</sup> (scarlato@ingv.it)<sup>1</sup>Dept. of Geology, Sonoma State University, 1801 East Cotati Avenue, Rohnert Park, CA 94985, United States<sup>2</sup>Center for Isotope Geochemistry, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Bldg 70A, 4418, Berkeley, CA 94720-8179, United States<sup>3</sup>Dept. of Seismology and Tectonophysics, Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, Rome 00143, Italy<sup>4</sup>Dept. of Earth Sciences, University "La Sapienza", P.le Aldo Moro 5, Rome 00185, Italy

It is unclear whether the Alban Hills volcano near Rome is extinct or whether it is inactive. To address this question we have been studying the chemical evolution of its eruptive products, where unaltered materials are found only as inclusions in phenocrysts. We measured the <sup>87</sup>Sr/<sup>86</sup>Sr of Sr in clinopyroxene phenocrysts from a complete suite of volcanic products (pyroclastic flows, lava flows, and granular ejecta) of the ultra-potassic Alban Hills Volcanic District, encompassing its entire eruptive history for the time span 608 - 35 ka. Each analyzed sample was dated by means of <sup>40</sup>Ar/<sup>39</sup>Ar geochronology, in order to investigate the evolution of the magmatic system. The <sup>87</sup>Sr/<sup>86</sup>Sr

of the pyroxenes ranges from 0.7112 to 0.7085, and a correlation between eruption age and <sup>87</sup>Sr/<sup>86</sup>Sr is apparent. In particular, <sup>87</sup>Sr/<sup>86</sup>Sr shows a near-linear, time-dependent decrease from the oldest to youngest samples. An exception to this occurs at 70 ka, the age of the start of the latest eruptive cycle in the Albano Maar, whose pyroxenes have <sup>87</sup>Sr/<sup>86</sup>Sr below this long-term trend. Based on the long duration of the eruptive history and the large volume of erupted products, we interpret the general trend as representative of variation in the magma source, rather than assimilation during storage in crustal magma chambers. Partial melting of metasomatically-veined and fertilized mantle has been proposed to explain the origin of these ultra-potassic magmas. If correct, the decreasing <sup>87</sup>Sr/<sup>86</sup>Sr with time could reflect the progressive exhaustion of the metasomatic components (i.e. veins) in the mantle source region. In contrast, in the light of independent petrologic and geochronologic data, we hypothesize that the 70 ka anomaly may be linked to a renewal of the magma source.

## V12D-0618 1330h POSTER

### Petrology and Geochemistry of Volcan Darwin, Isabela Island, Galapagos Archipelago

Terry R Naumann<sup>1</sup> (907) 786-6846; atrn@uaa.alaska.eduLisa K Krebs<sup>1</sup> (aslkk2@uaa.alaska.edu)<sup>1</sup>Univ of Alaska Anchorage Anchorage, Department of Geology 3211 Providence Dr, Anchorage, AK 99508, United States

The Galapagos Islands represent a hotspot system where the distribution and number of simultaneously active volcanoes, their petrologic and morphologic diversity, and the lack of a chemical evolutionary pattern distinguish them from the more familiar example of Hawaiian hotspot volcanism. The large western Galapagos shield volcanoes share many geomorphic and chemical attributes, yet in detail each is unique. 88 new major and trace element analyses document that Volcan Darwin, one of the large shield volcanoes of Isabela island, has erupted a range of compositions from basalt to andesite. The diverse compositions of Darwin are unlike those of the neighboring volcanoes of Wolf and Alcedo. On average, lavas of Darwin and Alcedo are much more highly evolved than the lavas of Wolf. For example, at Darwin, total alkalis (K<sub>2</sub>O+Na<sub>2</sub>O) range from 2.5 to 4.6 wt percent, SiO<sub>2</sub> ranges from 47.6 to 57.0 wt percent and MgO ranges from 2.9 to 6.2 wt percent. Geochemical modeling shows that this compositional range is due mostly to crystal fractionation involving olivine, plagioclase and clinopyroxene. Petrographically, the population of Darwin lavas are strongly bimodal. Eighty percent of the samples collected are extremely crystal-rich and contain up to forty percent plagioclase phenocrysts and zoned megacrysts up to 8 mm in diameter. Conversely, about twenty percent of the samples collected are aphyric or only sparsely phytic. These differences in crystallinity and the occurrence of highly evolved compositions suggest that the thermal flux and residence times for Darwin's magmas are highly variable. We believe that at Darwin, as has been shown for other Galapagos volcanoes, most batches of magma are mixed in a large, thermally regulated chamber which commonly results in the eruption of very uniform tholeiitic basalt. However, the structure and longevity of Darwin's lithospheric storage and transport system must be highly variable, as some isolated magmas have cooled and evolved to much greater degrees than most Galapagos magmas, resulting in the eruption of andesite.

