

of crystallizing mineral phases. We applied the crystal size distribution theory (CSD) to derived J and G of pyroxene, plagioclase and of Fe-Ti oxides in basalt glass during heat treatment [1,2,3,4]. The glass was sampled from active Pu'u O'o, Kilauea, Hawaii, by hammer-dipping and subsequent quenching [5]. Temperature (T) and time (t) dependent heat treatment of the glass above temperature of nucleation and growth maxima, about 930°C, allows one to derive the activation energy of J and G, E_J , E_G , which are at steady state after about 100 hrs, at 180/200, 353/307, 292/343 kJ/mol (E_J/E_G , for pyroxene, plagioclase and Fe-Ti oxides). On a logarithmic scale, J and G are linear with t. A comparison with growth rates of lava cooled within a lava lobe, from top to bottom [6], suggests that independent of depth, all mineral phases crystallized at $T < 1000^\circ\text{C}$. According to our results of t and T dependent J and G, such rock textures should first crystallize pyroxene, and intersertal plagioclase which is, indeed, observed. Slow cooling or a hold at $T > 1000^\circ\text{C}$, should result in a first crystallization of plagioclase. This is reported in the literature [e.g., 7]. In agreement with this, we detected anorthite nuclei in the glass with HRTEM [8]. [1] Randolph R.D., Larson M.A. (1979); Theory of particulate processes. Academic Press, New York. [2] Marsh B.D. (1988); Contrib.Mineral. Petrol. 99, 277-291. [3] Cashman K.V., Marsh (1988) Contrib. Mineral. Petrol. 99, 292-305. [4] Burkhard D.J.M. (2002); Contrib. Mineral. Petrol. 142, 724-527. [5] Burkhard D.J.M. (2001); J. Petrol. 42, 507-527. [6] Burkhard D.J.M. (2003); Bull. Volcanol. 65, 136-143. [7] Lofgren G.E. 1983; J. Petrol., 24, 229-225. [8] Burkhard D.J.M., Wirth, R. (2001); EOS Trans. AGU, 82 (47), Fall Meet. Suppl., abstract V51B-1014.

V11A-06 0915h

On the Relation Between Texture, Crystallinity, Nucleation, and Growth in Basaltic Rocks: A Numerical Approach

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One of the most challenging problems in discovering the fundamentals of magma crystallization is finding a proper metric or standard state to which to compare theoretical models of crystallization. This stems from the more basic problem of quantifying rock textures themselves. The critical information is the size, shape, number, and position in local 3D space of all crystals in a sample and then also the variation of these parameters globally within the thermal regime space of the pluton itself. Fortunately, it appears from the Crystallization Axiom (in essence, magmas become holocrystalline regardless of the thermal regime) that the kinetic problem can be separated from the thermal problem (i.e., large Avrami number). CSDs quantitatively link crystal size and number, leaving shape and position, including nucleation and growth reactions with neighbors, yet to be quantified. What we attempt here is to produce textures that first satisfy observed CSDs and then to compare the resulting spatial features of the derived texture to that of the real rock. A stochastic algorithm is used to generate a discretized three-dimensional spatial representation of simultaneous nucleation and crystal growth of randomly oriented and positioned crystals. The algorithm is simplified by assuming large Avrami number, thus allowing crystallinity to be calculated as a function of time using the Avrami method (i.e., JMA equation) and a kinetic model for crystal nucleation and growth. To begin with, we consider a simple kinetic model of exponential nucleation rate and constant crystal growth rate that reconcile observed batch CSD trends in natural samples. The crystallinity function (i.e., bulk crystal content as a function of time) and crystal growth rate model can uniquely determine the number and size of crystals during a simulation and a numerical nucleation rate is calculated as an output variable to compare with the analytical result as a condition for model acceptance. For a given time step during crystallization, having begun with a burst of nucleation, the crystallinity must be satisfied by first allowing growth of randomly chosen, pre-existing crystals and second, if and only if crystal mass is still available (i.e., growth having not satisfied the bulk crystallinity constraint), allowing creation of randomly located nuclei. Results of monomineralic simulations with the same crystallization parameters (i.e., total crystallization time, crystal growth rate, domain length) show that the number and mean sizes of crystals are sensitive to the degree of spatial and temporal discretization within the model. For a particular crystallization parameter group, a running average of the number and mean sizes of crystals with increasing realizations converges and a histogram of those metrics approximate a Gaussian distribution. For some time steps during most simulations, the crystallinity is completely satisfied by crystal growth and no additional nuclei are generated, which suggests that the kinetic model of steady exponential nucleation rate and constant growth rate is incorrect at the detailed

