on KRZ volcanism using deposits of the phreatomagmatic eruption that produced Hanauma Bay (a popular snorkeling spot) and spatially associated lava flows. Numerous continuous basaltic ash units within the walls of Hanauma crater contain lithic fragments of well-preserved coral reef, beach rock, and marine mollusks, indicating that the eruption occurred in a near shore environment. 238U-234U-230Th dating of coral clasts in the deposit demonstrates that the eruption breached reef of MIS stage 7 age (200 ± 30 ka), thereby ruling out the K-Ar age of 320 ka. U-series nuclides in normal MIS 7 coral lithics are indistinguishable from those in the island encircling Waianae Reef of the same age. However, U-series components in some originally aragonitic coral clasts were offset during the eruption when the rims recrystallized to calcite. 87Sr/86Sr, 234U/238U and Sr and U concentration indicate chemical mixing with host basaltic ash during this event, from which potential ages of the eruption can be constructed using isochron methods. More modeling of the data remains to be done but our preliminary estimate places the eruption at less than 100 ka. This result is consistent with new data on paleointensity and paleomagnetic secular variation within the lava flows exposed in or around the crater. This U-series dating approach should prove useful for eruptions in other locales where carbonate bioclast lithics are present in the deposits.

V71A MCC: Hall C Sunday 0830h

The Big Score: Twenty Years of Research on the Pu'u 'O'o - Kupaianaha Eruption, Kilauea Volcano, Hawai'i II Posters *(joint with G, H, S, T)*

Presiding: **J Kauahikaua,** U.S. Geological Survey**; M O Garcia,** University of Hawaii

V71A-1250 0830h POSTER

Tracking Multiple Tremor Sources Below Kilauea's Summit

Jean Battaglia[1,2] ((808) 967-8851; battag@hvo226.wr.usgs.gov)

Paul G. Okubo[2] ((808) 967-8802; pokubo@usgs.gov)

[1]Center for the Study of Active Volcanoes, 200 W. Kawili St., Hilo, HI 96720-4091, United States

[2]USGS, Hawaii Volcano Observatory, PO Box 51, Hawaii National Park, HI 96718, United States

Various tremor sources, shallow as well as deep, are commonly observed below the island of Hawaii. Eruption tremor is almost constantly and continually present since the onset of the Pu'u'O'o east rift zone eruption 20 years ago. Its source is found at shallow depth below the eruption crater. Indirectly related to the ongoing eruption, tremor is also recorded below the summit of Kilauea about 15 kilometers away from the eruption site.

Time-frequency transforms (sgram) are automatically processed in real-time at the Hawaii Volcano Observatory via the Earthworm system for several seismic stations situated in Kilauea's summit area. This processing indicates the presence of marked spectral peaks, sometimes common to several stations. It also emphasizes changes in tremor spectral content and cyclic behaviors. During small eruption crises, changes in the signal relative amplitude at the different stations suggest the presence of several tremor sources.

We locate the sources using seismic amplitude distributions corrected for the site effects. Amplitudes are calculated in several frequency bands and spatial amplitude distributions across the summit area are usually smooth and coherent. We search for the source of those distributions by approximating the decay of the amplitude as a function of the hypocentral distance. The application of our location method to tremor recorded between March and August 2001 indicates the presence of at least two shallow sources whose locations are persistent with time. In the case of a small crisis that occurred in April 2002, we distinguish two main sources of activity, with a first deeper one triggering the activation of a second shallower source. Those results suggest the possibility of using tremor for mapping fluid transport below Kilauea volcano.

V71A-1251 0830h POSTER

The Shallow Magmatic System of Kilauea Volcano

Peter F Cervelli[1] (808 967 8814; pcervelli@usgs.gov)

Asta Miklius[1] (808 967 8804; asta@usgs.gov)

[1]U.S. Geological Survey Hawaiian Volcano Observatory, P.O. Box 51, Hawaii National Park, HI 96718-0051

Geodetic leveling and Global Positioning System (GPS) measurements image a deflating magma reservoir in the southern part of Kilauea caldera. This reservoir, centered about 3.5 km below ground level, has been slowly deflating ($\sim 2.5 \times 10^6$ km^3 per year) since the beginning of the Pu'u 'O'o eruption. Electronic borehole tiltmeters reveal a secondary, much shallower magma chamber located just east of Halemaumau Crater at about 750 m below ground level. This secondary reservoir produces episodic deformation events, many of which share striking similarities that suggest a corresponding similarity of process.

The self-similar episodic events are characterized by a three-phase deformation pattern. In the first phase, tiltmeters surrounding Kilauea caldera record slow deflation centered at the Halemaumau magma reservoir that persists for about 24 hours. The second phase begins as the slow deflation abruptly gives way to rapid inflation, again centered at the Halemaumau reservoir. The inflation is short-lived, lasting about 20 minutes. In the final phase, tiltmeters record exponentially decaying deflation, lasting from 8 to 20 hours, that brings the final tilt close to pre-event levels. The seismicity during these events is dominated by bursts of volcanic tremor coincident with the onset of the second (inflationary) deformation phase.

We interpret these events as arising from an interruption in magma supply. At the onset of the interruption, deflation begins at the summit as magma continues to exit the system through flank vents at Pu'u 'O'o. When the interruption ends, rapid inflation ensues as the accumulated and over-pressurized magma below the locus of interruption surges up into the shallow magma system.

Several significant inferences follow from this interpretation of the episodic deformation events. First, from the duration of the initial deflation and from its size, we estimate the magma supply rate into the shallow system to be ($\sim 5 - 10 \times 10^5$ m^3 per day). Second, from the instantaneous volumetric inflation rate and the lag time between inflation at the summit and inflation at Pu'u 'O'o cone, we calculate the approximate radius of the connecting magma conduit to be 2 m. Finally, from the style and timing of the deformation and seismicity, we conclude that the conduit from Kilauea summit to Pu'u 'O'o probably begins at the shallow Halemaumau magma reservoir rather than at its deeper counterpart in the south caldera.

V71A-1252 0830h POSTER

Continuous GPS Monitoring of Deformation at Kilauea Volcano During the Latter Half of the Pu'u 'O'o eruption.

