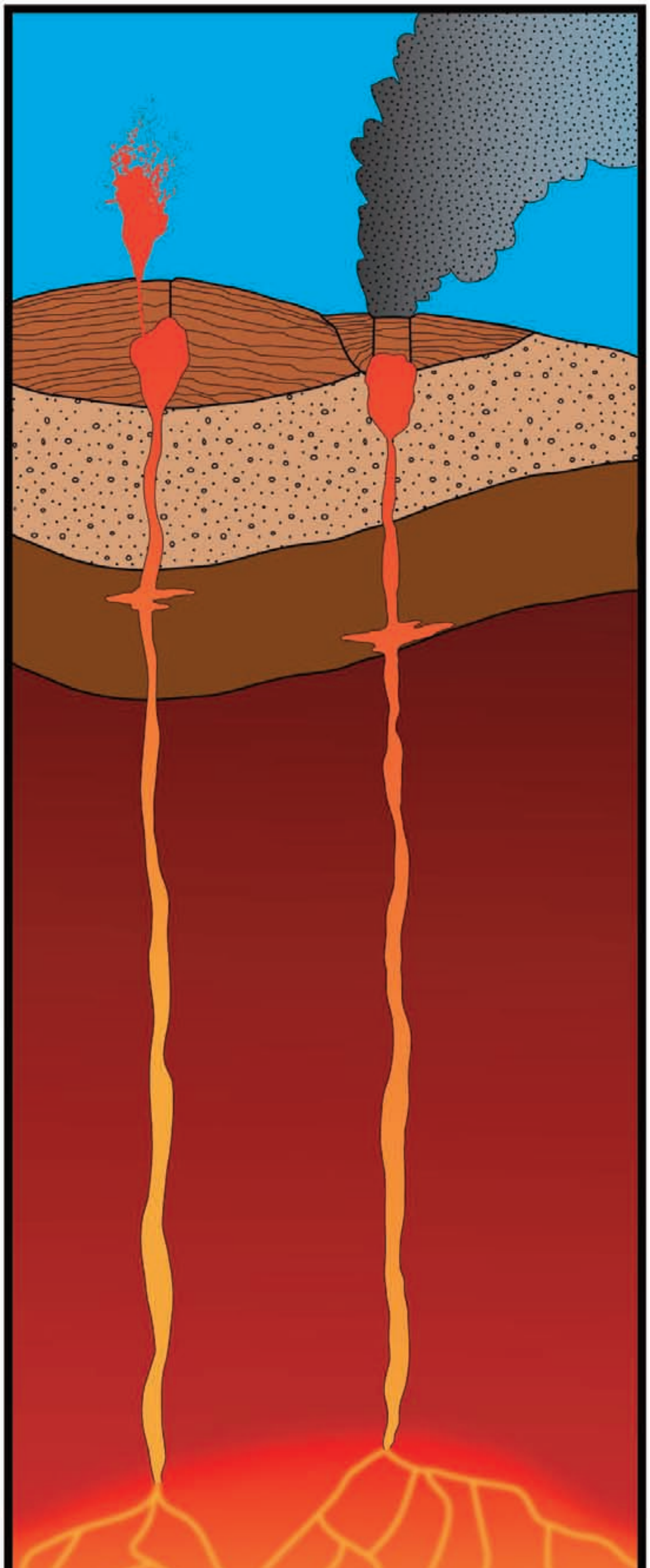
AGU CHAPMAN CONFERENCE

HAWAIIAN VOLCANOES: *From Source to Surface*



Waikoloa, Hawaii, August 20-24, 2012

AGU Chapman Conference on
Hawaiian Volcanoes: From Source to Surface Site

Waikolao, Hawaii
20 - 24 August 2012

Conveners

Michael Poland, USGS – Hawaiian Volcano Observatory, USA
Paul Okubo, USGS – Hawaiian Volcano Observatory, USA
Ken Hon, University of Hawai'i at Hilo, USA

Program Committee

Rebecca Carey, University of California, Berkeley, USA
Simon Carn, Michigan Technological University, USA
Valerie Cayol, Obs. de Physique du Globe de Clermont-Ferrand
Helge Gonnermann, Rice University, USA
Scott Rowland, SOEST, University of Hawai'i at Mānoa, USA

Financial Support

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AGU Chapman Conference on Hawaiian Volcanoes: From Source to Surface Site

Meeting At A Glance

Sunday, 19 August 2012

1600h – 1700h	Welcome Reception
1700h – 1800h	Introduction and Highlights of Kilauea's Recent Eruption Activity

Monday, 20 August 2012

0830h – 0900h	Welcome and Logistics
0900h – 0945h	Introduction – Hawaiian Volcano Observatory: Its First 100 Years of Advancing Volcanism
0945h – 1215h	Magma Origin and Ascent I
1030h – 1045h	Coffee Break
1215h – 1330h	Lunch on Your Own
1330h – 1430h	Magma Origin and Ascent II
1430h – 1445h	Coffee Break
1445h – 1600h	Magma Origin and Ascent Breakout Sessions I, II, III, IV, and V
1600h – 1645h	Magma Origin and Ascent III
1645h – 1900h	Poster Session

Tuesday, 21 August 2012

0900h – 1215h	Magma Storage and Island Evolution I
1215h – 1330h	Lunch on Your Own
1330h – 1445h	Magma Storage and Island Evolution II
1445h – 1600h	Magma Storage and Island Evolution Breakout Sessions I, II, III, IV, and V
1600h – 1645h	Magma Storage and Island Evolution III
1645h – 1900h	Poster Session

Wednesday, 22 August 2012

0800h – 1700h	Optional Field Trips
	Trip #1: Mauna Kea
	Trip #2: Explosive Kīlauea
	Trip #3: Mauna Ulu
	Trip #4: Mauna Loa North Flank
	Trip #5: Mauna Loa Southwest Rift Zone
	Trip #6: Hualālai
	Trip #7: Kohala
	Trip #8: Circle-Island Counter-Clockwise
	Trip #9: Circle-Island Clockwise
1700h – 2100h	Conference Dinner

Thursday, 23 August 2012

0900h – 1215h	Eruptions and Degassing I
0930h – 0945h	Coffee Break
1215h – 1330h	Lunch on Your Own
1330h – 1430h	Eruptions and Degassing II
1430h – 1445h	Coffee Break
1445h – 1600h	Eruptions and Degassing Breakout Sessions I, II, III, IV, and V
1600h – 1645h	Eruptions and Degassing III
1645h – 1900h	Poster Session

Friday, 24 August 2012

0900h – 1215h	The Future of Geoscience Research In Hawaii I
1030h – 1045h	Coffee Break
1215h – 1330h	Lunch on Your Own
1330h – 1530h	The Future of Geoscience Research In Hawaii I, II, III, IV, and V
1530h – 1615h	The Future of Geoscience Research In Hawaii II
1615h – 1700h	The Future of Geoscience Research In Hawaii – Discussion and Wrap-up

SCIENTIFIC PROGRAM

SUNDAY, 19 AUGUST

1600h – 1700h **Icebreaker Reception**

Introduction - Highlights of Kilauea's Recent Eruption Activity
Presiding: Michael P. Poland
Naupaka, I, II, III, IV

1700h – 1800h **Tim R. Orr** | Hightlights of Kilauea's recent eruption activity

MONDAY, 20 AUGUST

0830h – 0900h **Introduction - Welcome and Logistics**

Introduction - Hawaiian Volcano Obervatory: Its First 100 Years of Advancing Volcanism
Presiding: Michael P. Poland
Naupaka, I, II, III, IV

0900h – 0945h **Robert I. Tilling** | Hawaiian Volcano Obseratory: Its First 100 Years Of Advancing Volcanology ***(INVITED)***

Magma Origin and Ascent I
Presiding: Helge M. Gonnermann
Naupaka, I, II, III, IV

0945h – 1030h **Garrett Ito** | Seismic Structure and Dynamics of the Hawaiian Mantle Plume ***(INVITED)***

1030h – 1045h Coffee Break

1045h – 1130h **Dominique Weis** | What Do We Know About Mantle Plumes, What Can Hawaiian Volcanoes Tell Us About The Earth's Mantle And How Do They Compare to Other Oceanic Islands? ***(INVITED)***

1130h – 1215h **Donald J. DePaolo** | Deep Drilling Results and Models for the Growth and Chemical Evolution of Hawaiian Volcanoes

1215h – 1330h **Lunch on Your Own (Monday)**

Magma Origin and Ascent II

Presiding: Helge M. Gonnermann
Naupaka, I, II, III, IV

1330h – 1345h	**Robert S. White** | Magma Migration through the Crust beneath Iceland
1345h – 1400h	**Erik H. Hauri** | Volatile Element Systematics of Hawaiian Shield Volcanoes
1400h – 1415h	**Megan Pickard** | A Microanalytical Approach to Understanding the Origin of Cumulate Xenoliths from Mauna Kea, Hawaii
1415h – 1430h	**John M. Rhodes** | Mauna Loa Magmas in Space and Time
1430h – 1445h	Coffee Break

1445h – 1600h **Magma Origin and Ascent - Breakout Session I**

1425h – 1540h **Magma Origin and Ascent - Breakout Session II**

1445h – 1600h **Magma Origin and Ascent - Breakout Session III**

1445h – 1600h **Magma Origin and Ascent - Breakout Session IV**

1445h – 1600h **Magma Origina and Ascent - Breakout Session V**

Magma Origin and Ascent III

Naupaka, I, II, III, IV

1600h – 1645h	**Peter W. Lipman** | Growth of the Island of Hawaii: Deep-Water Perspectives ***(INVITED)***

1645h – 1900h Poster Session - Monday

Naupaka, V, VI & VI

M-1	**Rita A. Cabral** | Oceanic gabbro signature in Mangaia melt inclusions: Source versus assimilation
M-2	**Sofya Chistyakova** | Magma differentiation and crystallization in basaltic conduits by two competing petrogenetic processes
M-3	**Rohan Kundargi** | Melting and dehydration within mantle plumes and the formation of sub-parallel volcanic trends at intra-plate hotspots
M-4	**Jake Jordan** | Partial Melt Migration in a Heterogeneous Mantle During Active Upwelling
M-5	**Richard M. Allen** | Comparative plumeology: Contrasting seismic constraints on mantle plumes
M-6	**Nikolai S. Bagdassarov** | Hindered crystal settling in magma chambers

M-7 **Ashton Flinders** | A 3D Gravity Inversion of the Hawaiian Islands: From Niihau to Loihi

M-8 **Guillaume Girard** | From mantle to ash cloud: quantifying magma ascent rates and degassing processes at Kilauea using short-lived U-series radionuclide disequilibria

M-9 **Falk Amelung** | Numerical modeling of flank motion at Kilauea Volcano, Hawai'i

M-10 **Nicole C. Lautze** | Geothermal Resources and the Geologic Evolution of Hawaii's Volcanoes

M-11 **Ken Hon** | Petrologic evidence for a large, actively convecting summit magma chamber within Kilauea volcano

M-12 **Chiara Montagna** | The migration of pressure transients within elastically deforming magma pathways

M-13 **V. Dorsey Wanless** | Petrogenesis of High-Silica Magmas in Basalt-Dominated Systems

M-14 **Philippe Kowalski** | Evolution of monitoring networks of Piton de la Fournaise volcano over 30 years

M-15 **Falk Amelung** | Top-down inflation and deflation at the summit of Kilauea volcano, Hawaii, observed with InSAR

M-16 **Margherita Polacci** | Vesiculation and degassing in basaltic magmas: an example from Ambrym volcano, Vanuatu Arc

M-17 **Ellen M. Syracuse** | High-resolution seismic imaging of Kilauea volcano's summit region: Combined datasets, comparison of tomographic methods, and updated seismic velocity models

M-18 **Guoqing Lin** | Three-dimensional velocity structure of Kilauea and Mauna Loa volcanoes from local seismic tomography

M-19 **Jun Oikawa** | Crustal deformation and volcanic earthquakes associated with the 2008-2011 Shinmoe-dake eruption

M-20 **Nicole Richter** | Small-scale deformation associated with the summit eruption of Kilauea Volcano, Hawai'i, from TerraSAR-X Interferometry

M-21 **Daniel Dzurisin** | Our Emerging Understanding of Hawaiian and Yellowstone Volcanism: A Historical Perspective

M-22 **Itsushi Uno** | Eruption of Mt. Kilauea impacted Cloud Droplet and Radiation Budget over North Pacific

M-23 **Robin M. Tuohy** | Magma Transport, Storage, and Energetic Fountaining during Kilauea's 1955 Puna and 1960 Kapoho Eruptions

M-24 **Ashley G. Davies** | Kilauea, Hawai'i, as an analogue for Io's volcanoes

M-25 **Edward Ficker** | Volcano Mapper - A web-based GIS Application

M-26 **Mike Burton** | Recent advances in measuring and interpreting volcanic gas emissions

M-27 **Nickles B. Badger** | Infrasonic jetting from the Kamoamoa fissure eruption, Kilauea Hawaii, 5–9 March 2011

M-28 **Robert A. Craddock** | Basaltic Sand Dunes In The Ka'u Desert And Their Relationship To Kilauea Phreatic Eruptions

M-29 **Robert Wright** | Imaging Volcanic Plumes Using a Sagnac Interferometer

M-30 **Jacob E. Bleacher** | Comparison of inflation processes at the 1859 Mauna Loa Flow, HI, and the McCartys flow field, NM

M-31 **Jacob E. Bleacher** | A volcanic origin for sinuous and branching channels on Mars: Evidence from Hawaiian analogs

M-32 **John Lockwood** | THE ROLE OF PYRODUCTS (AKA "LAVA TUBES") IN GOVERNING THE LENGTHS OF LAVA FLOWS

M-33 **Christoph Kern** | Ultraviolet SO2 imaging systems allow insights into degassing processes occurring on short timescales at Kilauea's summit

M-34 **Eric M. Dunham** | Wave Propagation in Basaltic Fissure Eruptions

M-35 **David J. Ferguson** | Magma recharge and ascent during episode 1 of the 1959 Kilauea Iki eruption

M-36 **Milton A. Garces** | A Decade of Infrasound Array Measurements in Hawaii: Discovery, Science, and Applications

M-37 **Tamar Elias** | Degassing highlights during the 2011-2012 eruptive activity at Kilauea Volcano, Hawai'i

TUESDAY, 21 AUGUST

Magma Storage and Island Evolution I

Presiding: Valerie Cayol

Naupaka, I, II, III, IV

0900h – 0945h **Aaron J. Pietruszka** | Geometry of the Summit Magma Storage Reservoir of Kilauea Volcano: A View from High-Precision Pb Isotopes ***(INVITED)***

0945h – 1030h **Eleonora Rivalta** | Effects of Magma Compressibility on Volcano Deformation and Seismicity ***(INVITED)***

1030h – 1115h **Nikolai M. Shapiro** | Studying Piton de la Fournaise Volcano Based on Correlations of Ambient Seismic Noise ***(INVITED)***

1115h – 1130h Coffee Break

1130h – 1215h **Paul Segall** | Volcano Deformation, Seismicity, and Magma-Faulting Interactions ***(INVITED)***

1215h – 1330h **Lunch on Your Own (Thursday)**

Magma Storage and Island Evolution II
Presiding: Valerie Cayol
Naupaka, I, II, III, IV

1330h – 1345h **Andrea Di Muro** | The plumbing system of Piton de la Fournaise volcano (Réunion Island): a geochemical perspective

1345h – 1400h **Harmony V. Colella** | Seismicity rates changes during episodic fountaining in the early stages of Pu`u O`o at Kilauea volcano, Hawaii and possible implications for magma storage and supply to Pu'u O'o

1400h – 1415h **Vincent Famin** | A unified model for the deformation of basaltic volcanoes

1415h – 1430h **Marco Bagnardi** | The Galápagos style: space-geodetic observations of intrusions and eruptions at Fernandina and other Galápagos volcanoes

1430h – 1445h Coffee Break

1445h – 1600h **Magnum Storage and Island Evolution - Breakout Session I**

1445h – 1600h **Magnum Storage and Island Evolution - Breakout Session II**

1445h – 1600h **Magnum Storage and Island Evolution - Breakout Session IIi**

1445h – 1600h **Magnum Storage and Island Evolution - Breakout Session IV**

1445h – 1600h **Magnum Storage and Island Evolution - Breakout Session V**

Magnum Storage and Island Evolution III
Presiding: Valerie Cayol
Naupaka, I, II, III, IV

1600h – 1645h **Julia K. Morgan** | Observationally and Geophysically Constrained Geodynamic Models of Hawaiian Volcanoes ***(INVITED)***

1645h – 1900h **Poster Session - Tuesday**
Naupaka, V, VI & VI

TU-1 **Anna M. Courtier** | Structure of the Transition Zone and Upper Mantle beneath the Hawaiian Islands: Implications for Mantle Heterogeneity and Upwelling

TU-2 **Paul Hall** | Mantle plume-migrating mid-ocean ridge interaction and the bend in the Hawaii-Emperor Seamount Chain

TU-3 **Helge M. Gonnermann** | Dynamic coupling of Mauna Loa and Kilauea volcanoes, Hawai'i

TU-4 **Jeffrey M. Zurek** | Linking Gravitational Spreading and Magma Chamber Growth through Gravity Studies

TU-5 **Jessica H. Johnson** | A Background of Seismic Anisotropy at Kilauea Volcano and Changes Associated with the Summit Eruptive Vent

TU-6 **Valerie Cayol** | Magma assisted extension in an immature continental rift, based on InSAR observations of Nyamuragira and Nyiragongo Volcanoes

TU-7 **Valérie Cayol** | NINE YEARS OF INSAR MONITORING AT PITON DE LA FOURNAISE RESULTS AND PERSPECTIVES

TU-8 **Sarah Menassian** | Characterization of deformation source geometry for the October 2010 eruption at Piton de la Fournaise volcano, Réunion Island: a numerical modeling approach

TU-9 **Andrew Greene** | Temporal Geochemical Variations in Lavas from Kilauea's Puu Oo Eruption (1983-2012): The Changing Roles of Source and Crustal Processes

TU-10 **Silke Ballmer** | Studying temporal velocity changes with ambient seismic noise at Hawaiian volcanoes

TU-11 **Marie Chaput** | Sill zones and stress permutations: an alternative to the Hawaiian model of basaltic volcano deformation

TU-12 **Kevin J. Seats** | 3D Ambient Noise Tomography of the Sierra Negra Shield Volcano in the Galapagos

TU-13 **Paul Okubo** | The hunt for tectonic tremor during Kilauea's slow slip events

TU-14 **Christelle Wauthier** | Magma Sources Involved in the 2002 Nyiragongo Eruption, as Inferred from an InSAR Analysis

TU-15 **Kyle R. Anderson** | The Shallow Magmatic System at Kilauea Volcano: Insights from Episodic Ground Tilt

TU-16 **Carl R. Thornber** | Petrologic Testament to Changes in Shallow Magma Storage and Transport Associated with Prolonged Recharge and Eruption at Kilauea

TU-17 **Dara K. Merz** | Well-Constrained Hypocenters at Lo`ihi Volcano, Hawai`i Using a Network of Ocean Bottom Seismometers

TU-18 **Michael O. Garcia** | Controls on eruption of homogeneous magmas and their common failure to differentiate at Kilauea Volcano

TU-19 **M. Belachew** | Imaging magma storage reservoirs beneath Sierra Negra volcano, Galápagos, Ecuador

TU-20 **Manahloh Belachew** | Dynamics of Dike Intrusions and 3D Velocity Structure beneath an Incipient Seafloor Spreading Center in Afar, Ethiopia

TU-21 **Einat Lev** | Investigating Lava Rheology Using Video Analysis and Numerical Models of Experimental and Natural Lava Flows

TU-22 **Alexander Sehlke** | Characterizing Kilauea: The role of chemistry and crystallinity on rheology

TU-23 **Thomas Staudacher** | 60 years of volcanic eruptions at Piton de la Fournaise volcano

TU-24 **Thomas Staudacher** | Permanent and cinematic GPS network at Piton de la Fournaise

TU-25 **Katharina Unglert** | Towards a parameter space for volcanic tremor: Dependence of tremor amplitude on magma rheology

TU-26 **Simon A. Carn** | Three decades of satellite monitoring of Hawaiian volcanic sulfur dioxide emissions

TU-27 **Paul Lundgren** | Source models for the March 5-9, 2011 Kamoamoa fissure eruption, Kilauea Volcano, Hawai`i, constrained by InSAR and GPS observations

TU-28 **Marco Bagnardi** | Evidence for interaction between the Galapagos Islands volcanoes

TU-29 **Samuel A. Soule** | Airborne Laser Swath Mapping (ALSM) and Physical Volcanology of Hawaiian Volcanoes

TU-30 **Carolyn E. Parcheta** | Hawaiian Fountain Styles

TU-31 **Vincent J. Realmuto** | Thermal Infrared Remote Sensing of SO2 Emissions from Kilauea Volcano: Lessons Learned and Future Plans

TU-32 **Chelsea J. Mack** | VOLCANIC DEGASSING AND ERUPTIVE BEHAVIOR AT WEST MATA VOLCANO, LAU BASIN

TU-33 **Mary E. Rumpf** | Understanding lava–substrate heat transfer on Hawaii and the Moon using thermodynamic modeling and laboratory-scale lava flows

TU-34 **Erik H. Hauri** | Pyroclastic Volcanism on the Moon and at Kilauea Iki: Similarities and Differences

TU-35 **Paule-Annick Davoine** | Improving Volcanological Data Management by Innovative Geomatics Approaches: Application to the Piton de la Fournaise Volcano Data

WEDNESDAY, 22 AUGUST

0800h – 1700h **Optional Field Trips**

Conference Dinner - Key Note Talk
Naupaka, I, II, III, IV

1900h – 1945h **James G. Moore** | Hawaiian Pillow Lava ***(INVITED)***

1900h – 2100h **Conference Dinner**

THURSDAY, 23 AUGUST

Eruptions and Degassing I
Presiding: Simon A. Carn
Naupaka, I, II, III, IV

0900h – 0915h **Sylvie Vergniolle** | From Reservoirs to Conduits: the Role of Bubbles in Driving Basaltic Eruptions ***(INVITED)***

0915h – 0930h **Marie Edmonds** | Volatile Degassing in Basaltic Magmas ***(INVITED)***

0930h – 0945h Coffee Break

0945h – 1000h **Bruce F. Houghton** | Explosive Eruptions at Basaltic Volcanoes ***(INVITED)***

1000h – 1015h **Andrew Harris** | Effusion Rate: Measurement from Space and Input into Lava Flow Modelling ***(INVITED)***

1215h – 1330h **Lunch on Your Own (Thursday)**

Eruptions and Degassing II
Presiding: Simon A. Carn
Naupaka, I, II, III, IV

1330h – 1345h **A J. Sutton** | Eruptive processes revealed by variations in Kilauea gas release highlight the value of thoughtful care and feeding of long running datasets

1345h – 1400h **Frank Trusdell** | Does Activity at Kilauea Influence Eruptions at Mauna Loa?

1400h – 1415h **Richard S. Fiske** | Ultra-Energetic, Jet-Like Eruption at Kilauea: The Kulanaokuaiki-3 Tephra (~850-950 CE)

1415h – 1430h **Michael S. Ramsey** | Thermal emission from molten silicates: Implications for lava flow emplacement and hazards

1430h – 1445h Coffee Break

1445h – 1600h **Eruptions and Degassing - Breakout Session I**

1445h – 1600h **Eruptions and Degassing - Breakout Session II**

1445h – 1600h **Eruptions and Degassing - Breakout Session III**

1445h – 1600h **Eruptions and Degassing - Breakout Session IV**

1445h – 1600h **Eruptions and Degassing - Breakout Session V**

Eruptions and Degassing III
Presiding: Simon A. Carn
Naupaka, I, II, III, IV

1600h – 1645h **Donald Swanson** | Effusive and Explosive Cycles at Kilauea: What do They Mean? ***(INVITED)***

1645h – 1900h **Poster Session - Thursday**
Naupaka, V, VI & VI

TH-1 **Erika Gasperikova** | Kilauea Volcano 3D Imagining Using Magnetotelluric Data

TH-2 **Janine Kavanagh** | The Influence of Pre-Existing Structures on a Quaternary Fissure Vent Eruption: The Mt Eccles Volcanic Complex, The Newer Volcanics Province, Australia

TH-3 **Frederick A. Frey** | The Longevity of Geochemical Differences Between Lavas Erupted Along the Loa and Kea Spatial Trends Defined by the Hawaiian Islands

TH-4 **Lauren Harrison** | Li Isotopes of Hawaiian Lavas: Loa Trend Source Variation

TH-5 **Samuel M. Howell** | Numerical Modeling of Mantle Convection beneath the Aegir Ridge, a Shadow in the Iceland Hotspot

TH-6 **Michael P. Poland** | Kilauea's magma plumbing system

TH-7 **Christina King** | Ambient Noise Non-Linear Time Correction for Ocean Bottom Seismometers

TH-8 **Manoochehr Shirzaei** | Aseismic faulting of the south flank of Kilauea revealed by wavelet analysis of InSAR and GPS time series

TH-9 **Jared P. Marske** | Magma transport, mixing, and storage in Kilauea's rift zones: a high-resolution geochemical perspective from 1790-2011 AD lavas

TH-10 **Alan G. Whittington** | Thermo-rheological feedbacks during cooling and crystallization of basaltic lava

TH-11 **Rosalind L. Helz** | Evidence for a large range of melts present in Kilauea's summit reservoir

TH-12 **Eleonora Rivalta** | The Stress Shadow Induced by the 1975-1984 Krafla Rifting Event

TH-13 **Eleonora Rivalta** | On the physical links between the dynamics of the Izu Islands 2000 dike intrusions and the statistics of the induced seismicity

TH-14 **Bill Chadwick** | Comparison of Inflation/Deflation Cycles at Hawaiian Volcanoes and at Axial Seamount

TH-15 **Jennifer Nakata** | Seismic Monitoring at Kilauea with Evolving Network Capabilities Through a Long-Lived Eruption

TH-16 **Robin S. Matoza** | Systematic Re-Analysis of Seismicity on Hawaii Island from 1992 to 2009

TH-17 **Diana C. Roman** | Intermediate-term seismic precursors to the 2007 Father's Day intrusion and eruption at Kilauea Volcano, Hawai'i

TH-18 **Jackie Caplan-Auerbach** | Multiplet Analysis of Earthquake Swarms and T-phases at Lo`ihi Submarine Volcano

TH-19 **Weston A. Thelen** | A MODEL FOR RECENT SEISMICITY ON KILAUEA'S UPPER EAST RIFT ZONE

TH-20 **Cyndi L. Kelly** | Imaging Seismic Source Variations Throughout a Volcano's Eruptive Sequence Using Back-Projection Methods

TH-21 **John M. Sinton** | Ka'ena: The most recently discovered Hawaian volcano and its effect on the evolution of the island of O'ahu, Hawai'i

TH-22 **Samantha Jacob** | Post-shield magmatic processes: New insights from Haleakala ankaramites

TH-23 **Kelly Wooten** | Controls of DEM quality on lava flow modeling: Test cases from Kilauea Volcano, Hawai`i, and Piton de la Fournaise volcano, Réunion Island

TH-24 **Marie Edmonds** | Halogen and trace metal emissions from the ongoing 2008 summit eruption of Kilauea volcano Hawai`i

TH-25 **Marie Edmonds** | Degassing and lava fountain dynamics during the 1959 Kilauea Iki eruption, Kilauea Volcano, Hawai'i

TH-26 **Marie Edmonds** | Volatiles in gases and melt inclusions during the 2008-present summit activity at Kilauea Volcano, Hawai'i

TH-27 **Hannah R. Dietterich** | Complex Channel Networks in Hawai'i and the Influence of Underlying Topography on Flow Emplacement

TH-28 **Rachel Teasdale** | Opportunities for classroom use of near-real-time monitoring data of Kilauea Volcano with the Volcanoes Exploration Project: Pu'u 'O'o (VEPP)

TH-29 **Rebecca J. Carey** | Shallow triggered renewed bubble nucleation in basaltic magmas: Halema'uma'u 2008

TH-30 **Patricia A. Nadeau** | Examining the Role of Degassing in Recent Summit Activity, Kilauea Volcano, Hawaii

TH-31 **Atsuko Namiki** | Experiments on shear induced generation of large gas slugs

TH-32 **Thomas Shea** | Post shield-stage volcanism at Hualalai (Hawaii): shifts between explosive and effusive activities during the Pu'u Wa'a Wa'a-Pu'u Anahulu eruption (~114 ka)

TH-33 **Verity J. Flower** | Synergistic monitoring of Hawaiian volcanic activity from space

TH-34 **Anna B. Perttu** | Halema'uma'u's Infrasonic Signatures: Reawakening to Present

TH-35 **Julie A. Herrick** | Lava inundation probability for the north flank of Mauna Loa

TH-36 **Sarah A. Fagents** | Photogrammetric and global positioning system measurements of active pahoehoe lava lobe emplacement on Kilauea, Hawai`i

TH-37 **Matthew R. Patrick** | Tracking the hydraulic connection between Kilauea's summit and east rift zone using lava level data from 2011

TH-38 **Leif Karlstrom** | Coupling between magmatic landscape construction and fluvial erosion on ocean islands

TH-39 **James Foster** | Meteorology and Volcano Monitoring

TH-40 **Keith A. Horton** | Early Monitoring Results from the Halema`uma`u Vog Measurement and Prediction FLYSPEC Array

TH-41 **Patricia G. MacQueen** | Using Forward Modeling to Optimize the Geometry of Geophysical Networks at the Summit of Kilauea Volcano: A Matter of Great Gravity

FRIDAY, 24 AUGUST

The Future of Geoscience Research in Hawaii I

Naupaka, I, II, III, IV

0900h – 0945h **Matthew G. Jackson** | The Deep Mantle Feeding Hawaiian Volcanism: New Perspectives on Old Models ***(INVITED)***

0945h – 1030h **Peter M. Shearer** | Characterizing fault zones and volcanic conduits at Kilauea and Mauna Loa volcanoes by large-scale mapping of earthquake stress drops and high precision relocations

1030h – 1045h	Coffee Break
1045h – 1130h	**Sonia Calvari** | Monitoring Active Basaltic Volcanoes: New Techniques and Novel Results
1130h – 1215h	**James H. Dieterich** | Recent developments in regional simulations of fault and earthquake processes: Applications to volcanic systems
1215h – 1330h	**Lunch on Your Own (Friday)**
1330h – 1530h	**The Future of Geoscience Research in Hawaii - Breakout Session I**
1330h – 1530h	**The Future of Geoscience Research in Hawaii - Breakout Session II**
1330h – 1530h	**The Future of Geoscience Research in Hawaii - Breakout Session III**
1330h – 1530h	**The Future of Geoscience Research in Hawaii - Breakout Session IV**
1330h – 1530h	**The Future of Geoscience Research in Hawaii - Breakout Session V**
	The Future of Geoscience Research in Hawaii II Naupaka, I, II, III, IV
1530h – 1615h	**David Clague** | A 200-year look at Hawaiian volcanism—the last and the next 100 years
1615h – 1700h	**The Future of Geoscience Research in Hawaii - Discussion and Wrap-up**

ABSTRACTS

listed by name of presenter

Allen, Richard M.

