latter can be considered to be the "sediment production time." Our measurements of Late Pleistocene sediment retrieved from ODP Site 984 in the North Atlantic (mean grain size 10 - 20 micron, fractional loss rate 0.20) suggest that the timescale for sediment production there is about 20 kyr. Measurements of Bering Sea and North Pacific sediments from the literature (Yamada and Tsunogai, Marine Geol., v.54, 1983) suggest sediment production times of 60 and 250 Kyr respectively. Broader application of the technique will require further work to establish reliable approaches to removing diagenetic components.

V11H-08 1205h

On the 234,238U isotope systematics in two tropical estuaries: the Amazon and Fly Rivers.

Peter W Swarzenski[1] (727-803-8747 x 3072; pswarzen@usgs.gov)

Pamela L Campbell[3] (727-803-8747; psutton@usgs.gov)

Don Porcelli[2] (+44-1865-282121; Don.Porcelli@earth.ox.ac.u)

[1]US Geological Survey, 600 4th Street South, St Petersburg, FL 33701, United States

[2]Oxford University, Dept of Earth Sciences, Oxford OX1 3PR, United Kingdom

[3]ETI Profesionals, 600 4th Street South, St Petersburg, FL 33701, United States

Natural concentrations of 238U and d234U were determined in estuarine surface waters of the Amazon and Fly (Papua New Guinea) Rivers to investigate U transport phenomena across river-dominated land-sea margins. On the Amazon shelf, salinity-property plots of dissolved organic carbon (DOC), pH and total suspended matter (TSM) revealed two vastly contrasting water masses that were energetically mixed. In this mixing zone, the distribution of uranium isotopes was highly non-conservative and exhibited extensive removal from the water column. Uranium removal was most pronounced within a salinity range of 0 to 16.6, and is likely the result of scavenging and flocculation reactions with inorganic (i.e., Fe/Mn oxides) and organic colloids/particles. Removal of uranium may also be closely coupled to exchange and resuspension processes at the sediment/water interface. In the Fly River estuary, 238U appears to exhibit a reasonably conservative distribution as a function of salinity. The absence of observed U removal does not necessarily imply non-reactivity, but instead may record an integration of concurrent U removal and release processes. There is not a linear correlation between d234U versus 1/238U that would imply simple two component mixing. It is likely that resuspension of bottom sediments, prolonged residence times in the lower reaches of the Fly River, and energetic particle-colloid interactions contribute to the observed estuarine U distribution. The supply of uranium discharged from humid, tropical river systems to the sea appears to be foremost influenced by particle/water interactions that are ultimately governed by the particular physiographic and hydrologic characteristics of an estuary.

V11I MCC: 2000 Monday 1020h

Isotopic Constraints on Rates of Building Active Volcanoes I

Presiding: **A Calvert,** U.S. Geological Survey, Menlo Park**; B Singer,** University of Wisconsin-Madison

V11I-01 1020h INVITED

Application of K-Ar Dating to the Chronology of Young Volcanic Centers

Marvin A. Lanphere (1-650-329-4659; alder@usgs.gov)

Marvin A. Lanphere, 345 Middledfield Road MS-910, Menlo Park, CA 94025, United States

K-Ar dating and a derivative technique, $^{40}Ar/^{39}Ar$ dating, are methods of high-precision chronology applicable to young volcanic centers. Cascade volcanoes studied in detail by several USGS volcanologists, Duane Champion paleomagetist, and me include Mt. Baker, WA; Mt. Rainier, WA; Mt. Adams, WA; Mt. Hood, OR; Crater Lake, OR; and Medicine Lake, CA. For Mt. Adams using detailed geologic mapping by Hildreth and Fierstein and 74 K-Ar ages for 63 mapped units, Hildreth and Lanphere established a detailed chronology for the stratovolcano. Good agreement has been achieved for K-Ar ages and $^{40}Ar/^{39}Ar$ ages of rocks from Mt. Adams as young as 36 ka. A similar detailed chronology has been established for other Cascade volcanoes using andesites, in particular. These chronologies often take 10 years or more to develop. Major advantages of the $^{40}Ar/^{39}Ar$ technique are the ability to work with small sample sizes and the possibility to push the technique to very young ages. The Campanian Ignimbrite erupted from the Campi Flegrei crater near Naples, Italy is an example of the use of small samples. Nine incremental-heating ages were determined on samples of sanidine ranging in size from 47 mg to 67 mg. These samples yielded ages for the Campanian Ignimbrite ranging from 37.1 ± 0.75 ka to 39.5 ± 0.62 ka and averaging 38.1 ± 0.8 ka. Other workers have proposed $^{40}Ar/^{39}Ar$ ages for the Campanian Ignimbrite of 37.1 ± 0.4 ka and 39.3 ± 0.1 ka. An example of the use of $^{40}Ar/^{39}Ar$ dating of very young samples is the Christian Era (CE) age of the Vesuvius eruption of year 79. Eight packets of sanidine weighing 213-296 mg from two localities, Casti Amanti in Pompeii and Villa Poppea in nearby Oplontis, yielded a weighted-mean incremental-heating age of 1924 ± 66 years. The known age for the CE 79 eruption of Vesuvius is 1924 years. Earlier studies of Vesuvius by other workers yielded an $^{40}Ar/^{39}Ar$ age for the Villa Poppea locality of 1922 ± 72 years.