Anne Douglas[1] (808 967 7328; adouglas@hvomail.wr.usgs.gov)

Peter Cervelli[1] (808 967 8814; pcervelli@usgs.gov)

[1]U.S. Geological Survey Hawaiian Volcano Observatory, 1 Crater Rim Drive, Hawaii National Park, HI 96718, United States

The installation and development of a continuous Global Positioning System (GPS) network on Kilauea Volcano, Hawaii, has significantly improved the quality and resolution of deformation data for the volcano. The continuous GPS monitoring network of 17 stations on Kilauea was installed from 1995 onward in a collaborative project between the Crustal Deformation Group at Stanford University, the Hawaiian Volcano Observatory (HVO), and the University of Hawaii, Hilo.

Continuous GPS measurements made on Kilauea between 1996 and 2001 show a long-term signal of nearly constant velocity with respect to the Pacific Plate. The horizontal component of velocity is characterized by south- to southeastward motion of all stations, with maximum rates of up to 8 cm per year occurring on the south coast of Kilauea. The vertical component shows uplift of nearly 3 cm per year on the south flank and highlights an area of rapid subsidence (4.5 cm per year) in the southernmost part of Kilauea's summit caldera.

Combined with campaign GPS data from annual surveys made between 1990 and 1996, there is now a 12 year record of GPS for Kilauea. Using the new, high quality data set from the continuous GPS network we are able to model the deformation of Kilauea with greater confidence and to test and refine past models for deformation. For example, Owen et al. (2000) give a deformation model for Kilauea estimated from campaign GPS data. This model consists of two dislocations representing a basal decollement structure, two dislocations representing a deep rift system, and one point source for a summit magma chamber. We compare the predicted velocities from this model to the station velocities from the continuous GPS. Owen et al.'s model fits the recent data reasonably well, but there are significant disagreements. First, it fails to account for the uplift south of the east rift zone (indeed, it predicts subsidence). Second, it overestimates the amount of subsidence in the south caldera while also underestimating the horizontal velocities in the same area. Finally, their model does not well represent the velocities, both horizontal and vertical, at the stations located along the western and eastern edges of the network.

Using non-linear optimization techniques, we have refined the details of Owen et al.'s model to see if the gross character of that model can be preserved without significantly violating the new continuous GPS data. Moreover, we have explored alternative, considerably simpler, deformation models that depart from the coupled decollement/deep rift zone hypothesis. Early results suggest that the simpler models, consisting of a single dislocation plane, can fit the data equally well.

Owen, S., P. Segall, M. Lisowski, A. Miklius, R. Denlinger, and M. Sako, Rapid deformation of Kilauea volcano: GPS measurements between 1990 and 1996, *J. Geophys. Res.* **105**, 18,983–18,998, 2000.

V71A-1253 0830h POSTER

Magma Reservoir Processes Revealed by Geochemistry of the Ongoing East Rift Zone Eruption, Kilauea Volcano, Hawaii

Carl R Thornber (360-993-8901; cthornber@usgs.gov)

U.S. Geological Survey, Cascades Volcano Observatory 1300 SE Cardinal Ct., Vancouver, WA 98683, United States

Geochemical data were examined for a suite of 1,000 near-vent lava samples from the Pu'u 'O'o-Kupaianaha eruption of Kilauea, collected from January 1983 through October 2001. Bulk lava and glass compositions reveal short- and long-term changes in pre-eruptive magma conditions that can be correlated with changes in edifice deformation, shallow magma transfer and eruptive behavior. Two decades of eruption on Kilauea's east rift zone has yielded ∼2 km3 of lava, 97% of which is sparsely olivine-phyric with an MgO range of 6.8 to 9.6 wt%. During separate brief intervals of low-volume, fissure eruption (episodes 1 to 3 and 54), isolated rift-zone reservoirs with lower-MgO and olv-cpx-plg-phryic magma were incorporated by more mafic magma immediately prior to eruption. During prolonged, near-continuous eruption(e.g.,episodes 48-53 and most of 55), steady-state effusion is marked by cyclic variations in olivine-saturated magma chemistry. Bulk lava MgO and eruption temperature vary in cycles of monthly to bi-annual frequency, while olivine-incompatible elements vary inversely to these cycles. However, MgO-normalized values and ratios of highly to moderately incompatible elements (HINCE/MINCE), which nullify olivine fractionation effects, reveal cycles in magma chemistry that occur prior to olivine crystallization over the magmatic temperature range that is tapped by this eruption (1205-1155°C). These short-term cycles are superimposed on a long-term decrease of HINCE/MINCE, which is widely thought to reflect a 20-year change in mantle-source conditions. While HINCE/MINCE variation in primitive recharge magma cannot be ruled out, the short-term fluctuations of this signature may require unreasonably complex mantle variations. Alternatively, the correspondence of HINCE/MINCE cycles with edifice deformation and eruptive behavior suggests that the long-term evolving magmatic condition is a result of prolonged succession of short-term shallow magmatic events.

The consistent limits of repeated MgO and temperature variation imply end-member magma conditions that are regulated by open-system recharge of the shallow magmatic plumbing system. The low-end of MgO variation (7 wt%) approaches the low-pressure multiphase cotectic, which is maintained by open-system replenishment of a persistent magma reservoir. The high-temperature end-member (10 wt% MgO) is probably regulated by olivine fractionation in a zone of turbulent mixing between primitive recharge magma (15 wt% MgO) and resident cotectic magma. The highest temperature magmas are associated with eruption pulses that occur in response to intrusive events at the summit and initiate short-term increases of HINCE/MINCE. Subsequent changes toward lower magmatic temperatures are associated with periods of overall summit deflation, relatively low-level effusion, and frequent eruptive pauses. The long-term trends can be explained by episodic mixing of chemically uniform recharge melt with diminishing proportions of pre-1983 summit magma (maintained at cotectic conditions). Decreasing HINCE/MINCE may signify that a greater proportion of recharge magma is being diverted directly to Pu'u 'O'o with minimal summit interaction or that the mass ratio of those mixing end-members has changed due to a depleted summit chamber (or both). The coincidence of long-term summit deflation since the 1982 summit eruption suggests that shallow processes related to summit reservoir depletion may be responsible for decreasing HINCE/MINCE and Pb isotopes in post-1982 steady-state eruption products. Magma derived from a uniform mantle-source, after having flushed out older resident magma, may now completely occupy the shallow magmatic plumbing system.