Comparative plumeology: Contrasting seismic constraints on mantle plumes

Allen, Richard M.[1]; Cheng, Cheng[1]; Porritt, Robert[1]

1. Earth and Planetary Science, Univ California Berkeley, Berkeley, CA, USA

Ever since the whole mantle plume hypothesis was first proposed there has been a vigorous debate over the origins of volcanic hotspots. Many hoped that the ability of seismic tomography to image 3D velocity structure, when applied to hotspot locations, would resolve this question. This has not been the case. Today we have global tomography models that are interpreted to show mantle plumes and others that do not. Temporary seismic deployments in hotspot locations have been designed specifically to provide higher resolution images of mantle structure to constrain the origins of hotspots. While they usually show low velocities in the upper mantle beneath hotspots, they usually lack the simple vertical cylindrical structure predicted by simple geodynamic models. This again leads to multiple varied interpretations. Here we take a comparative approach in an effort to understand the real differences, or similarities, in mantle structure beneath hotspots. We use seismic data from dense regional seismic deployments above Hawaii, Yellowstone and Iceland and compare the mantle structures resolved beneath each. We account for the variable station distribution and identify where differences in mantle velocity structure really exist. We then compare the relative seismic structures to other constraints on mantle processes beneath each hotspot in an effort to identify whether a single mantle process can explain all three hotspots.

Amelung, Falk

Numerical modeling of flank motion at Kilauea Volcano, Hawai'i

Plattner, Christina[1]; Baker, Scott[2]; Amelung, Falk[2]; Govers, Rob[3]; Poland, Mike[4]

1. Geomatics Engineering, Florida Atlantic University, Port St. Lucie, FL, USA
2. Marine Geology and Geophysics, University of Miami, RSMAS, Miami, FL, USA
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Multiple causes have been suggested for the seaward motion of Kilauea's south flank, including forceful dike intrusions into the rift zone, and magmatic overpressurization or gravitational spreading of a deep partial-melt carrying olivine cumulate. The continuity of the flank motion during inflation and deflation of Kilauea summit suggest that gravity plays a substantial role. Using numerical modeling we test whether motion of the southern flank of Kilauea volcano can be understood as a 'secular' (continuous) gravity collapse that is modulated by intrusions or earthquake events. For comparison of our model results we use geodetic velocities based on data from a time period that shows little effect of episodic magmatic and tectonic events (2000-2003), which show the seaward motion of the south flank and subsidence at Kilauea summit. We find that gravity-only driven models can reproduce the geodetic surface velocities if we incorporate a regional decollement fault, and a shallow, low viscosity magma chamber. A rift above the magma chamber was necessary to add to the model geometry in order to allow reaching steady-state velocities, for which we estimate the magma mush viscosity to ~ 1 x 1019 Pa.s, with about half of the subsidence amplitude at Kilauea summit to be explained by flank motion only.

Amelung, Falk

Top-down inflation and deflation at the summit of Kilauea volcano, Hawaii, observed with InSAR

Amelung, Falk[1]; Baker, Scott[1]

1. Marine Geology and Geophysics, University of Miami - RSMAS, Miami, FL, USA

We use interferometric synthetic aperture radar (InSAR) to study the inflation-deflation sequence of the summit caldera at Kilauea volcano during 2000-2008, which led to the 2007 intrusion in the east rift zone and a summit eruption that started in 2008. The data set consists of small baseline subset (SBAS) time-series generated from 270 acquisitions on 3 separate beam modes from the Radarsat-1 satellite. We identify 12 time periods with distinct patterns of displacement that we attribute until 2004 to secular tectonic-driven deformation and from 2004-2008 to four different sources in the summit area. The shallow magmatic system consists of a spherical reservoir at 1.9 km depth to the northeast of Halema'uma'u (source 1) and 3 vertically stacked sills at greater depths in the southern caldera area (sources 2 at the southern edge of the caldera at 2.9 km depth, source 3 to the south-southeast of the caldera at 3.6 km depth, and source 4 south of the caldera at 3.6 km depth). The sequence for filling and emptying these shallow summit reservoirs reveal a top-down process, with the shallow sources being the first to inflate as well as the first to deflate. Inflation of source 3 is coincident with seismic swarm activity in the upper east rift zone in February 2006 and May 2007. Source 4 is elongated toward the southwest rift zone and also shows elevated seismicity that extends toward the southwest rift. The activation of the deeper sills (sources 3 and 4) correlates with the time-varying strength of the upper east rift zone. When the rift zone is strong (such as during 2006) magma cannot break into the rift. Dike intrusions fail and the deeper sills inflate. When the rift

zone is weak (such as in 2007 following several M4+ earthquakes), the magma can pass through this zone to intrude as dikes further down the rift. Inflation of the deeper sills may serve as a proxy for the degree of pressurization in Kilauea's shallow system. We also will discuss 2008-2011 InSAR data and their implications for magma storage within Kilauea's rift zone.

Anderson, Kyle R.

The Shallow Magmatic System at Kilauea Volcano: Insights from Episodic Ground Tilt

Anderson, Kyle R.[1]; Poland, Michael[1]; Miklius, Asta[1]

1. Hawaiian Volcano Observatory, Hawaii National Park, HI, USA

Episodic ground tilt has been observed at the summit of Kilauea Volcano for more than a decade. These deflationary and inflationary tilt cycles, termed "DI" events, typically last 1-4 days and are often followed after a delay of 30-90 minutes by similar behavior at the Pu`u `O`o eruptive vent, 20 km from the summit. While the events are most likely related to cycles of pressurization and depressurization in the magmatic plumbing system, the cause of this behavior is unclear. To date, more than 300 events have been recorded. To gain insight into the DI source mechanism, its evolution with time, and its relation to other volcanic processes, we carry out an investigation using tilt data collected since 1999, inverting the data using a kinematic model of a magma chamber in a homogenous elastic medium. We invert to estimate, among other parameters, the location of the source and its magnitude (volume times pressure change). Although simple kinematic models of this type cannot generally be used to independently constrain both the volume of the source and its pressure change, the summit lava level (when present) has closely tracked tilt events and suggests that both respond to variations in shallow magma reservoir pressure. Variations in lake level can be used to help constrain changes in magma reservoir pressure associated with tilt events, and therefore to place bounds on absolute volume of the reservoir. Future work will involve development of a physics-based model of DI events which will also allow us to use additional datasets (e.g., seismic, gravity, gas emissions, etc.) to constrain inversions, and will help us to explain the time evolution of the tilt signal during events and the relationship to tilt at Pu`u `O`o.

Badger, Nickles B.

Infrasonic jetting from the Kamoamoa fissure eruption, Kilauea Hawaii, 5–9 March 2011

Badger, Nickles B.[1]; Garces, Milton A.[1]; Perttu, Anna B.[1]; Poland, Michael[2]; Thelen, Weston[2]

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Following months of elevated seismic tremor and inflation at Kilauea Volcano, Pu`u `O`o and Hale`mau`mau craters underwent rapid deflation associated with the 5 March opening of the Kamoamoa eruptive fissure. This eruption sequence was captured in its entirety by a four-element infrasound array located ~12.5 km NW of the fissure and orthogonal to its strike. Acoustic signals from this array provided real-time, high-fidelity spatial and temporal constraints on volcanic jetting associated with the fissure eruption. Fountaining along the ~2.3 km fissure varied substantially both spatially and in intensity. We carry out array processing of infrasonic jetting signatures in the 0.5 – 10 Hz frequency band, which appear to be associated with fountaining activity. Infrasonic observations over the course of the eruptive episode suggest that the fissure progressed away from Pu`u `O`o and toward Napau crater, with at least four clear shifts in jetting activity between opposite ends of the fissure. We also observe multiple spatially-separated source regions with distinct infrasonic signatures, suggesting different yet synchronous acoustic source processes. In addition we note a reduction in mean infrasonic frequency over time, which may be related to changes in the volume flux and fissure geometry as the eruption evolved.

Bagdassarov, Nikolai S.

Hindered crystal settling in magma chambers

Bagdassarov, Nikolai S.[1]

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Hindered settling of crystals in magmatic systems containing about 40 or more vol.% of crystals is a widespread phenomenon. It is called hindered settling for a reason — the added number of crystals in an enclosed area creates a slower-moving sedimentation mixture than would normally be expected from Stokes sedimentation. Hindered settling of magmatic crystals play a decisive role in time scaling of gravitational cumulates formation in crystallizing magma chambers, sills, or lava lakes of typically mafic to ultramafic composition. The laboratory study of hindered crystal settling can be performed by using a centrifuge furnace. A series of crystal settling experiments in partially molten two pyroxene gabbro is conducted in order to understand the relations between cumulus texture and evolution of the chemical composition at grain boundaries and in interior of magma chamber during the crystal-melt settling-floating process. The settling-floating experiments were conducted in a centrifuging furnace at 1235°C under atmospheric pressure during 6 hours and with an acceleration range between 1g to 1000g of partially molten gabbro samples with the grain size 100μm. One experiment at 1290°C with a higher degree of partial melting is conducted in order to appreciate the influence of temperature on cumulate and settling-floating compaction. The total formation time of adcumulates does not simply correspond to the added periods necessary for crystal settling and chemical compaction, as chemical compactions begins as soon as a few layers of crystals are settled. Nevertheless, gravitational crystal settling is about two orders of magnitude faster than chemical compaction and thus becomes negligible for the adcumulate forming process. Similar, the lithostatic pressure at the bottom of the crystal column increase with increasing compaction, but also this is a second order effect. Finally, the numerical modelling has been used to mimic the centrifuge experiments using a hindered sedimentation model and to compare with the experimental data. The centrifuge experiments and numerical model provide a good agreement for a chosen value of a hindrance exponent 4,7. Formation time and melt fraction evolution of Muskox layered intrusion have been revisited using the hindered sedimentation model calculations.

Bagnardi, Marco

The Galápagos style: space-geodetic observations of intrusions and eruptions at Fernandina and other Galápagos volcanoes

Bagnardi, Marco[1]; Baker, Scott[1]; Amelung, Falk[1]

1. Marine Geology and Geophysics, RSMAS - University of Miami, Miami, FL, USA

Like in Hawai'i, the volcanism in the Galápagos Islands is presumably originated by a mantle hot-spot. However, the dynamics of magma intrusion and eruption seem to be substantially different. Twenty years of geodetic observations have provided the opportunity to study multiple eruptions, subvolcanic intrusions and the inter-eruptive dynamics of magma storage at different volcanoes. A time history (1998 – 2011) of the surface displacement at Wolf, Darwin, Alcedo, Sierra Negra, Cerro Azul and Fernandina volcanoes is generated using Intereferometric Synthetic Aperture Radar (InSAR) data from multiple satellites. We identify periods of inflation and deflation at the summit of each volcano representing phases of magma accumulation and withdrawal within shallow reservoirs. Rates of deformation reach the highest values at Sierra Negra Volcano with peaks of several tens of cm/year. We also find evidence for subtle interactions between neighboring volcanoes. The latest eruptions at Fernandina (1995, 2005 and 2009) and Cerro Azul (1998 and 2008) volcanoes are covered by an incredible set of InSAR measurements that provides evidence for characteristic styles of dike intrusion. Eruptions from radial and circumferential fissures, the typical eruptive pattern in the western Galápagos Islands, are both observed. Models for these eruptions show that, at least at Fernandina, they are fed by intrusive bodies that start as sub-horizontal sills propagating from a shallow reservoir and rotate as they propagate toward the surface. Depending on the status of stress within the volcanic edifice they either propagate vertically and feed circumferential fissures around the summit or slightly rotate about a horizontal axis and erupt as shallow dipping dikes feeding radial fissures on the flanks of the volcano. At Fernandina we also study the occurrence of two subvolcanic intrusions that are associated with moderate seismicity. The InSAR data spanning these events represents the first geodetic evidence for this type of activity in the Galapagos Islands. The occurrence of subvolcanic intrusions could provide the explanation for enigmatic volcanic events such as the rapid uplift at Punta Espinoza in 1927 (Fernandina), at Urvina Bay in 1954 (Alcedo) and the caldera collapse at Fernandina in 1968.

Bagnardi, Marco

Evidence for interaction between the Galapagos Islands volcanoes

Baker, Scott[1, 2]; Bagnardi, Marco[1]; Amelung, Falk[1]

1. Marine Geology and Geophysics, RSMAS, Miami, FL, USA
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The Galapagos Islands volcanoes are some of the most active in the world producing 7 eruptions at 4 different volcanoes in the last 20 years. Given the remote location and the difficulties involved with in situ measurements, multi-satellite interferometric synthetic aperture radar (InSAR) time series provide an ideal method for measuring surface displacements by providing both spatially and temporally continuous measurements at these volcanoes for monitoring past and ongoing activity. We present results from small baseline subset (SBAS) InSAR time series that show correlations between neighboring volcanoes and we provide evidence supporting the nature of the observed interactions. Surface displacement measurements from space geodetic data provide evidence for four interactions between the volcanoes related to earthquake and eruptive activity. First, in late 2006 and 2007, earthquakes located near Fernandina and Alcedo influenced deformation at each of these volcanoes. The earthquakes are located along a lineament running between Fernandina, Alcedo and Darwin and are associated with deflation at the summit of Fernandina (Dec 2006 and Aug 2007) and Alcedo (Feb 2007). Second, the 2009 eruption at Fernandina marks the end of a period of rapid inflation at Alcedo (occurring since the Feb 2007 earthquake) as well as an end to steady inflation at Wolf that had been happening for over 10 years. Third, the 2008 eruption of Cerro Azul creates a lull in the rapid inflation of Sierra Negra that was occurring since it last erupted in 2005. Fourth, a rapid deflation event at Alcedo in May 2010 correlates with a pause in rapid inflation occurring at Fernandina since the end of the 2009 eruption. The time series analysis provides timing for these interactions and clues to the nature of the processes occurring at each volcano.

Ballmer, Silke

Studying temporal velocity changes with ambient seismic noise at Hawaiian volcanoes

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In order to understand the dynamics of volcanoes and to assess the associated hazards, the analysis of ambient seismic noise – a continuous passive source - has been used for both imaging and monitoring temporal changes in seismic velocity. Between pairs of seismic stations, surface wave Green's functions can be retrieved from the background ocean-generated noise being sensitive to the shallow subsurface. Such Green's functions allow the measurement of very small temporal perturbations in seismic velocity with a variety of applications. In particular, velocity decreases prior to some volcanic eruptions have been documented and motivate our present study. Here we perform ambient seismic noise interferometry to study temporal changes in seismic velocities within the shallow (<5km) subsurface of the Hawaiian volcanoes. Our study is the first to assess the potential for using ambient noise analyses as a tool for Hawaiian volcano monitoring. For our analysis, we use data from the USGS Hawaiian Volcano Observatory (HVO) seismic network from 05/2007 to 12/2009. Our study period includes the Father's Day dike intrusion into Kilauea's east rift zone in mid-June 2007 as well as increased summit activity commencing in late 2007 and leading to several minor explosions in early 2008. These volcanic events are of interest for the study of potential associated seismic velocity changes. However, we find that volcanic tremor complicates the measurement of velocity changes. Volcanic tremor is continuously present during most of our study period, and contaminates the recovered Green's functions for station pairs across the entire island. Initial results suggest that a careful quality assessment (i.e. visually inspecting the Green's functions and filtering to remove tremor) diminishes the effects of tremor and allows for resolution of relative velocity changes on the order of less than 1%. The observed velocity changes will be compared with known volcanic activity in space and time, and interpreted in view of underlying processes.

Belachew, M.

Imaging magma storage reservoirs beneath Sierra Negra volcano, Galápagos, Ecuador

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3. SOC, Southampton, United Kingdom

Ocean island volcanoes initiate and grow through repeated eruptions and intrusions of primarily basaltic magma that thicken the oceanic crust above melt production zones within the mantle. The movement of oceanic plates over the hot, melt-rich upwellings produces chains of progressively younger basaltic volcanoes, as in the Hawaiian chain. As the magma chambers feeding these volcanic systems discharge or fill, causing pressure changes, rapid vertical crustal movements and/or faulting may occur. Nowhere are these surface variations more pronounced than along the chain of 7 active volcanoes in the western Galápagos, each of which has a large, deep summit caldera. We report the distribution of seismicity from double-difference earthquake relocations using waveform cross-correlation, including a magma intrusion event on the south flank during June 2010. Seismicity on Isabela is primarily localized to the ring fault system and the sinuous ridge marking the trap-door fault system within the 10 km-wide caldera. The sinuous ridge is characterized by very shallow seismicity and compressional earthquakes, consistent with the Jonsson et al. [2005] model. Our results indicate that the circumferential faults are steep reverse faults. The zone of persistent, sometimes deep seismicity on the eastern rim may be the next eruption site. Three-dimensional visualization allows for better understanding of zones that have been interpreted as hydrofracture along the margins of the magma chamber(s), and establishes a framework for wavespeed and ambient noise tomographic imaging and geodetic-seismic state-of-stress investigations. With these results, we can revise and improve models of crustal accretion above mantle hotspots, and predictive models of ocean island eruptions.

Belachew, Manahloh

Dynamics of Dike Intrusions and 3D Velocity Structure beneath an Incipient Seafloor Spreading Center in Afar, Ethiopia

Belachew, Manahloh[1]; Ebinger, Cynthia[1]; Roecker, Steve[2]

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A rifting episode started in September 2005 with an intrusion of a 60 km-long mega-dike along the Dabbahu-Manda Hararo (DMH) rift segment in Afar, Ethiopia. Between 2005 and 2009 thirteen smaller volume dikes intruded different portions of the rift segment. Out of the 13 dikes, 9 were recorded on a temporary network of 44

three-component broadband stations. The dynamics of the dike intrusions are studied using the detailed analysis of the spatial and temporal distribution of dike-induced earthquakes and their source mechanisms. In addition, a 3D model of seismic velocity structure is determined using local earthquake travel time tomography algorithm. The dike-induced migration patterns of the earthquakes show the dikes were fed from a ~5 km-radius zone at the middle of the DMH segment, and traveled northward and southward along the rift axis. The dikes that propagated north of the mid-segment have higher propagation rates and short migration duration relative to the dikes that propagated south. Faulting and graben formation above the dikes occurs hours after the passage of the dike tip, coincident with the onset of low-frequency earthquakes, and accounts for the large percentage of seismic energy release during an intrusion. The large deficit between total seismic and geodetic moment estimates, and the similarity between total seismic slip and geodetic slip estimates on normal faults above the dikes indicates that dike inflation and most of plate boundary deformation occurs largely "aseismically". Local earthquake travel time tomography reveals low velocity zones at depths >13 km beneath the Dabbahu volcanic complex, and a broad zone of low velocity beneath the mid-segment. These regions are interpreted to be the magma source zones at different stages of the rifting cycle along the DMH rift segment. However, the lack of migrating seismicity originating from the Dabbahu volcano suggest that only the magma source zone beneath the Ado'Ale Volcanic Complex is actively feeding the dikes. The DMH rift segment is at the magmatic stage of the tectono-magmatic cycle proposed for slow spreading ridges, where magma intrusion from a mid-segment magma reservoir accommodates most of the plate boundary deformation, and tectonic forces are less important.

Bleacher, Jacob E.

Comparison of inflation processes at the 1859 Mauna Loa Flow, HI, and the McCartys flow field, NM

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Basaltic lavas typically form channels or tubes during flow emplacement. However, the importance of sheet flow in the development of basaltic terrains received recognition over the last 15 years. George Walker's research on the 1859 Mauna Loa Flow was published posthumously in 2009. In this paper he discusses the concept of endogenous growth, or inflation, for the distal portion of this otherwise channel-dominated lava flow. We used this work as a guide when visiting the 1859 flow to help us better interpret the inflation history of the McCartys flow field in NM. Both well preserved flows display similar clues about the process of inflation. The McCartys lava flow field is among the youngest (~3000 yrs) basaltic lava flows in the continental United States. It was emplaced over slopes of <1 degree, which is similar to the location within the 1859 flow where inflation occurred. Although older than the 1859 flow, the McCartys is located in an arid environment and is among the most pristine examples of sheet flow morphologies. At the meter scale the flow surface typically forms smooth, undulating swales that create a polygonal terrain. The literature for similar features includes multiple explanatory hypotheses, original breakouts from adjacent lobes, or inflation related upwarping of crust or sagging along fractures that enable gas release. It is not clear which of these processes is responsible for polygonal terrains, and it is possible that one explanation is not the sole cause of this morphology between all inflated flows. Often, these smooth surfaces within an inflated sheet display lineated surfaces and occasional squeeze-ups along swale contacts. We interpret the lineations to preserve original flow direction and have begun mapping these orientations to better interpret the emplacement history. At the scale of 10s to 100s of meters the flow comprises multiple topographic plateaus and depressions. Some depressions display level floors with surfaces as described above, while some are bowl shaped with floors covered in broken lava slabs. The boundaries between plateaus and depressions are also typically smooth, grooved surfaces that have been tilted to angles sometimes approaching vertical. The upper margin of these tilted surfaces displays large cracks, sometimes containing squeeze-ups. The bottom boundary with smooth floored depressions typically shows embayment by younger lavas. It appears that this style of terrain represents the emplacement of an extensive sheet that experiences inflation episodes within preferred regions where lateral spreading of the sheet is inhibited, thereby forming plateaus. Depressions are often the result of non-inflation and can be clearly identified by lateral squeeze-outs along the pit walls that form when the rising crust exposes the still liquid core of the sheet. Our current efforts are focused on detailed mapping of the McCartys flow field and modeling of the inflation process.

Bleacher, Jacob E.

A volcanic origin for sinuous and branching channels on Mars: Evidence from Hawaiian analogs

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4. Planetary Science Institute, Tuscon, AZ, USA

Observations of sinuous and branching channels on planets have long driven a debate about their origin, fluvial or volcanic processes. In some cases planetary conditions rule out fluvial activity (e.g. the Moon, Venus, Mercury). However, the geology of Mars leads to suggestions that liquid water existed on the surface in the past. As a result, some sinuous and branching channels on Mars are cited as evidence of fluvial erosion. Evidence for a fluvial history often focuses on channel morphologies that are unique from a typical lava channel, for instance, a lack of detectable flow margins and levees, islands and terraces. Although these features are typical, they are not necessarily diagnostic of a fluvial system. We conducted field studies in Hawaiʻi to characterize similar features in lava flows to better define which characteristics might be diagnostic of fluvial or volcanic processes. Our martian example is a channel system that originates in the Ascraeus Mons SW rift zone from a fissure. The channel extends for ~300 km to the SE/E. The proximal channel displays multiple branches, islands, terraces, and has no detectable levees or margins. We conducted field work on the 1859 and 1907 Mauna Loa flows, and the Pohue Bay flow. The 51-km-long 1859 Flow originates from a fissure and is an example of a paired ʻaʻā and pāhoehoe lava flow. We collected DGPS data across a 500 m long island. Here, the channel diverted around a pre-existing obstruction in the channel, building vertical walls up to 9 m in height above the current channel floor. The complicated emplacement history along this channel section, including an initial ʻaʻā stage partially covered by pā hoehoe overflows, resulted in an appearance of terraced channel walls, no levees and diffuse flow margins. The 1907 Mauna Loa flow extends > 20 km from the SW rift zone. The distal flow formed an ʻaʻā channel. However the proximal flow field comprises a sheet that experienced drainage and sagging of the crust following the eruption. The lateral margins of the proximal sheet, past which all lava flowed to feed the extensive channel, currently display a thickness of < 20 cm. Were this area covered by a dust layer, as is the Tharsis region on Mars, the margins would be difficult to identify. The Pohue Bay flow forms a lava tube. Open roof sections experienced episodes of overflow and spill out. In several places the resultant surface flows appear to have moved as sheet flows that inundated the preexisting meter scale features. Here the flows developed pathways around topographic highs, and in so doing accreted lava onto those features. The results are small islands within the multiple branched channels that display steep, sometimes overhanging walls. None of these features alone proves that the martian channel networks are the result of volcanic processes, but analog studies such as these are the first step towards identifying which morphologies are truly diagnostic of fluvial and volcanic channels.

Burton, Mike

Recent advances in measuring and interpreting volcanic gas emissions

Burton, Mike[1]

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Volcanic gas emissions are surface manifestations of the sub-surface magmatic processes which drive volcanic activity, and as such their measurement and interpretation can be of critical importance in forecasting eruptions and quantifying mass budgets for magmatic systems. Recent advances in gas flux measurements, particularly of SO2 (thanks to its fortuitous ultraviolet absorption spectrum), now allow unprecedented insight into such processes. Here I present a review of three different approaches which have revealed time series variations in SO2 emissions using a variety of diverse but related methods. I conclude by examining the current challenges which exist in our ability to accurately interpret results arising from these novel methods.

Cabral, Rita A.

Oceanic gabbro signature in Mangaia melt inclusions: Source versus assimilation

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Lavas from Mangaia are isotopically homogeneous and exhibit an extreme HIMU (high-μ, or high $^{238}U/^{204}Pb$) signature that has been attributed to the melting of ancient recycled oceanic crust within their mantle source. In a landmark study, Saal *et al.* (1998), measured extreme lead isotopic diversity in melt inclusions from Mangaia despite observing homogeneous whole rock Pb-isotope ratios. In Pb-isotopic space, data from the melt inclusions span half of the global range observed in ocean island basalts (OIBs) and display a trend towards an unradiogenic end member similar to MORB. However, the origin of Pb-isotope diversity and the identity of the unradiogenic end member could not be unambiguously resolved due to lack of coupled major-trace-

volatile element abundances for the melt inclusions. This study examines homogenized olivine-hosted melt inclusions in Mangaia lavas. We present the first coupled measurements of major-trace-volatile element abundances and Pb-isotopic measurements on the same melt inclusions. Critically, the Pb-isotopic ratios correlate with ratios of major, trace, and volatile elements. For example, the anomalous melt inclusions with Pb-isotopic ratios trending toward MORB exhibit geochemical signatures associated with oceanic gabbro, including elevated Sr/Nd and Ca/Al, and signatures associated with seawater alteration, including elevated (Cl, K, H_2O)/La. It is difficult to constrain the origin—the modern Pacific plate beneath Mangaia or ancient recycled lithosphere—of the gabbroic signature in Mangaia melt inclusions. One hypothesis is that the gabbroic signature in the melt inclusions derives from melting of the gabbroic section of ancient, recycled oceanic crust. Alternatively, Saal *et al.* (1998) suggested that a gabbroic signature in OIB lavas could derive from shallow assimilation of gabbros during magmatic ascent. The primary difference between these two hypotheses is that the former requires gabbros processed in a subduction zone, and the latter does not. The elevated (Cl, K, H_2O)/La in the anomalous melt inclusions is not consistent with subduction zone processing, as Cl, K, and H_2O are fluid mobile and should be lost from the down-going slab. By contrast, altered oceanic gabbros have elevated (Cl, K, H_2O)/La. Based on the current dataset, we favor the hypothesis that the anomalous gabbro signature (and Pb-isotopic diversity) in Mangaia melt inclusions owes to assimilation of Pacific oceanic crust during magmatic ascent. This work has implications for melt inclusion studies done at other OIB localities through the use of coupled major-trace-volatile element abundances and Pb-isotopic measurements in the same inclusion. It also suggests that assimilation of oceanic crust during magmatic ascent may play an important role in modifying the geochemisty of melt inclusions, thereby providing insight to how assimilation processes can modify the geochemistry of whole rock lavas.

Calvari, Sonia

Monitoring Active Basaltic Volcanoes: New Techniques and Novel Results

Calvari, Sonia[1]

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The first, most common and widespread monitoring system applied to active basaltic volcanoes comprises a seismic network, used especially for detecting volcano unrest, the opening of eruptive fissures, or magma movement within the crust. This might be integrated by ground deformation systems such as tiltmeters, GPS (Global Positioning Systems) and/or EDM (electro-optical distance measurements). All together, these instruments allow a characterization of the shallow feeding system where persistent explosive activity might concentrate. They are also used to detect, localize and follow dikes emplacement, and their rise through the crust. Seismicity and ground deformations can also be useful to identify volcano instability, such as spreading, sliding or collapsing. After the 2001 and 2002-03 eruptions at Etna, forecasting lava fountains for air traffic safety became essential. Important information on impending lava fountain events at Etna and Stromboli volcanoes (southern Italy) have been recently furnished by a network of UV scanners, that allows us a continuous detection of the SO_2 flux released by the summit craters during the day. The accumulation of a foam of gas-rich magma at depth is in fact forecasted by a significant reduction of the SO_2 flux released by the summit craters a few hours before the start of the explosive event. SO_2 flux then increases by a factor of 10 or more after the conduit is opened by the emission of the gas-poor magma accumulated at the top, giving rise to the start of a fountain event. Once that the magma has found its way to the surface, it is important to follow its spreading in the air or on the ground when it forms lava fountain jets, sustained eruptive columns or lava flows. This is essential in order to describe the event, quantify the erupted material, and thus prepare the population to face the hazard and forecast its evolution. Significant results to this aim have been obtained by thermal imagery, using either portable or fixed cameras, and more recently especially from thermal sensors installed on satellites. Remote sensing thermal imagery allows a fast and safe update of the eruptive phenomena, a quantification of the erupted volume, and the collection of data that can be used in models predicting lava flow spreading or ash plume dispersion. Based on lava flow cooling curves, we have also developed a method of retrieving lava volume from satellite thermal images even when ash clouds obscure these. Low-cost radiometers installed in fixed positions close to the eruptive vents have also provided an important first alert, suggesting the possible start of explosive activity. Electric devices installed at Stromboli close to the eruptive vents have provided a quantification and characterization of the erupted ejecta, allowing recognizing the contribution of magma-water interaction in producing powerful vulcanian-type events. But the most striking results up to date have been obtained by the recently installed strainmeters, that on both Etna and Stromboli volcanoes evidenced deep processes occurring in the plumbing system, detecting medium to deep magma storage zones and allowing also an estimation of the speed of rising magma.

Caplan-Auerbach, Jackie

Multiplet Analysis of Earthquake Swarms and T-phases at Lo`ihi Submarine Volcano

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As the only example of a Hawaiian volcano still in the submarine phase, Lo`ihi provides an excellent opportunity to investigate the youthful stage of volcanic evolution. A primary means by which volcanic activity may be studied is through analysis of a volcano's earthquakes: hypocentral locations, temporal distribution, and the types of events recorded. Seismic monitoring of Lo`ihi has taken place for ~50 years, during which time numerous earthquake swarms have been recorded, providing insight into the volcano's level of activity and internal magmatic processes. Unlike earthquakes recorded at the older subaerial Hawaiian volcanoes, Lo`ihi's earthquakes do not clearly align with its summit and rift zones. Swarm events locate beneath Lo`ihi's northeast and southwest flanks, with the exception 1996 and 2005 swarms which locate beneath the summit platform. All of these locations are compromised, however, by Lo`ihi's position outside of the permanent seismic network operated by the Hawaiian Volcano Observatory. In this re-examination of Lo`ihi earthquake swarms we use cross-correlation to further investigate the types of earthquakes occurring beneath Lo`ihi and evaluate the relationship between earthquake swarms. Cross correlation of events in the 1996 swarm shows that the swarm comprised a large number of multiplets, clusters of earthquakes that are highly similar in time series. Similar events represent a repeating earthquake source, but catalog locations of these events span several kilometers, confirming that the events are poorly located. Using cross-correlated arrival times we relocate Lo`ihi earthquakes using a relative location technique in order to further investigate the relationship between the swarm and subsurface eruptive processes. While catalog locations extend over a broad region the multiplets locate in a tight cluster. Absolute locations are poorly constrained, but comparisons to catalog locations for the largest, and presumably best located events within the cluster places the cluster beneath the summit platform. The multiplets overlap one another temporally, and many endure for days or weeks. We propose that these events represent slip on a plug overlying a magma reservoir, the sinking of which generated the crater known as Pele's Pit. In contrast, earthquakes recorded in 1995 and 2005 show relatively little similarity, with only a few multiplets recorded on land-based stations. Seismograms from shallow Lo`ihi earthquakes recorded on coastal stations exhibit strong T-phases that also show waveform similarity. Correlations between T-phases are weaker than correlations between their associated body waves. Variations in T-phases could provide insight into subtle changes in earthquake locations.