V11I-02 1035h

New Insights Into Volcanic Hazards in Western Mexico: Multiple Cone-Building Episodes at Arc Stratovolcanoes Revealed by 40Ar/39Ar Geochronology

Holli M Frey[1] (hfrey@umich.edu)

Katherine Lewis-Kenedi[1] (katelk@umich.edu)

Rebecca A Lange[1] (becky@umich.edu)

Chris M Hall[1] (cmhall@umich.edu)

Hugo Delgado-Granados[2]

[1]University of Michigan Dept. of Geological Sciences, 425 E. University, Ann Arbor, MI 48109-1063, United States

[2]Instituto de Geofisica UNAM, Circuitio Exterior C.U., Coyocan DF 04510, Mexico

The detailed eruptive histories of two andesitic stratocones, Volcáns Ceboruco and Tequila, in the western Mexican arc have been documented using $^{40}Ar/^{39}Ar$ geochronology. The volumes of these volcanoes were obtained with mapping, airphotos, and digital elevation models. The age and volume data constrain the rate and duration of major cone-building events, which bears on the longevity of the underlying upper-crustal magma chambers that fed the eruptions. The results indicate that at each stratovolcano there were two discrete cone-building events, separated by a hiatus. At V. Tequila, six samples from the edifice yielded dates (196 ± 8, 196 ± 19, 178 ± 8, 191 ± 13, 216 ± 11, and 198 ± 11 ka; errors are 1 sigma) with a mean eruption age of 196 ± 12 ka. Thus the bulk of the main edifice (∼31 km^3) erupted within 24 kyrs (at the 2 sigma level), leading to a cone-building rate of > 1.3 km^3/kyr. After a hiatus of ∼110 kyrs, ∼14 km^3 of andesite erupted along the NW and SE flanks of V. Tequila at 90 ± 19 ka. The last activity at V. Tequila produced a ∼2 km^3 parasitic cone at ∼60 ka. Since an eruption has not occurred in the last 60 kyrs, V. Tequila is often considered an extinct volcano. This may be the view held by the > 75,000 inhabitants of the town of Tequila located on the northern flanks. A similar history of two discrete cone-building events is found at V. Ceboruco, ∼75 km to the NW. Seven samples taken from various parts of the edifice, including the inner caldera wall, indicate an initial cone-building event at ∼45 ka in which ∼37 km^3 of andesite erupted. After a hiatus of nearly 44 kyrs, a second eruptive period began ∼1000 years ago. The first eruption to occur after the hiatus was Plinian and released 3-4 km^3 of dacite. In the last 1 kyr, 9.5 km^3 of andesite and dacite erupted effusively, culminating in the historic 1870 flow. The sobering conclusion, in terms of volcanic hazards assessment, is that the only Plinian eruption to occur happened after a 44 kyr hiatus. Thus prior to the Plinian eruption, it would have been reasonable to conclude that the volcano was dormant and possibly extinct. Both V. Ceboruco and V. Tequila straddle prominent NW-SE faults, along which peripheral domes and cinder cones are also aligned. The location of these two large stratocones suggests that they each overlie a major passageway for magmas ascending from the lower/middle crust into the upper crust. Voluminous batches of magma appear to have collected episodically for relatively short periods in the upper crust, forming chambers. The short duration and recurring nature of voluminous cone-building eruptions have been documented at other stratovolcanoes, such as at Mt. Adams in the Cascade arc. Hildreth and Lanphere (1994) documented three discrete and relatively short-lived, cone-building events at ∼500, ∼450, and ∼30 ka. The emerging concern is that in a region of active subduction and faulting, the concept of an extinct volcano is tenuous. A hiatus of tens or even hundreds of kyrs, during which time no upper crustal magma chamber exists, cannot be used as evidence that the overlying volcano is unlikely to produce future eruptions. A new upper crustal magma chamber may form again along the same fracture system.