V71A-1254 0830h POSTER

Extremely Rapid Crystal Fractionation During Episodes 30-31 of the Pu'u O'o Eruption: Implications for Magma Chamber Processes

Michael O. Garcia[1] (808-956-6641; mogarcia@hawaii.edu)

J. Michael Rhodes[2] (jmrhodes@geo.umass.edu)

Aaron J. Pietruszka[3] (ajp@geol.umd.edu)

William I. Rose[4] (raman@mtu.edu)

[1]Univ. of Hawaii, Dept. of Geology-Geophysics, Honolulu, HI 96822, United States

[2]Univ. of Massachusetts, Dept. of Geosciences, Amherst, MA 01003, United States

[3]Univ. of Maryland, Dept. of Geology, College Park, MD 20742, United States

[4]Michigan Tech Univ., Geological Sciences, Houghton, MI 49931, United States

The Pu'u O'o eruption offers excellent opportunities to examine petrologic and geochemical processes in shallow, basaltic magma chamber due to the intense, multi-disciplinary monitoring of its activity, frequent sampling and repeated eruptions at the same vent. Strong compositional variations were observed during some of the high fire-fountaining (400 m) episodes in 1985. Following a 20-30 day hiatus in eruptive activity, the shallow magma chamber was largely evacuated during brief (1-2 day) eruptions. Samples collected during these episodes, especially at the beginning and end, document the compositional variation between and during eruptive episodes. Lavas and tephra from episodes 30 and 31 showed a remarkable and systematic variation (2 wt% increase in MgO; 7% decrease in incompatible elements like Ba) during and between these episodes. Most of the intra-episode lava compositional variation was observed during a brief period ($<$2 hours) with little variation before or after. Olivines in these weakly prophyritic Pu'u O'o lavas are in equilibrium with the host rock composition indicating that compositional variation is not related to magma mixing or accumulation of olivine. We interpret the variation to reflect crystal fractionation within the shallow (tens to hundreds of meter deep) Pu'u O'o magma chamber. This extremely high rate of crystallization (up to 0.3%/day) and cooling (2°C/day), compared to estimates of 1°C/year for the rift zone interior, must reflect the high surface area of the dike-shaped and open topped magma chamber. These features may represent the tapping of a diffusive interface separating well mixed zones of hotter and more primitive magma in the lower part of the chamber from cooler, somewhat evolved magma above.

V71A-1255 0830h INVITED POSTER

Progressive Melting of the Hawaiian Plume Inferred From the U-series Isotope Disequilibria of Puu Oo Lavas

Aaron J. Pietruszka[1]

Erik H. Hauri[1]

Richard W. Carlson[1]

Michael O. Garcia[2]

[1]Dept. of Terrestrial Magnetism, Carnegie Inst. of Washington, 5241 Broad Branch Rd., N.W., Washington, DC 20015, United States

[2]Dept. of Geology and Geophysics, Univ. of Hawaii, 1680 East West Rd., Honolulu, HI 96822, United States

High-precision measurements of the U-series isotope abundances of basaltic lavas from the current Puu Oo eruption of Kilauea Volcano are presented to investigate the dynamics of partial melting within the actively upwelling Hawaiian mantle plume. Lavas from the Puu Oo eruption are thought to partially bypass the shallow magma storage reservoir beneath the summit of Kilauea, and thus, may represent a relatively direct "window" to mantle. Previous studies show that these lavas display a systematic temporal decrease in their MgO-normalized abundances of CaO and highly incompatible elements with relatively constant Pb, Sr and Nd isotope ratios (after the early period of magma mixing within the volcano's rift zone). Modeling of these data suggests that Kilauea has tapped a mantle source component that was depleted of incompatible elements and clinopyroxene by "recent" prior melting within the Hawaiian plume. Our results show that Puu Oo lavas also display small, but significant, temporal decreases in their 230Th-238U and 226Ra-230Th disequilibria from 2.5 to 1.4% excess 230Th and 14 to 12% excess 226Ra (relative to our +/-2 sigma analytical uncertainty of 0.3%). These changes in the (230Th)/(238U) and (226Ra)/(230Th) activity ratios of the lavas correlate systematically with larger decreases in the abundance ratios of highly versus moderately incompatible trace elements from a maximum of 23% for Ba/Yb to a minimum of 4% for Nd/Sm, which is the dominant geochemical signature of the prior source depletion at Puu Oo. The systematic correlation between the 230Th-238U and 226Ra-230Th disequilibria and these trace element ratios shows that this depletion must have occurred within several half-lives of 230Th (375 kyr) and 226Ra (8 kyr), respectively. Modeling suggests that the decreases in the 230Th-238U and 226Ra-230Th disequilibria of Puu Oo lavas result from essentially zero-age depletion of the volcano's source region. Thus, we propose that relatively fertile mantle within the Hawaiian plume may have become progressively exhausted during the eruption, allowing the increasingly depleted, and thus, more refractory, residue to continue melting.

V71A-1256 0830h INVITED POSTER

DUCKS: A continuous thermal presence on the rim of Pu'u 'O'o

Andrew J. Harris[1] (808-956-3157; harris@higp.hawaii.edu); Dawn J. Pirie[2]; Keith Horton[1]; Luke P. Flynn[1]; Harold Garbeil[1]; Jeffrey B. Johnson[1]; Hans Ramm[1]; Eric Pilger[1]

[1]HIGP/SOEST, University of Hawaii, Honolulu, HI 96822, United States

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

For the past 2 years we have been monitoring the persistent activity at the Pu'u 'O'o crater (Kilauea, Hawaii) with a permanent system of infrared thermometers. Our intent has been to implement a cheap, robust, modular real-time thermal system capable of surviving the harshest of conditions. The system cost $10,000 to construct and consists of three modules: field-based sensors, a repeater station and a reception site. The field-based component consists of three thermal infrared thermometers, housed in pelican cases with selenium-germanium-arsenic windows. Two 1 degree field of view (FOV) instruments allow specific but small areas to be monitored, and a 60 degree FOV provides an overview for all crater floor activity. A hard wire connection extends 25 m to a pelican-case-housed microprocessor, modem, and power module. From here, data are transmitted using Yagi antennas, via the repeater site, to a dedicated PC in the lobby of the Hawaiian Volcano Observatory. Here, the three channels of data are displayed on-screen, with a delay of 3 seconds between data acquisition and display. Data are also used to automatically update web-based plots for general access. Aside from some minor glitches, such has sensor damage during probable tampering and unresolved data stream failures, the system has been in continuous operation since March 2001. In this regard, careful waterproofing of connectors, cables and protective cases has kept out the extremely wet and acidic atmosphere encountered at the crater edge. We have also constructed self-contained versions with internal loggers for $1500/unit. These have been deployed in a temporary fashion at Stromboli, Masaya and Erta Ale. Together these instruments have proved capable of detecting thermal signals associated with (1) gas puffing and jetting, (2) spattering, (3) lava effusion, (4) crater floor collapse, (5) vent blockage-and-clearing, and (6) lava lake overturn.