Carey, Rebecca J.

Shallow triggered renewed bubble nucleation in basaltic magmas: Halema'uma'u 2008

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Kilauea volcano on the Big Island of Hawai'i has been continuously active since 1983, and is one of the most well studied volcanoes on Earth. Recent new eruptive activity from the summit crater of Kilauea has provided an exceptional opportunity to probe and further the understanding of basaltic magmatic processes. The proximity of the Hawaiian Volcano Observatory (HVO) to the recent activity, diverse range of monitoring networks, and expertise of the HVO scientists have provided the research community with a wealth of data and observations of both 'open system' passive degassing, and explosive punctuations of this activity. Background activity at the new summit vent in March - October 2008 reflected conditions of relatively open-system degassing. Rockfalls into the active lava lake have enlarged the vent from 35m to presently 150 m. These rockfalls into the lava lake have triggered explosive eruptions and punctuated the steady degassing at the summit. The direct role of rockfalls inducing more explosive behavior is complex and elusive. The microtextures of erupted clasts are the only record of the state of the magma at the time of explosive fragmentation, and combined with theory and laboratory experiments, can be related back to magma ascent and degassing processes. I will present microtextural observations and data from erupted clasts in 2008, and propose a new model for a potential mechanism for the explosive punctuations.

Carn, Simon A.

Three decades of satellite monitoring of Hawaiian volcanic sulfur dioxide emissions

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As any resident of Kona or Honolulu will attest, the active Hawaiian volcanoes (Kilauea and Mauna Loa) can be strong sources of sulfur dioxide (SO_2) and derived sulfate aerosol ('vog') in the otherwise relatively pristine atmosphere of the central Pacific region. In addition to the impacts of volcanic emissions on health and air quality, SO_2 production has also been used as a proxy for lava effusion rate at Kilauea. Hence the Hawaiian Volcano Observatory (HVO) has monitored SO_2 emissions from Kilauea on a regular basis since 1979 [Elias et al., 1998]. Global satellite monitoring of SO_2 emissions began with the ultraviolet (UV) Total Ozone Mapping Spectrometer (TOMS) instruments in 1978. TOMS was not sensitive to most passive volcanic degassing of SO_2, but beginning in January 1983 the sensor did detect SO_2 emissions associated with lava fountaining events during 44 of the 48 episodes of the 1983-86 Pu'u 'O'o – Kupaianaha eruption. The onset and duration of the lava fountaining events is accurately constrained by eruption tremor, or other eruptive manifestations such as glow or audible roar. Knowledge of the timing of the TOMS overpasses permits calculation of SO_2 fluxes that are independent of wind speed, which can be a major source of error in SO_2 flux evaluation. The TOMS observations provide some unique constraints on SO_2 emission rates, and by proxy lava production rates, during the lava fountaining episodes, only 11 of which were captured by airborne COSPEC measurements [Casadevall et al., 1987]. The airborne measurements also suffered from saturation due to the high abundances of SO_2 in the fountain-fed plumes. Constraints on degassing in lava fountains are important since gas release exerts a control on the residual gas content and vesicularity of fountain-fed lava flows, which in turn affects lava rheology and hence subsequent flow behavior. TOMS also detected SO_2 emitted during the March 1984 eruption of Mauna Loa, which coincided with episode 17 of the Pu'u 'O'o – Kupaianaha eruption. The Mauna Loa eruption produced daily SO_2 loadings of ~200 kilotons or more, the highest measured to date in Hawaii. The resulting sulfate haze affected visibility at airports throughout the Pacific and reached Guam, more than 6000 km WSW of Hawaii. Since September 2004 the UV Ozone Monitoring Instrument (OMI) on NASA's Aura satellite has monitored SO_2 emissions from space, replacing TOMS. OMI has increased sensitivity to passive volcanic degassing, and detects the tropospheric SO_2 plume from Kilauea on a daily basis, providing valuable information on SO_2 emissions and plume dispersion. We will summarize ~8 years of OMI measurements of SO_2 degassing from Kilauea, including their relationship to major events such as the onset of the summit Halema'uma'u eruption in March 2008, but also more subtle, transient events such as lava high-stands and vent blockages, validating the use of OMI as a useful monitoring tool.

http://so2.gsfc.nasa.gov

Cayol, Valerie

Magma assisted extension in an immature continental rift, based on InSAR observations of Nyamuragira and Nyiragongo Volcanoes

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The active Nyamuragira and Nyiragongo volcanoes belong to the western branch of the east African rift. Both volcanoes are characterized by different preferencial diking directions associated with different eruptive behavior, suggesting that plate extension controls the eruptive style. Most of Nyamuragira dikes trend 40° from the rift axis, indicating that their direction is probably controlled by Precambrian basement faults [Smets et al., 2010], whereas Nyiragongo dikes trend parallel to the rift axis indicating that their direction is controlled by rifting. Nyamuragira erupts every other year, whereas only two historical eruptions of Nyiragongo have been recorded, in 1977 and 2002. Modelling of InSAR displacements show that Nyamuragira's recent eruptions are characterized by a ratio of intruded to erupted magma volume of 0.1, similar to the ratio determined at basaltic shield volcanoes such as Piton de la Fournaise [Fukushima et al., 2010] or Kilauea [Cayol et al., 2000; Poland et al., 2012]. On the other hand, the 2002 Nyiragongo eruption is characterized by an intruded to erupted magma volume ratio of 10, lower than the ratio determined in other rift contexts, but similar to the ratio determined at the end of the Krafla rifting episodes when rift extension was balanced by successive dike intrusions [Buck et al., 2006]. These volume ratios are inconsistent with this part of the rift extension driven uniquely by plate separation. At both volcanoes, we infer low overpressures (1 – 10 MPa) for the dikes, which is not predicted for a rift driven by plate tectonics. These values are consistent with isotropic lithostatic stresses close to the dikes, which can be attributed to the high eruption rate producing compressive stresses which are too great to be relaxed by the rift extension. As a consequence, Nyiragongo preferencial intrusion direction is probably not controlled by stresses but rather by a reduced tensile strength, inherited from previous rift intrusions. Such a stress state is incompatible with stretching of the crust via normal faulting and indicates that, although the rift is considered immature, strain localizes in magmatic segments and the rift extension is accommodated by the supply of magma from depth, rather than by faulting. The small amount of thinning in the western branch of the East

African Rift indicates that magma is not generated by adiabatic decompression of the mantle, but instead is probably supplied by a lateral flow of the mantle plume beneath East Africa [Ebinger, 1999].

Cayol, Valérie

NINE YEARS OF INSAR MONITORING AT PITON DE LA FOURNAISE RESULTS AND PERSPECTIVES

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Since 2003, systematic InSAR monitoring of the Piton de la Fournaise volcano, Reunion Island, has been carried out at the "Observatoire de Physique du Globe de Clermont-Ferrand". In 2010, this monitoring activity was integrated as a component of the French National Service for Volcanological Observations. In the framework of this monitoring, ENVISAT-ASAR, ALOS-PALSAR, RADARSAT-2, TerraSAR-X, TanDEM-X and COSMO-SkyMed data, supplied for free or low cost by ESA, JAXA, CSA-MDA, DLR and ASI, were used to produce interferograms. Based on these interferograms, the ground surface displacements related to 23 successive eruptions (from August 2003 to December 2010) have been measured. The interferometric data reveal two main categories of eruptions in terms of displacement pattern produced. Proximal eruptions (i.e., from vents localized at the summit or on the flank of the Piton de la Fournaise Central Cone) generally give an asymmetric displacement pattern, typical for eruptive fissures resulting from dike injection. In contrast, distal eruptions (i.e., from vents localized more than 3-4 km from the Central Cone) give a large displacement pattern assumed to be related to sill intrusion. The 2007 eruption differs significantly from this general scheme as the interferograms spanning this eruption show the superimposition of classic intrusion-related displacements with a large seaward sliding of the eastern flank of Piton de la Fournaise. Here we will present examples of these different eruptions as imaged with InSAR and will discuss ways in which the displacements can be used to provide information on the physical nature of the magma feeder system and on the way in which magma moves through this feeder zone. We will also show how the high resolution interferograms obtained by combining new X-band radar (TSX, TDX, CSK) with a 5 m lidar DEM produced on Reunion Island in 2008-2009 offer new applications for volcano monitoring, such as accurate characterization of the volume of material emplaced during an eruption.

http://wwwobs.univ-bpclermont.fr/SO/televolc/volinsar/indexEN.php

Chadwick, Bill

Comparison of Inflation/Deflation Cycles at Hawaiian Volcanoes and at Axial Seamount

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Axial Seamount is a basaltic submarine hotspot volcano on the Juan de Fuca spreading ridge, located 270 miles from the Oregon coast in the NE Pacific. It has a summit caldera that is 3 x 8 km across, ~100 m deep, with a floor at ~1500 m depth, and it has two rift zones extending north and south from the summit. It is the only submarine volcano in the world where an inflation/deflation cycle has been documented, using precise pressure sensors to measure vertical movements of the seafloor at the volcano's summit. Large (2-3 m), brief (6 day) deflation events were recorded during the last two eruptions at Axial Seamount in January 1998 and April 2011. Both of these eruptions occurred on the south rift zone and were fed by major dike intrusions that extend 30-50 km away from the summit (sub-caldera) magma reservoir. In the 13 years between the 1998 and 2011 eruptions, gradual inflation was measured at an average rate of 15 cm/yr. This pattern of re-inflation was used to successfully forecast the timing of the 2011 eruption, within a relatively wide time window of several years. In addition, for several months before and after both the 1998 and 2011 eruptions at Axial, the inflation rate was markedly higher, suggesting different pre- and post-eruption processes affecting the magma reservoir system. Here, we compare the inflation/deflation record at Axial Seamount to those at Kilauea and Moana Loa volcanoes in Hawaii to highlight similarities and differences between their patterns of deformation and examine implications for their underlying magmatic cycles. Specific comparisons will include: long-term inflation and magma supply rates between eruptions, rates of deflation and volumes of magma removed from summit reservoirs during diking events, rates of lateral dike propagation, both long-term (months-years) and short-term (minutes-hours) precursory signals before intrusions and eruptions, and the feasibility for eruption forecasting based on these data. One of the goals of this study is to assess whether or not the inflation/deflation cycle at Axial Seamount may be more repeatable (and therefore predictable) than at basaltic volcanoes on land, due to its location on thin oceanic crust at a seafloor spreading center.

Chaput, Marie

Sill zones and stress permutations: an alternative to the Hawaiian model of basaltic volcano deformation

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The deformation of Hawaiian volcanoes commonly implies the combined influence of a slip along a basal decollement and recurrent dike injections in linear rift zones. Such interplay between magma intrusions and deformation was investigated on Piton des Neiges (La Réunion Island), one of the world's largest basaltic shield volcano (~200 km in diameter, ~7000 m high). Intense erosion incised deep depressions around the summit in which the volcano inner structure outcrops. In the lower structural units of the northern depression (Salazie), piles of ~50 sheeted sills (i.e., sill zones), dipping 30° to the north, are intruded between a gabbroic body and debris avalanche deposits. Two perpendicular dike trends are evidenced in Salazie, oriented N90-130° and N00-40°. In the northwestern depression (Mafate), a rift zone trending N120-140° constitutes the western continuity of the N90-130° dike trend of Salazie. Fault-slip data analysis reveals the dominance of two perpendicular extensions N20° and N110° in the whole edifice. Compressive stress fields are also recorded, but only in the sill zones. The consistency between intrusion and stress orientations suggests a strong interplay between magma input mechanisms and stress organization on Piton des Neiges. Perpendicular extensions are explained by stress permutations caused by recurrent magma injections in rift zones. The final step of stress permutation yields to compression that enables sill injections. Sills tend to promote the lateral creep of the volcano flank and consequently restore extensive conditions and subsequent dike intrusions. Thus, sill zones constitute outward dipping detachment planes in the edifice. According to our results, two models of basaltic shield volcano deformation have to be considered: - The "Hawaiian" model, implying slip along a basal decollement. The constant extensive conditions favor repeated dike intrusions in well-developed rift zones, as evidenced in Kilauea and Mauna Loa volcanoes. - An alternative model of volcano deformation, the "Réunion" model, implying no or a poorly active basal decollement. Recurrent magma intrusions lead to stress permutations, which favor perpendicular rift zones and sill injections in outward detachments. This model may explain sill development and volcano destabilization for La Palma, La Gomera or Kauai volcanoes.

Chistyakova, Sofya

Magma differentiation and crystallization in basaltic conduits by two competing petrogenetic processes

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Magma differentiation processes that operate in conduits delivering basaltic magmas towards the Earth's surface still remain poorly understood. To get insight into this problem we have studied in detail whole-rock geochemistry of one section across a large dolerite dyke (21 m thick) and three sections across its narrow apophysis (69 cm, 29 cm and 17 cm thick) from the Fennoscandian Shield, Russia. The dyke is remarkably fresh, phenocryst-free with no apparent in situ contamination by crustal rocks. Chemical zonation is found to systematically change with a decreasing thickness of studied sections. In particular, a tendency to become more primitive inwards in a large dyke (e.g. an increase in MgO, Mg-number, normative An content and a decrease in P2O5) gives way to an opposite tendency to become more evolved inwards in narrow apophysis sections (e.g. a decrease in MgO, Mg-number, normative An content and an increase in P2O5). In addition, the chemical zonation of the apophysis is compositionally anomalous since compatible and incompatible components behave in a manner inconsistent with predictions of fractional crystallization of basaltic magma. To explain the spatial chemical zonation, we introduce a novel concept that attributes compositional trends in mafic dykes to a competitive operation of two petrogenetic processes. These are (a) the filling of dykes with magmas that become increasingly more evolved with time as a result of magma fractionation in deeper parts of conduits and (b) in situ cumulate growth against dyke sidewalls accompanied by effective removal of an evolved liquid boundary layer from growing crystals by the continuously inflowing magmas. The processes have opposite effects on rock geochemistry, with the first making dykes more evolved and the second more primitive inwards. A key idea is that dykes become more evolved inwards when quenching of inflowing magmas controls the distribution of all components, and become more primitive inwards when in situ cumulate growth governs the distribution of all components. Anomalous compositional trends develop when these two processes control the distribution of different groups of chemical components. The studied spatial chemical zonation can be attributed to a change from rocks mostly produced by quenching of progressively more evolved magmas (an apophysis) towards those predominantly formed by in situ cumulate growth of these magmas (a large dyke). This happens in response to the decreasing extent of magma (super)cooling in this direction. We believe that the combined operation of two competing petrogenetic processes is likely a general feature of magma differentiation and crystallization in basaltic conduits.

Clague, David

A 200-year look at Hawaiian volcanism—the last and the next 100 years

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In the past 100 years, our understanding of Hawaiian volcanoes has benefitted from increasingly sophisticated technologies and modeling of the partial melt origins of the lavas, the geometry of the magma transport and storage system, magmatic processes that occur along that pathway, and eruption dynamics and flow emplacement. At the same time, the long-term evolution of the volcanoes has been defined and refined and is still evolving as additional mapping and sampling of the subaerial and submarine parts of the volcanoes continues, with new and better geochemical studies and age dating of the flows. Many questions about how volcanoes work remain to be solved in the next 100 years. A primary question that remains is the depth at which Hawaiian magmas are generated. The best constraints from geophysics are the ~60 km depth of the deepest earthquakes related to magma migration and, from petrology, the phase equilibria of mantle xenoliths transported to the surface in some early and late alkalic magmas. A second question is a better understanding of the triggers that separate a small slippage of the island flanks from the catastrophic landslides that extensively modify the landscape and cause giant tsunami. Data like seismicity, deformation, gas emissions, and observations on the ground will almost surely continue to be the routine monitoring data that will be collected, but the equipment used to collect these data and its analysis will become ever more automated and remote. Models of what these data streams are telling us a volcano is doing or is about to do will become more sophisticated and more accurate as ever more different volcanoes and types of volcanoes are routinely monitored in a world where ever more people live within high hazard zones. Volcanologists are likely to provide and assess real-time data on a global scale, much like current weather or severe weather reports and warnings. The role of volcanologists will evolve from data collection and interpretation primarily to improve our understanding of volcano behavior, to working with government agencies, non-government organizations, and companies who plan land use, develop emergency plans, respond to emergencies, and minimize risk to people and property to a far greater degree. All these changes will require a much greater role of scientists in public education so the populations living in hazardous areas understand their surroundings. The Hawaiian Volcano Observatory should continue to play a significant role in public education and in training the next generation of volcanologists within the USGS, US and foreign academics, and from government agencies in the developing world, where the greatest risk from volcanic activity is concentrated. Kilauea (and Mauna Loa) remains among the safer active volcanoes in which to learn the tools of the trade. Activity in Hawaii will also change in the next 100 years with eruptions to monitor from Kilauea, Mauna Loa, and perhaps from Hualalai or Haleakala as well. Are we ready?

Colella, Harmony V.

Seismicity rates changes during episodic fountaining in the early stages of Pu`u O`o at Kilauea volcano, Hawaii and possible implications for magma storage and supply to Pu'u O'o

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The early stages of the Pu'u O'o-Kupaianaha eruption March 1983 – June 1986 allows for observation of the evolution of a lateral conduit system. During this time the Kilauea summit experienced 47 inflation-deflation event cycles with periods of approximately 30 days. Periods of inflation were characterized by accelerating rates of shallow tectonic earthquakes, or short period events, and punctuated by rapid deflation of the summit, a spike in volcanic earthquakes, or long period events, and fountaining at Pu'u O'o. This cycle is understood to be driven by magma accumulation beneath the summit followed by downrift transport to the eruption site. We employ the earthquake rate formulation from rate-state dependent friction to quantify Coulomb stress changes during deflation cycles at Kilauea volcano. The cumulative number of short period events during this phase of the eruption exhibits three distinct increases in earthquake rates, which coincide with increases in rates of deflation at the end of each cycle. Coulomb stress changes reveal the strongest stress change, a decrease in stress, occurs during deflation and is located away from the summit near Puhimau pit crater. We propose the increase in earthquake rates represent the breakdown or clearing of obstructions near the summit region, while the increase in deflation rates represents a shift from a "clogged" conduit to a more "free flowing" conduit between the Kilauea summit to the Pu'u O'o-Kupaianaha eruption site. Additionally, results from Coulomb stress changes suggest a possible secondary magma reservoir along the East Rift Zone or the location of the "clog" in the conduit.

Courtier, Anna M.

Structure of the Transition Zone and Upper Mantle beneath the Hawaiian Islands: Implications for Mantle Heterogeneity and Upwelling

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Using recently available data from the Hawaiian Plume-Lithosphere Undersea Melt Experiment (PLUME), we are able to present new images of upper mantle structure beneath the Hawaiian Swell. We conducted a detailed analysis of Ps converted waves, yielding a model of the mantle transition zone beneath the Hawaiian Islands and surrounding area. We find that there is substantial thinning in the transition zone over a broad region beneath the islands, consistent with the presence of a thermal anomaly at depth. We observe transition zone thinning both in the presumed plume location "upwind" of the Big Island, as well as beneath the islands of Maui and Hawaii. In addition to topographic variability along the boundary between the upper mantle and transition zone (the 410-kilometer discontinuity), we observe a low-velocity zone in the deep upper mantle beneath a significant portion of the study area. Similar features have been interpreted as signals of volatile-induced melting in other tectonic settings, though a different mechanism may be required to explain these observations beneath ocean islands. The low-velocity zone could also be a signature related to the base of small-scale convection in the upper mantle, perhaps related to local upper mantle anisotropy. The observations presented in this study represent key new data for testing chemical, mechanical, and dynamical models of the oceanic upper mantle.

Craddock, Robert A.

Basaltic Sand Dunes In The Ka'u Desert And Their Relationship To Kilauea Phreatic Eruptions

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Dark, fine-grained sediment is distributed over much of the surface of Mars. Frequently this sediment accumulates as dunes on the floors of craters or against topographic obstacles. Analyses of the mineralogy of these materials from multispectral data has established that they are dominantly mafic in composition and are most likely derived from volcanic tephra and the weathering of basaltic lavas. While common features on Mars, dunes consisting of basaltic sediments are rare on Earth. However, the dunes that have resulted from phreatic eruptions at Kilauea are one notable exception. The objectives of this study are to (1) determine the emplacement history of basaltic dunes located in the Ka'u Desert of Hawaii and their relationship to past phreatic eruptions in order to assess the extent to which sediments have been transported and reworked, (2) determine the changes in physical and chemical characteristics of basaltic sediments derived from the Keanakākoʻi Tephra as they are transported by eolian processes, and to (3) acquire the visible to near-infrared spectra of terrestrial basaltic sediments in order to better interpret remote sensing data from Mars. There are several dune types in the Ka'u Desert, including both climbing and falling dunes, parabolic dunes, crescentic dunes, and sand sheets. I will present the techniques were are developing to analyze and age-date the dunes in the Ka'u Desert with particular emphasis on a large, climbing dune located along the Kalanaokuaiki Pali fault scarp at 19° 20' 39" N, 155° 18' 26" W. This dune is ~6-7 m high and ~700 m long. Its surface is dominated by coarse-grained basaltic sand composed primarily of lithic and vitric fragments, olivine, feldspar, and pyroxene. Augering reveals that this basaltic sand occurs to depths of ~3 meters although a thin (<15 cm) clay-rich interbed also occurs at variable depths within this unit. Cross-bedding is well developed throughout most of this deposit, suggesting that it has aggraded over time from eolian activity. Below ~3 m depths the dune is composed of vitric-rich sand. Our preliminary analyses show that many of these particles are fragile (e.g., consisting of glass rods). When compared to the vitric-rich part of the Keanakako'i Tephra, it is clear that these deposits have also been transported by eolian processes, suggesting that tephra was being reworked as it was being emplaced.

A climbing dune located along the Mauna Iki Trail. At 6.7 m high, this may be the largest basaltic climbing dune in the world. Dune forms such as these are common features on the surface of Mars.

Davies, Ashley G.

Kilauea, Hawai'i, as an analogue for Io's volcanoes

Davies, Ashley G.[1]

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The jovian satellite Io is intensely volcanic [1] with a wide range of styles of explosive and effusive activity [1,2]. Although Io's eruptions have effusion rates that dwarf those of their terrestrial contemporaries, Kilauea is an excellent terrestrial analogue for much of Io's volcanic activity. As seen by visible and short-wavelength infrared instruments on the NASA Voyager, Galileo and Cassini spacecraft, and utilizing multi-decadal ground-based telescope observations, many of Io's volcanic eruptions are very similar to what is seen almost every day at Kilauea. The Io volcano Prometheus, for example, is persistently active; shows episodic activity; has emplaced extensive lava flows with pahoehoe-like insulated crusts, probably through a lava tube system; is likely supplied from a shallow reservoir [e.g., 1]; and creates a dust and gas plume through interaction with volatiles on the surface as well as from the main vent. At other locations on Io, as in Hawai'i, larger-volume eruptions create open-channel, possibly turbulent, lava flows. Kilauea's persistent lava lakes have contemporaries at Pele and (perhaps) Janus Patera on Io, where thermal emission spectra are similar to those of active terrestrial lava lakes undergoing regular, rapid resurfacing. In other locations on Io, lava fountains erupt along fissures. All of these processes are observed and recognized by workers studying Kilauea. The difference with Io is that effusion rates are generally one or more orders of magnitude larger than at Kilauea. Io's lava flow fields cover thousands to hundreds of thousands of km^2. Io's lava lakes may have areas of hundreds or thousands of km^2. The shape of the infrared thermal emission spectrum of an eruption, and how this changes with time, yields many clues as to the style of eruption taking place [2]. It is useful to quantify the 2:5-μm radiant flux ratio, radiant flux density, and temperatures and areas from fitting black-body thermal emission models [e.g., 2], and then apply models of lava flow cooling adapted to Io's environment and likely lava compositions. Kilauea is a prime study area for examining and understanding remote-sensing techniques for designing observations, instruments, and operational constraints to gather data of lava lakes, lava fountains, and lava tube skylights, in order to answer the biggest questions about Io's volcanic activity: the composition of Io's dominant silicate magma (ultramafic or basaltic?). Knowing the answer immediately applies constraints on the state of Io's interior. Study of hot lava will aid understanding of Io remote-sensing data by quantifying the variability of emissivity of hot lava as a function of temperature and wavelength. The possibility that Io is erupting ultramafic magmas in some locations tantalizingly offers the promise that the emplacement of such lava bodies, so important in Earth's geological history, can be studied on Io. References. [1] Davies, A. G. (2007) Volcanism on Io – A Comparison with Earth. Cam. Univ. Press, 372 pages. [2] Davies, A. G., et al. (2010) JVGR, 194, 75-99. Acknowledgements. This work was performed at the Jet Propulsion Laboratory–California Institute of Technology, under contract to NASA. AGD is supported by NASA PG&G and OPR Program grants.

Davoine, Paule-Annick

Improving Volcanological Data Management by Innovative Geomatics Approaches: Application to the Piton de la Fournaise Volcano Data

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The Geographical Information Systems (GIS) are widely recognized for their capacity to manage spatial information. However, these tools are not suitable for managing the large, heterogeneous and multidimensional spatio-temporal data acquired by the volcanological observatories. In the frame of the conception and realization of a GIS for data management at the Volcanological Observatory of Piton de la Fournaise (OVPF, La Réunion, France), we have identified limitations of these systems, especially in terms of structuring, modeling, querying data and cartographic visualization. These limitations lead us to propose formalisms and tools (1) to evaluate the heterogeneity and quality of data, (2) to specify metadata, (3) to define methods to homogeneize and to make the data interoperable, and (4) to visualize geophysical, geological and geochemical data. We have specified functionalities based on web and XML technologies and a multidimensional geovisualization interface allowing the users to access simultaneously to a set of data (seismic, geochemical, surface observations) for a given period of time and a given area. The aim is to conduct interactive spatio-temporal analysis, taking into account the characteristics of data in terms of quality, completeness and uncertainty. The data model is based on the MADS approach (Modelling Application Data Spatial), allowing the integration of spatial and temporal dimensions of the various phenomena of volcanological processes. The visualization interface is organized following several components. (1) A cartographic component, which displays the user-selected phenomena related to the volcanic activity (lava, ...) on a 2D or 3D object representing the volcanic edifice. (2) A temporal component, which displays the sequences of eruptions at different levels of granularity (year, month, day). This temporal component also allows the data selection by date or time period chosen by the user. (3) An information component which allows the user-selected display of the available data and their metadata. The proposed application, dedicated to the Piton de la Fournaise volcano, will be used to show how recent advances in methodological and technological fields of geomatics and GIS can contribute to improve volcanological data management.

DePaolo, Donald J.

Deep Drilling Results and Models for the Growth and Chemical Evolution of Hawaiian Volcanoes

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The Hawaii Scientific Drilling Program (1993 to 2007) added a new dimension to the study of Hawaiian volcanoes through the recovery of 4600 meters of core from Mauna Kea and Mauna Loa. The core has been intensively characterized, including geochronology, petrology and geochemistry. The ages from the cores extend to 600,000 to 700,000 years and hence cover 2/3 of the lifetime of the Mauna Kea volcano. The results yield a clearer view of the timescale of volcano construction, and allow us to develop models for the island's growth and evolution that present a considerably different picture than that formed from near-surface sample studies. Such models allow us to deduce the internal structure of the island, understand better how magma production relates to volcano growth, how to map geochemical and petrological variations in the lavas to structure in the mantle plume, and ultimately, infer geochemical structure near the base of the mantle. To first-order, we can account for the formation and evolution of the Island of Hawaii "from the bottom up," starting with geodynamical models for mantle flow and melting rates, and using HSDP geochronology as a guide. Using the volume of Hawaii (215,000 km3) as a further constraint, the volcanic output of the plume is about 0.15 km3/yr over the past 1.5 m.y. The total output is usually distributed unevenly among three volcanoes at any one time. The implied ages of the volcanoes are older than those inferred from study of near-surface lavas. Kohala must have originated on the seafloor about 1.4 m.y. ago, and presumably almost all of its volume was formed by 0.6 m.y. Mauna Kea was already a large volcano at 0.4 m.y., when the HSDP drill site was located at its shoreline. The age and size of Mauna Kea makes it difficult to imagine a configuration that would allow for the lower part of the ridge northeast of Hilo to be part of Kohala. The volcano growth models used by DePaolo and Stolper (JGR, 1996) and revisited in DePaolo et al. (Gcubed, 2000) are still only loosely based on geodynamic models. There may be more to learn, but it would require a new generation of geodynamic model that accounts for melting and its effects on plume rheology and subsidence. The model of Farnetani and Hofmann (EPSL, 2010), does not integrate melting and flow, but can be used for further evaluation of volcano growth models. A major unknown is how to relate the magma supplied to a particular volcano to a melting region within the plume. The growth history of Mauna Kea, and its relation to isotopic geochemical structure, supports a relatively simple model. If the whole Earth is non-chondritic, as suggested by Nd-142 data, some of the isotopic characteristics of the plume are close to those of primitive (non-chondritic) mantle. The high He-3 signal in the plume appears to be restricted to an even smaller-diameter portion of the center of the plume, suggesting it comes from closest to the core-mantle boundary and is not distributed over as great a vertical distance as other isotopic anomalies.

Di Muro, Andrea

The plumbing system of Piton de la Fournaise volcano (Réunion Island): a geochemical perspective

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Volcanic activity (intrusive and eruptive) occurs scattered on the whole massif of Piton de la Fournaise volcano. Activity has relatively long return times on the flanks (decades on the eastern flank, centuries on the western flank) and its frequency increases when moving closer to the summit cone (1 eruption/year, on average). Central activity is related to magma ascent below the summit cone and possible further lateral propagation, which in most cases remains confined inside the horseshoe shaped caldera of Enclos Fouqué. Composition of magmas emitted from central activity is bimodal, ranging from Mg-poor cotectic basalts (MgO < 7wt%) to olivine-rich end-members (MgO up to 30wt%). Olivine rich basalts are emitted everywhere, while cotectic basalts appear concentrated close to volcano summit. Primitive basalts are very rare inside the Enclos Fouqué caldera, while occur scattered on the western flank. Degassing activity is also bimodal, with emission of SO2 limited to the syn-eruptive phases and permanent emissions of H2O-rich and S-depleted vapours during intra eruptive phases. Volatile content of melt inclusions in olivines (H2O< 1.7 wt%; CO2 < 4400 ppm) permits to track magma ascent and storage in the pressure range shallower than 7.2 kbar (<22-27 km depth). Trapping pressure of cotectic and olivine-rich basalts (Fo< 85) is systematically low (<0.5 kbar) and is associated with shallow seismicity located inside the subaerial portion of the PdF edifice, below the summit craters (Bory-Dolomieu). Rare deeper magmas are associated with deeper seismic swarms (up to 7 km below sea level). We discuss a model in which differentiation of deep magmas (> 7 km bsl) occurs in a shallow storage range (2-3 km bsl), but deep enough to result in only weak permanent degassing emissions. Ascent of low volumes of deep magmas triggers the ascent and eventual eruption/shallow intrusion of magmas located at shallower depth. Only major rushes of deep and CO2-rich magmas can bypass the upper system, and in most cases they deviate laterally with respect to the central system. These events represent the most hazardous ones at Piton de la Fournaise as they can potentially affect densely inhabited areas.

Dieterich, James H.