V11I-03 1050h

Short Magma Residence Times at Mt. Rainier and the Probable Absence of a Large, Integrated, and Long-lived Magma Reservoir System

Thomas W Sisson[1] (650 329-5247; tsisson@usgs.gov)

Marvin A Lanphere[1]

[1]US Geological Survey, Volcano Hazards, 345 Middlefield Road, Menlo Park, CA 94025-3561, United States

Intensive, high-precision K-Ar and $^{40}Ar/^{39}Ar$ geochronology have proven essential for producing modern geologic maps of volcanoes and from these determining the volcanoes' time-volume histories. If sufficiently abundant, these data can also reveal aspects of the magma supply system. For Cascade volcanoes a general result has been the demonstration that edifice growth is highly episodic. Mount Rainier grew in the last 500,000 years atop the remains of an ancestral edifice that was active in the same location 1 - 2 Myr ago. The 500,000 year history of the modern edifice falls into four stages of alternating high and low magmatic output of subequal duration, but major and trace element compositions of eruptives show no correlation with volcano growth stages. Instead, the same spectrum of magmas (andesite to low-Si dacite) erupted throughout the history of the volcano with compositions in the same relative abundances. Superimposed on this seemingly null result are at least 6 brief but pronounced excursions in magma trace-element compositions. Concentrations of Zr, Ba, or Sr can double and then return to background values passing into and out of a single flow or flow-group. Some excursions are tightly bracketed by mapping and by measured ages and have durations no more than the geochronologic measurement precision of about 10,000 years. True excursion durations are potentially much shorter. The brevity and abrupt onsets and cessations of these compositional excursions are evidence against the presence of a sizeable, long-lived magma reservoir anywhere beneath the volcano, including a MASH zone in the lower crust, that would have attenuated, dampened, and homogenized compositional excursions introduced into the magmatic system. Instead, we take 10,000 years as a probable upper limit to the average residence time of magma batches transiting the crustal portion of Mount Rainier's plumbing system. A consistent scenario is that parental magmas enter the crust, differentiate, assimilate, and either erupt or solidify in less than 10,000 years. Geochronologic evidence from much larger magmatic systems (Reid and coworkers, Long Valley, Yellowstone) suggests that more productive systems can have much longer average residence times than modestly active arc stratovolcanoes like Mt. Rainier.

V11I-04 1105h

Pleistocene-Recent Growth and Collapse of an Island arc Volcano: Precise $^{40}Ar/^{39}Ar$ Dating of Seguam Island, Central Aleutian arc, Alaska

Brian R Jicha[1] (608 262 8960; bjicha@geology.wisc.edu)

Brad Singer[1] (608 265 8650; bsinger@geology.wisc.edu)

[1]Department of Geology and Geophysics, University of Wisconsin-Madison, 1215 W. Dayton Street, Madison, WI 53706, United States

Quantifying the long term growth of arc volcanoes can be done through geologic mapping supported by K-Ar or $^{40}Ar/^{39}Ar$ age determinations, and is essential to connect rates of geochemical and petrologic processes to a volcano's eruptive history. Yet, few island arcs have benefitted from K-Ar or $^{40}Ar/^{39}Ar$ dating. No $^{40}Ar/^{39}Ar$ data is published from the 24 active volcanoes in the Aleutian Island arc. Seguam Island, located in the central Aleutian Island arc, is a ∼ 80 km^3, low-K, tholeiitic complex with multiple eruptive centers. Previous K-Ar dating of 11 whole rock samples from Seguam indicated a 1.07 myr eruptive history. Using $^{40}Ar/^{39}Ar$ furnace incremental heating techniques on replicate samples of 200-400 mg groundmass separates, we have obtained precise ages from Seguam lavas and pyroclastics. Twenty one of the 23 new $^{40}Ar/^{39}Ar$ age determinations constrain the duration of most of the Pleistocene-recent volcanism to 142 ± 2 ka. Experiments from two different 0.5 km^3 eroded dike swarms yielded older, less precise ages of 155 ± 78 ka and 230 ± 70 ka. We suspect that the ∼ 1 Ma K-Ar ages obtained from a basalt and basaltic andesite reflect low