URL: http://hotspot.higp.hawaii.edu/puuoo/

V71A-1257 0830h POSTER

Ground-based Thermal Observations of Gas Pistoning at Pu'u O'o

Jeffrey B Johnson[1] (808 956-3149; jbj@higp.hawaii.edu)

Andrew J.L. Harris[1] (808 956-3157; harris@higp.hawaii.edu)

Richard P Hoblitt[2] (808 967-8883; rhoblitt@usgs.gov)

Lizabeth S Clabaugh (808 933-7029; lclabaugh@fhsd.health.state.hi)

[1]HIGP/SOEST, University of Hawaii, POST Bldg. Room 602, 1680 East-West Road, Honolulu, HI 96822, United States

[2]Hawaiian Volcano Observatory, United States Geological Survey, P.O. Box 51, Hawaii National Park, HI 96718, United States

Three IR-sensitive (8 to 14 micron) radiometers situated on the north rim of Pu'u O'o provide University of Hawaii and HVO with real-time telemetered thermal time-series (2 Hz) data. During the past two years, these instruments have targeted the crater floor as well as various hornitos and pit vents to monitor fluctuations in eruptive activity, understand cycles in the ongoing eruption, and investigate linkage of various vents.

Between June 18th and July 23rd, 2002, our system recorded spectacular thermal signals associated with 'gas pistoning' at one of the Pu'u O'o central pit vents. This pistoning is characterized by discrete and vigorous gas jets (possibly ballistic-laden) that recur regularly at intervals ranging from 2 to 10 minutes. The thermal intensity of these pulses produces radiation equivalent to a blackbody at 400 degrees C, a marked contrast to the background that radiates at only 20 degrees C. Central vent gas pistoning rarely occurs as an isolated pulse. Instead, our thermal records show intervals of quasi-continuous gas emission (mean equivalent blackbody temperature 100 degrees C) alternating with sequences of ten or more gas piston pulses. Between July 16th and July 21st, 2002 the central vent activity was nearly dominated by pistoning, with as many as 300 individual pulses occurring in succession over 12 hour periods. The onset of this period of elevated gas pistoning appears to coincide with a series of lava flows (detected by our radiometers) that erupted from the central crater pit vent starting on July 11th. We hypothesize that pistoning is a stable mode of degassing for volatile-rich basaltic magmas with particular supply rates and conduit geometries.

Our current work focuses on forward modeling of eruption phenomena to produce various thermal signals (both gas pistoning as well as lava flow emplacement/cooling curves). The end goal is to convert our thermal records to calibrated temperature-time waveforms that will be used to constrain mass transport estimates.

V71A-1258 0830h POSTER

Thermal Efficiency of Lava Tubes of the Pu'u O'o-Kupaianaha Eruption, Kilauea Volcano, Hawaii

Rosalind Tuthill Helz[1] (1-703-648-6986; rhelz@usgs.gov)

Christina Heliker[2] (1-808-967-8807; cheliker@usgs.gov)

Ken Hon[3] (kenhon@hawaii.edu)

Margaret T. Mangan[4] (1-650-329-5738; mmangan@usgs.gov)

[1]US Geological Survey, MS 926A, Reston, VA 20192, United States

[2]Hawaiian Volcano Observatory, PO Box 51, Hawaii National Park, HI 96718, United States

[3]Department of Geology , University of Hawaii at Hilo, Hilo, HI 96720, United States

[4]US Geological Survey, MS 910 345 Middlefield Road, Menlo Park, CA 94025, United States

We have applied glass geothermometry to a suite of very glassy lava samples collected from the upper (pond) and lower (coast) ends of the Episode 48 tube system, throughout the lifetime of the Kupaianaha pond, and also to a small suite of skylight samples collected from various tubes active between 1987 and 1993. The results for the pond-coast pairs are: (1) From November 1986 through January 1988 (15 months), the average change in glass quenching temperature from pond to coast (for 12 pairs) is 12.4°C. The average increase in crystallinity (inferred from observed enrichment of TiO2 and K2O in the coastal glasses) is 11-12% by weight. (2) For the 23 months from February 1988 through November 1989, the average change in inferred quenching temperature (for 25 pairs) is 8.4°C. The average increase in crystallinity is 4-5% by weight. Within this part of the data set, pond and coastal temperatures rise and fall together much of the time, even though these temporal fluctuations are at or below the limit of resolution of glass geothermometry ($\Delta T < 3$ degrees). (3) The minimum difference in temperature for any pond-coast pair is 7°C. Twenty-four (out of 37) pairs have $\Delta T = 7\text{-}9^{\circ}$C , over the three year period.

About half of the skylight samples have glass MgO contents consistent with their linear position along the tube system. In other samples, the skylight glasses are displaced to lower MgO contents, suggesting that such samples are not consistently as well-quenched as the pond and littoral spatter samples. For the data from 1992-93, the new tube system was 2 km shorter than the earlier, Kupaianaha-fed tubes. The best-documented ΔT of 6°C for some 1993 samples observed for this 10-km long tube, gives exactly the same temperature decrease with distance (0.6°/km) as the limiting ΔT of 7°C observed for the 12-km Kupaianaha tube systems. This cooling rate may represent the limiting thermal efficiency of tubes of the current Kilauea East Rift eruption.

V71A-1259 0830h POSTER

Lava Tube Seismicity at Kilauea

Richard P. Hoblitt[1] (808-967-8883; rhoblitt@usgs.gov)

Jean Battaglia[1] (808-967-8851; battag@hvo226.wr.usgs.gov)

James P. Kauahikaua[1] (808-967-8824; jimk@usgs.gov)

Paul G. Okubo[1] (808-967-8802; pokubo@usgs.gov)

[1] Hawaiian Volcano Observatory U.S. Geological Survey, P.O. Box 51, Hawaii National Park, HI 96718, United States

We have begun to collect seismic data on lava tubes at Kilauea volcano in an effort to develop a real-time method for monitoring lava tube flux. Utilizing seismometers whose responses collectively vary from about 1 Hz to 1000 Hz, we find that most tube signals range between about 1 to 150 Hz, though some sites exhibit transient signals that range upward to several hundred Hz or more. Part of the lower frequency band–perhaps 1-10 Hz–may be volcanic tremor from Pu'u 'O'o, the source of the lava flowing in the tubes. We attribute the higher frequencies to flowing lava, though wind noise and helicopter noise complicate interpretation. At a given site, both the amplitude and frequency spectrum change with time. We strongly suspect that at least some of the changes are related to changes in lava velocity and/or lava flux. Our strongest evidence that the part of the spectrum greater than 10 Hz contains velocity/flux information is that the signal amplitude of this band decreased by about 90 percent when the independently measured VLF (Very Low Frequency) tube flux decreased from about 300,000 m^3/day in early February, 2002 to less than 5,000 m^3/day in late August. Qualitative field observations of this tube system are in agreement with the VLF measurements.