Recent developments in regional simulations of fault and earthquake processes: Applications to volcanic systems

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Volcanic systems are preeminent natural laboratories where magmatic, deformation, and earthquake processes are tightly coupled. This coupling means that investigation of volcanoes has a profoundly multidisciplinary characteristic, and advances in understanding at the system level could greatly benefit from coordinated efforts by the entire research community. System-scale simulations have the potential to integrate the wide range of observations from active volcanoes into a more comprehensive and predictive multidisciplinary science. Earthquake and fault slip simulation capabilities, which have recently been developed and are being applied to plate-boundary fault systems, could contribute to, or possibly serve as a model for, regional system-level modeling of active volcanoes. The Earthquake and Fault System Dynamics Project, which is supported by the NSF Frontiers in Earth Systems Dynamics Program, has participants from seven institutions and seeks to develop large-scale regional models the North American plate boundary fault systems. The simulations span intervals >10,000yrs and generate earthquake catalogs of over one million events. In addition to earthquakes, the simulations include continuous fault creep where it is documented to occur, and slow slip events (SSEs) along the Cascadia megathrust. Applications of this simulation approach to Kilauea volcano will be presented.

Dietterich, Hannah R.

Complex Channel Networks in Hawai'i and the Influence of Underlying Topography on Flow Emplacement

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Lava flows in Hawai'i often feature complex channel network geometries. New LiDAR data of the Mauna Loa 1984 and Kilauea December 1974 flows reveal numerous flow bifurcations and confluences that make up intricate lava distribution systems. In order to investigate the origins of these channel networks, we analyze morphologic data gathered from (1) these LiDAR datasets, (2) a pre-eruptive DEM of the Mauna Loa 1984 flow reconstructed from aerial photographs, and (3) new SAR coherence maps of the ongoing eruption of the east rift zone of Kilauea. We also perform experiments with both syrup (an isothermal analogue fluid) and cooling molten basalt to explore the formation of a bifurcation as a flow encounters an obstacle and the creation of a confluence as the flow rejoins below it. This work reveals a strong topographic control on the formation of channel networks by way of the underlying slope and obstacles. We find that pre-eruptive slope correlates positively with both the number of parallel channels across the flow and flow width. Topographic obstacles in the flow path play a dual role, acting either to split the flow or confine it. Interactions with obstacles therefore yield numerous bifurcations throughout the Mauna Loa 1984 flow, as well as multiple large confluences in the Kilauea December 1974 flow. These observations suggest that the ratio of the flow height to obstacle height, as well as the size and geometry of the obstacle, controls the presence or absence of bifurcations. When the flow thins over high slopes, obstacles are more likely to influence the flow path. This effect is not apparent in the syrup analogue experiments, in which a bow wave forms behind the obstacle at high slopes and causes overtopping. Cooling also plays a role in confluence formation. In isothermal analogue experiments, flow lobes produced by a bifurcation rejoin because of lateral spreading. However, in cooling basalt experiments, these confluences can be prevented by levee formation. The implications of channel network geometry and underlying topography are significant for flow behavior, as well as for flow prediction and diversion attempts. By controlling the distribution of lava flux from the vent through the flow, the channel network can govern both the final flow length and advance rate. Flow advance data collected during the early episodes of the Pu'u 'O'o eruption show reductions in flow front velocity caused by flow bifurcations. Conversely, topographic focusing may allow flows to travel further and faster. The channel network, and the underlying topography that produces it, are therefore key parameters that must be incorporated into future models for flow prediction in Hawaii. The scale and geometry of underlying topography that can split or confine the flow can also inform the size and placement of diversion barriers.

Dunham, Eric M.

Wave Propagation in Basaltic Fissure Eruptions

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We have developed a code that couples flow of a viscous, compressible magma through a deformable volcanic conduit with plane strain elastodynamic response of the surrounding wall rock. Magma is described by a nonlinear equation of state that accounts for compressibility changes caused by gas exsolution. We apply this code to basaltic fissure eruptions, first finding a steady state solution featuring a depth-dependent dike width determined self-consistently with the distribution of excess pressure. Self-excited oscillations from flow instabilities do not arise in our model, leading us to investigate the role of external forcing as a mechanism for volcanic tremor. We therefore study the ability of various types of perturbations, in either the fluid or solid part of the system, to excite seismic and acoustic waves. Fluid-solid coupling is most pronounced below the exsolution depth, so perturbations within the conduit (e.g., bursting of gas bubbles) efficiently excite crack waves along the conduit walls that convert to seismic waves at both the exsolution surface and the edge of the dike. In contrast, fluid perturbations in the upper part of the conduit primarily excite acoustic waves within the highly compressible magma, with minimal coupling to the solid. We also investigate the system response to moment tensor sources (e.g., earthquakes) in the conduit wall rock. Our aim is to quantify the amplitude and type of sustained perturbations required to explain observed levels of continuous volcanic tremor in these systems. This approach can also provide linear transfer functions relating the amplitude and location of small perturbations in the fluid or solid to seismic waves recorded on the surface. These transfer functions, which are sensitive to conduit geometry and steady state flow, could be used in inversion studies to determine source processes responsible for exciting volcanic tremor.

Dzurisin, Daniel

Our Emerging Understanding of Hawaiian and Yellowstone Volcanism: A Historical Perspective

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"Science is a social process. It happens on a time scale longer than a human life. If I die, someone takes my place. You die; someone takes your place. What's important is to get it done." (Alfred L. Wegener, originator of the theory of continental drift) Three years after Thomas A. Jaggar founded the Hawaiian Volcano Observatory a century ago, Alfred A. Wegener published his ideas on the breakup and dispersal of a protocontinent he named Pangaea. His treatise, "The Origin of Continents and Oceans," was published in 1915 and met with general skepticism long after his death in 1930—until compelling evidence for plate tectonics emerged in the 1960s. A crucial piece of that evidence came from the site of this conference. In 1963, J. Tuzo Wilson proposed that the distinctive linear trend of the Hawaiian Islands–Emperor Seamounts chain resulted from the Pacific Plate moving over a deep magma source beneath the current location of the Big Island. Eight years later, W. Jason Morgan (Nature, 1971) proposed that "...hotspots are manifestations of convection in the lower mantle which provides the motive force for continental drift." Thus began a multi-decade period of discovery that revolutionized Earth science. In 1972, sixty years after HVO came into being and one hundred years after Yellowstone National Park was established, Morgan (GSA Memoir, 1972) postulated that the Snake River Plain–Yellowstone volcanic province represented the hotspot track formed by the North American plate moving across a fixed mantle plume. That same year, D.A. Swanson (Science, 1972) proposed that the magma supply rate from the mantle source region to Hawai'i's Kilauea volcano is nearly constant. Three years later, in response to the M 6.1 Yellowstone Park earthquake in June 1975, the U.S. Geological Survey and the University of Utah began releveling the Yellowstone vertical control network that had been established by the U.S. Coast and Geodetic Survey in 1923. When the resurvey was completed in 1977, a surprising result emerged. The central part of the Yellowstone caldera had been uplifted more than 70 cm since the 1923 survey—spurring another period of intense investigation and discovery. Much has been learned about the nature and causes of ground deformation at Yellowstone during the ensuing 35 years. We know that the floor moves down as well as up, and that there are at least three deformation centers that interact with each other on timescales of a few months or less. The flux of basaltic magma required to produce the measured heat flow, CO2 output, and ground deformation at Yellowstone is comparable (within a factor of 3) to the magma supply rate to Hawai'i's volcanoes over timescales ranging from a few years to a few million years. Since 2001, much of the research that led to these discoveries has been conducted under the auspices of the Yellowstone Volcano Observatory. Both at Yellowstone and in Hawai'i, multidisciplinary research by government and university scientists continues to elucidate the interrelationships among magma generation, transport, storage, and eruption. Thus, one hundred years after Jaggar ushered in the era of observatory science in volcanology, HVO and its continental cousin, YVO, are poised to make additional inroads into our understanding of hotspot volcanism.

Edmonds, Marie

Volatile Degassing in Basaltic Magmas *(INVITED)*

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Volatiles play an important role in the dynamics of basaltic magma transport and eruption. Kilauea Volcano has been the focus of studies of degassing since the birth of volcanology and many of the synoptic insights in the field have been prompted by observations made here over the past 30 years. Volatile behavior in basaltic melts is governed by solubility and by the geochemical and rheological properties of the melt. Eruption style at basaltic volcanoes is largely dependent on how volatiles behave under variable magma ascent rates and on the plumbing system. In order to understand volatile behavior in melts and in the gas phase a holistic approach is required, combining gas geochemistry, petrology and thermodynamic modeling. In recent years, there have been a number of technological developments that have improved our observations of the gas phase, such as automated sensor packages to measure multiple gas species and sophisticated spectroscopy applications in both UV and IR. In the melt phase, it is now possible to achieve lower detection limits for SIMS analysis of melt inclusions, and we have new integrated methods to characterize the total volatile concentration of melt inclusions, such as using Raman spectroscopy to measure the CO_2 content of the bubbles. The ability to measure the abundances of the primary magmatic volatiles H_2O, CO_2 and SO_2 at a high temporal resolution from central eruptive vents using multi-species gas sensors and FTIR have allowed remarkable datasets to be amassed. These datasets, in combination with petrological and other monitoring data, allow development of models to describe melt degassing, melt-gas segregation and eruption processes. We will use examples from Kilauea, Etna and Stromboli volcanoes, as well as from other systems, to illustrate the important processes operating in basaltic volcanic systems, such as pervasive "fluxing" of stored magmas by CO_2-rich gases, the contrasting influence of H_2O and CO_2 on lava fountain dynamics, mixing of deep and shallow-derived gases, and magma convection in conduits and lava lakes. We will explore the difficulties associated with measurements of basaltic degassing and the challenges for the future. An important goal is associated with understanding of the CO_2 budget of basaltic volcanism.

Owing to the low solubility of CO_2, melt inclusions record only a fraction of the original CO_2 and gas measurements may include CO_2 exsolved from unerupted magma. Understanding the origin and segregation processes of CO_2 is key to both quantifying the carbon budget and for monitoring.

Edmonds, Marie

Halogen and trace metal emissions from the ongoing 2008 summit eruption of Kilauea volcano Hawai`i

Mather, Tamsin A.[1]; Witt, Melanie L.[1]; Pyle, David M.[1]; Aiuppa, Alessandro[2, 3]; Bagnato, Emanuela[2]; Martin, Robert S.[4]; Sims, Ken W.[5]; Edmonds, Marie[6]; Sutton, A. J.[7]; Ilyinskaya, Evgenia[8]

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Volcanic plume samples taken in 2008 and 2009 from the Halema`uma`u eruption provide new insights into Kilauea's degassing behaviour. The Cl, F and S gas systematics are consistent with syn-eruptive East Rift Zone measurements suggesting that the new Halema`uma`u activity is fed by a convecting magma reservoir shallower than the main summit storage area. Comparison with degassing models suggests that plume halogen and S composition is controlled by very shallow (<3 m depth) decompression degassing and progressive loss of volatiles at the surface. Compared to most other global volcanoes, Kilauea's gases are depleted in Cl with respect to S. Similarly, our Br/S and I/S ratio measurements in Halema`uma`u's plume are lower than those measured at arc volcanoes, consistent with contributions from the subducting slab accounting for a significant proportion of the heavier halogens in arc emissions. Plume concentrations of many metallic elements (Rb, Cs, Be, B, Cr, Ni, Cu, Mo, Cd, W, Re, Ge, As, In, Sn, Sb, Te, Tl, Pb, Mg, Sr, Sc, Ti, V, Mn, Fe, Co, Y, Zr, Hf, Ta, Al, P, Ga, Th, U, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Er, Tm) are elevated above background air. There is considerable variability in metal to SO_2 ratios but our ratios (generally at the lower end of the range previously measured at Kilauea) support assertions that Kilauea's emissions are metal-poor compared to other volcanic settings. Our aerosol Re and Cd measurements are complementary to degassing trends observed in Hawaiian rock suites although measured aerosol metal/S ratios are about an order of magnitude lower than those calculated from degassing trends determined from glass chemistry. Plume enrichment factors with respect to Hawaiian lavas are in broad agreement with those from previous studies allowing similar element classification schemes to be followed (i.e., lithophile elements having lower volatility and chalcophile elements having higher volatility). The proportion of metal associated with the largest particle size mode collected (>2.5 μm) and that bound to silicate is significantly higher for lithophiles than chalcophiles. Many metals show higher solubility in pH 7 buffer solution than deionised water suggesting that acidity is not the sole driver in terms of solubility. Nonetheless, many metals are largely water soluble when compared with the other sequential leachates suggesting that they are delivered to the environment in a bioavailable form. Preliminary analyses of environmental samples show that concentrations of metals are elevated in rainwater affected by the volcanic plume and even more so in fog. However, metal levels in grass samples showed no clear enrichment downwind of the active vents.

Edmonds, Marie

Degassing and lava fountain dynamics during the 1959 Kilauea Iki eruption, Kilauea Volcano, Hawai'i

Sides, Isobel[1]; Edmonds, Marie[1]; Houghton, Bruce[2]; Swanson, Don[3]; Maclennan, John[1]

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We present a study of volatile degassing during the 1959 Kilauea Iki eruption, which was associated with a sequence of high lava fountains. We have analysed olivine-hosted melt inclusions from tephra associated with episodes 1-3, 5-8, 10 and 15-16 for major, trace and volatile elements. The aims of the work are to investigate the contrasting roles of H_2O and CO_2 in fountain dynamics, and to establish whether the geochemistry of the melts supplied to the volcano determines eruptive style. The trends in the melt inclusions are consistent with changes in eruption parameters and we propose that they record syn-eruptive geochemical changes. The melt inclusions show a trend of decreasing MgO content through episodes 1 to 16, and the host olivine compositions become less forsteritic with time. Trace element concentrations in melt inclusions and glasses show that both mixing and fractionation must be operating to produce the range in magma compositions. The melt inclusions record changes in the volatile content of the melts with time, becoming poorer in H_2O as the eruption proceeded. The CO_2 concentration of the melt inclusions correlates inversely with fountain height; whereas H_2O shows no correlation with fountain height. There is an inverse correlation between the cumulative volume of drained-back lava and the H_2O concentration in the melt inclusions. The CO_2 concentration of the melt inclusions correlates positively with the Mg# of the matrix glass. We support a model whereby drained-back lava mixes with both summit-stored, and more primitive magma from depth. After mixing of summit-stored magma with drained-back

lava, the melt becomes undersaturated with respect to H_2O and CO_2. Even in the absence of fresh magma supply, there is a continual flux of CO_2-rich vapour from depth, which acts to further dehydrate and enrich the magmas in CO_2 with time. The CO_2 content of the magmas is determined by the relative magnitudes of the deep flux of CO_2 gas, versus mixing of the magma with drained back lava. Melt CO_2 content has a direct impact on fountain dynamics: the richer the melt in CO_2, the lower the lava fountain.

Edmonds, Marie

Volatiles in gases and melt inclusions during the 2008-present summit activity at Kilauea Volcano, Hawai'i

Sides, Isobel[1]; Edmonds, Marie[1]; Martin, Robert[2]; Swanson, Don[3]; Sawyer, Georgina[2]; Mather, Tamsin A.[4]; Witt, Melanie L.[4]; Sutton, A. J.[3]; Elias, Tamar[3]; Werner, Cindy[5]

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The 2008-present summit eruption at Kilauea Volcano offers a unique opportunity to characterise the volatile concentrations in both gases and melts that originate directly from the summit magma reservoir. We conducted a variety of gas and aerosol measurements during a field campaign in April-May 2009. Electrochemical sensors and NDIR spectrometers analysed the concentrations of SO_2, H_2S and CO_2, while SO_2 flux was measured using both scanning and traverse-mode DOAS. Gas and aerosol concentrations were measured using filter packs. In this way, we were able to characterise the plume arising from the eruptive vent in Halema'uma'u at the summit of Kilauea Volcano during this period. We collected tephra samples produced during four discrete explosions that occurred in 2008 and 2010. Olivine-hosted melt inclusions and matrix glasses were analysed for major, trace and volatile elements. The melt inclusion and glass compositions are more evolved than many previous historical summit lavas erupted within Halema`uma`u, indicating more prolonged storage and extensive fractionation at shallow crustal levels prior to eruption. Melt inclusion CO_2 and H_2O concentrations span a restricted compositional range from 39 – 337 ppm and 0.13 – 0.36 wt% respectively. These concentrations are significantly lower than those erupted during fissure or fountain-producing eruptions at the summit of Kilauea in historical times. H_2O and S concentrations both decrease with time throughout the sampled events. We infer that the melts have been progressively depleted in volatiles due to extensive degassing prior to entrapment at pressures less than 100MPa. We surmise that the magma has previously degassed the bulk of its CO_2 during residence in the main summit storage reservoir, the locus of which lies to the east of the current active vent. The magmas have undergone shallow crystallisation and equilibration with respect to H_2O and sulphur. The high proportion of vapour over melt erupted from this vent implies efficient melt-gas segregation, as well as shallow magma overturn. The gas and melt geochemistry together indicate that pre-eruptive degassing during the current eruption occurs under open-system conditions and is consistent with geophysical models which suggest that the explosive events in 2008-10 were triggered by external conduit processes rather than volatile-driven magma ascent and fragmentation.

Elias, Tamar

Degassing highlights during the 2011-2012 eruptive activity at Kilauea Volcano, Hawai'i

Elias, Tamar[1]; Sutton, A. J.[1]

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An exciting era of innovative technologies has allowed the cultivation of gas measurement methods with much improved temporal resolution. UV camera systems, scanning spectrometer networks, stationary spectrometer arrays, FTIR measurements, and continuous sensor-based instruments facilitate comparisons of gas emission data to a range of geophysical datasets. Through the use of these techniques, the potential for revealing relationships between degassing and other geophysical phenomena has been greatly improved, and many heretofore untold mysteries are being uncovered. In a nod to the still useful legacy techniques, however, this presentation examines the highlights of changes in gas emission activity at Kilauea during the dynamic 2011, and still evolving 2012 summit and rift eruptive sequences by reviewing campaign style emission rate, and continuous sensor-based data. Notable 2011-2012 gas events include: record low east rift SO_2 emissions due, at least in part, to prior degassing from the summit lava pond within the Overlook vent; record high (11,000 tonnes per day) but short-lived SO_2 emissions associated with the 2011 Kamoamoa fissure eruption; an increase in east rift SO_2 emissions leading up to the August 2011 intrusion and breakout at Pu`u `O`o; an increase in $SO_2$ accompanying the September 2011 fissure eruption on the east flank of Pu`u `O`o; and gas emission variations accompanying seismic tremor and lava level fluctuations at the summit (as previously noted by Patrick, et al., 2010, Nadeau et al., 2010). The campaign style SO_2 measurements confirm the continuing shallow nature of the summit degassing activity, and provide information on storage and timing details of east rift intrusive and eruptive events. While dynamic eruptive events are often reflected as short (days to weeks) pulses in SO_2 release, longer term (months to years) emissions at Kilauea are in decline. Total SO_2 emissions for Kilauea decreased by 38% and 20% for 2010 - 2012 as compared to 2008 and 2009 respectively (table 1) and are among the lowest annual emissions measured since the onset of the current rift activity in 1983 (Elias and Sutton,

2012, USGS OFR). In addition, summit CO_2 emissions continue at the low levels first observed in mid-to-late 2008. Time will reveal what these long term waning gas emissions portend for future activity at Kilauea. As well as helping to characterize eruptive activity, general trends in low time resolved emission rate data may help guide future studies utilizing techniques with increased temporal resolution. Campaign style SO_2 measurements at Kilauea serve to validate innovative techniques such as the upward-looking fixed FLYSPEC array (Horton et. al, this meeting) and contribute to improvements in SO_2 retrieval processes (Kern et. al, 2012, JGR, in review).

Annual SO_2 emission rates

Year	Summit Annual SO_2 t/y	Summit Days of data	Summit Daily SO_2 t/d	ERZ Annual SO_2 t/y	ERZ Days of data	ERZ Daily SO_2 t/d	Total t/y
2007	5.20E+04	92	140	6.50E+05	103	1780	7.02E+05
2008	3.10E+05	210	850	8.25E+05	85	2260	1.14E+06
2009	3.00E+05	178	820	4.25E+05	67	1160	7.25E+05
2010	1.90E+05	146	520	2.50E+05	56	690	4.40E+05
2011	2.05E+05	157	560	2.16E+05	97	590	4.21E+05
2012[1]	NA	26	700	NA	18	500	NA

[1] January-March 2012

Fagents, Sarah A.

Photogrammetric and global positioning system measurements of active pahoehoe lava lobe emplacement on Kilauea, Hawai`i

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Basalt is the most common rock type on the surface of terrestrial bodies throughout the solar system and—by total volume and areal coverage—pahoehoe flows are the most abundant form of basaltic lava in subaerial and submarine environments on Earth. A detailed understanding of pahoehoe emplacement processes is necessary for developing accurate models of flow field development, assessing hazards associated with active lava flows, and interpreting the significance of lava flow morphology on Earth and other planetary bodies. Here, we examine the active emplacement of pahoehoe lobes along the margins of the Hook Flow from Pu`u `O`o on Kilauea, Hawai`i. Topographic data were acquired between 21 and 23 February 2006 using stereo-imaging and differential global positing system (DGPS) measurements. During this time, the average discharge rate for the Hook Flow was 0.01–0.05 m^3/s. Using stereogrammetric point clouds and interpolated digital terrain models (DTMs), active flow fronts were digitized at 1 minute intervals. These areal spreading maps show that the lava lobe grew by a series of breakouts that broadly fit into two categories: narrow (0.2–0.6 m-wide) toes that grew preferentially down-slope, and broad (1.4–3.5 m-wide) breakouts that formed along the sides of the lobe, nearly perpendicular to the down-flow axis. These lobes inflated to half of their final thickness within ~5 minutes, with a rate of inflation that generally deceased with time. Through a combination of down-slope and cross-slope breakouts, lobes developed a parabolic cross-sectional shape within tens of minutes. We also observed that while the average local discharge rate for the lobe was generally constant at 0.0064 ± 0.0019 m^3/s, there was a 2 to 6 fold increase in the areal coverage rate every 4.1 ± 0.6 minutes. We attribute this periodicity to the time required for the dynamic pressurization of the liquid core of the lava lobe to exceed the cooling-induced strength of the lobe margins. Using DGPS-derived DTMs of the topography before and after pahoehoe lobe emplacement, we observed that the lava typically concentrated within existing topographic lows, with the lobe reaching a maximum thickness of ~1.2 m above the lowest points of the initial topography and above reverse-facing slopes. Lobe margins were typically controlled by high-standing topography, with the zone directly adjacent to the final flow margin having average relief that is ~4 cm higher than the lava-inundated region. This suggests that irregularities ~25% of the height of the smallest breakout elements (i.e., toes) can exert a strong control on the paths of low-discharge pahoehoe lobes, with stagnated toes forming confining margins that allow interior portions of flow to topographically invert the landscape by inflation.

Famin, Vincent

A unified model for the deformation of basaltic volcanoes

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Basaltic edifices undergo a contiuous deformation during their history of magmatic activity. In the case of the Kilauea in Hawaii, this deformation involves the repeated injection of magma into long, linear ridges known as rift zones, and the slip of a decollement plane between the base of the volcanic edifice and the ocean floor. However, Many basaltic volcanoes, like those in La Reunion and in the Canary islands, do not follow this scheme of growth and deformation. Here we review some deformation features shared by basaltic volcanoes that do not behave as the Kilauea. These features include (1) the absence of true rift zones, or their pesence only as arcuate zones of moderate dike concentration (i.e. < 0.5 intrusions per meter) ; (2) the existence of two perpendicular directions of dike injections; (3) the occurrence of sill zones containing tens to hundreds of sills in contact with each other (i.e. > 2 intrusion per meter); (4) evidence of stress permutations in the edifice (in the field or in focal mechanisms of earthquakes); (5) the absence of compressive structures at the base of the edifice; (6) a record of multiple events of debris avalanches. For basaltic volcanoes showing such combination of features, we suggest that deformation does not proceed by gravitational spreading alone, but rather by the repeated injection of sills oriented subparallel to the slopes of the edifice. Sill injection

results from the permutation of principal stresses after several dike injections in the two perpendicular directions. These sills act as detachement planes accomodating large co- and inter-intrusion displacements, which may occasionnally lead to rapid destabilizations of the edifices. Because sill injections induce larger displacements in the vertical axis, monitoring networks may need some improvement to detect these kinds of intrusions and better assess the hazard represented by non-Kilauea-like active basaltic volcanoes.

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Ferguson, David J.

Magma recharge and ascent during episode 1 of the 1959 Kilauea Iki eruption

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The 1959 eruption at Kilauea Iki crater produced the highest Hawaiian fountains yet recorded and resulted in the formation of the Kilauea Iki lava lake and an exceptionally well preserved tephra fall. Episode 1 lasted for 7 days and involved fountain heights of up to 380 m, which deposited material up to 5 km downwind of the vent [1]. This was also the only episode of the 1959 eruption that was not influenced by lava drain-back into the conduit. To understand the processes leading to the initiation of the eruption and the dynamics of magma ascent during fountaining episodes, we measured compositional profiles across olivine crystals erupted during the most vigorous part of episode 1 as well as the volatile contents of melt inclusions hosted within the crystals. To minimize the effects of post-entrapment re-equilibration or water-loss of the melt inclusions, we restricted our analysis to free crystals (<500 microns in diameter) found in fall deposits. Core to rim profiles of crystal composition measured by LA-ICP-MS reveal a population of crystals with reverse Fo zonation (Mg-rich crystal rims), implying mixing with a more mafic melt at a late stage in their growth. Modeling the timescales of Fe-Mg diffusion between these high Fo crystal rims and lower Fo cores allows us to estimate the timing between this mafic recharge and the eruption, which is on the order of months. This is the same timescale as the onset of deep-seated volcanic tremor (~55 km depth), which has been linked to ascending melt from the mantle [2]. Thus both the diffusion chronometers and seismic records point to an influx of melt to shallow levels beneath Kilauea in the months leading up to the eruption. Several volatile species (CO2, H2O, S, Cl, and F) derived from the melt inclusion data follow remarkably simple degassing trends, consistent with magma ascent from depths of ~3.5 km. We find no evidence for CO2 gas fluxing, and our results suggest that excess volatiles were not involved in driving the eruption. [1] W. K. Stovall et al. (2012), Bull. Volcanol. 73, 511-529 [2] J. P. Eaton & K. J. Murata. (1960), Science. 132, 3432

Ficker, Edward

Volcano Mapper - A web-based GIS Application

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The “Volcano Mapper”, is a web-based GIS application that adapts spatial data contained in the Digital Database of the Geologic Map of the Island of Hawai‘i, released in 2005 by Frank A. Trusdell et al [available on the World Wide Web at http://pubs.usgs.gov/ds/2005/144/] and the Google Maps application programming interface (API). The Google Maps API is provided for free in accordance with Google’s Terms of Service and is easily incorporated into a webpage or mobile framework. The JavaScript API utilizes source code and image tiling techniques to display two dimensional maps and imagery at fixed zoom levels. In addition, the API includes methods to incorporate outside data sets such as points, lines, polygons, and raster images similar to desktop GIS software that store data in shapefiles, KML, geodatabases, etc. Unlike desktop GIS systems, Google maps is familiar to the public and being incorporated with GPS devices on “smart phones”, tablets, and other mobile devices. The interactive aspect and functionality of Google maps is largely responsible for the popularity of “AJAX” methods in web and mobile app development and provides an ideal means to transfer knowledge between scientists in different disciplines and career levels. The Volcano Mapper uses HTML select forms (drop-down boxes & check boxes) to trigger server-side PHP scripts that query and select tabular data stored in a MySQL database. Similarly, image tiles are added or removed in a seamless manner. These types of asynchronous exchanges performed “behind the scenes” to display the age-based framework of geologic map units, structures, 14C samples, or chemical data demonstrate exciting potential to disseminate Hawaii’s geologic information to a wide and varied audience.

Fiske, Richard S.

Ultra-Energetic, Jet-Like Eruption at Kilauea: The Kulanaokuaiki-3 Tephra (~850-950 CE)

Fiske, Richard S.[1]; Rose, Tim[2]; Swanson, Don[3]

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Far-traveled lithic clasts, contained in a thin, small-volume scoria deposit, provide clues that a highly energetic, jet-like eruption took place at Kilauea. The driver for this event is interpreted to have been the voluminous eruption of CO2, known to be a dominant gas phase (after water) released at the summit (e.g. TM Gerlach). Evidence for this event, overlooked by previous workers, is best seen on a ~2000-year old pahoehoe surface preserved on the volcano’s south flank. Lithic clasts erupted during the event, all of which are fresh, consist mostly of a wide variety of lava-flow lithologies; ~18 % are fine-coarse gabbro (some containing interstitial, vesicular glass). No pillow fragments or clasts of hyaloclastite debris have been found. The most accessible Kulana-3 lithics occur as lag clasts, where the host scoria has been eroded away— leaving them, much like Easter eggs, waiting to be found. Using a sampling grid 700 m on a side and containing 112 collecting sites, we document that clast nominal diameters decrease regularly toward the south; grapefruit-size clasts occur near Kulanaokuaiki Pali (7-8 km south of the summit) and "golf-ball rocks" are widely scattered along the south coast of the island (17 km distant). Kulana-3 scoria, 2-12 cm thick, hosts the lithic clasts and is massive at most south-flank sites. In places, however, a thin layer of medium ash separates the scoria into two subunits. Whole-rock XRF analyses of cm-by-cm "slices" through the deposit revealed cryptic internal zonation. MgO values of the lower subunit are variable, averaging ~8 wt %; those in the upper subunit increase regularly upward from ~9-11 wt % to a maximum of ~14% MgO. The upside-down compositional pattern of the upper Kulana-3 subunit extends over an area of >70 sq km and suggests a zoned magma source and a highly organized dispersal process. Estimated volumes of the lower and upper Kulana-3 subunits (~7 million and 13 million cubic meters, respectively) correspond to eruptions having VEI values in the mid 2s to lowermost 3s. Such events are about two orders of magnitude too small to explain the remarkable distances traveled by the large and dense lithic clasts. A small piece of marine limestone (containing fragments of a filamentous cyanobacterial mat) was discovered in reworked Kulana-3 scoria about 900 m above sea level (far above tsumani range)— suggesting a deep origin for at least part of the K-3 event... but how deep? Our data files contain the locations (e.g. estimated distances traveled) and nominal diameters of about 1100 lag lithic clasts. Specific gravities have been determined for about half of these clasts. This unique body of information will be useful to those interested in modeling the structure and kinetics of the jet-like column that must have risen high above Kilauea's summit. And building on the kimberlite-related interpretations of L Wilson and JW Head (Nature, v 447, 2007), the relevance of downward traveling decompression waves to the deep and voluminous release of CO2 may emerge as being especially important.

Flinders, Ashton

A 3D Gravity Inversion of the Hawaiian Islands: From Niihau to Loihi

Flinders, Ashton[1]; Ito, Garrett[2]; Garcia, Michael O.[2]; Taylor, Brian[2]

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While the Hawaiian Islands are part of the most geologically studied intra-plate volcanic island chain world-wide, surprisingly, the only chain wide compilation of marine and terrestrial gravity data is now more than 40 years old. Early terrestrial studies conducted by J. G. Moore, H.L Krivoy, G. P. Woollard, W. E Strange and others in the early 1960's were meant to serve as reconnaissance surveys only. In addition, early marine surveys were limited in both accurate positioning and data density. Detailed analysis of the crustal density structure of the island chain was limited. We present a new chain-wide gravity compilation incorporating the original island-specific survey data, recently published data on the island of Kauai and Hawaii, as well as more than 10 years of newly incorporated marine data collected aboard the University of Hawaii's R/V Kilo Moana. This data was supplemented by surveys aboard the R/V Farnella among others. We present free-air (FAA), simple/complete Bouguer, and residual gravity maps on an unprecedented resolution and geographical extent for the area. We invert the residual gravity anomaly to calculate a model of the 3D density structure of magmatic plumbing system of island formation, including both island centered reservoirs and rift zones.