## V12D-0619 1330h POSTER

### Evidence for Differentiation by Crystal Fractionation in Theo's Flow, Canada

Rachel C. Lentz<sup>1</sup> (865-974-3874; rrlentz@utk.edu)Lisa E. Collins<sup>2</sup>Timothy J. McCoy<sup>2</sup>Jeffrey Taylor<sup>3</sup><sup>1</sup>University of Tennessee, Dept. of Earth and Planetary Sciences, Knoxville, TN 37996, United States<sup>2</sup>Smithsonian Inst., Dept. of Mineral Science, Washington, DC 20560, United States<sup>3</sup>Univ. of Hawaii, HIGP, Honolulu, HI 96826, United States

Theo's Flow, a 120-m thick differentiated lava flow in Munro Twp, Ontario, is an unusual magma body which calls for an unusual formation mechanism. New systematic sampling of the flow for geochemistry and petrography offers additional clues to its post-emplacement differentiation. Evidence for differentiation comes from both petrography and geochemistry. Theo's has four lithologic units: a basal peridotite (3-9 m), a thick pyroxenite (50 m) and gabbro (40 m),

and a capping (8-12 m) hyaloclastite. Contacts between lithologic layers are gradual, mostly marked by changes in modal mineralogy, although there is also a distinct change in plagioclase morphology concurrent with its modal increase. From pyroxenite to gabbro, plagioclase shifts from fine, interstitial sprays to large laths in a subophitic intergrowth with pyroxene. Whole rock and pyroxene compositions display typical fractionation trends (e.g. Fe/Mg, Ti, Zr, Nb increase up-section). Furthermore, a weighted sum of 22 whole rock compositions from the internal layers match the hyaloclastite composition well for most non-mobile elements. All these factors suggest formation of the three internal layers by fractional crystallization and evolution of a magma whose composition is represented by the hyaloclastite. Any proposed differentiation process must address some specific observations. Cluster and CSD analysis reveal that pyroxene grains grew in clusters under steady-state conditions of nucleation and growth. Pyroxene grain size is nearly uniform throughout the pyroxenite, suggesting thermal conditions were maintained over a long crystallization interval. Progression of a typical solidification front would produce a fine-grained roof crust beneath the quenched top, but there is no evidence of such a layer in Theo's. Unlike magmas for which solidification fronts are invoked, Theo's parent magma was highly mafic and Al-poor, yielding a low viscosity magma (4 Pa-s) that crystallized only pyroxene over a long temperature interval. We will consider two formation models in which differentiation was driven by crystallization at flow top and bottom, but accumulation only occurred at the base. One model addresses the possible role of convection.

## V12E MCC: 3008 Monday 1340h

### Volcanic Emissions to the Troposphere: Origins, Processes and Monitoring (joint with A, B)

**Presiding:** M Herzog, University of Michigan; S A Carn, Joint Center for Earth Systems Technology, University of Maryland, Baltimore County

## V12E-01 1340h

### The Chemistry of Tropospheric Volcanic Plumes

Tamsin A Mather<sup>1</sup> (+44 (0)1223 333474; tam21@cam.ac.uk); Andrew G Allen<sup>2</sup> (a.g.allen@bham.ac.uk); David M Pyle<sup>1</sup> (dmp11@cam.ac.uk); Clive Oppenheimer<sup>3</sup> (co200@cam.ac.uk); Andrew JS McGonigle<sup>3</sup> (ajsm2@cam.ac.uk); Vitchko I Tsanev<sup>3</sup> (vip20@cam.ac.uk)

<sup>1</sup>Dept. of Earth Sciences Cambridge Univ, Downing St., Cambridge CB2 3EQ, United Kingdom

<sup>2</sup>School of Geography Earth and Environmental Sciences Birmingham Univ, Edgbaston, Birmingham B15 2TT, United Kingdom

<sup>3</sup>Dept. of Geography Cambridge Univ, Downing Place, Cambridge CB2 3EN, United Kingdom