V71A-1260 0830h POSTER

Satellite-Borne and Field-Based Hyperspectral Measurements of Active Lava Flows at Kilauea Volcano, Hawaii

Leon R. Geschwind[1] (808-956-3159; leon@higp.hawaii.edu)

Luke P. Flynn[1] (flynn@higp.hawaii.edu)

Andrew J. L. Harris[1] (harris@higp.hawaii.edu)

Steve Sahetapy-Engel[1] (sahetapy@higp.hawaii.edu)

[1] Hawaii Institute of Geophysics and Planetology, SOEST, University of Hawaii at Manoa, 1680 East West Road, Honolulu, HI 96822

A better understanding of the evolving surface thermal structure of active lava flow fields is possible with the synoptic view and high spatial resolution afforded by satellite-borne hyperspectral instruments such as the Hyperion sensor aboard Earth Observing-1. Hyperion data collected on March 21, 2001, over the active Kilauea flow field, allow us to examine the surface structure of each thermally active 30-m pixel over an entire flow field. Because Hyperion offers 220 measurements within the 0.4-2.5 μm spectral range, it enables us to solve for numerous thermal components. Field-based spectroradiometer and single-channel radiometer measurements of active lava flow surfaces provide spatial and spectral detail necessary for validation of satellite observations. Data collected from an Analytical Spectral Devices field spectroradiometer with a wavelength range of 0.4 to 2.5 μm and a spectral resolution of 1-5 nm has been used to calculate radiative temperatures of active pahoehoe flows on Kilauea Volcano, Hawaii. A portable Minolta/Cyclops radiometer roughly encompassing the same field of view ($\sim$60-250 cm^2) provided an integrated surface temperature as an independent means of validation. A total of 1075 spectra of cooling pahoehoe flows were collected over three periods of observation on July 7^{th}, 8^{th}, and 21^{st} of 2002. A two component numerical model (*Flynn et al. 1992*) has been applied to the spectroradiometer data in order to describe the pahoehoe surface in terms of temperature and radiant area. Over small spatial scales ($\sim$60-250 cm^2) a single temperature component is sometimes adequate in describing the surface structure of a cooling pahoehoe lobe. However, previous studies (*Flynn et al. 1992; Harris et al. 1998*) and our new data describe the exposed molten surface as a mesh-like structure, which is actually an integrated temperature of $\sim$800 °C composed of two thermal components. Setting an appropriate integrated high-temperature component is essential when understanding the overall thermal budget of a lava flow. This becomes especially true over larger spatial scales when multiple temperature components are necessary to describe a 900 m^2 satellite pixel.

V71A-1261 0830h POSTER

Kilauea 1991-2002: Insights into the Cooling, Crystallization, and Hardening of Pahoehoe Lava Flows

Laszlo Keszthelyi[1,2] (lpk@lpl.arizona.edu)

Andrew Harris[2] (harris@higp.hawaii.edu)

Kirti Sharma[3] (k.sharma@open.ac.uk)

[1] Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, United States

[2] Hawaii Institute for Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, United States

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

The since 1986 (with the beginning of episode 48) activity at Kilauea has been dominated by pahoehoe lavas. The nearly continuous presence of active pahoehoe lava flows in the past decade has allowed for repeated field experiments to refine models for different aspects of the emplacement of pahoehoe lava flows. For example, in 1995 a simple field experiment was conducted to verify theoretical predictions for the cooling at the base of pahoehoe lava flows. The thermocouple temperatures from the base of pahoehoe lobes showed an unexpected increase in temperature a few minutes after the lobe was extruded. The proposed explanation was that the dynamics of crystallization led to a rapid release of latent after a few tens of degrees of super-cooling had developed. Field experiments in 1999 were conducted in which pahoehoe lobes were quenched at various points in their early cooling history, allowing the temporal progression of crystallization to be directly observed. The conclusions of this experiment will be presented. Another example is the comparison of different heat loss mechanisms determined by tuning a numerical model to match 1991-1995 radiometer and thermocouple data for the cooling of the top of pahoehoe lava flows. The results indicated that cooling by the wind was the dominant heat loss term, over the life of a pahoehoe lava flow. However, this term was extremely poorly constrained, requiring a new set of field measurements. While attempts to collect these field data started in 1995, the complexity of quantifying the turbulent airflow over active lava defeated us until 2002. The results from this series of field experiments will be presented. Theoretical and field studies of the rheology of pahoehoe flows have also been conducted. It had been suggested that a visco-elastic layer, close to the solidus temperature, controlled much of the behavior of pahoehoe lava flows. Field measurements from 1991 and 2002 on the rheological properties of the initial skin to form on pahoehoe lava will be reported on.

V71A-1262 0830h POSTER

Lava Flow Facies Evolution, Pu'u 'O'o-Kupaianaha Eruption, Kilauea Volcano, Hawai'i

Adam Soule[1] (541-346-5987; ssoule@gladstone.uoregon.edu)

Kathy Cashman[1] (541-346-4323; cashman@oregon.uoregon.edu)

[1] Dept. of Geological Sciences, 1272 University of Oregon, Eugenge, OR 97403-1272, United States

Hawaiian 'a'a lava flows often erupt from the vent as pahoehoe and undergo a down-flow evolution in surface morphology. This evolution can be characterized by mapping the two dominant surface morphologies (pahoehoe and 'a'a) as a function of distance from the vent. The fraction of the flow surface covered by pahoehoe typically decreases in a sigmoidal fashion, reflecting three distinct regions: iso-morphic pahoehoe, followed by a transitional region containing both pahoehoe and 'a'a, and iso-morphic 'a'a. The surface morphology distribution can be fit by an equation of the form $P = 1 / [1 + (K \times d)^m]$, where P is the fraction of the flow surface that is pahoehoe and d is the distance from the vent in kilometers. The fit parameter K describes the location of the transition from iso-morphic pahoehoe to mixed pahoehoe and 'a'a and m describes the rate of transition between the iso-morphic regions. K and m can be used to infer some physical parameters of the eruption, such as eruption temperature, effusion rate, flow advance rate, cooling rate, and topographic gradient, provided that other parameters can be constrained by observation or analysis of flow features.