Flower, Verity J.

Synergistic monitoring of Hawaiian volcanic activity from space

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Hawaiian volcanoes produce a rich variety of eruptive phenomena including lava lakes, lava flows, lava fountains, strombolian activity, ash plumes and persistent degassing. Satellite remote sensing at ultraviolet (UV) and thermal infrared (TIR) wavelengths can be used to detect and monitor sulfur dioxide (SO_2) emissions and radiative heat fluxes associated with such activity, but despite the potential benefits of analyzing space-based SO_2 and TIR measurements in concert, there have been few efforts to exploit this synergy. The initial aim of this work is to build a database of characteristic SO_2 and heat fluxes, and their temporal variability, for different styles of activity at basaltic volcanoes including Kilauea (Hawaii), Etna (Italy), Ambrym (Vanuatu), Nyiragongo (DR Congo) and Piton de la Fournaise (Réunion). Kilauea, Ambrym and Nyiragongo all host active lava lakes, whilst Etna has produced frequent paroxysmal lava fountaining events in 2011-12. Our hypothesis is that it may be possible to distinguish different styles of activity remotely based on these characteristic signals, and ultimately develop an improved satellite-based eruption warning or monitoring system. We focus on operational SO_2 measurements made by the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite, and TIR MODVOLC data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua platform. Both Aqua/MODIS and Aura/OMI are in NASA's A-Train satellite constellation, providing daily, near-coincident observations of SO_2 emissions and heat flux at active volcanoes. OMI data can be used to estimate SO_2 emission rates, whilst MODVOLC radiance data provide constraints

on lava effusion rates or magma flux rates at volcanoes with active lava flows or lava lakes. Synergy between OMI and MODIS measurements offers several advantages, e.g., OMI SO_2 observations could permit screening of some non-volcanic TIR hot-spots from the MODVOLC dataset, on the assumption that significant SO_2 emissions would be expected from a hot volcanic vent. Conversely, high SO_2 column amounts in the absence of a TIR signal could indicate an optically thick volcanic plume obscuring hot lava below, or perhaps a deep magma source. We will also assess whether any systematic changes in heat and SO_2 flux prior to known eruptions can be identified in the satellite measurements. Statistical techniques will be used to analyze the OMI and MODIS time-series data and extract any information on characteristic timescales and patterns of activity. Given the nature of volcanic datasets, we plan to explore stochastic techniques that permit the characterization of behavior based on sparse time-series containing data gaps, and statistical methods for analysis of non-stationary time-series, such as Fourier functions and wavelet analysis.

Foster, James

Meteorology and Volcano Monitoring

Foster, James[1]; Businger, Steven[1]; Hobiger, Thomas[2]; Cherubini, Tiziana[1]; Brooks, Benjamin[1]

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The atmosphere is inextricably linked to many volcano monitoring techniques. The refraction of radio waves by the atmosphere impacts any measurements based on these types of signals, such as GPS, one of the workhorses for deformation monitoring. Many of the deformation processes observed at active volcanoes, like Kilauea and Mauna Loa, have temporal periods of minutes to hours and spatial scales of kilometers. These scales are similar to the characteristic scales for the transport and evolution of water vapor perturbations in the atmosphere, leading to considerable ambiguity between ground motion and atmospheric artifacts. For sub-daily GPS positioning, the atmosphere over Hawaii is one of the primary factors limiting the accuracy of the solutions. To mitigate this noise source, we have installed a near-real-time numerical weather model ray-tracing package, "KARAT", which uses weather predictions for the Big Island from the Mauna Kea Weather Center to predict the atmospheric refraction along each ray path and correct the GPS data files. We explore the impact of this mitigation technique using a data base of one year of near-real-time sub-daily position solutions for the joint HVO/UH/Stanford GPS network. The impact of the atmosphere on volcano monitoring is not always just a negative one however. Correlating the arrival of perturbations in the GPS estimates of atmospheric delay between GPS sites in the Big Island network provides direct insight into the wind field. We generate estimates of the "water vapor wind" vector field over the network and show that this has promise as a "nowcasting" technique for tracking the transport of the volcanic plume: a significant hazard to local communities.

Frey, Frederick A.

The Longevity of Geochemical Differences Between Lavas Erupted Along the Loa and Kea Spatial Trends Defined by the Hawaiian Islands

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Differences in Pb isotope ratios between lavas from Loa- and Kea-trend volcanoes have been used to infer geochemical zonation in the Hawaiian plume [1,2]. However, the significance of Kea geochemical signatures in Loa-trend volcanoes and vice versa is debated [3]. The longevity of these differences is also uncertain; Weis et al. [2] claim that geochemical zonation has persisted "for at least 5 million years", but Abouchami et al. [1] suggested that the geochemical differences "terminate at the Molokai Fracture Zone" (~2 Ma). We have determined the geochemical characteristics of three contemporaneous volcanoes whose strike crosses that of the Loa- and Kea-trends (Fig. 1), specifically late shield and postshield lavas, ~1.5 to 1.75 Ma, from East Molokai volcano, the northernmost Kea trend volcano recognized by Jackson et al. [4], shield and postshield lavas, ~1.7 to 1.9 Ma, from West Molokai volcano, a Loa trend volcano, and shield lavas, undated but inferred to be 1.8 to 2.0 Ma, from the submarine Penguin Bank volcano which we infer to be a distinct Hawaiian volcano west of the Loa trend. These Loa- and Kea-trend volcanoes are distinguished by incompatible element abundance ratios (Zr/Nb) as well as isotopic ratios of Sr, Nd, Hf and Pb. East Molokai lavas are clearly Kea-like whereas West Molokai and Penguin Bank lavas range from Loa-like to Kea-like (Fig. 2). This result is consistent with more geochemical heterogeneity in Loa volcanoes than in Kea volcanoes [1,2]. These results are consistent with a randomly distributed heterogeneity model [5,6] with Loa volcanoes sampling a higher proportion of components with low solidii, perhaps recycled oceanic crust and sediment (black color), whereas Kea volcanoes, which are closer to the plume center, sample a higher proportion of components (grey background) with high solidii such as peridotites (Fig. 3). References 1. Abouchami et al., 2005, Nature, 434:851-856; 2. Weis et al., 2011, Nature Geoscience, 4:831–838; 3. Rhodes et al., 2012, Geochem. Geophys. Geosyst. doi10.1029/2011GC003812; 4. Jackson et al., 1972, GSA Bulletin, 83:601-618; 5. Huang & Frey, 2005, EOS Trans. AGU 86(52):V51A-1466; 6. Ren et al., 2005, Nature, 436:837-840.

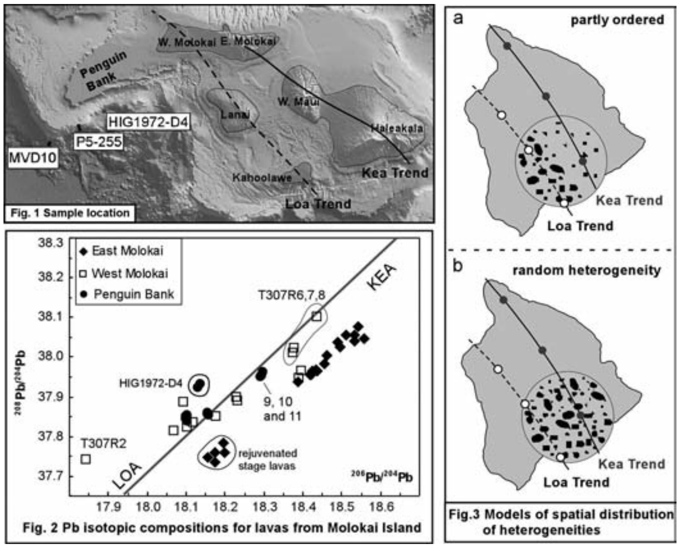

Fig. 1 Sample location

Fig. 2 Pb isotopic compositions for lavas from Molokai Island

Fig.3 Models of spatial distribution of heterogeneities

Garces, Milton A.

A Decade of Infrasound Array Measurements in Hawaii: Discovery, Science, and Applications

Garces, Milton A.[1]; Badger, Nickles[1]; Perttu, Anna[1]; Thelen, Weston[2]

1. Infrasound Laboratory, HIGP, University of Hawaii, Kailua Kona, HI, USA
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A brief experiment on the slopes of the Pu'u 'O'o Crater Complex in 2002 shattered the myth of acoustic quiescence at effusive basaltic volcanoes. Despite their apparent quiet demeanor, the subsurface craters and lava tubes at Kilauea can trap and amplify the overpressure produced by magma oscillations, fluid movement and vigorous degassing. Since the discovery of Kilauea's hidden soundscape in 2002, we have found a wealth of intriguing signatures associated with classic Hawaiian eruptions as well as crater collapses, fissure genesis, and gas piston events, amongst others. Just the diversity in infrasonic tremor radiated by Kilauea's various open-vent systems suggests that we do not completely understand the physical processes shaping these sounds. Even without this detailed geophysical knowledge, it is possible to infer practical information from the timing, intensity, duration, location, and spectral distribution of the observed acoustic signatures. We summarize scientific results from the last decade of infrasound research in Hawaii, and present fresh insights from the expanded infrasound array network at Kilauea.

Garcia, Michael O.

Controls on eruption of homogeneous magmas and their common failure to differentiate at Kilauea Volcano

Garcia, Michael O.[1]; Rhodes, J. M.[2]; Pietruszka, Aaron[3]

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The composition of basaltic lava reflects many factors including mantle melting and transport processes, crustal storage times and conditions, and possible magma mixing and contamination. These processes have led to diversity in lava composition between and even during some eruptions at Kilauea Volcano (e.g., Puu Oo eruption). Given the various processes that can cause changes in lava composition, it is remarkable that many of the 20th century eruptions of Kilauea produced relatively homogeneous lava, especially from vents in and near Halemaumau Crater (1924-1982) and Puu Oo Cone (1983-6). These lavas have narrow ranges in MgO content (7.3 ± 0.3 wt.% MgO) reflecting nearly constant temperatures (1160°C), although between eruptions lavas show differences in trace element and isotopic ratios. This common MgO composition in Kilauea lavas represents where clinopyroxene and plagioclase join or replace olivine as crystallizing phases. These summit and rift zone eruptions produced relatively small volumes of magma (10's of millions of cubic meters of lava) over short periods (hours to days). Mauna Loa Volcano also shows a preference for erupting nearly homogeneous magma with compositions "perched" at end of olivine control lines (Rhodes, 1995). What conditions promoted the formation of these magmas with relatively constant temperatures and compositions? Mittelstaedt and Garcia (2007) showed that the depth and geometry of the magma reservoir strongly influences magma cooling rate because of thermal gradients in the country rock. Here we consider the effects of latent heat of crystallization on controlling magma composition. The addition of clinopyroxene and plagioclase as a crystallizing phase releases heat to the magma that potentially balances the effects of cooling. We examine the effects of this process for lavas erupted from the Puu Oo vent, where magma reservoir conditions have been well studied. One peculiar feature of a few larger volume Puu Oo episodic eruptions was the sharp transition in time from multiphase-saturated lava to olivine-only lava with 2 wt% higher MgO. Above and below this sharp compositional gradient, magma was relatively homogenous. About 10 million cubic meters of multiphase magma formed over brief (about 37 days) repose periods. The causes of this steep thermal and composition gradient, and the failure of the magma to differentiate beyond about 7 wt.% MgO will be examined in this presentation. Mittelstaedt and Garcia (2007) Geochem. Geophys. Geosyst. 8, Q05011, doi:10.1029/2006GC001519. Rhodes (1995) AGU Mono. 92, 241-262.

Gasperikova, Erika

Kilauea Volcano 3D Imagining Using Magnetotelluric Data

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Kilauea Volcano, Hawaii, is currently the world's most active and most intensively studied volcano in the world. A collaborative effort of several institutions has been undertaken to study the Kilauea volcano in Hawaii using the Magnetotelluric (MT) technique. Total of 70 MT stations were acquired in two field campaigns during 2002-2003. MT data were acquired over the Southwest (SWRZ) and Eastern Rift Zones (ERZ), including the central caldera, Halema'uma'u and Pu'u O'o areas, using a recording system with up to eight stations operating simultaneously, with multiple remote reference sites, and using multi-station robust data processing techniques. Good-to-excellent quality data were recorded even in the harshest conditions, such as those encountered on the fresh lava flows of the ERZ, where electrical contact resistances are extremely high. In three-dimensional (3D) MT inversion (Newman and Alumabugh, 2000) data sensitivity to the magmatic structure beneath the volcano was increased by accurately accounting for island topography and coastal effects. The derived conductivity (inverse of resistivity) structure correlated well with previously reported seismic velocity anomalies beneath Kilauea. In particular, we have been able to map regions of active magma transport and storage beneath the locus of ERZ activity near the Pu'u O'o-Kupaianaha vents, and in adjacent areas. In addition, we have resolved upper portions of the vertical magma ascent conduit beneath the summit caldera, as well as low-resistivity domains of magma storage beneath Halema'uma'u and the southwestern caldera region. Active fault zones imaged by seismic velocity tomography as low velocity zones tie to low resistivity zones beneath the inverted MT lines. We have resolved groundwater-saturated regions within the Kaoiki fault zone, and regions of inferred saline waters, forming conductive domains within these fractures over the depth range of 1 to >6 km in the Hilina fault zone. Our results demonstrate successful acquisition and interpretation of MT data in the challenging environment found on Kilauea. Foremost among the challenges were the rough topography, extremely high contact resistance on fresh lava flows, and difficult access to areas of interest around active volcanic activity. In addition to acquisition difficulties were the interpretational difficulties imposed by the necessity of modeling both topography and costal effects on the MT data. This paper will present the first 3D conductivity structure beneath Kilauea and its rift zones derived from MT data inversion. The imaging of this data set and its correlations with previous work illustrate that MT data can provide structural information about the magma transport and storage regions of an active volcano, and their hydrothermal surroundings. The ultimate goal is to integrate our 3D conductivity model from MT inversion with existing gravity, seismic and other electrical data to provide an improved understanding of the internal structure of the volcano.

Girard, Guillaume

From mantle to ash cloud: quantifying magma ascent rates and degassing processes at Kilauea using short-lived U-series radionuclide disequilibria

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We analyzed basalt lavas, scoria and tephra erupted between 1982 and 2008 from Halema'uma'u Crater and the east rift zone (Pu'u 'O'o Crater) of Kilauea Volcano, Hawaii, for ^{238}U-^{234}U-^{230}Th-^{226}Ra-^{210}Pb-^{210}Po disequilibria. The relative activities of these nuclides help quantify rates and timing of magma evolution processes including magma ascent and storage, and degassing. The 2008 samples were analyzed multiple times for ^{210}Po in order to assess ^{210}Po ingrowth towards secular equilibrium and calculate $(^{210}Po)_0$ and $(^{210}Pb)_0$ values at time of eruption. Lavas and scoria from both vents exhibit $(^{210}Po)_0 \sim 0$, suggesting that Po had entirely degassed from the magma at time of eruption. By contrast, 2008 Halema'uma'u ash and Pele's hair samples have very high $(^{210}Po)_0$ that resulted from degassed Po condensing on tephra particles. Activities of $(^{210}Pb)_0$ in the ash and Pele's hair are higher by a factor of ~ 1.5 – 2 than that of scoria and lavas. These samples also have higher Pb concentrations than other 2008 samples. Hence, they likely gained fumarolic Pb shortly before or during eruption. Lava and scoria samples erupted since 1982 have $(^{210}Pb)/(^{226}Ra)_0$ = 0.75 – 1.04; with most samples having ^{210}Pb deficits. There appears to be no clear difference in this ratio between summit and rift samples, or between scoria and lavas, and no clear temporal variations could be identified. However, $(^{210}Pb)/(^{226}Ra)_0$ variations from 0.75 to near equilibrium are observed among samples erupted within a few days of each other. Plagioclase-phyric lavas erupted in episode 54 have near equilibrium $(^{210}Pb)/(^{226}Ra)_0$. Since Kilauea is persistently degassing and erupts with $(^{210}Po) \sim 0$, it is reasonable to assume that magmas also entirely degas ^{222}Rn

before eruption. The repeated $(^{210}Pb)/(^{226}Ra)_0$ ~ 0.75 – 0.80 suggest that this degassing occurs for up to ~ 8 years before eruption. We speculate that CO_2-rich gases carrying Rn continually emanate from magmas as they rise to the surface from the base of the crust over this interval of time. The shifts towards equilibrium $(^{210}Pb)/(^{226}Ra)_0$ values at some phases of eruptions suggest a reduced efficiency of Rn degassing, faster ascent rates, or prolonged storage of some magmas in the rift-zone before they erupt. The near equilibrium $(^{210}Pb)/(^{226}Ra)_0$ values for the differentiated episode 54 lavas illustrate that these eruptions involved magmas that were stored for ~ 3 decades in the east rift zone before they erupted at Nāpau Crater, in agreement with existing petrologic models (Thornber et al., 2003, J. Petrol. 44:1525-1559).

Gonnermann, Helge M.

Dynamic coupling of Mauna Loa and Kilauea volcanoes, Hawai'i

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Global Positioning System (GPS) records reveal that Kilauea, which was actively erupting, and Mauna Loa, which has not erupted since 1984, inflated concurrently during the past decade. This raises the questions whether and how both volcanoes might be dynamically connected (Miklius & Cervelli, Nature, 2003), and if an eruption of Mauna Loa would be more likely in the near future. Here we show how stress transfer by pore pressure diffusion, within an asthenospheric melt layer, is a viable mechanism for coupling both volcanoes, potentially causing them to erupt simultaneously. Paradoxically, by the same mechanism the eruption of one volcano may, in turn, inhibit that of an adjacent one. Using a lumped parameter model we investigate the interplay between changes in asthenospheric melt supply (Poland et al., Nature Geosci., 2012), magma effusion and shallow intrusive activity at both Kilauea and Mauna Loa. The model is constrained by SO_2 emission rates at Kilauea's east rift zone and is able to explain a full decade of deformation (2001-2011) at both volcanoes. We find that stress transfer by pore-pressure diffusion is consistent with time constraints for asthenospheric magma flow from U-series disequilibria (Sims et al., Geochim. Cosmochim. Acta, 1999). To erupt isotopically distinct magmas (DePaolo et al., J. Geophys. Res., 1996; Weis, et al., Nature Geosci., 2011), each volcano's relatively open lithospheric plumbing system has to sample melt from different parts of an isotopically heterogeneous melt accumulation layer. This is consistent with porous melt flow, where each volcano's lithospheric plumbing system is analogous to an artesian well that can 'capture' geochemically distinct regions of melt. Changes in pore pressure may affect the rates of upward magma flow into each volcano's plumbing system and summit reservoirs without significantly altering horizontal flow paths within the porous layer. Likewise, changes in summit magma storage will affect reservoir pressure and, hence, upward flow from and melt pressure within the porous layer. The model predicts that over the past decade the estimated volume of magma added to Mauna Loa's crustal reservoir is similar to historical eruptions at Mauna Loa. Had Kilauea not gone through a period of heightened eruptive and intrusive activity, pressures within the asthenospheric porous melt accumulation zone, and consequently within Mauna Loa's summit reservoir, would have been higher.

Greene, Andrew

Temporal Geochemical Variations in Lavas from Kilauea's Puu Oo Eruption (1983-2012): The Changing Roles of Source and Crustal Processes

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Geochemical time-series analysis of lavas from Kilauea's ongoing Puu Oo eruption chronicle mantle and crustal processes during a single, prolonged (1983 to present) magmatic event. This eruption has shown dramatic variations in eruption style (episodic high lava fountaining to continuous effusion) and magma effusion rates (nearly two-fold increase), both of which correlate with geochemical variations. Here we present an update of our monitoring of the geochemical variations of Puu Oo lavas and the results of a new high-precision isotopic (Pb, Sr) study. Detailed isotopic measurements, made of lavas erupted at ~6 month intervals for the entire eruption, show gradual variations and a reversal in the long-term composition for Kilauea. The geochemical and isotopic trends for the first half of the eruption (until ~2000), including the early episodic, high fountaining period (1983-1986) and the continuous effusion at Kupaianaha and Puu Oo vents, continued the 20th century Kilauea geochemical trends. Starting in ~2000, these trends reversed towards Mauna Loa lava compositions for Pb and Sr isotopes, some trace element ratios and normalized SiO2 abundances. A surge in magma supply began in 2003 (Poland et al., 2012), which was followed about a year later by

a return to the long-term geochemical variation trends for Kilauea. The rate, range and pattern of Pb-Sr isotope and geochemical variations for lavas from the Puu Oo eruption provide insights about melting dynamics and structure of the Hawaiian plume. The overall isotopic and geochemical variations for this single eruptive sequence require contributions from at least three distinct mantle source components with the early Puu Oo lavas deviating in Pb-Sr space from the overall Kilauea-Mauna Loa trend. Short-term periodicity of Pb isotope ratios (two cycles lasting 10 years) may reflect melt extraction from mantle with a fine-scale pattern of repeating source heterogeneities. Crustal processes were highlighted by two brief uprift lava outbreaks in and near Napau Crater in 1997 and 2011. These lavas have major and trace elements indicating mixing of new mafic and stored evolved magmas prior to this episode. Thus, the east rift zone contains multiple pockets of magma that were periodically intruded, differentiated for variable periods and were locally tapped (with or without mixing with new magma) as the stress regime within the volcano evolved. The cooperation of the Hawaiian Volcano Observatory staff over the 29 years of this eruption is gratefully acknowledged. Poland et al., 2012, Nature Geoscience 5:295-300.

Hall, Paul

Mantle plume-migrating mid-ocean ridge interaction and the bend in the Hawaii-Emperor Seamount Chain

Hall, Paul[1]

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Paleomagnetic data obtained from the Hawaii-Emperor Seamount Chain (HESC), the most iconic of all hotspot traces, suggests that the Hawaiian hotspot moved rapidly (~40 mm/yr) southward relative to the Earth's magnetic poles during the period of 81 – 47 Ma before coming to rest at its present latitude, and that this abrupt change in the motion of the hotspot created the well-known bend in the HESC [Tarduno et al., 2003]. Subsequently, Tarduno et al. [2009] proposed that the period of rapid hotspot motion from 81 – 47 Ma might have been the surface expression of the conduit of the presumed Hawaiian plume returning to a largely vertical orientation after having been entrained and tilted by the passage of a migrating mid-ocean ridge (the Pacific-Kula ridge system) over the plume. While geophysical and geochemical observations have suggested that ridges can influence the dispersion of plumes in the upper mantle at great distances (>1000 km), much about the interaction between mantle plumes and mid-ocean ridges remains poorly understood. I report on a series of complementary 2-D numerical and 3-D analog geodynamic experiments designed to characterize the evolution of a plume conduit as a migrating mid-ocean ridge approaches, moves over the conduit, and then continues to move away. Numerical experiments model the upper 400 km of the mantle as a Boussinesq fluid with infinite Prandtl number and a temperature dependent diffusion creep rheology using the COMSOL Multiphysics finite element modeling package. Analog experiments were conducted in a clear acrylic tank (150 cm x 50 cm x 50 cm) filled with commercial grade high-fructose corn syrup. Plate-driven flow is modeled by dragging two sheets of Mylar film (driven by independent DC motors) in opposite directions over the surface of the fluid. Ridge migration is achieved by moving the point at which the mylar sheets diverge using a separate motor drive. Buoyant plume flow is generated using a small electrical heater placed at the bottom of the tank. Results show that the range of plume-ridge separation distances over which plume material will appear at the ridge axis increases with increasing plume temperature, increasing migration rate, and decreasing spreading rate. The location at which the plume conduit impinges on the overriding plate, a proxy for the surface location of hotspot volcanism, is tracked over time in each experiment and the resulting hotspot migration velocities compared to those from the HESC.

Harris, Andrew

Effusion Rate: Measurement from Space and Input into Lava Flow Modelling ***(INVITED)***

Harris, Andrew[1]

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Lava discharge rate could be argued to be one of the fundamental measures of effusive activity. It can control lava flow length and innudation area, is a primary source term for most lava flow emplacement models and is, itself, controlled by the dynamics of the erupting system. However, it can be one of the most difficult parameters to measure, and errors on measurements are usually large if, that is, measurement is possible. This talk will review means to measure lava discharge rate, with a special focus on obtaining this key measurement, in real-time, using satellite thermal data. The review will cover the progress that has been made over the last 20 years, concluding with recent attempts to extract, and validate, lava flow discharge rates from geostationary (SEVIRI) data. Such data have a spatial resolution of 15 minutes, but a pixel size of 3 km. As a result, realiable volumes for lava effused during short (hour-scale) fountaining events on Etna have been extracted from SEVIRI data during the last year. However, recent debate has also focused on the assumptions underlying the methodology used to convert between thernal flux and discharge rates, and the limits within which the conversion can be applied. We will finish by reviewing models available to simulate lava flow emplacement, and a consideration of recent attempts to run such models in real-time using discharge rates automatically extracted from on-reception satellite data. This raises the thorny problem of (information) dissementation issues.

Harrison, Lauren

Li Isotopes of Hawaiian Lavas: Loa Trend Source Variation

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Hawaiian volcanism delineates into two distinctive geographical series, the Kea and the Loa trends, which are also identified by their geochemical and isotopic characteristics. Traditionally, the geochemical differences among volcanoes have been attributed to mixing of different components in the source of the Hawaiian mantle plume, mainly an enriched end-member (Ko'olau) characterized by the presence of recycled oceanic crust ± sediment, a more depleted end-member (Kea) with high ε_{Nd}, ε_{Hf}, and $^{206}Pb/^{204}Pb$, and a more primitive component defined by high $^{3}He/^{4}He$ (Lo'ihi). Because of the sizeable fractionation of lithium isotopes in low temperature environments, lithum serves as a powerful tracer for the presence of altered oceanic crust and sediments in the sources of oceanic island basalts. Lithium can thus be used to help distinguish the source components of Hawaiian lavas. This study examined forty-two samples of Hawaiian shield lavas for Li isotopes, expanding on analysis of post-shield and rejuvenated lavas. Shield basalts exhibit the highest δ^7Li among Hawaiian lavas, ranging from 3.03 ± 0.27‰ to 5.19 ± 1.07‰, with a difference between Kea (higher δ^7Li) and Loa (lower δ^7Li) volcanoes. Li isotopes also correlate positively with Pb and Nd isotopes. This correlation suggests that Li isotopic signatures survive billion-year residence times in the deep mantle and are suitable tracers of ancient subducted oceanic crust and/or sediments in Loa-trend shield lavas [1]. In $^{206}Pb/^{204}Pb$ and ε_{Nd} vs δ^7Li diagrams, Loa shield lavas have lower δ^7Li, ε_{Nd} and $^{206}Pb/^{204}Pb$ and plot along the extension of Kea-trend shield lavas. Enriched Loa shield lavas from West Ka'ena Ridge, the Mile High Section of Mauna Loa, and Ko'olau exhibit higher δ^7Li than other Loa-trend volcanoes, and their lower ε_{Nd} and $^{206}Pb/^{204}Pb$ define sub-parallel trends that indicate there are at least two enriched end-members in the Loa source, one in Ko'olau [2] and one in Mauna Loa lavas older than 120 ka [3]. In addition, Li isotopic analysis of Cretaceous oceanic crust near Hawaii (ODP Site 843) will be investigated to evaluate the possibile lithospheric contamination of Hawaiian lavas [4]. Li isotopes may contribute valid information on this question because the Li isotopic signature of altered oceanic crust is significantly heavier than both fresh MORB and OIB due to incorporation of Li from seawater (δ^7Li ~32‰). Addition of this heavy δ^7Li may account for some of the Hawaiian lava outliers. In Hawaiian shield basalts, Li isotopes not only may reflect the presence of a recycled component in Loa shield lavas, they also help distinguish between Loa enriched source components. Further characterization of the trends in lithium isotopes may unearth some additional insights into the source of Loa-type volcanism [5]. [1] Vlastélic et al (2009) Earth and Planetary Science Letters 286, 456-466. [2] Tanaka et al. (2007) Earth and Planetary Science Letters 265, 450-465. [3] Weis et al. (2011) Nature Geoscience 4, 831-838. [4] Fekiacova et al (2007) Earth and Planetary Science Letters, 261, 65-83. [5] Hanano et al (2010) G3 11, doi:10.1029/2009GC002782

Hauri, Erik H.

Volatile Element Systematics of Hawaiian Shield Volcanoes

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The compositions of shield-stage lavas erupted from Hawaiian volcanoes are characterized by distinctive ranges in major elements, trace elements and radiogenic isotopes. These distinctions are also observed within stratigraphic sections from Kilauea, Mauna Loa, Mauna Kea and Koolau where major elements, trace elements and isotope compositions all vary in correlated fashion over the timespan of each volcano's shield stage evolution. This variability is undoubtedly related to variations in the composition of several different mantle sources present within the Hawaiian mantle plume that contribute to Hawaiian volcanism. Given this variability, we wish to discern whether there are related differences in the abundances of volatile elements (H2O, CO2, F, S, Cl, others) and isotope ratios of hydrogen (D/H) among the different components present in erupted Hawaiian lavas. To this end, we have undertaken ion microprobe measurements of the concentrations of H2O, CO2, F, S and Cl and the isotopic composition of hydrogen in shield-stage submarine glasses and melt inclusions from Loihi, Kilauea, Mauna Loa, Mauna Kea and Koolau volcanoes. Published data for submarine glasses and populations of olivine-hosted melt inclusions [1-13] show large ranges in volatile contents that reflect several pre- and syn-eruptive processes, such as degassing (decreases in CO2, H2O and S) and assimilation of seawater-derived components (increases in Cl and Cl/Nb ratios). Post-eruptive loss of H2O from melt inclusions is also commonly observed in olivines separated from surface lava flows, which rapidly degas their water and set up diffusion gradients between olivine-hosted inclusions and the external melt; when cooling rates are slow, these inclusions lose water via proton diffusion through olivine, with consequent positive shifts in the D/H ratios of the residual hydrogen in the melt inclusion. For this reason, melt inclusions from ash, tephra and scoria deposits are preferred in order to maximize the retention of water in olivine-hosted melt inclusions. In total,

the sparse data for reliable volatile concentrations in submarine glasses and rapidly-cooled melt inclusions show hints of systematic differences between Loa- and Kea-trend volcanoes, but there is a paucity of data from all the volcanoes mentioned above. Further work on select submarine glass samples, and melt inclusions collected from shield-stage scoria cones (Pu'u) will shed further light on the possibility of volatile-element heterogeneity in the sub-Hawaiian mantle. [1] Rison & Craig (1983) EPSL 66, 407. [2] Kyser & O'Neil (1984) GCA 48, 2123. [3] Byers et al. (1985) GCA 49, 1887. [4] Garcia et al. (1989) JGR 94, 10525. [5] Dixon et al. (1991) J. Geol. 99, 371. [6] Clague et al. (1995) J. Petrol. 36, 299. [7] Garcia et al. (1998) Bull. Volc. 59, 577. [8] Wallace & Anderson (1998) Bull. Volc. 59, 327. [9] Kent et al. (1999) Chem Geol 156, 299. [10] Kent et al. (1999) GCA 63, 2749. [11] Dixon & Clague (2001) J. Petrol. 42, 627. [12] Hauri (2002) Chem. Geol. 183, 115. [13] Schipper et al. (2010) EPSL 295, 497.

Hauri, Erik H.