level, even though it may appear true in the bulk product. With an increased exponential nucleation rate, however, this occurrence is less common and the numerically calculated CSD approaches a linear trend as naturally observed. The algorithm is also extended to multiphase crystallization, which simulates the simultaneous crystallization of plagioclase and clinopyroxene in tholeiitic basalt. Overall, reasonable adjustments nucleation and growth can lead to realistic histories of crystallization, even though the detailed processes of growth and nucleation may be, in reality, much more involved.

V11A-07 0930h

Monitoring and Quantifying Texture Evolution During Experimental Crystallization and Melting Using Crystal Size Distributions

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A study designed to relate crystal size distributions (CSDs) quantitatively to specific magmatic conditions has been conducted using a series of high temperature heating and cooling experiments with defined initial crystal populations and controlled thermal trajectories. These experiments provide a method for empirically exploring the development of textures under particular conditions and for testing models of crystallization kinetics. Textural evolution during melting was examined by heating a mixture of olivine crystals and synthetic glass at three different temperatures (1545, 1500, 1450 °C) for durations ranging from 0 to 60 min before quenching. CSDs were measured for each sample, and the texture evolution was quantified in terms of the population density as a function of experimental duration. Initially, the population density for the smallest size classes sharply decreased as these crystals melted. With increasing duration, the maximum grain size and the population density in the larger size classes increased. This may have been due to coalescence or crystal growth. Textural evolution during cooling was determined by melting an olivine + glass mixture at 1545 °C for 5 min, and then cooling along a 100 °C/hr gradient. Samples were quenched at different points along the crystallization trajectory. This series of samples serves as a monitor for the texture evolution during a 100 °C/hr cooling run. The CSDs show minor changes in the smaller size classes and major increases in population density in the larger size classes. These changes are interpreted to be the result of ongoing nucleation and rapid growth of skeletal olivine crystals at the top of the charge. The results of these experiments can be used to estimate the olivine growth rate under conditions similar to those experienced by porphyritic olivine chondrules.

V11A-08 0945h

Crystal nucleation theory applied to hydrous magma

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Examination of natural volcanic products shows that the crystal nucleation kinetics determine crystal number density and ultimately crystal size distributions, and thus govern the texture of crystallized materials. Crystallization in hydrous magmas undergoing decompression and devolatilization is especially pertinent in application to volcanological problems. We examine nucleation rate data in the context of kinetic theory and attempt to reconcile observations with aspects of silicate melt structure. Feldspar nucleation rate data obtained by laboratory decompression of hydrous silicate melt are interpreted in view of the classical theory of nucleation (CNT) and a non-classical variation, the diffuse interface theory (DIT). Several simplifying assumptions are needed to compare data with theory, including the Stokes-Einstein approximation, Turnbull's approximation ($\Delta G = \Delta H \Delta T / T_L$) and a means of estimating ΔG of solidification. The crystal-liquid interfacial free energy (σ) is a key parameter in nucleation theory that is difficult to obtain independently. Lack of σ data precludes direct testing of the CNT's validity. Instead, σ is calculated using nucleation rate data assuming the CNT formalism is appropriate; this assumption would be considered valid if each experiment yielded the same value of σ . The interfacial free energies computed in the present case are not constant, but vary by a factor of four (0.024-0.098 J m⁻²) and decrease systematically with increasing H₂O content (over the range 0.8-4.8 wt.%). The nucleation rate data can be modeled only if σ is allowed to vary as a function of composition, suggesting that a non-classical

theory may be justified. The DIT states that a region between the bulk solid (at the core of subcritical clusters) and bulk melt has intermediate thermodynamic properties, and that the interfacial free energy σ may be defined as the difference between the interfacial enthalpy (H_{int}) and interfacial entropy (TS_{int}). If the DIT model is correct, the nucleation rate data for feldspar suggest (1) that dissolved H₂O content controls the spatial gradients of TS_{int} and H_{int} around incipient crystals, and (2) these gradients diverge during devolatilization.