Persistently degassing volcanoes contribute substantial amounts of many different chemical species to the troposphere, including acidic gases (sulfur dioxide, HF and HCl), toxic trace metals (including mercury, cadmium and lead) and aerosols of different types. The continuous release of such species from active volcanoes may lead to significant short- and medium-range environmental impacts as well as constituting an important contribution to global natural emissions inventories. However, the emissions from many important volcanic centers remain poorly characterized meaning that the global volcanic emissions of many species are not reliably constrained. Further, the chemical evolution of volcanic plumes from emission source (magma) to the point of deposition remains poorly understood. Our work seeks to build upon and extend previous efforts in this field. We have deployed a range of field instruments at active volcanoes (including those in Nicaragua, Italy and Chile) in order to study different aspects of volcanic plume chemistry. These studies have included the use of an impactor (particles), sun photometry (particles), filter packs (particles and gases) and UV spectrometry (gases). Our primary aims are to look for trends in emission composition with style of degassing (e.g. open-vent vs fumarolic) and to consider how the emittants are processed during transport under different atmospheric conditions. As well as contributing to the understanding of local and regional scale impacts of volcanic plumes, this work will enable us to improve global flux estimates of volcanic emissions, such as trace metals and aerosols (particularly important given the ongoing efforts of climate modelers to include particles in their models). We are also working to identify previously unconsidered components in volcanic plumes. We have recently identified

nitric acid emissions from volcanoes, suggesting that volcanoes are not only important atmospheric sources of chemicals exsolved from magma, but may also be important as high temperature reaction environments for plume-air mixtures.

## V12E-02 1355h

### Aerosol Evolution Within a Low-Temperature Volcanic Plume

Melissa A Pfeffer<sup>1</sup> (pfeffer@dkrz.de)

Frans JM Rietmeijer<sup>2</sup> (fransjmr@unm.edu)

Adrian J Brearley<sup>2</sup> (brearley@unm.edu)

Tobias P Fischer<sup>2</sup> (fischer@unm.edu)

<sup>1</sup>Max Planck Institute for Meteorology, Bundesstrasse 55, Hamburg 20146, Germany

<sup>2</sup>University of New Mexico, Department of Earth and Planetary Sciences, Albuquerque, NM 87131, United States

In order to investigate the early evolution of aerosols within a volcanic plume, atmospheric samples were collected at Poas, a persistently degassing volcano in Costa Rica. Chemical bulk compositions and morphologies of the collected aerosols were examined using transmission electron microscopy. Aerosol morphologies correlate with distinctions in composition and with sampling location. A bimodal size distribution of aerosols is observed at all sampling locations. The small aerosols exist in clusters of semi-spherical bodies averaging 35nm across, characteristic of homogeneously nucleated aerosols. The large aerosols are solid and/or liquid, with the solid aerosols averaging 150nm across, characteristic of primary aerosols. The large liquid aerosols have more complex bulk chemistry than the small homogeneously nucleated aerosols, both size and composition suggesting they condensed on already existing aerosols. Both size modes of aerosols are 300nm larger 280m distant from source, indicating that coagulation commences immediately and occurs uniformly for both modes of aerosols. Aerosol compositions were compared with predictions of an equilibrium model assuming homogeneous nucleation of aerosols generated by mixing the 92°C volcanic gases with ambient temperature air. The collected aerosols have different and more complex compositions than the model predicts to be stable in the plume. We suggest that heterogeneous nucleation and coagulation are important processes in the first seconds of plume travel and these processes, as well as the inclusion of airborne, locally-produced mineral dust must be considered in an accurate model of plume evolution.

## V12E-03 1410h

### The Critical Role of UV Satellite Data in Monitoring Volcanic Sulfur Dioxide Emissions in the Troposphere

Simon A. Carn<sup>1</sup> (410-455-1454; scarn@umbc.edu)

Gregg J.S. Bluth<sup>2</sup> (gbluth@mtu.edu)

Arlin J. Krueger<sup>1</sup> (akrueger@umbc.edu)

<sup>1</sup>Joint Center for Earth Systems Technology (UMBC/NASA GSPC), University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, United States

<sup>2</sup>Department of Geological Engineering and Sciences, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931, United States

From the Congo to the Galápagos Islands to Iceland, effusive eruptions of sulfur-rich basaltic magma often liberate prodigious quantities of SO<sub>2</sub> (~0.05-5 Tg) over days or weeks of continuous emissions. Much of this SO<sub>2</sub> (and hence derived sulfate aerosol) resides in the troposphere, although there is evidence that small amounts reach the stratosphere following larger eruptions. Measurements by the Total Ozone Mapping Spectrometer (TOMS) instruments since 1978 indicate that such emissions represent an important and persistent source of tropospheric SO<sub>2</sub>, contributing >30% of the total volcanic SO<sub>2</sub> measured by TOMS to date. Continued monitoring of this SO<sub>2</sub> source is therefore critical to any assessment of global volcanic degassing and its potential environmental or climatic impacts. Detection of SO<sub>2</sub> emissions from space also acts as an important signature of eruptive activity in the absence of other observations, allowing eruptions from remote volcanoes to be monitored. The ultraviolet wavelengths used by TOMS are comparatively insensitive to the effects of atmospheric water vapor, which perturbs retrievals of SO<sub>2</sub> in the infrared. Since the most prolific sources of tropospheric SO<sub>2</sub>, such as Nyamuragira (D.R. Congo) and the Galápagos volcanoes, are located in the tropics, TOMS has been the most suitable tool for measuring these emissions, which are also very difficult and hazardous to study using ground-based or airborne techniques. UV measurements at higher spatial and spectral resolution than TOMS will be continued