Pyroclastic Volcanism on the Moon and at Kilauea Iki: Similarities and Differences

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The Moon is thought to have formed in a giant impact collision between a Mars-sized object and an early-formed proto-Earth [1]. Though all of the inner planets, including Earth, are depleted in water and other volatiles when compared with primitive meteorites, the more extreme depletion of volatiles in lunar volcanic rocks has long been taken as key evidence for a giant impact that resulted in high temperature catastrophic degassing of the material that formed the Moon [2,3]. However, recent work on rapidly quenched lunar pyroclastic glasses [4] has detected the presence of water dissolved in lunar magmas at concentrations up to 46 parts per million (ppm), and the studied glass beads exhibit clear diffusion profiles indicative of kinetic degassing. These results not only indicate that the Moon is not a perfectly anhydrous planetary body, the also suggest that some fraction of the Moon's observed depletion in highly volatile elements may be the result of magmatic degassing during the pyroclastic eruption of lunar magmas into the near vacuum of the Moon's surface. This suggestion is supported by the ~100X higher water contents of olivine-hosted melt inclusions from the Moon [5]. The 1959 Kilauea Iki fire fountain eruption has often been viewed as a terrestrial analogue of the types of eruptions that produced the lunar volcanic glasses, as it also produced spherical glass beads of varying size. To this end, we measured volatile abundances in several size fractions of Kilauea Iki glass beads. Compared with Kilauea Iki melt inclusions, the Kilauea Iki glass beads have water contents that are lower by a factor of 5-8 and CO2 contents lower by an order of magnitude, indicative of syn-eruptive degassing. However, none of the Kilauea Iki glasses exhibit the kinds of kinetically-driven diffusion profiles exhibited by lunar glass beads; indeed, Kilauea Iki glasses appear to be largely homogeneous and this observation is independent of bead size. In addition, the D/H ratios of Kilauea Iki beads are on average 20‰ lower than Kilauea Iki melt inclusions, and this is consistent with equilibrium degassing of H2O-rich vapor. Kilauea Iki glass beads are much more vesicular than lunar glass beads, which rarely contain vesicles; Kilauea Iki beads display vesicles in virtually all size fractions, and it is likely that several differences in both magma properties and eruption environment

Helz, Rosalind L.

Evidence for a large range of melts present in Kilauea's summit reservoir

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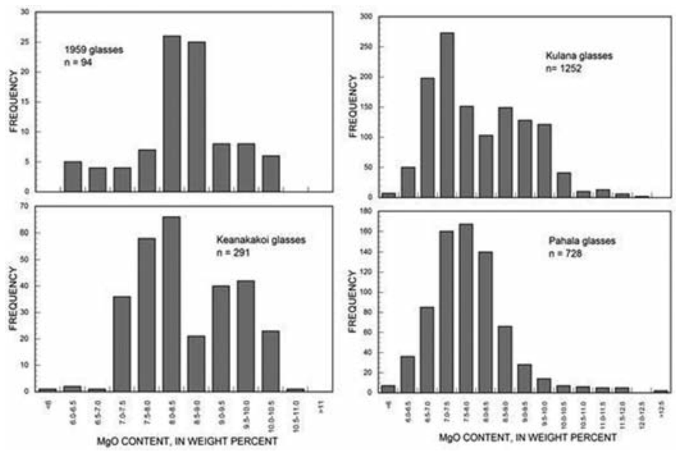
We have over a century's worth of petrologic observations on Kilauean lavas, including abundant microprobe analyses of glasses (= quenched melts). These melt compositional data show the range of melts available in Kilauea's summit reservoir over time. Compositional variation of melts erupted effusively within the caldera is limited, ranging from 6.4-7.5 weight percent (wt.%) MgO. Kilauea has erupted such melts almost continually over the last two centuries. These crystal-poor melts represent magma from the top of the reservoir, but are not representative of the entire reservoir. Effusive extracaldera summit lavas of the 1959, 1971, and 1974 eruptions contain melts with up to 10.2, 8.9, and 8.2 wt.% MgO respectively. The ongoing presence of more magnesian liquids is further supported by the occurrence of Pele's tears containing up to 8.7 wt.% MgO in the 1924 tephra. The pattern of eruption suggests that the more MgO-rich liquids are stored at greater depth, and implies the presence of a (density?) barrier within the upper part of the caldera, such that, in the absence of major explosive activity, such liquids erupt only around its edges. Histograms of melt compositions in the major explosive episodes at Kilauea show large ranges of MgO contents for the Keanakako'i (1500-1800 A.D.), Kulana (400-1000 A.D.) and Pahala (older than 10 ka) tephra units (figure); the 1959 summit eruption is shown for comparison. Important features of the histograms include: (1) the overall range of MgO is similar (6.5-11.0 wt.% for 1959 and Keanakako'i, with a small tail extending to 12% MgO for Kulana and Pahala ashes, and rare shards >13% MgO in the Pahala). (2) The dominant melt compositions lie at 7-10 wt.% MgO, mostly higher than typical intracaldera glasses erupted from the top of the reservoir. (3) Two histograms (Keanakako'i, Kulana) are bimodal, which raises the possibility that there is preferential magma storage at two different depths. A further important feature of the tephra data is that individual vitric layers are of two types: the first have a limited range of MgO, while the other show a wide range of glass MgO within a thin layer. The stratigraphic position of these layers is random. These observations establish that Kilauea's summit reservoir contains melts ranging from at least 6.5 to 11.0 wt.% MgO, and that such melts were available for sampling instantaneously and repeatedly over centuries. The former belief that the summit reservoir contains only melts lying at the low end of this range is not supported by current observations.



Herrick, Julie A.

Lava inundation probability for the north flank of Mauna Loa

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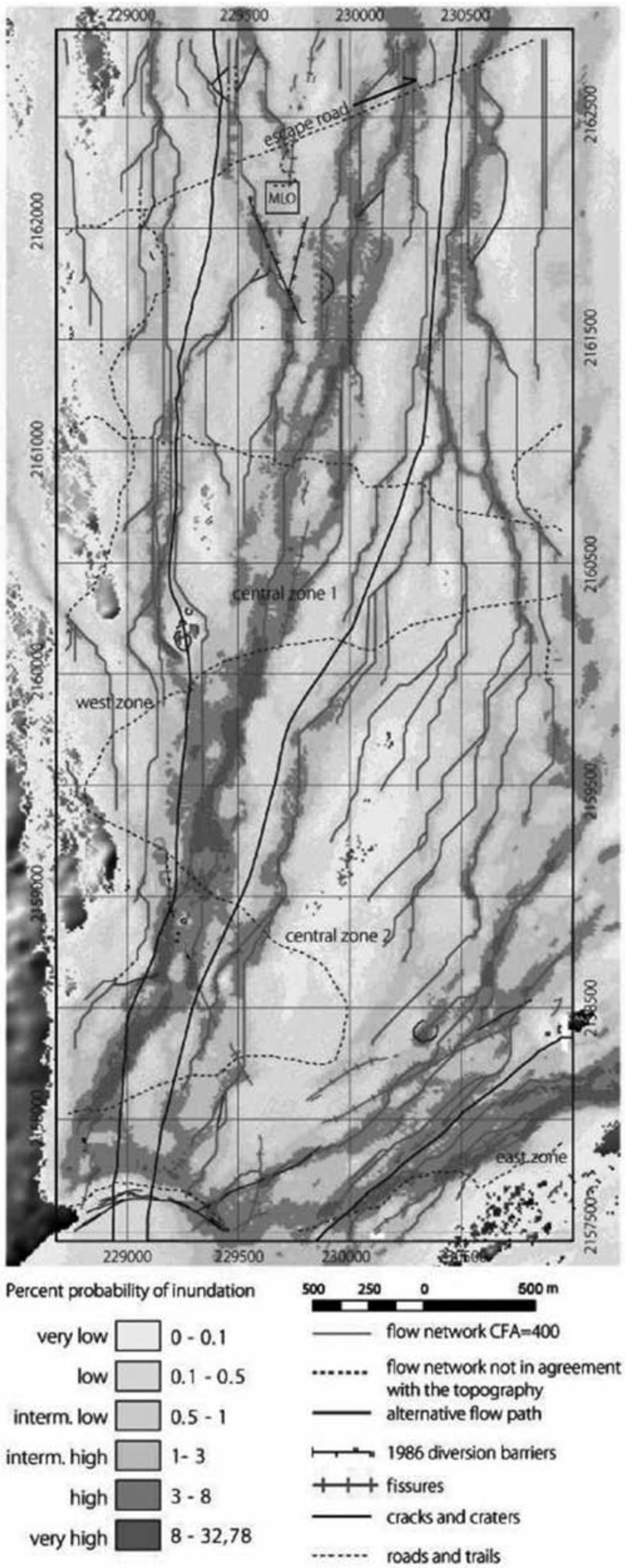
The NOAA Mauna Loa Observatory (MLO), located high on the north flank of Mauna Loa, provides the world with CO_2 baseline data used to track global warming. The facility is located within 4 km of the junction of the summit caldera (Moku`aweoweo) and the North East Rift Zone (NERZ), and is therefore at risk from future lava flows. Having already weathered the eruption of 1975, NOAA constructed a lava inundation barrier built in 1986 as a precaution against potential damage from future eruptions. Mauna Loa erupts frequently. Over the past 3,000 years, Mauna Loa has erupted lava flows, on average, every 6 years. The volcano has erupted 33 times since 1843, averaging one eruption every 5 years. The NOAA MLO facility suffered a close encounter with lava during the 1984 eruption, when the observatory's power lines were cut off by `a`a flows from the NERZ. Results from a field mapping campaign, covering a 2.5 x 5.5 km area, provided the basis for a lava flow inundation analysis. Using geospatial analysis methods, we investigated the probability of inundation from radial vent, rift zone, and summit eruptions. We also focused an analysis on the 1.0 x 1.0 km area of the NOAA facility. Lava flows originating from all three potential source regions have been mapped in the study area. We combined two DEM-based simulation models to examine lava flow paths with the purpose of developing a hazard assessment for the NOAA facility. Two GIS programs (BASIN1 and VORIS) were used to analyze the digital terrain, based on a 10 m DEM in order to outline possible inundation zones. The BASIN1 results provide clear delineation of the flow network, allowing preliminary inundation zones to be drawn. Additional information provided by VORIS defined the probabilities of each flow network branch being inundated. By overlapping the inundation zones with the map of inundation probability within a 50-year time interval, it is clear that the NOAA facility is not likely to be affected by lava flows originating from the NERZ. Its main threats are posed by lava flows originating from the western edge of Moku`aweoweo and the formation of radial vents.



Hon, Ken

Petrologic evidence for a large, actively convecting summit magma chamber within Kilauea volcano

Hon, Ken[1]; Thornber, Carl[2]

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2. US Geological Survey, Cascades Volcano Observatory, Vancouver, WA, USA

Convection can transfer heat, volatiles, and new magma between stably stratified layers in magma chambers. Magmatic convection has previously only been inferred by static compositional variation, crystal zonation, laboratory experiments, and modeling. We document temporal variations in crystal content, temperature, composition, and mineral chemistry from Kilauea lava samples that are consistent with an actively convecting large magma chamber (10-20 km3) Throughout the current eruption, magma has moved from the summit chamber through the east rift over periods of hours to weeks. From mid–1986 to mid–1990, lava erupted from Kupaianaha with little or no local storage, providing a clear record of processes within the summit magma chamber. Geochemical data show broad positively correlated fluctuations in MgO content and temperature for both rocks and glasses. Measured and calculated olivine compositions suggest that olivine was in equilibrium with the higher MgO whole–rock compositions for a short period in late 1986. By mid–1987, most olivine phenocrysts were nearly in equilibrium with lower MgO host glasses indicative of olivine entrainment. Sulfur contents (800-1200 ppm) of olivine melt-inclusions from Kupaianaha indicate an origin in the summit magma chamber. Olivine crystals with high-sulfur melt inclusions also have a range of MgO contents that record a strong roofward cooling gradient in the summit chamber (1200–1170°C). Roofward cooling is accompanied by degassing of SO_2 and H_2O from Halema‘uma‘u Crater. Water loss increases the density of the magma creating denser descending plumes that convectively stir the underlying magma. During vigorous convection, small (<1 mm) olivine crystals are kept in suspension producing the observed semi-annual sinusoidal MgO and temperature fluctuations. The opening of the new vent within Halema‘uma‘u in 2008 increased degassing by nearly an order of magnitude and provided evidence of convection within the summit magma chamber. Lava samples from the new vent showed a rapid increase in temperature from 1155 to nearly 1170°C, followed by a slow decline back to 1155°C over the next 3 years. In addition, hot, olivine-only lava reappeared at Pu‘u ‘O‘o for the first time in a decade. The temperature rise and fall was coupled with a dramatic spike in SO_2 (and probably H_2O) followed by a drop in sulfur content of olivine glass inclusions. The strong degassing associated with opening of the vent initiated vigorous convection that has mixed, cooled, and degassed a significant portion of the uppermost magma chamber. We also hypothesize that stronger convective stirring occurred during past eruptions, such as those of Mauna Ulu, disrupted thermal and chemical zonation of the summit magma chamber and caused relatively rapid compositional

shifts. Convection and mixing is probably ongoing at the base of the summit chamber as new, CO2 rich magma is introduced. Vigorous injections may trigger eruptions, such as the 1959 Kilauea Iki eruption. Major explosive and tectonic events, appear to cause widespread convective overturn and chaotic mixing within the summit magma chamber followed by major geochemical changes.

Horton, Keith A.

Early Monitoring Results from the Halema`uma`u Vog Measurement and Prediction FLYSPEC Array

Horton, Keith A.[1]; Garbeil, Harold[1]; Sutton, A. J.[2]; Elias, Tamar[2]; Businger, Steven[3]

1. HIGP, University of Hawaii, Honolulu, HI, USA
2. Hawaiian Volcano Observatory, Hawaii National Park, HI, USA
3. Meteorology, University of Hawaii at Manoa, Honolulu, HI, USA

From early 2010 to late 2011, a multifaceted feasibility project called Vog Measurement and Prediction (VMAP), was carried out by the University of Hawaii at Manoa and the USGS Hawaiian Volcano Observatory (HVO). The two tasks distinguishing VMAP were: (1) develop, deploy and test an array of FLYSPEC UV spectrometer systems that could provide continuous, near real-time measurements of SO_2 emissions from the Halema`uma`u eruptive vent at the summit of Kilauea Volcano during daylight hours; (2) create a real-time volcanic gas modeling and forecast capability to predict the concentration and dispersion of SO_2 and sulfate aerosol particles (PM2.5) from Kilauea's summit based on gas dispersion and numerical wind prediction models. The goal was to feed the new high-temporal resolution SO_2 source measurements from the first task into the prediction capabilities of the second task. This presentation highlights some of the early results from the VMAP FLYSPEC array. We have modified the commercially available FLYSPEC instrument, which is used routinely by HVO for campaign-style measurements, to be operated remotely in a stand-alone fashion. We have, in collaboration with HVO, deployed an array of 10 of these stand-alone sensor packages linked through a WiFi communications node to transmit the data collected by each instrument back to HVO in real-time. The central location of the array at F0, is also the location of the WiFi communications node. A high gain directional antenna is used to relay data back to HVO, approximately 5km away. The array is deployed along a 3 km long arc approximately 2.7 km downwind from the summit eruptive vent. Units F0 and F1 are aligned along the average trade wind axis and are approximately 200m apart. SO_2 path-concentration data, which is calculated in real-time by each of the 10 field units, is transmitted to a base computer at HVO, which automatically calculates the current emission rate, nominally at 1 Hz. Units F0 and F1 are used to calculate the plume velocity along the most likely plume direction through correlation techniques described in Williams-Jones, et al. (2006). In the event that the primary plume direction shifts, existing weather stations near the vent can be used to substitute wind velocities to calculate the emission rates. Examples of the variability of the gas burden from the vent for any variable interval can be shown. The overall system collects these data for 8-9 hours per day. Initial comparisons of VMAP array gas data to Real-time Seismic-Amplitude Measurements (RSAM), which represent a general measure of seismicity, show encouraging correlation. Kilauea is an ideal real-world laboratory in which a highly monitored volcano can bring multiple techniques and monitoring disciplines together. The new VMAP FLYSPEC array can provide continuous measurement inputs relating to the driving force of volcanism and gas emissions, in a way that has been unavailable until now.

Houghton, Bruce F.

Explosive Eruptions at Basaltic Volcanoes *(INVITED)*

Houghton, Bruce F.[1]; Carey, Rebecca J.[1, 2]; Swanson, Don A.[3]; Gonnermann, Helge M.[4]

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2. CODES, University of Tasmania, Hobart,, TAS, Australia
3. Hawaiian Volcano Observatory, USGS, HVNP, HI, USA
4. Earth Science, Rice University, Houston, TX, USA

Eruption parameters suggest that basaltic eruptions cover a weak to moderately strong range of explosivity, equating to discharge rates of 10^2 to 10^8 kg/s and erupted volumes of 10^3 to 10^9 m3. Current classification systems for explosive eruptions offer a 2D perspective that quantifies some measure of mass discharge rate versus involvement of external water from the eruptive products. Basaltic systems fit this space awkwardly and really require at least two extra parameters: to constrain how sustained/steady the eruptions were and the vent/conduit shape. Studies at 3 frequently active volcanoes strongly influence our current picture of basaltic explosive volcanism: Kilauea, Stromboli and Etna. Key factors that we discuss in considering the mechanisms for basaltic explosive eruptions are: - Pre-eruption volatile contents and the role of outgassing of CO_2. - Depth and time scales of shallow melt storage and mingling. - Nature and depth of generation of the gas phase that powers eruption. - Relevant times scales of bubble nucleation, growth and relaxation. - Rheological state of the magma at fragmentation. - Vesiculation state and crystallinity of the melt phase - Extent to which the gas phase(s) is mechanically coupled. - External triggering of explosions. - Active versus passive roles of external water and wall rock in the explosions and plumes. We focus principally on the complex relationships between melt and exsolved volatiles in basaltic explosive eruptions, and the applicability of couple/decoupled or open/closed system behaviors to low viscosity magmas.

Howell, Samuel M.

Numerical Modeling of Mantle Convection beneath the Aegir Ridge, a Shadow in the Iceland Hotspot

Howell, Samuel M.[1]; Ito, Garrett[1]; Breivik, Asbjorn[2]; Hanan, Barry[3]; Sayit, Kaan[3]; Vogt, Peter[4]; Mjelde, Rolf[5]

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2. Department of Geosciences, University of Oslo, Oslo, Norway
3. Department of Geological Sciences, San Diego State University, Sandiego, CA, USA
4. Marine Science Institute, University of Santa Barbara, Santa Barbara, CA, USA
5. Department of Earth Science, University of Bergen, Bergen, Norway

The Iceland Hotspot has produced extensive volcanism spanning much of the ocean basin between Greenland and Norway, forming one of the world's largest igneous provinces. However, an apparent igneous "shadow" in hotspot activity is observed at the fossil Aegir Ridge, which accommodated seafloor spreading northeast of present day Iceland from continental breakup ~55 Ma until ~25 Ma. At this point, the spreading center ceased to produce new crust and all spreading moved west to the Kolbeinsey Ridge, which opened ~30 Ma. Enigmatically, normal-to-anomalously thin crust formed along the Aegir ridge, despite its close proximity to the Iceland Hotspot. To address this disparity, we use three-dimensional numerical models to simulate the interaction between a mantle plume, rifting continental lithosphere, and the time-evolving North Atlantic ridge system. Two end-member hypotheses for Aegir's anomalously low production are investigated. First, that material emanating from the hotspot was diverted away from the Aegir Ridge by the thick lithosphere of the Jan Mayen Microcontinent, starting ~30 Ma, as the Kolbeinsey Ridge began rifting it apart from Greenland just east of the projected center of the Iceland hotspot. Second, that plume material was not blocked and did reach the ridge, but had already experienced partial melting closer to the hotspot. This material was then unable to produce melt volumes at the Aegir Ridge comparable to those of pristine mantle. To test these hypotheses, model predictions are compared with seismologically constrained crustal thicknesses, boundaries in seafloor geology, and preliminary geochemistry analysis to explore likely and unlikely scenarios which result in the observed Aegir shadow.

Ito, Garrett

Seismic Structure and Dynamics of the Hawaiian Mantle Plume ***(INVITED)***

Ito, Garrett[1]; Wolfe, Cecily[1]; Ballmer, Maxim[1]

1. SOEST, Univ Hawaii, Honolulu, HI, USA

Seismic observations and geodynamic models provide insights into the origin of the Hawaiian hotspot. The regional PLUME experiment involved deployments of land and ocean seismometers to image the mantle seismic structure at high resolution. Surface waves constrain structure down to ~200 km depth, and reveal anomalously low velocities in the lower lithosphere and asthenosphere extending along the island chain beneath the Hawaiian swell. P and S wave tomography produce consistent results. The body waves also reveal a low velocity anomaly SE of the chain that protrudes downward well into the topmost lower mantle. Thus, the seismic structure is consistent with a mantle plume rising from the lower mantle, tilting with plate motion, and feeding a hot ponded layer beneath the lithosphere, all as predicted by classical plume theory. One problem, however, is that the anomaly beneath the lithosphere is too asymmetric and far too thick to be explained by a classical thermal plume. Geodynamic models of a thermochemical Hawaiian plume provide an explanation for these enigmatic seismic features. Calculations of a plume composed of peridotite and chemically dense eclogite predict plume material to pool in a layer within the depths of 300 to 410 km where mineral physics studies indicate that the density excess of eclogite should be maximal. Material escaping out of the top of this deep pool feeds the shallow ponded layer beneath the lithosphere. Seismic resolution tests show that this double-layering can explain the large seismic anomaly beneath the lithosphere. Furthermore, thermochemical plumes can display strong time-dependence and spatial asymmetry, behaviors that, respectively, can account for observations of long-term variability in Hawaiian volcanic activity as well as bilateral asymmetries in the swell topography, upper mantle seismic structure and geochemistry. PLUME may therefore be revealing the first seismic evidence for a thermochemical plume even though geochemical evidence for such compositional heterogeneity has been known for over a decade. It has further been suggested that the Hawaiian plume is part of a thermochemical upwelling rising from the northern margin of the Pacific Large Low S-wave Velocity Province in the lowermost mantle, a feature imaged by global tomography. The PLUME project also shows evidence for seismic anisotropy beneath the Hawaiian hotspot. Shear-wave splitting (SWS) analyses show average fast polarization directions that roughly parallel the local fracture zones. The simplest interpretation is that SWS is dominated by fossil mineral fabric in the lithosphere. However, geodynamic models of plume-plate interaction and mineral fabric development show that mineral fabric in the lithosphere plus fabric in the plume can explain much of the variability in the SWS directions. Thus Hawaii is a case where SWS is heavily influenced by the lithosphere and has a small plume signal, whereas other simulations show that SWS at the Eifel and Iceland hotspots probably originates primarily in the plume and has a small lithosphere signal. The physical and chemical dynamics of the Hawaiian hotspot as well as other hotspots worldwide are rich in processes that have yet to be well explored with integrated studies involving geodynamic modeling, computational seismology, and seismic observations.

Jackson, Matthew G.

The Deep Mantle Feeding Hawaiian Volcanism: New Perspectives on Old Models *(INVITED)*

Jackson, Matthew G.[1]

1. Dept. of Earth Sciences, Boston University, Boston, MA, USA

The Earth's mantle is a dynamic environment where crustal materials are injected into the mantle at subduction zones and stirred in the ambient mantle on geologic timescales. Subducted crust is stretched and thinned and its geochemical identity is likely greatly attenuated, and the ultimate fate of material sent into the mantle is not well known. The geochemistry of Hawaiian lavas may provide some important clues. Strong evidence is emerging for the recycling of subducted materials into the mantle beneath Hawaii, where they are melted and thus complete the mantle recycling circuit. Ancient subducted materials contribute enriched isotopic signatures and major element heterogeneity to the Hawaiian mantle that give rise to unusual melt compositions. The unparalleled geochemical database available for Hawaiian lavas reveals striking relationships between major elements and radiogenic isotopic compositions that suggest long-term isolation of distinctive, mafic lithologies that must have their origins in ancient subduction zones. In order to better constrain the origin of recycled material in Hawaii, it is important to place the geochemistry of Hawaiian lavas in the context of the initial starting compositions of the Bulk Silicate Earth (BSE). A recent, landmark discovery demonstrated that modern terrestrial lavas have $^{142}Nd/^{144}Nd$ ratios ~18 ppm higher than chondrites (Boyet and Carlson, Science, 2005). The new result implies that the $^{143}Nd/^{144}Nd$ composition of the BSE is ~0.5130—a value closer to MORB than to chondritic—and this ratio may now be the standard for determining whether a reservoir is considered "enriched" (<0.5130) or "depleted" (>0.5130). In a chondritic world, all reservoirs with $^{143}Nd/^{144}Nd$ > 0.51263 (i.e., the chondritic ratio) are considered depleted, and reservoirs with $^{143}Nd/^{144}Nd$ < 0.51263 are enriched. Therefore, it is the range of $^{143}Nd/^{144}Nd$ ratios from 0.51263 to 0.5130 that is affected by a change of reference frame: considered "depleted" in a non-chondritic world, lavas with $^{143}Nd/^{144}Nd$ ratios from 0.51263 to 0.5130 would be considered "enriched" in the non-chondritic BSE model. Hawaiian lavas plot almost entirely within this range of values, and would be considered geochemically depleted (i.e., $^{143}Nd/^{144}Nd$ ratios are most > 0.51264) relative to a chondritic Earth; this would imply a history of depletion in the mantle source of Hawaiian lavas, which is contrary to the commonly held notion that hotspot lavas sample a dominantly enriched mantle. However, if the Earth is non-chondritic, the bulk of Hawaiian shield lavas are actually enriched ($^{143}Nd/^{144}Nd$ < 0.5130), which implies a history of geochemical enrichment for this plume relative to the composition of BSE. Another implication of the $^{142}Nd/^{144}Nd$ discovery is that that surviving primitive reservoirs in the mantle may have a very different isotopic make-up than traditionally believed. If the Earth's primitive mantle is not chondritic, the best candidate for a surviving portion may be the mantle reservoir sampled by lavas with the highest $^3He/^4He$. The highest $^3He/^4He$ lavas from Loihi have Nd-isotopic compositions consistent with sampling a component of the primitive (but not chondritic) mantle.

Jacob, Samantha

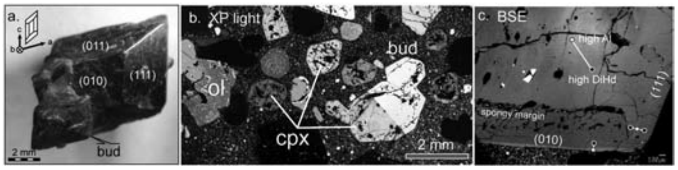
Post-shield magmatic processes: New insights from Haleakala ankaramites

Jacob, Samantha[1]; Welsch, Benoit[1]; Hammer, Julia[1]; Sinton, John[1]

1. Geology and Geoyphysics, University of Hawaii at Manoa, Honolulu, HI, USA

Volcanic rocks are envisioned as probes of the magmatic plumbing system that created them, with reservoir temperatures and pressures revealed by well-calibrated mineral-melt thermobarometers. Because Ca-clinopyroxene (cpx) is a dominant phenocryst phase in mildly alkalic magmas and cation exchange equilibria are sensitive to temperature and pressure, cpx-melt thermobarometry is a promising tool for inferring the depth and thermal structure of post-shield magma reservoirs. Do cpx crystals in Hawaiian post-shield magmas grow at near-equilibrium conditions, as suggested by faceted surfaces and inferred in assessment of magma chamber pressure (Chatterjee 2005, JVGR 145, 1-22)? An ankaramite lava (194-230 ka) representing Kula stage postshield volcanism (Stearns and Macdonald 1942, Div Hydrol Bull 7) is the basis for our morphological, petrographic, and microanalytical study of cpx typical of Haleakala ankaramite. Crystal forms and three-dimensional surface features of phenocrysts are exceptionally well-preserved in single crystals that weather out from the lava. The dominant forms of these euhedral 2/m crystals are the (010) pinacoid, (110) prism, and (111) prism, in order of increasing prominence. In addition, crystals are characterized by crystallographically-aligned contact crystals, or "buds", attributed in olivine (Welsch, in press, J Petrol) to maturation of dendritic crystals. Spongy margins (~400 μm thick) are compositionally heterogeneous; the absence of spongy margins on the slowest-growing (111) faces suggests that spongy texture is a growth phenomenon rather than a resorption feature. Electron microprobe transects across regions of high BSE contrast reveal concentrations of Al^{3+}, Ti^{4+}, Na^+ and other non-stoichiometric cations anticorrelated with $Ca(Mg,Fe)Si_2O_6$. These compositional trends are nearly identical to results of dynamic cooling experiments on Etnean basalt (Mollo et al., in review, J Petrol), in which the concentrations of non-stoichiometric cations progressively increase as cooling rate increases. We suggest the compositional and morphological features of Haleakala ankaramite are the product of extreme fluctuations in crystal growth rate. Rapid growth connotes cpx supersaturation, a situation that is incompatible with steady-state magmatic conditions usually associated with post-shield magma storage reservoirs. Rather, fluctuations in crystal growth rate may occur in mushy margins of magma reservoir where thermal gradients are steepest, and

as magma ascends during volcanic eruptions. If cpx grows predominantly at far-from-equilibrium conditions, cpx-melt thermobarometry yields erroneously high crystallization pressure and temperature. Thus, distinguishing various origins of intra-crystal cpx compositional heterogeneity is profoundly important for understanding of magmatic plumbing systems.



Johnson, Jessica H.

A Background of Seismic Anisotropy at Kilauea Volcano and Changes Associated with the Summit Eruptive Vent

Johnson, Jessica H.[1, 2]; Poland, Michael P.[1]; Okubo, Paul G.[1]

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Using shear wave splitting analysis, we have analyzed volcano-tectonic earthquakes at Kilauea Volcano, Hawaii, recorded since April 2007, for anisotropy using shear wave splitting. We use an automatic algorithm and assume that the polarization of the fast shear wave is parallel to the maximum horizontal compressive stress or the orientation of strong geologic structures. Stations more than 5 km from Kilauea's summit eruptive vent record fast directions that are strongly aligned in a NE-SW direction, consistent with studies in the 1980s and 1990s and suggesting that regional stress is stable over decadal time periods. We also observe fast directions aligned with prominent faults trending obliquely to the regional shear wave splitting direction of NE-SW when the stations are close (< 1 km) to the fault, and fast directions tangential to the summit caldera, parallel to the caldera ring faults, at stations close to the summit eruptive vent. Our observations indicate that highly fractured zones associated with faulting overprint the anisotropy from micro-cracks that are aligned with the regional stress. We observe significant temporal variations over time-scales of months to years at stations on the caldera floor, suggesting that we might be able to measure changes in the local stress associated with volcanic activity. We observe the fast direction of anisotropy to be radial to the summit vent at these stations in 2008 and tangential to the summit vent at all other times. The variations in anisotropy most likely reflect stresses associated with the formation of the summit eruptive vent in March 2008. These stresses may not be transmitted through the caldera bounding faults, preventing these changes from being observed at stations outside the caldera. The return of the local anisotropy to its background state correlates with a major collapse of the vent wall and a pause in the eruption in late 2008. Additional comparison with local travel-time tomography and numerical models will complement interpretations of temporal changes in seismic anisotropy at Kilauea.