V11B MCC: 3006 Monday 0800h

The Growth and Collapse of Hawaiian Volcanoes I (joint with OS, T)

Presiding: M L Coombs, U.S.

Geological Survey; B Eakins, U.S.

Geological Survey

V11B-01 0805h

Submarine Rejuvenated-Stage Lavas Offshore Molokai, Oahu, Kauai, and Niihau, Hawaii

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Rejuvenated-stage lavas from the Hawaiian Islands form many distinctive landmarks, such as Diamond Head. They have been relatively well studied due to their primitive, strongly alkaline compositions (alkalic basalt, basanite, nephelinite, mellilitite, phonolite). More recently, compositionally similar lavas have been mapped and sampled on the deep seafloor around the islands. Rejuvenated-stage cones also occur on the submarine flanks of the islands. A Pisces V submersible dive collected samples from the only submarine cone on the north slope of East Molokai. The alkalic basalt to basanite composition lava is similar to the subaerial Kalaupapa basalt (Clague and Moore, 2003). MBARI Tiburon ROV dives recovered nephelinite from a lone steep cone on the northeast slope of Oahu, alkalic basalt from two shallow steep cones just west of the Koko Rift, and alkalic basalt from the submarine flank of Diamond Head on Oahu's south flank. These lavas are generally similar to subaerial Honolulu Volcanics, although the isotopic data extend to higher Sr isotopic values. Other MBARI Tiburon ROV dives recovered alkalic basalt and basanite from 8 separate steep cones on the south flank of Kauai. Once again, these lavas are chemically similar to those from the subaerial Koloa Volcanics. Samples from one of these cones contained common xenoliths of upper mantle lherzolite and harzburgite. Seven MBARI Tiburon ROV dives on the northwest flank of Niihau sampled 6 flat-topped cones and 5 pointed cones. The lavas from the flat-topped cones are alkalic basalt similar to rejuvenated Kiekie Basalt on Niihau Island whereas the lavas from the pointed cones are basanite, hawaiite, and tephrophonolite that are chemically distinct from the Kiekie Basalt, but similar to rejuvenated-stage lavas on Kauai and Oahu. Volcaniclastic deposits were observed and sampled at many of the sites offshore Niihau, Kauai, and Oahu, as well as the North Arch. Breadcrust and spindle bombs and spatter were found offshore Kauai as deep as 1500 m, in addition to finer volcaniclastic deposits consisting of vesicular angular glass fragments, which also occur offshore Oahu and in the North Arch as deep as 4100 m (Davis and Clague, submitted). The glass data from all these deposits as well as on pillow and sheet flow rinds from Oahu, Molokai, Niihau, Kauai, North Arch, South Arch, Southwest Oahu volcanic field, and some of the cones between Oahu and Kauai demonstrate that rejuvenated stage lavas did not erupt as near-primary melts, but rather as crystal-rich magmas whose bulk compositions approach primary

magma compositions. The low-MgO contents of almost all the glasses indicate that these magmas cooled and crystallized significantly during transit through the cool lithosphere. The distribution of these lavas on the islands, on the flanks of some islands, and on the deep seafloor suggest that the melting region around the Hawaiian hot-spot is at least 400 km across.