We apply this technique to selected lava flows from episodes 1 to 48 of the Pu'u 'O'o-Kupainaha eruption to further refine our understanding of how flow facies evolution relates to parameters of flow emplacement, as well as to constrain the type of eruption (e.g. vent type, duration, etc.) that are candidates for this type of analysis. Surface morphology maps are created using geo-spatially registered airphotos taken after each episode. The surface morphology maps are then made into binary images and divided into slices at given intervals from the vent. We determine the fraction of surface area that is pahoehoe (P) for each slice using NIH image, and plot it as a function of distance from the vent.

Within the subset of flows examined, a sigmoidal surface morphology distribution is always observed in fissure-fed flows (episodes 1 and 11) and in some point source flows (episodes 5, 12, 25, and 40). The effusion rate and flow advance rate of these flows do not differ dramatically from those of episodes with more complex surface morphology distributions (2, 3, 18, 21, 22, and 39). More complex signatures, marked by a flattening of $P(d)$ in the transitional zone, develop under conditions of protracted flow duration or when flow paths are strongly influenced by pre-existing topography. In flows that show a sigmoidal surface morphology distribution, our results suggest that the parameter K is influenced primarily by the eruption temperature and effusion rate of the flow, with higher temperatures and effusion rates producing smaller K values (i.e., a greater distance to the pahoehoe to 'a'a transition). The parameter m shows greater variability, but in general is larger (i.e. a more rapid transition) in fissure fed flows that have larger fields of pahoehoe in the proximal region of the flow.

V71A-1263 0830h POSTER

Emissivity Changes in Basalt Cooling After Eruption From PUU OO, Kilauea, Hawaii

Ali A Abtahi[1] (818-354-4272; ali.a.abtahi@jpl.nasa.gov); Anne B Kahle[1] (818-354-7265; anne.b.kahle@jpl.nasa.gov); Elsa A Abbott[1] (818-354-2815; elsa.a.abbott@jpl.nasa.gov); Alan R Gillespie[2] (206-685-8265; alan@rad.geology.washington.edu); Don Sabol[2] (206-616-7157; don@rad.geology.washington.edu); Gail Yamada[2] (206-354-6229; gail@rad.geology.washington.edu); David Pieri[1] (818-354-6299; dave.pieri@jpl.nasa.gov)

[1] Jet Propulsion Lab, Caltech, 4800 Oak Grove Dr., Pasadena, CA 91109, United States

[2] Earth and Space Sciences, Campus Box 32 University of Washington, Seattle, WA 98195, United States

Temperature measurements of lava lakes and active flows from erupting volcanoes are important because they indicate the degree of activity and may be used to estimate flow viscosity and effusion rates, and therefore to predict ultimate flow length and width. Temperatures are measured in situ with thermocouples or radiometers, or from aircraft or spacecraft with radiometers. Remote measurement allows rapid response to eruptions in inaccessible areas and therefore is a reasonable approach to global monitoring of volcanic activity and hazard. In measuring radiometric temperatures, there are two unknowns: (1) the kinetic temperature, and (2) the emissivity, which in order to solve for the temperature is generally assumed to be the same as for the cooled lava. Kinetic and radiometric temperatures, however, appear to differ substantially for lava; for example, during the 1984 eruption of Mauna Loa we measured apparent radiometric temperatures of 750°C near the vent, rising to 900°C 1 km downstream. In contrast, thermocouple measurements near the vent are 1140°C. Explanations include: (1) absorption of emitted radiance by gases evolving from the lava near the vent (SO_2, H_2O, CO_2); and (2) emissivity rising as the lava cools. Since our ground radiometry in 1984 was made looking downwind, absorption alone cannot explain the observations. To test possibility 2, we measured the emissivity of cooling lava from PuuOo (kinetic T = 1050-400°C) using paired broadband (1.25-15 um) radiometric measurements made under clear sky (R(T)) and in a hemispheric reflector (BB(T)) on the lava. Under the hemispheric reflector the lava emits as though in a cavity (blackbody radiation) and therefore emissivity=R/BB. We also made narrow-band radiometric measurements to test the sensitivity of the recovered emissivities to the spectral shape of the blackbody spectrum alone and for better comparison to laboratory emissivity spectra. Broadband emissivities appear to rise systematically as the lava cools, from 0.55 at 1050°C to 0.85 at <500°C, and <5% of that rise can be attributed to the methodology. The emissivities of metals are known to rise with temperature, and the emissivities of dieletrics are known to decrease, consistent with our findings. We conclude that the rise in emissivity as the lava cools is real. These results suggest that emissivity must be treated as a function of temperature if accurate lava temperatures are to be recovered for active flows. In addition, accurate recovery probably requires compositional classification of the erupting lava, an unsolved problem.

V71A-1264 0830h POSTER

High-Temperature Surface Alteration of Basalt Lava

Dorothee JM Burkhard[1,2] (+49-6131-392-2370; burkhard@itc-wgt.fzk.de)

[1] University of Mainz, Department of Geosciences, Mainz 55099, Germany

[2] Research Center Karlsruhe, Technical Mineralogy, ITC-WGT, Karlsruhe 76021, Germany

At Kilauea, Hawaii, one may observe red-brown surfaces on basalt lava. Such surfaces are not unique to basalt but are typical for any oxidation horizon and are due to the formation of Fe-oxides or -hydroxides. Contrary to expectation, however, these lava surfaces are not well-exposed to rain-weathering. Instead, they are found where the lava is in the shadow of direct exposure to rain, for example a the interface between lava lobes or at the interior of former skylights. Elemental distribution line profiles from the surface to the lavas interior confirm an Fe-enrichment of a few microns at these surfaces. By contrast, this basalt quenched to glass, if re-heated in air at temperature between 775 and 900°C, shows a Ca-enrichment at the surface. The underlying Ca-diffusion is a result of the oxygen gradient between glass and air, and was assigned to the very negative ΔG for the CaO-formation [1]. According to microprobe analyses of pyroxene and plagioclase that form during re-heating above 930°C, both phases increase in Ca with increasing T. It is therefore possible that Ca becomes largely fixed in these crystals and is hence not available for diffusion at higher T.