Jordan, Jake

Partial Melt Migration in a Heterogeneous Mantle During Active Upwelling

Jordan, Jake[1]

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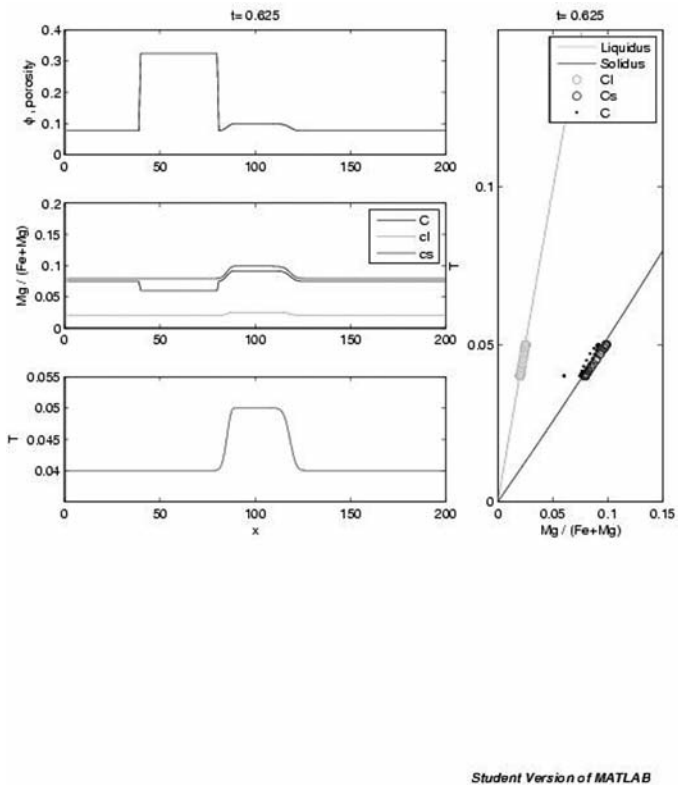
We explore the effect of heterogeneities on partial melting and melt migration during active upwelling in the Earth's mantle. To examine heterogeneity and its dynamic affects on porosity, temperature and chemical composition of the (Mg,Fe) solid solution in partial melts of olivine we have constructed simple, explicit nonlinear models in one dimension. The two component solid solution, is represented by a phase loop where concentration, 0 corresponds to fayalite and 1 is forsterite. We have normalized temperature such that 0 is the initial melting temperature and 1 represents a completely fluid solution. We study the evolution of an Fe-rich heterogeneity in an imposed, background flow field with a constant fluid flux. Preliminary results, as shown in the figure, show that the Mg-rich material can advect through Fe-rich material as a pulse. As the surrounding Mg-rich material flows through the Fe-rich inclusion, the concentration pulse splits. At the front of the inclusion the Mg-rich wave pulse widens in slope under the influence of the higher porosity material and develops asymmetry. The Fe-rich region remains in place and is further depleted of Mg. The temperature and porosity pulses associated with the initial condition advect along with the Mg-rich wave once they have exited the initial Mg-poor inclusion. After the pulses pass out of the location of the initial condition, they stabilize and advect with constant speed. The area left behind by the initial condition is further depleted in Mg, and the moving wave is fortified with Mg. In this preliminary simulation, we observed an Fe-rich inclusion with a Mg number 1.33% lower and a temperature about 8.5 degrees K higher than the ambient surroundings. The small inclusion had a porosity of 34% volume fraction within a 7.6 % background. After the fluid of high Mg number advected through the Fe-rich inclusion, a spike of 32% porosity remained while 5.8% of the initial porosity spike advected along with the temperature pulse, resulting in a moving peak of 9.2% porosity. The depleted Mg number was 8.04% lower than the ambient surroundings, about 6 times lower than the initial condition, after the pulse advected through. This seemingly, simple initial condition yielded counterintuitive results suggesting that a more comprehensive study on heterogenity is needed.



Karlstrom, Leif

Coupling between magmatic landscape construction and fluvial erosion on ocean islands

Karlstrom, Leif[1]; Perron, J. Taylor[2]

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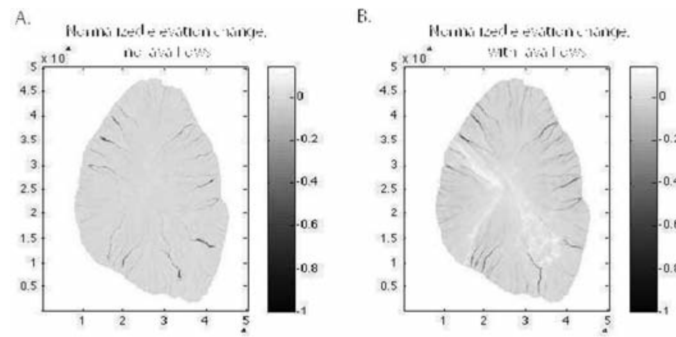
Volcanic ocean island landscapes are defined by construction through magmatism, an evolving boundary condition for dissection by geomorphic processes. We are interested in the interactions between magmatic landscape construction and erosion, during and after shield building. The combination of subsurface intrusions and surface flows provides surface roughness for physical weathering and raw materials for chemical weathering. We focus here on fluvial dissection and the coupling to magmatism. Lava flows fill in topography. Incision removes mass, affecting the distribution of topographic elastic stresses. If mass removal happens quickly, an active crustal magma column magma may respond through increased eruption rates. Most effective during edifice flank collapse, slower fluvial sculpting might also affect eruption rates and locations. We focus on 1) what are the characteristics of channel networks in a constructional environment? 2) Are evolving rates of magmatism recorded by channel networks when both processes are active? 3) Can fluvial incision modulate eruption rates or locations? To address these questions, we modify a landscape evolution model (Perron et al., 2008, 2009) by adding an elevation source term for lava flow emplacement. Volcanic vent locations are set by topography, an approach that allows for mass removal to affect vents via analytic scalings for perturbations to elastic stresses by incision. Lava flow emplacement is stochastic (Favalli et al., 2005), accounting for thickness variations, flow over small topographic barriers and length constraints (Harris and Rowland, 2009). We allow a stochastic number of flows per time step, constraining only the time-averaged eruption rate. We measure how magmatic surface roughness is imprinted on channel networks and how channels competing with lava flows differ from the null case of no lava. By varying initial roughness, lava effusion and erosion parameters, we quantify evolving drainage density and incision efficacy compared to lava emplacement. Although incision and lava flows both focus towards convergent areas, positive feedbacks in drainage basin growth promote azimuthal asymmetry in channel development. Initial results are shown in figure 1, which shows that lava flows act to restrict both the areal extent and the magnitude of erosion.



Example calculations with a lava effusion rate of 10 m^3/year, distance in meters. Initial topography is a cone with red noise as surface roughness. A. Normalized erosion after 200 ka, for the null model of no lava. B. Normalized erosion after 200 ka, including lava flows.

Kavanagh, Janine

The Influence of Pre-Existing Structures on a Quaternary Fissure Vent Eruption: The Mt Eccles Volcanic Complex, The Newer Volcanics Province, Australia

Kavanagh, Janine[1]; Cas, Ray[1]; Trowbridge, Rebecca[1]

1. Geosciences, Monash University, Clayton, VIC, Australia

Mt Eccles Volcanic Complex (MEVC; 38°3.66'S, 141°55.34'E) comprises a spectacular NW-SE trending fissure vent system that is aligned with several small southern cinder and spatter cones, forming a ~2 km long array. Hawaiian fire-fountaining was a dominant eruptive style at the MEVC, with minor Strombolian and phreatomagmatic behaviour. The fissure vent is breached to the north by a substantial lava field that is thought to originate from a lava lake that once filled the fissure vent. The longest of these lavas, the Tyrendarra flow, extends over 50 km in length reaching the current coastline to the south. These sizeable flows indicate a sustained high effusive phase in the MEVC eruption that allowed the development of an extensive lava tube network (preserved as numerous lava caves), channels and tumuli. Fluctuations in magma ascent rate, and occasional interaction with ground water, was likely responsible for the range of eruptive behaviours recorded. The MEVC eruptive period was likely short-lived,

with punctuated events lasting in total several weeks to months. The MEVC forms part of the Newer Volcanics province (NVP) of south-eastern Australia, the site of Australia's most recent volcanic activity. This Quaternary volcanism (the MEVC has been dated as young at 7 ka) occurred in an intra-plate setting where the contemporary regional stress field was compressive. The development of trans-tensional windows has been invoked as a method to instigate magma ascent in the region, with large-scale crustal structures then assisting and focusing the volcanism. The strong alignment of the MEVC fissure vent and cone array suggests dykes utilized pre-existing structures during magma ascent, a hypothesis supported by the array trend being sub-parallel with other large-scale faults in the area. The MEVC is the only known preserved fissure vent system in Australia and represents a unique opportunity to study this type of eruptive behaviour in an intra-plate Plains Province setting. The erupted products are composed of hawaiites, nepheline-hawaiites, basanites and alkali-olivine basalts. They have a strong Ocean Island Basalt character that is consistent with other erupted products in the NVP. There are similarities between the MEVC and Hawaiian volcanoes, and though on a smaller scale, the MEVC represents a 'snap-shot' into the intermediate stages of shield volcano development. Further work will focus on the risks associated with this type of volcanism to the five million residents of Australia's second largest city, Melbourne, whose homes are in part built on deposits from the NVP.

Kelly, Cyndi L.

Imaging Seismic Source Variations Throughout a Volcano's Eruptive Sequence Using Back-Projection Methods

Kelly, Cyndi L.[1]; Lawrence, Jesse[1]

1. Geophysics, Stanford University, Stanford, CA, USA

Our knowledge of the mechanisms and plumbing at work within volcanic systems is limited by our ability to measure weak motions within the Earth using remote observations. Seismic records from volcanoes typically contain apparently noisy records that are actually a compilation of many overlapping low-magnitude displacements. Prior studies traditionally focused on short bursts within the "noise" associated with high-amplitude signals from a relatively small number of events that occurred during only a very small percentage of the total eruption cycle time. However, it has been shown that the much more abundant low-magnitude events in the "noise" are directly linked to magma and fluid movement at depth in volcanic systems and therefore likely contain critical information about the system's subsurface dynamics and properties. This study provides seismic observations of very small seismic events at depth in volcanic systems in order to map out plumbing networks as they develop through an eruption cycle. A back-projection search algorithm is used to determine where coherent seismic signal is coming from during distinct phases of a volcano's eruption cycle. This approach utilizes data from the entire seismic record before, during and after volcanic activity and allows for a more complete understanding of how the seismic source changes through time during an eruptive sequence rather than only during a particular event or an active eruption. This information helps to 1) answer fundamental geologic questions about volcano-tectonic processes, and 2) make more accurate assessments of volcanic hazards. This method is currently being tested on various volcanoes around the globe and the feasibility of applying it to Hawaiian volcanoes is being assessed.

Kern, Christoph

Ultraviolet SO2 imaging systems allow insights into degassing processes occurring on short timescales at Kilauea's summit

Kern, Christoph[1]; Elias, Tamar[2]; Kelly, Peter[1]; Mastin, Larry[1]; Sutton, A. Jeff[2]; Thelen, Wes[2]; Werner, Cynthia[3]

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2. Hawaiian Volcano Observatory, USGS, Hawaii Volcanoes Nat'l Park, HI, USA
3. Alaska Volcano Observatory, USGS, Anchorage, AK, USA

Ultraviolet (UV) cameras facilitate the two-dimensional imaging of SO2 distributions at temporal resolutions on the order of 1Hz. Optical bandpass filters that selectively transmit only radiation of the UV wavelengths at which SO2 absorption occurs (or, for reference, radiation of wavelengths at which absorption is negligible) are positioned in the camera's optical system, thus providing selective sensitivity to SO2. Behind H2O, SO2 is the second most abundant volatile species emitted at Kilauea's Overlook vent, located within Halema`uma`u crater. Once in the atmosphere, SO2 is chemically converted to neutral and acidic sulfate aerosols which (together with oxygen and moisture) form the main constituents of acid rain and volcanic smog (vog). These products are known to impact vegetation down wind, and have also negatively affected agricultural crops, livestock and human respiratory health. Impressive imagery is readily obtained from UV camera systems, but some challenges regarding the SO2 retrieval process remained until recently. First, when dealing with high SO2 column densities and large plume aerosol optical thicknesses (conditions representative of recent activity at Kilauea's summit), accurate calibration of the instrument requires compensating for the complex radiative transfer in and around the volcanic plume. Next, the ability to derive high temporal resolution SO2 emission rates truly representative of instantaneous volcanic output requires that measurements be made from a location close enough to the vent to capture degassing behavior before it is skewed by atmospheric dynamics. In addition to applying radiative transfer corrections, closer measurement position and wider angle lenses to compensate for the challenges above, we have developed sophisticated image processing algorithms in order to obtain velocity fields in the plume, thus further improving the quality of the derived emission rates. The improved time resolution of UV imaging systems when compared to conventional spectroscopic techniques (e.g. COSPEC, FLYSPEC, mini-DOAS) allows a direct comparison of degassing behavior with other geophysical measurements (e.g. seismicity, deformation). Nadeau et al. (2010) have already identified differences in SO2 release at Kilauea's summit depending on the level of the lava lake within the active vent. The measurements presented here build on the work of Nadeau et al. (2010) but were recorded in closer proximity to the vent (2 km instead of 7 km) and with a better view of the vent itself. This has allowed us to investigate links between processes observed to be occurring on shorter time scales, e.g. linking individual gas clouds to single seismic or rock fall events, or identifying seismic frequencies directly correlated to SO2 release. These links may now be more straightforwardly interpreted in regard to their connection to physical processes occurring within the volcanic system.

King, Christina

Ambient Noise Non-Linear Time Correction for Ocean Bottom Seismometers

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Ambient noise analysis of Ocean Bottom Seismometers (OBS) has lead to realization that clock times may vary non-linearly with deployment. Modern methods include linear interpolation between deployment and recovery of the OBS. Linear interpolation thus leaves significant error that affects all time based seismic analysis and tomography. We use 24 OBS stations from the PLUME 2005 deployment and 4 land stations from the Global Seismograph Network and GEOFON network to complete this study. We preformed Earthquake response removal, frequency filtering and resampling to 20 samples per second on daily seismic traces. Between station pairs, we calculate the Empirical Green's Function (EGF), stacking daily EGFs into 2-month stacks and cross correlating these stacks with a reference EGF. Least squares optimization of our data shows that the mean absolute clock drift is 0.08s with a maximum time drift of 0.3s. Variance in the residuals, the difference between the data and calculated clock drift, constrains our uncertainty.

Kowalski, Philippe

Evolution of monitoring networks of Piton de la Fournaise volcano over 30 years

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Piton de la Fournaise volcano (Reunion Island, Indian Ocean) is one of the most active volcanoes in the world with more than 200 eruptions and intrusions over the last 2 centuries. The volcanological observatory of the Institut de Physique du Globe de Paris (IPGP) has been built in 1980, in the aftermaths of 1977 eruption, whose lava invaded the village of St. Rose. During 30 years, geophysical and geochemical networks have been progressively developed and extended initially over Piton de la Fournaise Volcano and then on the whole island. We focus here on the compared evolutions of these networks, the technological constraints, and the consequences for improving our understanding of volcano behaviour. Over the first half of the 1980's, the observatory deployed approximately 15 analog seismic stations, 6 magnetic stations and 6 geodetic stations. Nearly all these sensors were located close to volcano summit and inside the horseshoe-shaped Enclos Fouqué caldera, where most recent eruptions have been confined. During the 1990's, the networks has evolved according to recent technological jumps and increasing knowledge of the volcano plumbing system. On one side, the quality of sensors has significantly improved the signal to noise ratio. On the other side, the spreading of the seismic network was associated with the first deployment of real-time differential GPS stations. The most important changes have occurred in the period 2000-2012. Former magnetic, Radon, distancimeter, extensometer networks were basically dismissed and remplaced by (D)GPS network and new geochemical networks (DOAS + Multigaz). In this period, the DGPS network (25 station) has for the first time allowed the measurement of the slow but continuous sliding of the eastern volcano flank. Enlargement of the seismic network will permit for the first time to track deep seismicity with the aim at assessing its link with the phases of unrest of Piton de la Fournaise.

Kundargi, Rohan

Melting and dehydration within mantle plumes and the formation of sub-parallel volcanic trends at intra-plate hotspots

Kundargi, Rohan[1]; Hall, Paul S.[1]

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One of the defining characteristics of plume-fed hotspots is the formation of a linear chain of age-progressive volcanoes [Wilson, 1963; Morgan, 1971; Courtillot, 2003]. The most prominent example of this is the Hawaii-Emperor Seamount Chain, a 6000-km long age-progressive chain of volcanoes that stretch from the present-day island of Hawaii to the Aleutian Trench [van Ark and Lin, 2004; Sharp and Clague, 2006] However, recent volcanism at Hawaii does not form a simple linear trend, but rather is organized into two physically distinct sub-parallel chains, known as the Loa and Kea trends [Jackson, 1972]. Furthermore, recent studies have revealed that volcanism at several other hotspots, including the Samoa [Workman et al., 2004], Marquesas [Chauvel et al., 2009; Huang et al., 2011], and Society [Payne et al., submitted] hotspots is similarly organized into sub-parallel trends. Hieronymus and Bercovici [1999] developed a model in which lithospheric flexure in response to loading,

combined with a change in plate motion, could generate sub-parallel trends of discrete volcanoes at plume-fed hotspots. Here, we develop an alternative mechanism for the formation of dual-chain volcanism at hotspots in which melting and dehydration of upwelling material within the plume conduit creates a buoyant, highly viscous plug of residuum that extends downwards from the base of the lithosphere above the plume conduit, causing the flow to bifurcate [Hall and Kincaid, 2003]. We report on a series of 3-D numerical experiments using CitcomCU in which an upwelling plume impinges on the base of an overriding oceanic plate. These experiments employ a diffusion creep rheology that includes the effect of water content on viscosity. Melting and dehydration are modeled using a Lagrangian particle method. The experiments encompass a range of plume diameters, excess temperatures, and plate speeds. Our results demonstrate the formation of the proposed viscous plug is plausible under within a range of parameter space relevant to the Earth. The presence of this plug inhibits upwelling directly above the plume conduit, diverting plume flow to the edges of the plug and effectively bifurcating magma production in the mantle in the process.

Lautze, Nicole C.

Geothermal Resources and the Geologic Evolution of Hawaii's Volcanoes

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Hawaii's location in the mid-Pacific and origin due to hot-spot volcanism make it a fascinating natural laboratory for fields including oceanography, biology, astronomy, and volcanology. At the same time, as an island state, our ~90% energy dependence on outside oil is increasingly problematic. The Hawaii Clean Energy Initiative declares a goal of achieving a 25% clean energy economy by 2020, 70% by 2030, and 100% in decades following. Geothermal presents what is arguably the most promising clean energy source, because, unlike wind and solar, it can provide a constant, non-fluctuating energy supply. This presentation will give a brief history of geothermal resource development in the state, and discuss three active projects that have (or include) a goal of advancing this prospect. The projects are to: 1) digitize and serve up all geothermal information relevant to Hawaii that is not currently in digital form (funded by DOE), 2) conduct magnetotulluric surveys in areas of the Big Island, Maui, and Oahu (funded by DOE and the State of Hawaii), and 3) drill at least one (possibly 2) ~ 2km deep, continuously-cored, boreholes in the Pohakuloa Training Area (PTA; near the Saddle Road) of the Big Island (funded by the US Army). Analysis of the core recovered in the last project (and from anticipated future drilling as part of geothermal exploration) would promise to enhance our understanding of the development of Hawaii's volcanoes. From the PTA core for example, fundamental outstanding questions regarding Mauna Kea's evolution (including its explosive history) could be addressed.

Lev, Einat

Investigating Lava Rheology Using Video Analysis and Numerical Models of Experimental and Natural Lava Flows

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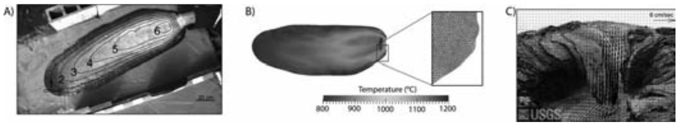
The mechanical and thermal properties of lava play a key role in controlling lava flow dynamics. It is very difficult to measure these properties at field conditions or to correctly extrapolate from the lab scale. We present a new methodology for investigating lava properties through a combination of video analysis and numerical forward modeling, and demonstrate it on controlled lava flow experiments, as well as on field data. Our experimental setup, part of the Syracuse University Lava Project, includes a furnace capable of melting up to 450 Kg of basalt, at temperatures well above the liquidus. The lava is poured onto a variety of fabricated substrates to produce meters-long flows. Above the flow we place the LDEO lava filming apparatus – a high-resolution visible-light video camera and an infrared camera, to document the evolution of the flow velocity and temperature, respectively. Thermocouples are used to measure temperatures within the lava and in the substrate. We analyze the recorded footage for lava deformation using Differential Optical Flow (DOF), which uses the time-variations of the spatial gradients of the image intensity to estimate flow velocity. We verify that the DOF results agree with other measures of the flow velocity, and estimate the error to be under 30 percent of the measured velocity. Figure A displays a velocity field for an unconfined flow of 10 degrees slope. We compare the measured lava deformation and temperature fields to those predicted by analytical and numerical models. We employ a multiphysics finite-element package that contains multiple rheologies and solves the equations on an unstructured mesh (Figure B). Our models explore a range of rheological and thermal properties, including the lava's apparent viscosity, the power-law exponent m and the thermal activation energy. Our measurements of apparent viscosity agree well with predictions of the composition-based Shaw (1972) and GRD model (Giordano, Russell and Dingwell 2008). We find that in the high-temperature portion of the flow, lava behaves as a weakly shear-thinning or Newtonian rheology ($m>0.7$). We are currently exploring ways to make the inversion process more formal, for example using Monte Carlo simulations. Finally, our methodology can also be applied to natural lava flows where video recordings are available. We display highly detailed surface velocity fields for natural flows in Hawai'i (e.g., Figure C), and discuss the implication for flow conditions and lava properties.

http://www.ldeo.columbia.edu/~einatlev/Research.html
http://lavaproject.syr.edu



Results and modeling setup: (A) Snapshot of an experimental unconfined lava flow, on a sand bed with a 10-degree slope. Contours show velocity magnitude in cm/sec. (B) FEM model for the flow shown in panel A. Color indicates prescribed temperatures. The inset shows mesh resolution and style. (C) Velocity analysis of a lava cascade, during the September 2011 eruption of Pu'u o'o, Hawai'i. The maximum velocity, assuming the cascade width is 3m, is 6 cm/sec. Arrows show velocity direction and magnitude.

Lin, Guoqing

Three-dimensional velocity structure of Kilauea and Mauna Loa volcanoes from local seismic tomography

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4. University of Hawaii at Manoa, Honolulu, HI, USA

We present a new model of the three-dimensional crustal and upper mantle seismic velocity structure at Kilauea and Mauna Loa volcanoes, Hawaii. The seismic data for our tomographic inversions are the first-arrival times of the compressional and shear waves from about 53,000 events recorded on and near the island of Hawaii between 1992 and 2009 by the Hawaiian Volcano Observatory. In order to take advantage of the vast majority of the available picks and to improve model resolution especially for Vp/Vs, we apply the recently developed composite event selection method. The composite picks are computed by adding source-specific station terms, which are the average residuals of all the nearby events recorded by each station, to the theoretical travel times calculated from a one-dimensional (1-D) velocity model. This method results in 1,817 events consisting of 64,863 P- and 25,438 S-wave picks. We input these composite events and picks to our tomographic inversions. Our model has a uniform horizontal node spacing of 3 km and depth nodes positioned at -1, 1, 3, 6, 9, 12, 15, 20, 25 and 35 km (relative to mean sea level). We apply the simul2000 tomography approach and algorithm to solve for Vp, Vp/Vs variations, and earthquake locations. Our Vp model generally agrees with previous studies, showing high-velocity anomalies beneath Mauna Loa and Kilauea calderas from the surface to about 6 to 9 km depth. The most significant difference between our model and previous ones is in Vp/Vs. Our Vp/Vs model is dominated by low values (1.6 to 1.7) from the surface to ~5 km depth and high values (1.75 to 1.85) below 6 km depth. We also observe an anomalous region with low Vp, low Vs and high Vp/Vs beneath Kilauea's upper east rift zone at ~9 km depth, which might be seismic expression for the deep magma body proposed by previous studies. The new 3-D velocity model is used to relocate all the seismicity of Kilauea and Mauna Loa for improved absolute locations and ultimately to develop a high-precision earthquake catalog using waveform cross-correlation data.

Lipman, Peter W.

Growth of the Island of Hawaii: Deep-Water Perspectives ***(INVITED)***

Lipman, Peter W.[1]; Sisson, Thomas W.[1]; Calvert, Andrew T.[1]

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In the 25 years since the HVO Diamond Jubilee, underwater studies of Hawaiian volcanoes have provided new perspectives on the growth of intraplate ocean-island volcanoes. Studies have been especially productive for the Island of Hawaii, where USGS GLORIA surveys, dives and dredging by Univ. Hawaii vessels, and collaboration with the Japan Marine Science and Technology Center (JAMSTEC) have complemented on-land scientific drilling and abundant data from HVO. New age, composition, and volume data from underwater samples document that the evolutionary stages during volcano growth on Hawaii Island have varied more than previously recognized. Common division into preshield, shield, and postshield stages primarily reflects subaerial morphology, and modeling of these stages commonly has assumed uniformly progressing compositions and magma production as an oceanic plate moves across a hot spot. Independently of edifice morphology and whether on land or underwater, edifice growth increasingly can be tracked by composition and magma-production rate: waxing alkalic, sustained tholeiitic, and waning alkalic stages. Eruption frequency and volume can vary over wide time ranges during any stage, and prior distinction between postshield and rejuvenated stages seems inapplicable to many volcanoes. Among recent results, samples from the deep south flank of Kilauea define a waxing alkalic stage of ~150 ky duration. Element compositions are more diverse (e.g., nephelinite, tephriphonolite) than at Loihi, merging with the most alkalic known for waning stages at older volcanoes. Mauna Loa lavas underlie Kilauea rocks on the south flank, constraining Kilauea's volume (~10,000 km3) and volcano inception (<300 ka) to be smaller and younger than previously estimated. In contrast, Kohala volcano is much larger than previously recognized; its long east rift zone includes the Hilo Ridge. Transitional-composition basalts, erupted there at ~1,150 ka, document development of long rift zones early during submarine growth and provide the first measured duration of a complete tholeiitic stage (~870 ky) for any Hawaiian volcano. Other data suggest that durations and magma-production rates vary substantially among Hawaiian volcanoes; for example, the tholeiitic stage of Mauna Kea, estimated at about 600 ky from results of the HSDP drill hole, is only about 2/3 that for Kohala. Yet volume and eruption rate of the alkalic waning stage at Mauna Kea (875 km3 since 250 ka) are much larger than for the large Haleakala edifice on Maui (300 km3 since 950 ka). Hilo Ridge results also demonstrate that Mauna Kea is a relatively small-volume (but high) volcano on the flank of a much larger Kohala, consistent with geophysical evidence for absence of sizable rift zones on

Mauna Kea. Sparse alkali and transitional basalt on submarine flanks of Kilauea and Mauna Loa may indicate continued availability during sustained tholeiitic volcanism, or just relatively recent transition to tholeiite at Kilauea and incipient waning at Mauna Loa. Recent underwater observations have also augmented understanding of the scale and frequency of flank failures and attendant catastrophic landslides and tsunami, as well as stability versus mobility of rift zones. Such results permit improved geometric, temporal and compositional models for growth of Hawaiian volcanoes.

Lockwood, John

THE ROLE OF PYRODUCTS (AKA "LAVA TUBES") IN GOVERNING THE LENGTHS OF LAVA FLOWS

Lockwood, John[1]

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Many factors govern the distances lava flows travel, and thus impact their threats to communities on the slopes of effusive volcanoes. As was discussed by Walker (1973), chief amongst these factors are the volumes of lava ultimately produced, lava production rates, lava chemical compositions, and the steepness of the slopes over which flows travel. The physical nature of the flows is also critical, since 'a'a flows have greater aspect ratios than do pahoehoe flows and thus travel less far, other factors being equal. So far as the lengths of pahoehoe flows, the principal factor governing their ultimate lengths is related to the constancy of supply rates, and thus to whether or not pyroducts are formed and are maintained as supply conduits. Constant lava production rates at source vents is conducive to the formation of single pyroduct systems that can transport lava efficiently great distances to flow fronts without significant heat loss. If production rates vary, pyroducts may not form, or if they do are subject to collapse when flow rates wane. Subsequent waxing of production will likely form alternate supply conduits and resultant flows will consist of multiple flow units and thick flows that do not travel so far as do flows fed by single pyroducts. Monitoring of pyroduct formation is thus essential for determination of the lava flow hazards associated with long-lived pahoehoe flows.

Lundgren, Paul

Source models for the March 5-9, 2011 Kamoamoa fissure eruption, Kilauea Volcano, Hawai`i, constrained by InSAR and GPS observations

Lundgren, Paul[1]; Poland, Michael[2]; Miklius, Asta[2]; Yun, Sang-Ho[1]; Fielding, Eric[1]; Liu, Zhen[1]; Tanaka, Akiko[3]; Szeliga, Walter[4]; Hensley, Scott[1]

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2. 2Hawaiian Volcano Observatory, U.S. Geological Survey, Hawaiian Volcanoes Nat'l Park, HI, USA
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4. 4Dept. of Geological Sciences, Central Washington University, Ellensburg, WA, USA

On March 5, 2011, the Kamoamoa fissure eruption began along the east rift zone (ERZ) of Kilauea Volcano. It followed several months of pronounced inflation at Kilauea's summit and was the first dike intrusion into the ERZ since June 2007. The eruption began in the late afternoon of March 5, 2011 (Hawaii Standard Time; UTC-10:00 hrs) with rapid deflation beginning at Pu'u 'O'o crater along the ERZ and followed about 30 minutes later at the summit. Magma from both locations fed the intrusion and an eruption that included lava fountaining along a set of discontinuous eruptive fissures ~2 km in length located between Napau and Pu'u 'O'o craters. Eruptive activity jumped between fissure segments until it ended on the night of March 9. A rich interferometric synthetic aperture radar (InSAR) data set exists for this eruption from the COSMO-SkyMed (CSK), TerraSAR-X (TSX), ALOS PALSAR, and UAVSAR sensors. By March 11, after the eruption had ended, we had three CSK acquisitions and one ALOS scene acquired and processed. A total of 7 satellite SAR acquisitions for March 6-11 are used in the analysis. UAVSAR airborne SAR data were acquired in early May 2011 and provided three viewing directions. These SAR data allowed us to examine dike opening during and after the eruption. We used a combination of unwrapped interferograms, azimuthal pixel offsets, and data from the Hawaiian Volcano Observatory (HVO) continuous GPS network to constrain source models. To model the Kamoamoa dike we first use a Bayesian approach to solve for the dike dip, and then use a whole-Kilauea model consisting of near vertical rift dikes from the SW-summit-ERZ (the latter modified smoothly to account for the Kamoamoa dip to the SE), plus a 9 km deep horizontal detachment fault, to solve for the distributed dike opening and detachment motion. Preliminary models of the dike show ~1.5 m of dike opening at the beginning of the eruption, reaching ~2.8 m meters of opening by the end of the eruption. UAVSAR and GPS constrained models from early May 2011 show additional dike opening at depth. The main portion of the dike plunges from the surface up-rift to a depth of ~3 km. A secondary arm extends towards P`u `O`o between 1.5-2 km depth. Progression of the dike opening gives dike volumes of ~13, 16, and 22 MCM (million cubic meters) for the early, end, and 8 weeks following the eruption, respectively. Initial estimates of the net volume losses from Kilauea summit, P`u `O`o, and the erupted lava is ~4 MCM. This 4x dike volume at the end of the eruption is consistent with magma compressibility and dike compliancy in accounting for volume ratios of 4-5 [Rivalta and Segall, 2008].