V11B-02 0820h

A Magma Genesis Model to Explain Growth History of Hawaiian Volcanoes: Perspectives of 2001-2002 JAMSTEC Hawaii Cruises

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JAMSTEC Hawaii Cruises 2001-2002

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The 2001 and 2002 JAMSTEC Hawaii cruises have been carried out using RV-Kairei with ROV-Kaiko and RV-Yokosuka with submersible Shinaki-6500, respectively. The main focus of these cruises is 1) to clarify the growth history of Hawaiian volcanoes through geological study on deep submarine exposures, 2) to understand the nature of submarine rifts, 3) to understand the nature of magmas erupted on the deep ocean floor away from the center of the Hawaiian plume. The geologic reconstruction of gigantic landslides (Moore et al., 1989) provided opportunities to study the long-term growth history of Hawaiian volcanoes, approaches complementary to those by HSDP. Using this approach, we studied the growth histories of Kilauea (Lipman et al., 2002), Koolau (Moore & Clague, 2002; Yokose, 2002), and Mauna Loa (Yokose et al. this conference). The geochemical reconstruction of Koolau volcano showed a secular variation in basalt magma types; from Kilauea-like to Mauna Loa-like and finally the silica-rich Koolau-type tholeiites (Shinozaki et al. 2002). These chemical changes are associated with significant changes in Sr, Nd and Pb isotopes (Tanaka et al., 2002). Similar changes in basalt magma types have been found in the growth history of Haleakala volcano (Ren et al., 2003) and in HSDP cores representing the growth history of Mauna Kea. Accordingly, it is plausible that the basalt magma types found among Hawaiian shield volcanoes are not representing geographic trends (e.g., Kea-trend and Loa trend) but are representing different growth stages. In order to elucidate secular changes in the geochemistry of Hawaiian volcanoes newly revealed by this project, I have carried out high-pressure melting studies at 2-3 GPa with eclogite/peridotite composite starting materials (experimental detail will be given by Takahashi, this conference V03). In eclogite/peridotite reactive melting, magmas produced above the solidus of peridotite (1480°C at 2.8 GPa) are silica deficient alkalic picrites (MgO=15 wt%, SiO₂=45). In temperatures slightly below the peridotite solidus (1470-1450°C), olivine-rich tholeiite magmas similar to those in Kilauea (MgO=13-15, SiO₂=46-48) are produced. At temperatures well below the peridotite solidus (1450-1400°C), opx reaction bands are formed at eclogite/peridotite interfaces and the partial melts formed in eclogite domains (saturated only with cpx and garnet) increase in SiO₂ and decrease in MgO. These experimental results suggest that the systematic change in SiO₂ composition from Loihi, Kilauea and Mauna Loa may represent lowering temperatures in magma feeding zones. The very silica-rich tholeiite that appeared at the final growth stage of Koolau volcano would have been produced in an eclogite pocket chemically isolated from ambient peridotite. The silica-undersaturated basanite and nephelinite magmas occurring in the post-shield stage and in the Hawaiian Arches may represent incipient partial melts rich in volatiles (H₂O and CO₂) and low in temperatures (1300-1400°C). If these magmas are derived from the tail of the Hawaiian plume, large volumes of the plume must consist of entrained asthenospheric peridotite judging from their depleted Nd and Sr isotopes.

V11B-03 0835h

Modeling the Growth of Hawaiian Volcanoes

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We have developed a numerical model that simulates the growth of either single or multiple volcanoes upon the sea floor. The goal is to visualize the coupled

growth, subsidence, and interactions of Hawaiian volcanoes as they move over their underlying mantle sources. Volcano growth is modeled in 2000-year time steps. In each time step, magma is distributed over the surface of each volcano according to simple rules (e.g., magma always flows downhill via a steepest descent path), after which the volcanic edifice subsides assuming it rests upon an elastic plate of fixed thickness. The flux of magma for each volcano in each time step is based on the plume flux model of DePaolo & Stolper [1996], in which each volcano captures all the melt flux within the intersection between a circular capture area centered beneath the volcano's summit and a cylindrical mantle plume (zoned with respect to melt flux from the center to the edge of the plume). Thus, the magma flux to each volcano varies with time as the circular capture area passes over the mantle plume. Using this model, we explored volcano growth rates (and related parameters such as basal and island radii and ratio of submarine to subaerial lava) as functions of a variety of factors such as the offset of the volcano relative to the center of the plume, the relative positions of multiple volcanoes, and the existence and orientations of rift zones. We have also investigated the three-dimensional shape of the submarine-to-subaerial transition surface; subsidence rates as a function of plate thickness, distance from a volcano's summit, and time; and the geometries of zones in which lavas from two or more volcanoes interfinger. For the case of a single volcano growing on an elastic plate, growth rates and ratios of submarine to subaerial lavas are similar to those calculated by DePaolo & Stolper [1996] from simple geometrical constructions. A seven-volcano model with volcanic centers located at the positions of actual Hawaiian volcanoes reproduces the overall morphologies of volcanoes on the island of Hawaii (elevations, slopes, shorelines) as well as the surface distributions of lava flows from the different volcanoes, and makes model-dependent predictions of the volumes and subsurface structure of the individual volcanoes. DePaolo & Stolper [1996] JGR 101, 11643-11654.