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K_2O contents (0.3-0.4 wt.%) and thus low radiogenic Ar yields, weathering leading to K loss from matrix glass, or the incorporation of xenocrysts into the enormous ($\sim$ 25 g) whole rock samples melted for the K-Ar analyses. $^{40}Ar/^{39}Ar$ plateau ages indicate that over 85% of the complex, $\sim$ 70 km^3 of material, was erupted almost continuously between 142 ka and 32 ka with pulses of increased activity at 80 and 55 ka, which included the construction of a 5 km^3 andesitic stratocone on the eastern half of the island between 80 and 53 ka. At 7.6 $\pm$ 1.9 ka, the stratocone partially collapsed producing a 0.5 km^3 andesitic ash flow tuff , which was followed by the eruption of several rhyolitic domes in the newly created caldera floor, and continued basaltic eruptions from Pyre Peak to the west. Estimating eruptive rates is complicated by glacial erosion and exposures limited by vegetation or ash. Nonetheless, eruptive rates based on estimates of individual flow volumes and $^{40}Ar/^{39}Ar$ ages were 0.5 km^3/k.y. for the predominantly mafic activity between 142 and 8 ka, but slowed to 0.15 km^3/k.y. for the post-collapse rhyolitic volcanism.

V11I-05 1120h

$^{40}Ar/^{39}Ar$ Geochronology of the Pleistocene to Historic Puyehue-Cordon Caulle Volcanic Complex, Andean Southern Volcanic Zone, Chile

Melissa A. Harper[1] ((608) 262-8960; mharper@geology.wisc.edu)

Brad S. Singer[1] ((608) 265-8650; bsinger@geology.wisc.edu)

Hugo A. Moreno Roa[2] ((56) 45-270701; hmoreno@surnet.cl)

[1]Department of Geology and Geophysics, University of Wisconsin-Madison, 1215 West Dayton St., Madison, WI 53706, United States

[2]Observatorio Volcanologico de los Andes del Sur, Casilla 23-D, Temuco, IX Region, Chile

Linking magma reservoir processes beneath arc volcanoes to their surficial expression as eruptive events is hampered, in part, by an incomplete knowledge of long-term eruptive flux. To address this problem, we have begun to quantify the eruptive history of the 105 km^3 Puyehue-Cordon Caulle Volcanic Complex at 40.5°S in the Andean Southern Volcanic Zone (SVZ) using a combination of $^{40}Ar/^{39}Ar$ dating and geologic mapping. Puyehue-Cordon Caulle has erupted low-medium K basaltic to rhyolitic magma that spans the largest range of major element compositions in the southern SVZ. Low radiogenic argon contents necessitate the incremental heating of multiple aliquots (200-800 mg) of groundmass from each lava using a low-blank resistance furnace. New $^{40}Ar/^{39}Ar$ plateau ages from 26 lavas suggest that volcanism began ca. 250 ka. Numerous Mid- to Late Pleistocene vents were active between 250 and 33 ka and produced at least 85 km^3 of basaltic to andesitic lava, tephra, and ignimbrites. More recently, the large Puyehue stratovolcano, built between 45 and 2.7 ka, erupted 18-21 km^3 of basaltic to rhyolitic lava and tephra. Puyehue began to grow after 45 ka with the eruption of 8-10 km^3 of dacitic and rhyodacitic lava followed by several km^3 of basalt and basaltic andesite that erupted between 15.1 $\pm$ 2.6 ka and 10.0 $\pm$ 1.1 ka. The final stage of cone growth, comprising 1-2 km^3 of rhyolitic and rhyodacitic lava and tephra, began by 10 ka and culminated at 2.66 $\pm$ 0.19 ka (^{14}C date) with the plinian eruption of several km^3 of airfall deposits zoned from dacite to basaltic andesite. The average eruptive rate for Puyehue volcano is 0.4-0.5 km^3/k.y., twice that of Tatara-San Pedro volcano located $\sim$ 500 km to the north. Glaciers eroded extensive parts of the complex between 200 and 15 ka, making our growth rate a minimum estimate. The Cordon Caulle fissural zone, which extends for 15 km to the NW of the modern Puyehue edifice, has erupted 2 km^3 of rhyodacitic to rhyolitic lavas, tephras, domes, and pyroclastic cones during the past 1 kyr, with explosive and effusive historic eruptions occurring in 1921-22 and 1960. In contrast to adjacent Puyehue, historic Cordon Caulle rhyolite and rhyodacite erupted at a much faster rate of 6.7 km^3/k.y.