in 2004 by the Ozone Monitoring Instrument (OMI) on the EOS/Aura satellite. The increased sensitivity of OMI will permit detection of smaller volcanic clouds, along with lower tropospheric and boundary layer SO<sub>2</sub> plumes and hence expand the capabilities of UV satellite data. Temporal resolution is the major constraint on polar-orbiting UV satellite data, with only one image per day available at low latitudes. This complicates attempts to estimate the mass of SO<sub>2</sub> produced by continuously-emitting effusive eruptions, and will also apply to observations of passive degassing using OMI. We are exploring several techniques to combat this, including derivation of SO<sub>2</sub> fluxes and loss rates from TOMS data and use of contemporaneous geostationary satellite imagery to constrain eruption timing. Several examples will be presented, including eruptions of Nyamuragira and Cerro Azul (Galápagos Is).

URL: <http://skye.gsfc.nasa.gov>

## V12E-04 1425h

### Forward modeling of volcanic aerosols transmissions at different latitudes; quantifying the effects of varying tropospheric water vapor on ash detection.

I. Matthew Watson<sup>1</sup> (19064872045; watson@mtu.edu)

William I Rose<sup>1</sup> (raman@mtu.edu)

Vincent J Realmuto<sup>2</sup> (Vincent.J.Realmuto@jpl.nasa.gov)

Gregg J.S. Bluth<sup>1</sup> (gbluth@mtu.edu)

<sup>1</sup>Department of Geological and Mining Engineering and Sciences, Michigan Technological University, Houghton, MI 49931, United States

<sup>2</sup>Visualization and Scientific Animation Group, MS 168-414 Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

Current algorithms for volcanic ash cloud detection by satellite, based upon a difference in transmissivity of silicate ash at 11 and 12 microns, are subject to significant and yet poorly quantified modulation by atmospheric water vapor. In order to investigate these effects we have written an aerosol forward model, based upon Mie-scattering code, and embedded it in a MODTRAN-based atmospheric radiative transfer model. This facilitates investigation of errors associated with inverse solutions derived from satellite data, and more importantly for this study, can be used to vary the atmosphere within which a hypothetical volcanic ash cloud is contained. We have taken images of the most well parameterized ash clouds of the satellite age, the sequence of eruptions of Mt. Spurr in mid to late 1992, and applied the forward model to predict transmission spectra of the ash clouds. Calculations were performed for the ash clouds both within the cloud's original atmosphere and within that of a sequence of eruptions of Soufriere Hills Volcano, Montserrat, in the British West Indies in the late 1990s. Preliminary results indicate a +1-3.5 K brightness temperature difference (BTD) effect associated with increasing the temperature and water vapor content of the atmosphere. This translates to a significant loss of detectability in terms of cloud area; up to half the area of the clouds no longer have a negative brightness temperature difference, and an effect on reducing the optical depth and mass of the cloud. In most cases there was very good agreement between the 'clear ocean' BTD and the modeled effect, suggesting a potential source of in-image calibration for detection algorithms. In terms of mass and optical depth retrievals however, it is obvious that both 11 and 12 micron channel radiances are affected by the presence of water vapor, clearly indicating the need for atmospheric correction before quantifying the size or concentration of ash in clouds from satellite data.

## V12E-05 1440h

### Investigation Of Volcanic Gas Emission By MAX-DOAS And I-DOAS

Nicole Bobrowski<sup>1</sup> (nbobrows@iup.uni-heidelberg.de)

Falko Lohberger<sup>1</sup> (Falko.Lohberger@iup.uni-heidelberg.de)

Gerd Hoenninger<sup>2</sup> (Gerd.Hoenninger@ec.gc.ca)

Ulrich Platt<sup>1</sup> (Ulrich.Platt@iup.uni-heidelberg.de)

<sup>1</sup>Institut fuer Umweltphysik, INF229, Heidelberg 69120, Germany

<sup>2</sup>Meteorological Service of Canada, 4905 Dufferin St., Toronto M3H 5T4, Canada

Simultaneously measurements of BrO, SO<sub>2</sub> and other trace gases in volcanic plumes were made. With a Mini - MAX-DOAS (Multi Axis Differential Optical Absorption Spectroscopy) an image of the BrO and SO<sub>2</sub>