V11B-04 0850h

The magma reservoir of Mauna Loa volcano, Hawaii: Constraints from InSAR geodetic measurements

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Mauna Loa volcano in Hawaii is among the most active volcanoes on Earth and a natural laboratory for volcano dynamics. Geodetic measurements of the deformation of the volcanic edifice before, during, and after the last eruption in 1984 have profoundly formed our understanding of how basaltic volcanoes work. After a 10 year period of summit deflation, a new episode of summit inflation on Mauna Loa volcano started in May 2002. Continuous GPS measurements detected lengthening of a baseline across the summit caldera at a rate of 20 cm/yr. The rate of lengthening decreased in November 2002 to 8 cm/yr. Summit inflation is caused by the arrival of new magma in the summit reservoir and provides an opportunity to constrain key features of this magma reservoir. We present interferometric geodetic data of this inflation period and discuss elastic models to constrain the location, shape, and size of the magma reservoir. The data are derived from imagery acquired by the Radarsat satellite which is imaging the volcano with 6 different viewing geometries since 1997. The interferograms show up to 10 cm inflation since May 2002. The center of inflation is located 4 km east of the summit caldera. This suggests that this is also the location of the magma reservoir and that the volcano does not have a central magma reservoir beneath the summit caldera.

V11B-05 0905h

Post-Hotspot Collapse Feature and Shield-Building Volcanism on Detroit Seamount

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In July-August of 2001, ODP Leg 197 drilled Detroit Seamount of the Emperor seamount chain to obtain cores of basaltic lava flows. Prior to drilling, the JOIDES Resolution conducted high-resolution single-channel seismic surveys in the vicinity of preliminary

site locations to help confirm suitability for drilling and to collect digital seismic data. At least two seismic lines (about 10 km in length) cross directly over each of the two drill sites. The seismic data provide evidence for volcanism 24-42 Myr after the main shield building event, and for collapse faults possibly coincident with that volcanism. Detroit Seamount, one of the northernmost seamounts of the Hawaiian-Emperor seamount chain, was formed at c. 76 Ma. Combined with drill core data from the summit and northeast flank of Detroit Seamount, new seismic data suggest renewed volcanism occurred during the Eocene between 52 Ma and 34 Ma, 24-42 Myr after initial seamount formation. Hence the age difference between the shield-building lavas and the post-shield edifices on Detroit is far greater than the shield/post-shield age differences observed on the Hawaiian Islands. The seismic data reveal peaks in the basement, centered c. 7-11 km north of ODP Sites 883 and 1204, and buried by the Meiji drift sediment cap. These peaks are older than the earliest Meiji sediment (34 Ma) as Meiji sediment horizons onlap onto the slopes of the peaks. Ash layers recovered in cores from ODP Sites 883, 884 and 1204 appear to be mafic in composition, and erupted locally and subaqueously. We interpret the peaks as volcanic edifices, possibly the source of the ash layers cored at ODP Sites 883, 884, and 1204. On Detroit Seamount, a significant west-northwest-striking normal fault, Summit Fault, occurs in the basement with the downthrown block to the northeast. Though we were unable to image the fault plane below the volcanic basement, the fault scarp in the basement suggests a low-angle normal fault, dipping c. 19°. The apparent offset in the basement increases to the northwest from approximately 160 m to nearly 450 m over an along-strike distance of c. 10 km. Interpreted in the context of ocean bottom current deposition, sediment horizon patterns suggest that Summit Fault is much older than 34 Ma. Though Summit Fault possibly formed soon after shield building ceased at 76 Ma, it is also possible that Summit Fault's formed c. 52 Ma, concurrent with Eocene volcanism mentioned above.