V11I-06 1135h INVITED

The Plio-Quaternary Volcanic Evolution of Gran Canaria Based on new Unspiked K-Ar ages and Magnetostratigraphy

Herve Guillou[1] (33 1 69 82 35 56; herve.guillou@lsce.cnrs-gif.fr)

Juan Carlos Carracedo[2] (jcarracedo@ipna.csic.es)

Francisco Jose Perez Torrado[3] (fperez@dfis.ulpgc.es)

[1]LSCE -CEA/CNRS, Domaine du CNRS - Bat.12 Avenue de la Terrasse, Gif sur Yvette 91198, France

[2]University La Laguna, Estacion Volcanologica de Canarias, Tenerife 38206, Spain

[3]University of Gran Canaria, Dpto. Física-Geología. Facultad de Ciencias del Mar, Las Palmas 35017, Spain

The combined use of radioisotopic dating, magnetostratigraphy and field geology is a powerful tool to provide reliable chronological frameworks of volcanic edifices. This approach has been used to investigate the last two stages of the volcanic evolution of Gran Canaria. Fifty samples were dated using the unspiked K-Ar method and had their magnetic polarity measured both in the field and in laboratory. Ages were compared to their stratigraphic positions and magnetic polarities before accepting their validity. The unspiked K-Ar chronology constrains the timing of lateral collapses, eruption rates and the contemporaneity of different volcano-magmatic stages at Gran Canaria. Our new data set modifies significantly the previous chronological framework of Gran Canaria, especially between 4 and 2.8 Ma. Based on these new ages, we can bracket the age of the multiple lateral collapses of the Roque Nublo stratovolcano flanks between 3.5 and 3.1 Ma .This time interval corresponds to a main period of volcanic quiescence. Calculated eruptive rates during the stratovolcano edification are about 0.1 km3/kyr which is significantly lower than the published estimates. The dating also reveals that the two main last stages are not separated by a major time gap, but that the early stages of the rift forming eruption and the vanishing activity of the Roque Nublo strato-volcano were contemporaneous for at least 600 kyrs. These results support that our combined approach provides a rapid first-pass and reliable geochronology. Nevertheless, this chronology can be amplified and made more precise where necessary through detailed Ar-Ar incremental-heating methods. Samples which should be investigated using this method are the oldest and youngest K-Ar dated flows of each volcanic stage, and samples from stratigraphic sections that hold potential to study the behaviour of the earth's magnetic field during reversals (Gauss-Gilbert transition, Olduvai and Reunion events).

V11I-07 1150h

Comparison of U-series ages with (U-Th)/He apatite ages at Damavand Volcano, Iran

Jon P Davidson[1] (UK 191 334 2328; j.p.davidson@durham.ac.uk)

Louise E Thomas[2] (L.E.Thomas@open.ac.uk)

Daniel F Stockli[3] (stockli@ku.edu)

Jamshid Hassanzadeh[4] (jamshidh@khayam.ut.ac.ir)

[1]University of Durham, Department of Earth Sciences, University of Durham,, Durham DH13LE, United Kingdom

[2]The Open University, Department of Earth Sciences, The Open University,, Milton Keynes MK7 6AA, United Kingdom

[3]University of Kansas, 3Department of Geology, University of Kansas, 1475 Jayhawk Boulevard,, Lawrence, KS 66045-7613, United States

[4]University of Tehran, Department of Geology, University of Tehran, PO Box 14155-6466, Tehran 14155-6466, Iran (Islamic Republic of)