[1] Burkhard D.J.M. (2001) J. Petrol. 42, 507-527.

V71A-1265 0830h POSTER

Piggyback Tectonics: Long-Term Growth of Kilauea on the South Flank of Mauna Loa

Peter W. Lipman[1] (650-329-5295; plipman@usgs.gov)

Thomas W. Sisson[1] (tsisson@usgs.gov)

Michelle Coombs[1] (mcoombs@usgs.gov)

Marvin Lanphere[1] (alder@usgs.gov)

[1]U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, United States

New compositional and age data from offshore pillow lavas and volcaniclastic sediments, along with onland geologic, seismic, and deformation data, provide broad perspectives on the ancestral growth of Kilauea volcano and the long-term geometric evolution of its rift zones. Sulfur-rich glass rinds on pillow lavas and volcaniclastic sediments derived from them document early underwater growth of a large compositionally diverse alkalic edifice. The alkalic rocks yield 40Ar/39Ar ages as old as about 275 ka; transitional-composition lavas, which mark beginning of the shield stage while the edifice remained below sea level, were probably first erupted at about 200 ka. Breccias from Papau Seamount, long interpreted as a landslide mass from the south flank of Kilauea, instead are fragments derived from subaerial Mauna Loa, requiring that the flank of a large Mauna Loa edifice underlies western parts of Kilauea at shallow depth. Seismic and gravity data show that the deep plumbing system for Kilaueas magma supply extends through the oceanic crust to depths of at least 30-35 km, directly below its present-day caldera. Proximity of Kilaueas caldera to the surface boundary with Mauna Loa and the presence of Mauna Loa rocks at shallow depth are difficult to reconcile with a submarine origin for early Kilauea alkalic lavas, unless geometric relations between the two volcanoes changed substantially during growth of the Kilauea shield since its inception at about 200 ka. Seismic and ground deformation data suggest seaward spreading of the entire south flank of Hawaii Island, independently of the boundary between Kilauea and Mauna Loa, along a landward-dipping detachment fault system largely following the basal contact of the composite volcanic edifices with underlying sea-floor sediments. Current steady-state horizontal displacements increase progressively seaward, at rates of 1.5 cm/yr on the lower flank of Mauna Loa and reaching 5-8 cm/yr at the Kilauea coastline. Infrequent (100 yr) large earthquakes generate similar displacement geometries, but 102 larger displacements per event. Prior to inception of Kilauea and during its early growth, Mauna Loa is inferred to undergone more active volcano spreading, involving the Kaoiki-Honuapo fault system (considered a geometric analog of the Hilina system on Kilauea). Cumulative deformation of Mauna Loas south flank during growth of Kilauea since 200-300 ka is estimated to have involved 10-15 km of seaward spreading, displacing the rift zones of Kilauea while its deep plumbing system and summit magma reservoir remained nearly fixed in space. Kilaueas rift zones, rather than migrating southward with time solely due to dike emplacement preferentially on the mobile seaward side, alternatively are interpreted to have largely been transported passively southward, "piggyback" style, during shield-stage growth of Kilauea on a still-mobile south flank of Mauna Loa. Such an evolution of Kilauea can account for the arcuate geometry of the present-day rift zones, proximity of the summit magma supply to the exposed flank of Mauna Loa, initial submarine growth of the ancestral edifice, and present-day location of Mauna Loa rocks at shallow depth beneath the south flank of Kilauea.

V71A-1266 0830h POSTER

Shallow Eruption Depths for Ancestral Kilauea: Implications for its Growth

Michelle L. Coombs[1] (650-329-5251; mcoombs@usgs.gov)

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

Peter W. Lipman[1] (650-329-5295; plipman@usgs.gov)

[1]U.S. Geological Survey, 345 Middlefield Road MS 910, Menlo Park, CA 94025, United States

The midslope bench on the submarine south flank of Kilauea volcano consists of volcaniclastic breccias and sandstones shed from Mauna Loa and Kilauea. Highly alkalic clasts (alkali basalt to nephelinite and phonotephrite), previously dated between 275 and 130 ka, record early Kilauea volcanism. High S concentrations (>750 ppm) in clasts and many sandstone glasses have suggested that early Kilauea alkalic magmas were erupted in deep water. To better evaluate eruption depths, we have measured (FTIR) H_2O and CO_2 dissolved in glasses from early alkalic breccias and sandstones and overlying alkalic to tholeiitic pillow lavas. Saturation pressures were calculated from mixed-volatile solubility models, then converted to eruption depths assuming gas saturation pressure is equal to or greater than eruption pressure.

Despite high dissolved S concentrations in most samples, 22 of 31 alkalic glasses were erupted at or near sea level (H_2O ∼0.1 wt %, CO_2 below detection). Of the remaining nine, none were erupted below ∼3000 m water depth (CO_2 < 130 ppm). High S in otherwise degassed alkalic glasses indicates incomplete S degassing due to rapid ascent rate, compositional dependence, or both; S content is not a reliable indicator of eruption depth. The subaerial to relatively shallow submarine eruption depths for the alkalic magmas indicate that early Kilauea grew high on the submarine shoulder of the Mauna Loa edifice, well above the surrounding sea floor at ∼5500 m depth. These results require that Mauna Loa is larger, and Kilauea smaller, than commonly postulated. Glass rinds of in-place transitional pillow basalts (pre-shield-phase Kilauea), from three sites above and east of the midslope bench, have H_2O (0.2-1.0 wt %) and CO_2 (170-270 ppm) concentrations that indicate eruption depths of 3500 to 5500 m. As the alkalic phase waned (post-130 ka) and transitional lavas erupted, activity propagated eastward into deeper water, marking the inception of Kilauea's east rift zone (Puna Ridge). During the volcano's mature shield stage, tholeiitic magmas have erupted subaerially and as pillow lavas along the east rift zone, reflecting continued growth both upward and laterally to the east.