V11B-06 0920h

Vertical Motions and Lithosphere Rheology at Ascension Island

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Ascension Island is a 4 km volcano built on 7 Ma lithosphere 90 km west of the Mid-Atlantic Ridge. The island's western shelf includes terraces to 400 m depth, which are difficult to correlate unambiguously with glaciogenic sealevel fluctuations but nevertheless suggest significant subsidence over the past few hundred ka. A geothermal exploration borehole drilled in 1986 penetrated 3 km into the volcanic edifice, and cuttings were archived for each 3 m interval. Despite strong alteration down most of the hole, we found several samples from a range of depths that were reasonably fresh. Glass-free fresh groundmass of aphyric lavas were dated by the laser-heating 40Ar/39Ar dating technique. Stepwise-heating analysis on a several mg aliquot of each sample returned plateau ages with a 1σ error of 3-4%. Although published ages of surface samples from the island are all 1.5 Ma or less, the borehole samples yield ages of up to 3.6 Ma. Volcanic growth rates in the hole are ~ 0.4 km/Myr since 2.5 Ma and ~ 1.0 km/Myr between 2.5 and 3.6 Ma. The transition from submarine to subaerial eruption occurs at ~ 900 m depth in the hole and ~ 720 m below present sea level, and at an age of 2.5 Ma. Hence since 2.5 Ma, there has been ~ 530 m of subsidence over and above the expected ~ 190 m due to lithospheric cooling. Although this anomalous subsidence is consistent with Airy isostasy, gravity and seismic tomographic data indicate that the lithosphere has had significant flexural strength during the growth of the island. Plausible elastic thicknesses and volcanic growth histories would generate a maximum elastic subsidence since 2.5 Ma of ~ 200 m. We infer that the subsidence since 2.5 Ma includes a component of viscoelastic relaxation resulting from the period of more rapid load emplacement prior to 2.5 Ma, and use our data to place constraints on the time constant of this relaxation.

V11B-07 0935h

Growth and Collapse of Reunion Island

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Rising above a seafloor of Paleocene age, the Reunion oceanic volcanic system is a flattened cone having a basal diameter of 200 to 240 km and height of about 7000 m. The island, has a diameter of 50 to 70 km and reaches 3000 m in height. The dormant Piton des Neiges and the highly active Piton de la Fournaise volcanoes constitute the island, which represents only a small percentage, about 3%, of the volume of the whole system. Bathymetric and sonar surveys of the submarine flanks, as well as gravity, magnetic and seismic surveys inland and offshore, permit to image part of the remaining 97%. Gravity data show the presence of 2 large and deeply rooted dense bodies beneath the center of Piton des Neiges and the eastern coast. These bodies are hypovolcanic complexes that formed during the growth of Piton des Neiges and that of an other, now concealed, main volcanic focus named Les Alizés. The young Piton de la Fournaise volcano has not yet developed a large, dense hypovolcanic complex. The relationship between these large dense bodies and depressions at the surface is being investigated. Available high-precision bathymetric and sonar images of the submarine flanks show that products resulting from flank collapses are present virtually all around the island. At least 15 individual units can be recognized on the surface of the submarine flanks. The dimensions of most units imply large source areas on land. The most recent landslide events that affected Piton de la Fournaise and their source areas on land are well defined. This is not the case for older landslides. On the basis of topographic features and available geological data we have attempted to locate their most probable sources areas. We conclude that the headwalls of several huge landslides intersect in the central area of Piton des Neiges. A unique case of collapse is that of the central area of Piton de la Fournaise. We propose a mechanism of passive collapse of this area in response to the lateral collapse of eastern flank of the edifice.