Damavand Volcano, Alborz Mountains, N. Iran is an isolated voluminous (>400km^3) composite volcano, built from small-volume eruptions of trachyandesite. The stratigraphy has been calibrated using Ar-Ar and (U-Th)/He apatite dating to establish a broad volcanic history. Eruptions as young as 7,000 yrs and as old as 445,000 years bracket activity at Damavand; although rocks as old as 1.8 Ma are believed to represent a precursor cone occupying a similar footprint. The lavas and pyroclastic deposits are uniformly porphyritic (fspr + oxide + apatite + px $\pm$ amph $\pm$ bi), representing a very restricted compositional range 57-63% SiO_2. The ubiquitous presence of large apatite crystals has allowed us to compare potential crystallization ages with those of eruption. Apatite strongly concentrates Th, leading to low U/Th ratios (0.13-0.17) compared with the magmas from which they crystallize (0.24-0.28). By analyzing the ($^{230}Th/^{232}Th$) and ($^{238}U/^{232}Th$) activity ratios of coexisting apatite-whole rock pairs we can generate a 2-point isochron, which, in the case of simple closed-system crystallization, should represent the age of apatite crystallization. These ages can then be compared with ages from (U-Th)/He apatite analyses, which represent the time at which alpha particles from U and Th decay begin to accumulate as diffusion is effectively stopped when cooling through temperatures of c. 70°C - i.e. the age of eruption. The results suggest that

1. Damavand magmas are characterized by initial ($^{230}Th/^{232}Th$) = 0.65 - 0.90.
2. There is no significant "residence time" of apatite in the magmas prior to eruption
3. Some of the samples have apparent crystallization ages younger than that of eruption, clearly not a realistic scenario.

The young isochron "ages" can be reconciled with eruption ages, if the isochron slopes represent mixing rather than simply a crystallization event. Given that the whole rock samples are de facto mixtures, the most likely scenario is one of mixing relatively low ($^{230}Th/^{232}Th$) cumulate material lying on the equiline into the whole rock - a suggestion which is consistent with petrographic observations and geochemical data.

V12A MCC: Level 1 Monday 1330h

Modern Trends in Petrography: Textural and Microanalysis of Igneous Rocks III Posters

Presiding: **D A Jerram,** University of Durham**; B D Marsh,** Johns Hopkins University**; J P Davidson,** University of Durham

V12A-0548 1330h POSTER

Textural Constraints on Physical and Chemical Communication in Crystal Dominated Magmatic Systems

Glen S Wallace[1] (gsw@u.washington.edu)

George W Bergantz[1] (bergantz@u.washington.edu)

[1]Univ. of Washington, Box 351310, Seattle, WA 98195, United States

We have developed a set of statistical tools that identify shared characteristics in sets of crystals. This includes a means of addressing the geometric effects of sampling from randomly oriented sections through crystals. Rim-to-core compositional profiles of individual crystals provide a putative record for the evaluation of changes in environment during crystal growth. The profile segments in which chemical characteristics are the same in pairs of profiles imply shared growth history in a common environment. However, crystals sometimes record different patterns of shared history for different chemical tracers. This reflects independent variation of either chemical or physical parameters in the magmatic environment. Thus, comparison of the distribution of shared history between profiles provides a way to observe the relative length scales over which characteristics are homogeneous within magma chambers. Chemical tracers with more shared history are inferred to have a longer relative length scale. This framework provides a way to assess the efficiency of chemical communication between magma volumes- an important constraint in light of the increasing consensus that many magma chambers are dominated by crystal mushes. Application of the technique to Anorthite (An) profiles from plagioclase in mafic enclaves at Chaos Crags, California, show little shared history between crystals. $^{87}Sr/^{86}Sr$ profiles from enclaves (Tepley, 1999) show more similar histories. This indicates that the length scale over which An content of plagioclase varies is shorter than that for $^{87}Sr/^{86}Sr$. If changes in An are compositionally controlled, the An and $^{87}Sr/^{86}Sr$ should show similar shared histories. The shorter length scale for An is more likely due to passage of the crystals through steep thermal gradients. This is consistent with resorption and crystallization near interfaces between the commingling magmas. An profiles from crystals in the host rhyodacite also show little shared history. This implies a heterogeneous magma chamber prior to intrusion of the basaltic andesite.

V12A-0549 1330h POSTER

Windows Into an Open-System Magma Chamber: Cognate Xenoliths From the Kameni Islands, Santorini, Greece

Victoria M Martin[1] (vmar01@esc.cam.ac.uk)

Marian B Holness[1] (marian@esc.cam.ac.uk)

David M Pyle[1] (dmp11@esc.cam.ac.uk)

[1]Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, United Kingdom

The composition of the dacite forming the Kameni Islands has been remarkably uniform over the last 2200 years, attesting to significant replenishment and mixing in the shallow open-system chamber. Insights into chamber evolution can be gained from the abundant