V71A-1267 0830h POSTER

Ultra-high Chlorine in Submarine Kilauea Glasses: Evidence for Assimilation of Brine by Magma

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

Michelle L Coombs[1] (650-329-5251; mcoombs@usgs.gov)

Jun-Ichi Kimura[2] (81-852-32-6462; jkimura@riko.shimane-u.ac.jp)

[1]Volcano Hazards Team, U.S. Geological Survey, 345 Middlefield Rd., Menlo Park, CA 94025, United States

[2]Department of Geoscience, Shimane University, Nishikawatsu 1060, Matsue 690-0853, Japan

Basaltic glass grains in sandstone from the submarine south flank of Kilauea, Hawaii, have Cl concentrations of 0.01-1.68 wt%, and are products of brine assimilation by tholeiite magma. To our knowledge, these include the highest dissolved Cl concentrations reported for mid-ocean ridge or ocean island basaltic glasses. The ultra-high Cl glasses are grains in a sandstone clast in bedded breccias draping the southwestern end of Kilaueas submarine mid-slope bench, collected by the JAMSTEC ROV Kaiko in 2001. The clast contains two distinct suites of comagmatic glass grains. Most abundant are degassed (low S, Cl, H_2O; CO_2 < detection) Loa-type tholeiite grains (n=22 analyzed) likely from subaerial lavas of Mauna Loa that shattered upon ocean entry. A second suite of Kea-type tholeiite grains (n=17 analyzed), has higher S (780-1050 ppm) and a wide range in Cl (110-16800 ppm). Ten grains in this group have Cl >1000 ppm, six >5000 ppm, and two grains have >10,000 ppm dissolved Cl. The grains contain traces of olivine, clinopyroxene, and spinel, but no plagioclase. FTIR analyses show that the glasses have elevated water (0.42-1.27 wt%) and CO_2 (<50-130 ppm) concentrations, consistent with eruption at 2000-3000 m water depth. Water and Cl concentrations increase together to ∼1.2 wt% H_2O and ∼3000 ppm Cl; H_2O remains at ∼1.2 wt% in grains with >3000 ppm Cl. The correlation of H_2O with Cl indicates assimilation of fluid, not salt or rock. Coupled major-element variations characterize the assimilant as ∼70 % H_2O (wt), 17 % Cl, 5.5 % Na, and 3.8 % each Ca and K (a brine, not seawater) and that ∼10 wt% assimilation was necessary to produce the highest Cl glasses. Assimilation of this composition as a single-phase brine at magmatic temperature would require pressure >175 MPa. Subsequent ascent to a submarine vent degassed H_2O from the more strongly contaminated magmas, reducing H_2O to ∼1.2 wt% without lowering Cl, Na, or K measurably. Small amounts of crystallization accompanied fluid assimilation, but plagioclase crystallization was suppressed due to elevated H_2O. Cl-rich glasses are strongly enriched in Ba (to 1.6x), Rb (to 2x), and Pb (to 3x) (LA-ICPMS) relative to grains with normal tholeiite Cl contents (110-200 ppm); other trace elements correlate weakly (Sr), or not at all (F, Zr, Nb, REE), with Cl. The high-H_2O, -Cl Kilauea glasses show that droplets of hydrothermal fluid can enter and be absorbed by active magma bodies. Under rare circumstances, the quantities of assimilated fluid can be substantial (to 10 wt%), can modify the course of crystallization-differentiation, and can dominate the budgets of some petrogenetically important trace elements. Fluid assimilation would be difficult to recognize in degassed subaerial magmas or for assimilation of Cl-poor fluids.

V71B MCC: Hall C Sunday 0830h

Flood Basalts and LIPs Posters *(joint with T)*

Presiding: **C R Neal,** University of Notre Dame

V71B-1268 0830h POSTER

How do Your Flood Basalts Grow? Facies Architecture of Large Igneous Provinces

Dougal A Jerram (+44 1913744791; d.a.jerram@dur.ac.uk)

University of Durham, South Rd, Durham DH1 3LE, United Kingdom

In terms of their detailed volcanology and facies architecture, Continental Flood Basalts (CFBs) and associated volcanic rifted margins reveal important information to help our understanding of their evolution. Mafic volcanism, which makes up the majority of preserved material, is characterized by flows 2-3 m to several 10s of meters thick, with ponded flows and occasional massive flow events of the order of 100 m thick. Although most of the flows are emplaced by the same mechanism as passive inflated sheets, a variety of different facies associations exist dependent on flow volumes and to some extent flow composition. The largest silicic volcanic events are comparable in size to the largest recorded mafic events, however, they are potentially more catastrophic if erupted as ignimbrite flows. Facies, and facies associations identified in CFBs include: Tabular-Classic flows, Compound Flows, Ponded flows, truncation-onlap volcanic disconformities, burial-onlap volcanic disconformities, prograding hyaloclastite facies, preserved shield volcanic features, and sill facies. Many of these features occur on an intermediate to large basin wide scale and may only be revealed by detailed fieldwork, photogrammetry and 3-D geological models

URL: http://www.dur.ac.uk/d.a.jerram/

V71B-1269 0830h POSTER

Basaltic Lava Floods on Continents: A Case of Exothermic Magma Mixing in the Columbia River Basalt Group, American Northwest

Sedelia R. Durand[1,2] (305-348-2365; sduran06@fiu.edu)

Gautam Sen[1,2] (305-348-2299; seng@fiu.edu)

[1]Florida International University, 11200 SW 8th Street, Miami, FL 33199, United States

[2]Florida Center for Analytical Electron Microscopy, 11200 SW 8th Street, Miami, FL 33199, United States

The Columbia River Basalt Group (CRBG) in the northwestern United States is one of the smallest (approx. 174,000 km^2) and youngest example of a continental tholeiitic flood basalt province that was once generated by the Yellowstone plume. Individual lava flows of the CRBG have flooded over hundreds of km^2 area. The CRBG has been divided into several formations based on their first order geochemical differences. Among them, the Grande Ronde Formation (GR) is volumetrically most significant, constituting about 87% of the CRBG. GR lavas are chemically quite evolved (SiO_2: 52-57 wt%, MgO: 3-6%) and erupted essentially as melts carrying no more than about 5% phenocrysts (large crystals of plagioclase, pigeonite, and augite). Basalts from elsewhere in the world that are chemically as evolved as the GR generally contain 15-20% phenocrysts, and therefore the scarcity of phenocrysts in the GR basalts on such a large spatial scale is a fundamental problem. One view is that these lavas represent primary or near primary melts generated by large-scale melting (30-50% melting) of eclogite in Yellowstone plume. A second view is that the magmas had high dissolved H_2O, which kept the magmas close to their liquidi and prevented crystals from forming. On a normative cpx-ol-pl-qz projection, GR lavas plot very close to the 1 atmosphere pseudo-cotectic; clearly indicating that the erupted melts underwent fractionation and mixing processes at a very shallow level, possibly in an upper crustal network of sills and dikes, and thus these lavas cannot be primary melts. Analysis of whole

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