V11C MCC: Level 1 Monday 0830h

Volcanic Emissions to the Troposphere: Posters I (*joint with A, B*)

Presiding: R J Andres, University of North Dakota; I M Watson, Michigan Technological University

V11C-0504 0830h POSTER

The Volcanic Contribution to the Global Atmospheric Mercury Cycle

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Mercury is a highly volatile, bioaccumulating toxic trace metal with a long (ca. 1 year) atmospheric residence time. Mercury is strongly enriched in volcanic emanations, where it exists as gaseous elemental or reactive Hg, as well as particulate Hg. Volcanoes are the only natural sources of direct Hg emission to the free troposphere and stratosphere, and the principal natural sources of reactive and particulate mercury. The other natural sources (surface water and soil emissions) predominantly release gaseous elemental mercury to the atmospheric boundary layer. The paucity of relevant volcanic plume data means that there is considerable uncertainty over the annual emission rate of mercury from volcanoes. Previous estimates span three orders of magnitude (~1-1000 Mg Hg/yr), or from 1% to ~50% of total natural Hg emissions. Critical assessment of the literature reveals strong evidence for the important role of volcanoes in the global mercury cycle. Using data from active volcanoes and natural ice-core and peat-bog archives, we estimate that the time-averaged volcanic Hg emission rate is ~700 Mg/yr, or 20-40% of total natural emissions. Year-on-year release of Hg from continuously erupting and

degassing volcanoes is ~75 Mg/yr, or only about 10% of this time-averaged flux. 75% of volcanic Hg is released during 'smaller' sporadic eruptions (<10-100 Mg Hg/event). Several individual explosive eruptions per century will be large enough (>1000 Mg Hg) to overwhelm the total atmospheric burden, with subsequent deposition rates rivaling anthropogenic maxima. Large eruptions account for about 15% of total volcanic Hg emissions, and the records of past emissions will be preserved in ice core and peat bog archives. Previous 'low' global volcanic flux estimates (<50 Mg/yr) were based on inappropriate extrapolation of data from low-temperature fumaroles at non-erupting volcanoes to the high-temperature emissions from active volcanoes. Considerable work remains to be done to define the Hg:S ratios in high temperature volcanic emissions. Individual persistently active volcanoes (e.g. Etna, Sicily) may act as important local point sources of mercury emission to the atmosphere, and their contribution to regional emissions inventories should not be neglected.

V11C-0505 0830h POSTER

Volcanic Gas Emissions Through History and Geography

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The total gaseous output of a volcano is in most cases closely related to its actual phase of activity. A volcano undergoes different stages of activity during its "life-time". For estimating the gas input into the atmosphere from ancient volcanoes these activity stages have to be considered very intensely. We considered the global distribution of 360 subaerial active volcanoes that erupted at least once during the past 100 years. A significant feature is the high concentration of active volcanoes along the subduction zone of the Circumpacific Ring of Fire. Volcanoes related to subduction zones are the major gas-emitters because of the large number of very active and highly explosive volcanoes. More than 300 of the 360 active subaerial volcanoes are related to subduction zones, 24 to rift zones and 22 to ocean islands. There is no tendency for volcanoes of a certain tectonic setting to be located at a specific latitude. We summarized altitudes of 360 volcanoes and determined their altitudinal range for each tectonic setting. Volcanoes of the three main tectonic settings show average heights between 1-3km: a) subduction zones: 2-3km, b) rift zones: 1-3km, and c) ocean islands: 1.5-2.5km. Active volcanoes cluster in the equatorial latitudes (0° to 30°) on both hemispheres with volcanoes in the southern hemisphere reaching heights of over 6000m a.s.l. Thus, most eruptions (30 eruptions/a) occurred at equatorial latitudes (0° - 30°). In general, the number of volcanoes located in the northern exceeds those in the southern hemisphere by 3:1. We assume a higher SO₂ input into the northern hemisphere. But we found also a relatively high volcanic SO₂ output in the southern hemisphere, which may be caused by higher magma supply rates. The increased frequency of eruptions in the southern hemisphere in the equatorial latitudes could be partly caused by shorter intervals between eruptions (Takada, 1999). Volcanoes between 50°-60° N showed also a relatively high annual number of eruptions (7 eruptions/a). Volcanoes at polar latitudes 60°-90° are contributing 3 eruptions/a, because only 16 out of the 360 active subaerial volcanoes are located at high latitudes. Fourteen volcanoes are located at 60°-90°N and two between 60°-90°S. In summary, 54 eruptions/a are injecting gas into the atmosphere. Ref.: Takada A (1999) Variations in magma supply and magma partitioning: the role of tectonic settings. J Volcanol Geotherm Res 93: 93-110

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An Updated Time-Averaged Inventory of Subaerial Volcanic Sulfur Emissions

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An updated time-averaged inventory of subaerial volcanic sulfur emissions to the atmosphere is presented. This work builds upon an inventory previously compiled by Andres and Kasgnoc (1998, JGR 103:25,251-25,261), which covered a time period from the early 1970s to the mid 1990s. The updated inventory extends to the end of 2002. Data contained within

the inventory consist primarily of sulfur dioxide measurements taken at volcanoes, listed as a time-averaged flux in Mg/d. This inventory may provide input to global sulfur and sulfate models, inventories of other volcanic species compiled by the species:sulfur ratio, and volcano-atmosphere interaction models. This work also contributes to the Global Emissions Inventory Activity (GEIA), whose goal is to create, maintain, and distribute reliable inventories of species important for understanding global atmospheric chemistry at a one-degree global scale.

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A Satellite-Derived Global Inventory of Volcanic Thermal Emissions Into the Atmosphere

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During the last decade an average of 60 volcanoes erupted each year, around 20 of which were erupting on any given day. Some of these, such as Erta Ale in Ethiopia, are persistently active, whereas others, such as Bezymianny in Russia, erupt more sporadically. Satellite remote sensing offers a convenient way to monitor changes in the thermal budgets of these volcanoes from space, in addition to quantifying the contribution active volcanism makes to the Earth's energy budget. Using data provided by the HIGP MODVOLC algorithm we show how the amount of heat radiated into the Earth's atmosphere by more than 50 active volcanoes has varied during 2001, 2002, and 2003. In 2001, the total amount of heat radiated into the Earth's atmosphere from these volcanoes was 5.3×10^{16} J year⁻¹, with the total amount of heat energy perhaps as much as 9×10^{16} J year⁻¹ when heat loss by convection is taken into account. This is three orders of magnitude less than the amount of energy consumed (and, ultimately liberated into the atmosphere) by the United States of America in 1999, as a result of manufacturing, transportation and residential activities. From the geographic perspective of the authors, the amount of energy released into the atmosphere by Kilauea volcano during 2001 (2.3×10^{16} J year⁻¹) was approximately equal to the amount consumed by the State of Hawai'i for residential purposes.

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Phosphorus-bearing Aerosol Particles From Volcanic Plumes

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Particles rich in P or bulk geochemical data of volcanic aerosol particles showing high P contents are known from many volcanic plumes (Stanton, 1994; Obenholzer et al., 2003). FESEM/EDS analysis of individual particles obtained from the passively degassing plume of Popocatepetl volcano, Mx. (1997) and from the plume of Stromboli (May 2003) show P frequently. Even at the high resolution of the FESEM, euhedral apatite crystals could not be observed. At Popocatepetl (1997) spherical Ca-P-O particles are common. Fluffy, fractal or botryoidal particles also can contain EDS-detectable amounts of P. The EDS spectrum of such particles can comprise various elements. However most particles show P, S and Cl. P-S-metal species are known in chemistry but do they occur in volcanic plumes? Stoichiometric considerations had been made in the past suggesting the existence of P-S species in plumes (Stanton 1994), gas sampling and remote gas monitoring systems have not detected yet such molecules in plumes. The particle spectrum of the reawakened Popocatepetl volcano might be related to accumulation of volatiles at the top of a magma chamber during the phase of dormancy. P-Fe rich, Ca-free