Mack, Chelsea J.

VOLCANIC DEGASSING AND ERUPTIVE BEHAVIOR AT WEST MATA VOLCANO, LAU BASIN

Mack, Chelsea J.[1]; Caplan-Auerbach, Jackie[1]; Dziak, Robert P.[2]

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2. Oregon State University, Newport, OR, USA

West Mata submarine volcano is located in the northeast Lau Basin, with its summit at approximately 1.5 km below the sea surface. It was found to be erupting in late 2008. The composition of the magma erupted at West Mata is primarily boninitic, composed of magnesium and silica rich rocks formed in the mantle wedge above the subducting Pacific Plate. Because West Mata's depth is comparable to that of Lo'ihi in Hawai'i (about 1 km depth), studying its eruptive behavior can provide a window into how Hawaiian volcanoes may erupt during early stages of volcano-building activity. For a period of five months in 2009-2010 scientists from the National Oceanic and Atmospheric Association (NOAA) deployed a network of 4 moored hydrophones surrounding the volcano to listen to its eruptive behavior. These are the only existing continuous data recorded during the eruption. The eruption lasted for the entire duration of the deployment, and it is speculated that it lasted for more than this time period. We examined durations of the signal types (individually and over the course of the 5-month deployment) to determine how the eruptive behavior changes over time. Most signals are one of two types: (1) diffuse, broadband (10-400 Hz) signals that last for several seconds to several minutes, vary in amplitude, and usually have a gradual onset and abrupt termination, and (2) short, lower frequency (0-25 Hz) discrete signals, that can occur up to several times per second. The diffuse signal is thought to represent continuous degassing at the summit, and discrete signals are thought to represent single lava bubble bursts. Video footage of the eruption suggests that degassing is a mix of passive and active over the 5 months of data. Typically, the data show only one signal type at a time, lasting up to several hours or a few days, but these signal types can be mixed. Overall the 5-month deployment, about 40% of the activity is discrete, and 60% diffuse. The first month of data (December) shows more discrete signals, evolving to a steady increase of diffuse activity. The last month of data (April) is dominantly diffuse activity. Some of the data also show low-frequency (<5 Hz) signals suggestive of volcanic tremor, which would indicate magma below the volcano is moving through cracks and the conduit. Using techniques that have been done with subaerial studies, we have estimated the eruption velocities for both the diffuse and the discrete signals. Comparing these data to those recorded on subaerial volcanoes allows us to infer the types of eruptive activity occurring at West Mata, because these studies have already identified specific eruptive types for distinct acoustic waveforms. Studying why and how eruption types at West Mata are different from those at subaerial volcanoes will give us a window into volcanic processes in the early stages of volcano building.

MacQueen, Patricia G.

Using Forward Modeling to Optimize the Geometry of Geophysical Networks at the Summit of Kilauea Volcano: A Matter of Great Gravity

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Small changes in the gravitational field of a volcano can give early warning of subsurface magma accumulation or withdrawal, sometimes before other more traditional precursors (e.g., seismic, deformation, degassing, etc.). Gravity data also are an important compliment to other geophysical, geochemical, and geological data. Gravity changes have been monitored across a network of stations at the summit of Kilauea Volcano, Hawaii, for decades, and these data sets have yielded valuable insight into volcanic activity at Kilauea. Until recently, however, we have had a poor understanding of the detection capabilities of the Kilauea gravity network or any bias imposed by the network geometry. Forward modeling of three known magma storage areas beneath Kilauea's summit indicates that the current network can distinguish volume changes as small as $8x10^6$ m^3 at depths from 0 to 8 km from sources near Halema`uma`u Crater and Keanakakoi Crater (assuming a magma/crust density contrast of 300 kg m^{-3}). Furthermore, additional station coverage is needed to decrease bias of 10s-of-μGal from network geometry in the south caldera region — known to be the primary magma storage reservoir beneath the summit. Our modeling has also shown that stations within the caldera are most useful for monitoring known sources of subsurface magma storage, suggesting that more distal stations could be surveyed less frequently. To optimize the network's ability to detect smaller changes in the south caldera, the addition of only 3 new measurement sites in the south caldera area can reduce bias from network geometry by 85%. These stations were added to the Kilauea gravity network starting in 2011. This work shows that even simple forward modeling can be a powerful tool to improve data acquisition strategies on active volcanic systems.

Marske, Jared P.

Magma transport, mixing, and storage in Kilauea's rift zones: a high-resolution geochemical perspective from 1790-2011 AD lavas

Marske, Jared P.[1, 2]; Garcia, Michael[2]; Pietruszka, Aaron[3]; Rhodes, J. Michael[4]; Norman, Marc[5]; Heaton, Daniel[3]

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4. University of Massachusetts, Amherst, MA, USA
5. Australian National University, Canberra, ACT, Australia

Over 220 years of frequent, voluminous (~4.5 km3), and compositionally variable (5-18 wt. % MgO) eruptions at Kilauea's summit, and east (ERZ) and southwest (SWRZ) rift zones provide an excellent opportunity to delineate the volcano's magmatic architecture, and to infer shallow magma storage times. Here, we present Pb, Sr, and Nd isotopic ratios, and major- and trace-element abundances for 66 historical Kilauea rift lava samples (1790-2011 A.D), which significantly expand our existing data set for this time period. These data allow us to trace the passage of geochemically distinct batches of magma within the volcano in unparalleled detail. Overall, olivine-controlled historical Kilauea rift and summit lavas (>7 wt. % MgO) display overlapping temporal geochemical variations (e.g. Nb/Y, 87Sr/86Sr, and 206Pb/204Pb) indicating that they originated from similar parental magmas for a given time period. The compositional variation of most Kilauea rift eruptions (e.g. 1790, 1840, 1868, 1919-23, 1955, 1960-74, and the short-lived Puu Oo eruptive episodes in 1983, 1997, 2011) is a consequence of mixing new mantle-derived magma with stored or hybrid magmas residing in the volcano's summit and rift zone reservoirs. Olivine, clinopyroxene, and plagioclase fractionation and/or accumulation are superimposed on these processes. MELTS modeling indicates most ERZ and SWRZ magmas fractionate over a narrow range of pressures (0.5-1.5 kbars) equivalent to a depth of ~2-5 km. Geochemical similarities between coeval summit and SWRZ lavas indicate historical SWRZ eruptions were shallowly fed from Kilauea's upper summit reservoir or directly from active caldera lava lakes, consistent with deformation studies, visual observations, and geologic mapping. Most historical ERZ magmas are delivered to the volcano's summit reservoir before entering and erupting along the rift zones, although lavas from prolonged ERZ eruptions (i.e. 1969-74 Mauna Ulu and 1983-present Puu Oo) may partially bypass the summit reservoir and/or intrude directly from deeper levels of the ERZ. The more evolved (<6 wt. % MgO) ERZ lavas (1790, 1955, 1977, 1983, 1997, and 2011, and the Puna dacite drilled in 2005) plot off the temporal geochemical trends suggesting they originated from differentiated, rift-stored magmas. High precision Pb isotopic ratios provide a precise method to determine the magma residence time in the rift zone prior to eruption based on the offset of evolved lavas from the systematic temporal trends of summit lavas. Overall, the magma storage times in the ERZ increase from the upper (~0.2-7 years) to middle (~12-48 years) to lower (~31-165 years) rift zone. These estimates are generally shorter than previous estimates of magma storage times in the ERZ (~30 to >500 years).

Matoza, Robin S.

Systematic Re-Analysis of Seismicity on Hawaii Island from 1992 to 2009

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The interpretation of seismicity from mantle depths to the surface plays a key role in understanding how Hawaiian volcanoes work. We present preliminary results from a comprehensive re-analysis of waveforms from more than 130,000 seismic events recorded by the USGS Hawaiian Volcano Observatory (HVO) seismic network from 1992 to 2009. We have produced a comprehensive multi-year catalog of relocated seismicity for all of Hawaii Island using waveform cross-correlation and cluster analysis. We converted all waveform data to a standard format to facilitate fast and systematic analysis, and performed high-precision relative relocation, using methods similar to those developed for Southern California seismicity [Lin et al., 2007]. The 17 years of relocated seismicity exhibits a dramatic sharpening of earthquake clustering along faults and magmatic features, consistent with previous studies that have focused on specific regions of Hawaii. We are now estimating spectra systematically from every event recorded at every station to aid with event discrimination and to analyze spatial variations in Brune-type stress drop of shear-failure earthquakes. Lin, G., P. Shearer and E. Hauksson (2007), Applying a three-dimensional velocity model, waveform cross correlation, and cluster analysis to locate southern California seismicity from 1981 to 2005, J. Geophys. Res., 112, B12309, doi:10.1029/2007JB004986

Menassian, Sarah

Characterization of deformation source geometry for the October 2010 eruption at Piton de la Fournaise volcano, Réunion Island: a numerical modeling approach

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2. Laboratoire Magmas et Volcans, Observatoire de Physique du Globe de Clermont-Ferrand, Université Blaise Pascal, Clermont-Ferrand, France
3. Observatoire Volcanologique du Piton de la Fournaise, Institut de Physique du Globe de Paris, La Plaine des Cafres, Reunion

Following the 24 September intrusion and the 14–31 October, 2010 eruption at Piton de la Fournaise volcano, Réunion Island, surface displacements near the eruption site were observed with TerraSAR-X InSAR data. Displacement maps produced from unwrapped interferograms show displacement patterns along an approximately north-south axis running from the Dolomieu Crater to the eruption fissure, located 2.2 km southeast of the main crater. The east-west displacement components indicate opening of ~40 cm along this axis and the vertical displacement components show general uplift up to ~30 cm along the axis. The presence of both opening and uplift patterns is typical for displacements stemming from the injection of a dike. The amplitude of these displacements increases from north to south, with the maximum vertical displacements occurring just east of the eruption site. This suggests the depth of the source changes along this trajectory, becoming shallower toward the eruption site. We attempted to model the source of the observed surface displacements using a method that combines a mixed boundary element model with an exploration of the source parameter space using a neighborhood algorithm. This first approach did not satisfactorily reproduce the surface displacements, perhaps because of the complexity of the source geometry. To better constrain the geometry of the source, we implemented a second approach in which the subsurface was discretized into a regular grid of unit sources whose volume changes produce surface displacements. During each model run we looked for the most influential sources and refined the spatial extent and resolution of the grid accordingly. Through this iterative process we were able to reach a more precise estimate of the source geometry.

Merz, Dara K.

Well-Constrained Hypocenters at Lo`ihi Volcano, Hawai`i Using a Network of Ocean Bottom Seismometers

Merz, Dara K.[1]; Caplan-Auerbach, Jackie[1]; Thurber, Cliff[2]

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As Lo`ihi Submarine Volcano is the youngest expression of Hawaiian volcanism, it is fundamental to the understanding of the initial stages of hot-spot volcano evolution. Assuming that all Hawaiian volcanoes evolve in the same fashion, Lo`ihi is a prime example of the adolescent stage of an evolving hot spot volcano. Previous studies of Lo`ihi seismicity using predominantly the HVO network calculated epicenters northwest and southeast of Lo`ihi's summit, but with large epicentral uncertainty due to the distribution of the HVO network in relation to the volcano. Because the HVO network sits >30km from the summit of Lo`ihi, many of the smaller earthquakes associated with the volcano go undetected, and ones that are recorded have poorly constrained depths. To address this, a network of 12 ocean bottom seismometers (OBS) was deployed on and around Lo`ihi in September 2010 and retrieved July 2011, recording continuous seismic and hydroacoustic data. With a local network of OBSs, approximately 100 Lo`ihi area events were recorded while the HVO network recorded less than 30, confirming that small Lo`ihi events go undetected by the land-based network. A number of proposed Lo`ihi area events identified in the HVO catalog were not visible in the OBS data, suggesting these events are not, in fact, near Lo`ihi. During the ~9 month deployment we recorded many Lo`ihi earthquakes, as well as earthquakes originating from Kilauea's summit, East and the Southwest Rift Zones, the active ocean entry, Kilauea's submarine South Flank, and deep seismic zone beneath Pahala. Many signals thought to be submarine landslides were also detected by the seismic network and associated hydrophones. Events locating deep beneath the area of Pahala, thought to be associated with recharge from the deep plume feeding Lo`ihi, Kilauea and Mauna Loa, are also better constrained by the offshore network. We calculated earthquake hypocenters using the Antelope software package (dbloc2) and the Loihi-3 velocity model (Caplan-Auerbach and Duennebier, 2001). Where possible, data from both the OBS and HVO networks were used to best constrain earthquake locations and depths. The addition of the OBS data to the HVO catalog resulted in a shift in hypocentral location, often toward Hawai`i Island, with Lo`ihi area events moving a greater distance than events located near or on shore. We present both catalog and relocated hypocenters for Lo`ihi and other offshore quakes, using HypoDD, and including adjusted station elevations and a 3D P-wave velocity model.

Montagna, Chiara

The migration of pressure transients within elastically deforming magma pathways

Montagna, Chiara[1]; Gonnermann, Helge[1]; Poland, Michael[2]

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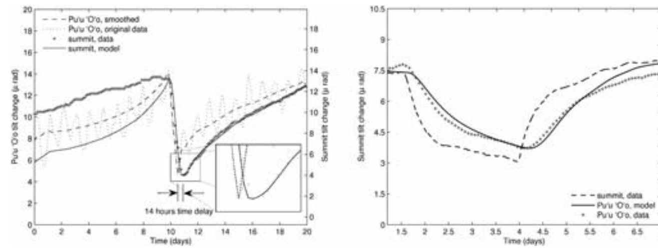
Volcanic eruptions are often accompanied by spatiotemporal migration of ground deformation, a consequence of pressure changes within magma reservoirs and pathways (e.g., Tryggvason, J. Volcanol. Geotherm. Res., 1986; Sturkell et al., J. Volcanol. Geotherm. Res., 2006; Wolfe, USGS Prof. Pap., 1988; Cervelli & Miklius, USGS Prof. Pap., 2003). For example, tilt measurements between 1983 and 1986 at Kilauea volcano, Hawai`i, show that the onset of eruptive episodes at Pu`u `O`o was typically accompanied by abrupt deflation and followed by gradual inflation during repose periods. Approximately 18 km to the northwest, tilt of Kilauea's summit underwent similar patterns of deflation and inflation, albeit with a time delay of several hours (Wolfe, USGS Prof. Pap., 1988). Analogously, during the past decade tilt records at Kilauea's summit reveal events of deflation that are followed by inflation and are often also observable at Pu`u `O`o, but with a time delay of minutes to hours (Cervelli & Miklius, USGS Prof. Pap., 2003). Here we show how such spatiotemporal patterns of deflation and inflation can be produced by the propagation of pressure transients during magma flow within an elastically deforming elliptical conduit. At Kilauea's summit, deflation and inflation are likely caused by changes in pressure within a shallow magma reservoir beneath Halemau`ma`u crater (Cervelli & Miklius, USGS Prof. Pap., 2003). A magmatic pathway associated with Kilauea's east rift zone (ERZ) connects this summit reservoir with a shallow magma storage reservoir at Pu`u `O`o. Under certain conditions dispersive pressure transients can propagate between Kilauea's summit and Pu`u `O`o, and produce measurable surface deformation. We model the propagation of such pressure transients using a convection-diffusion model for the averaged flow of a viscous, incompressible magma through an elastic medium (Bokhove et al., Theor. Comput. Fluid Dyn., 2005). We find that the attenuation and time delay of pressure transients and, hence, surface deformation, depends on the elasticity of the wall rock, conduit dimensions, magma viscosity, as well as amplitude of the perturbations themselves. For combinations of these parameters that are well within range for Kilauea and Pu`u `O`o, it appears that a variety of behavior may arise. Consistent with observations, pressure transients may propagate between summit and Pu`u `O`o with negligible to nearly complete dissipation in amplitude and time delays ranging from minutes to several hours.



Measured and modeled tilt at Kilauea summit and Pu`u `O`o during eruptive episode 17 (left) and March 21, 2010 deflation-inflation event (right).

Moore, James G.

Hawaiian Pillow Lava ***(INVITED)***

Moore, James G.[1]; Tepley, Lee[2]

1. USGS, Menlo Park, CA, USA
2. Moonlight Productions, Kailui-Kona, HI, USA

HVO spearheaded some of the earliest marine investigations of pillow lava. Among the first deepwater photographs of pillows ever taken were those on the submarine East Rift Zone of Kilauea in 1962 using an early Edgerton, Germerhausen, and Grier camera. The first submarine investigation of pillows on a historic lava flow was made on the 1801 Hualalai flow in 1969. Many dated historic lavas that crossed the shoreline were then sampled by diving to evaluate the rate of weathering (palagonitization) of glassy basalt, useful as a dating tool. This led in 1970-73, when the opportunity presented itself, to dives on live shore-crossing lava flows, which enabled the first observations and motion pictures of the actual formation of pillow lava. The film, released as Fire under the Sea, revealed for the first time how pillows actually grow. The pillows commonly enlarge and develop new crust by the opening of spreading cracks, which expose the glowing molten interior. As the crack walls separate, quenching and solidification of their outer margins keeps pace with spreading so that the crack maintains about the same width of incandescence even though pillow enlargement and growth of new crust is rapid. The sliding of new crust away from the spreading crack imposes shear on the underlying melt initiating longitudinal rolls, which generate corrugations in the crust at right angles to the spreading crack. Glassy submarine pillow lava erupted and quenched under pressure is unique in that it retains much of its original volatile content. Analyses of these rocks collected by dredging off Hawaii provided some of the first data on the original CO2, H2O, and S content of basaltic melt. The movie, Fire under the Sea, is a common staple in undergraduate geology courses. A number of professional researchers have told us that when they were exposed to it as students, it provided the stimulus that caused them to choose earth or marine sciences as a life work.

Morgan, Julia K.

Observationally and Geophysically Constrained Geodynamic Models of Hawaiian Volcanoes *(INVITED)*

Morgan, Julia K.[1]

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In recent decades, we have gained significant understanding about the present day structure and dynamics of Hawaiian volcanoes. This knowledge stems from extensive onshore monitoring of volcanic and geodetic activity and seismicity, as well as a range of geophysical studies. Offshore studies, including bathymetric mapping, seismic surveys, and direct submersible observations and sampling, yielded constraints about the submarine flanks of the volcanoes. Onshore-offshore tomographic and gravity inversions provide additional insights into the internal structure of Hawaiian volcanoes. The integrated view arising from these studies has led to a new understanding of the long- and short-term dynamics of the of Hawaiian volcanoes, and new hypotheses in need of rigorous testing. Geodynamic models offer an efficient means to test hypotheses relating to the growth, internal structure, and dynamics of Hawaiian volcanoes. We conducted numerical simulations using the discrete element method (DEM), constrained by observations and interpretations. These studies explore the influences of basal decollement strength, a dense ductile cumulate core, and edifice interactions. The results demonstrate the fundamental role of gravitationally-driven processes in the long-term volcanotectonic evolution of Hawaii volcanoes, and also capture the intermittent nature of dynamic events, such as landsliding and deep flank earthquakes. A weak decollement proves to be key to generating the shallow volcanic slopes observed in Hawaii, and enables continuous outward displacement of Kilauea's south flank. The presence of a weak substrate and a weak ductile core (e.g., of cumulate mush) enables summit subsidence, consistent with present-day geodetic observations at Kilauea and near-summit normal faults that accommodate such subsidence. In addition, axial subsidence drives the outward displacement of the volcano flanks, and results in inward dipping strata and thrust faulting along the distal flanks, consistent with the frontal benches found at many Hawaiian volcanoes. The interaction of active volcanoes also leads to complex evolution. Edifice overlap influences dynamic behavior significantly. The degree of volcanic buttressing depends on the relative positions of the two edifices. If a new edifice grows high upon the flanks of an older edifice, outward spreading of the underlying flank is enhanced. If the younger edifice is built low upon the pre-existing flanks, spreading of the underlying flank is prevented and possibly reversed. Furthermore, as the second edifice grows, it subsides into the underlying flank, partitioning it into a mobile downslope region entrained by spreading of the second edifice, and a comparatively stable upper flank region. These results suggest that much of the mass of Kilauea volcano may lie deeply buried within the underlying flank of Mauna Loa, while older Mauna Loa rocks may lie far from their source beneath the mobile flank of the younger volcano.

Nadeau, Patricia A.

Examining the Role of Degassing in Recent Summit Activity, Kilauea Volcano, Hawaii

Nadeau, Patricia A.[1]; Werner, Cynthia A.[2]; Waite, Gregory P.[3]; Brewer, Ian D.[2]; Carn, Simon A.[3]; Elias, Tamar[4]; Sutton, A. J.[4]

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2. Volcano Science Center, USGS Alaska Volcano Observatory, Anchorage, AK, USA
3. Department of Geological and Mining Engineering and Sciences, Michigan Technological University, Houghton, MI, USA
4. USGS Hawaiian Volcano Observatory, Hawaii Volcanoes National Park, HI, USA

Measurements of volcanic SO_2 emission rates have been part of routine volcano monitoring since the advent of COSPEC measurements in the 1970s. However innovative at the time, such data were limited in their temporal resolution and were generally scaled up to a daily average emission rate. Improved technologies in later years (e.g., mini-DOAS, FLYSPEC) did not offer substantial advances with respect to higher temporal resolution. Recent years have seen the advent of UV cameras as a means to measure SO_2 emission rates at a rate (~1 Hz) more comparable to those of other geophysical datasets such as seismicity and infrasound. Kilauea is already one of the world's best-studied volcanoes, outfitted with a range of geophysical instruments, and is currently experiencing concurrent flank and summit eruptive activity. By integrating high temporal resolution SO_2 emission rates from a UV camera with datasets like infrasound and seismicity, we aim to better decipher the relationships between degassing and other geophysical phenomena in the summit eruption. UV camera measurements at Kilauea volcano, Hawaii, in May of 2010 captured two occurrences of lava filling and draining within the summit vent. During these high lava stands we observed diminished SO_2 emission rates, decreased seismic and infrasonic tremor, minor deflation of the entire summit area, and slowed motion of the convecting lava lake surface. Similar events at Kilauea and other volcanoes, and in modeling experiments, have been linked to deep gas slug rise, gas accumulation beneath a viscous crust, cyclic pressure variations, and variable convection regimes. Previous work (Patrick et al., 2010) has indicated that accumulation of gas beneath a viscous crust is the likely cause of the recent events at the summit of Kilauea. We revisit the gas accumulation model using UV camera data and develop a gas budget in an attempt to evaluate plausibility. Our analysis of UV camera data time-series gives credence to the likelihood of shallow gas accumulation as the cause of such events. We further exploit the high-temporal resolution SO_2 data by comparing degassing to other geophysical phenomena. Reference: Patrick, M., T. Orr,

D. Wilson, A. J. Sutton, T. Elias, D. Fee, and P. A. Nadeau (2010), Evidence for gas accumulation beneath the surface crust driving cyclic rise and fall of the lava surface at Halema`uma`u, Kilauea Volcano, Abstract V21C-2339 presented at 2010 Fall Meeting, American Geophysical Union, San Francisco, Calif., 13-17 Dec.

Nakata, Jennifer

Seismic Monitoring at Kilauea with Evolving Network Capabilities Through a Long-Lived Eruption

Nakata, Jennifer[1]; Okubo, Paul[1]; Koyanagi, Robert[1]

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Kilauea's frequent eruptions offer many opportunities to observe a volcano's often-spectacular behaviors. Perhaps no eruption has offered a greater opportunity than the current east rift zone eruption centered at Pu`u O`o, which has been associated with a concurrent eruption at Kilauea's summit caldera since 2008. With established geodetic and seismographic monitoring networks that have been in operation for a significant part of the Hawaiian Volcano Observatory's (HVO) first one hundred years, observations and data are available to better understand processes and interactions between Kilauea's caldera, rift zones, and adjacent flanks. Recent improvements to HVO's monitoring networks offer new and more detailed analytical and interpretive capabilities. At the same time, the long-term record offers a framework for newer and improved interpretations to be integrated or tested. Pu`u O`o's early high-fountaining episodes between 1983 and 1986, with consistently repeating patterns of seismicity and tilt, afforded new insights into inflation and deflation cycles at Kilauea's summit. These observations led to the need for more detailed classifications of summit seismicity that have since been routinely applied first-order interpretations of the monitoring data streams. Improved tilt-monitoring has revealed smaller-scale deflation-inflation cycles centered near Halema`uma`u that have become more prominent since the start of the eruption in 2008 at Halema`uma`u. We are currently looking for parallels between the present patterns of seismicity and tilt and those recognized during Pu`u O`o's early fountaining episodes. Geodetic measurements made along Kilauea's south flank revealed surface deformations suggestive of stress build-up prior to the 1975 M7.7 Kalapana earthquake. While details of the 1975 earthquake rupture process are difficult to infer due to lack of adequate strong-motion instrumentation, it is reasonable to suspect that the earthquake helped establish conditions that led to brief eruptions, intrusions, and, eventually, the Pu`u O`o eruption. Now, due to numerous continuously recording GPS instruments, we recognize that significant Kilauea flank movement occurs aseismically in slow slip events (SSE). While SSEs are a relatively recent discovery, we have to view these also as fundamental behaviors at Kilauea that, along with microearthquakes and large earthquakes, should be incorporated into a better understanding of Kilauea's behavior.

Namiki, Atsuko

Experiments on shear induced generation of large gas slugs

Namiki, Atsuko[1]

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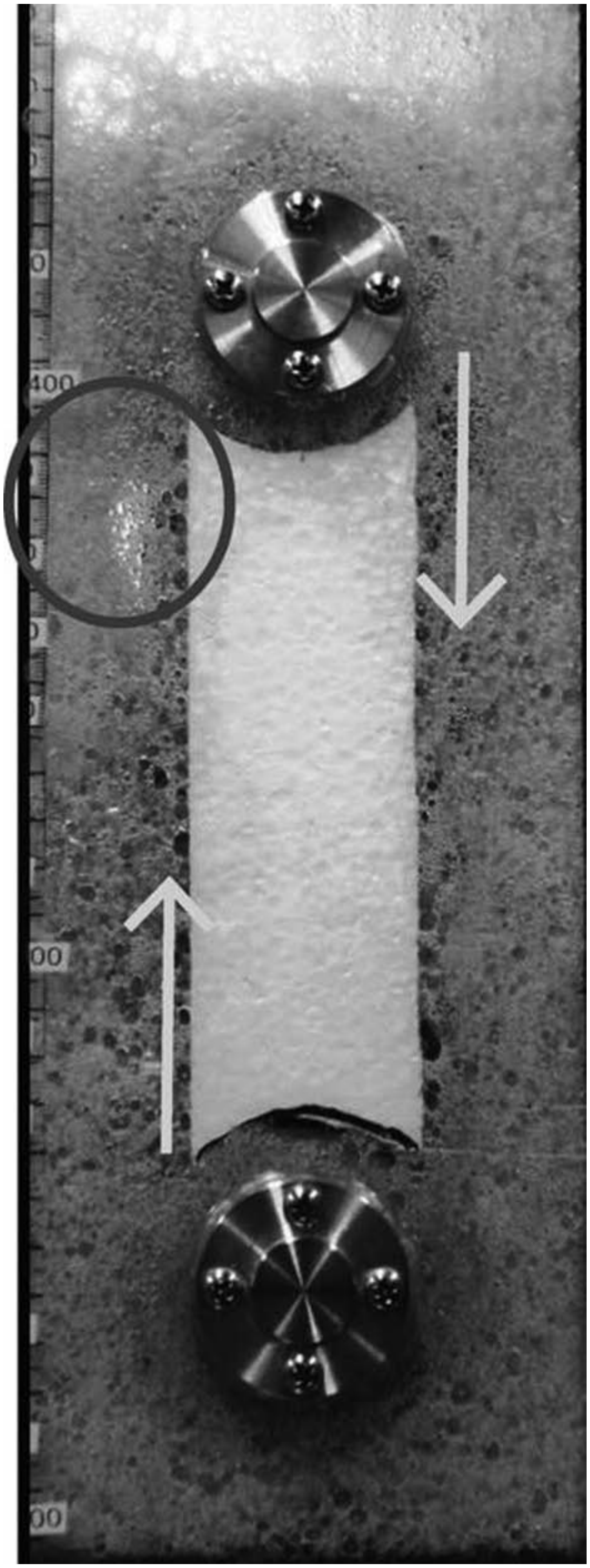
Basaltic magmas sometimes release volcanic gases explosively accompanied by very long period (VLP) seismic signals. Expansion and burst of a large gas slug may cause such an explosive gas emission. If there is a geometrical trap in a conduit, small bubbles coalesce so that a large slug forms (Jaupart and Vergniolle, 1988). During the recent summit eruptive activity at Kilauea, the bursting slug has been detected by seismological observations (Chouet et al., 2010). The slug ascends from a depth of < 150 m. It is not obvious whether there exists a geometrical trap at such a shallow depth. Here I perform a series of model experiments to test whether the shear deformation of bubbly magma ascending in a volcanic conduit can make a large gas slug. Syrup foam including CO_2 gas as an analogue of bubbly magma is deformed by using a timing belt. When the imposed shear strain is large enough, shear localization of syrup foam makes large bubbles or a crack-like void space. Measured CO_2 concentration above the foam increases after bursting of the large bubbles. The asymmetric shape of the time dependent CO_2 concentration in which sharp rises and slow drops are observed is similar to the time series of volcanic gas measurements during explosive gas emissions. Experiments also show that the height of the foam decreases after the gas emission indicating that outgassing occurs. There is a critical strain,γ, above which outgassing occurs depending on the Capillary number, Ca, $\gamma > 1$ for $Ca < 1$ and $\gamma > Ca^{-1}$ for $Ca > 1$. Here γ is the ratio of the ascending distance and conduit radius. Experimental results suggest that continuously ascending magma more than conduit radius can make large gas slugs.



A snap shot of the shear deformation experiment. The circle indicates a large bubble generated by the shear deformation. The timing belt moves in the direction indicated by arrows. The width of the tank is 125 mm.

Oikawa, Jun

Crustal deformation and volcanic earthquakes associated with the 2008-2011 Shinmoe-dake eruption

Oikawa, Jun[1]; Nakao, Shigeru[2]

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2. Graduate School of Science and Engineering, Kagoshima Univ., Kagoshima, Japan

Kirishima volcanic chain is one of the active volcanoes in southern Kyushu, Japan and is categorized into a composite volcano whose active vents are Shinmoe-dake and Ohachi. The latest eruptive activity of Shinmoe-dake started on August 22, 2008. Subsequently, it erupted on March 30, April 17, May 27, June 27 and 28, and July 5 and 10, 2010. In 2011, the eruption started on January 19 included subplinian and vulcanian explosions. and was followed by sub-Pulinian eruption on 27 January. Eruptive activity gradually ceased since February 2, and moved to Vulcanian activities. Before the 2011 eruption, an inflated crustal deformation around the western area of Karakuni-dake started after the end of 2009. By GPS observation, the inflation source is found at the depth of 9.7km beneath the point of about 6 km WNW-ward from the summit crater of Shinmoe-dake. The total volume charged at the source is estimated 32 million cubic meters under the assumption of Mogi's model. An abrupt volume change of the source was observed during the sub-Pulinian eruption. The Volume defect reached to 24 million cubic meters, that is the almost coincide with the estimated equivalent magma volume emitted during the sub-Pulinian episode. Hypocenter distributions around Kirishima volcano group indicates intense seismic activity under Shinmoe-dake, Ohachi, western and northern area of Karakuni-dake. The seismic activity around the volcanoes became high at the same time the crustal deformation started, we interpret that the pressure change at the magma reservoir caused both ground deformation and elevated seismic activity.

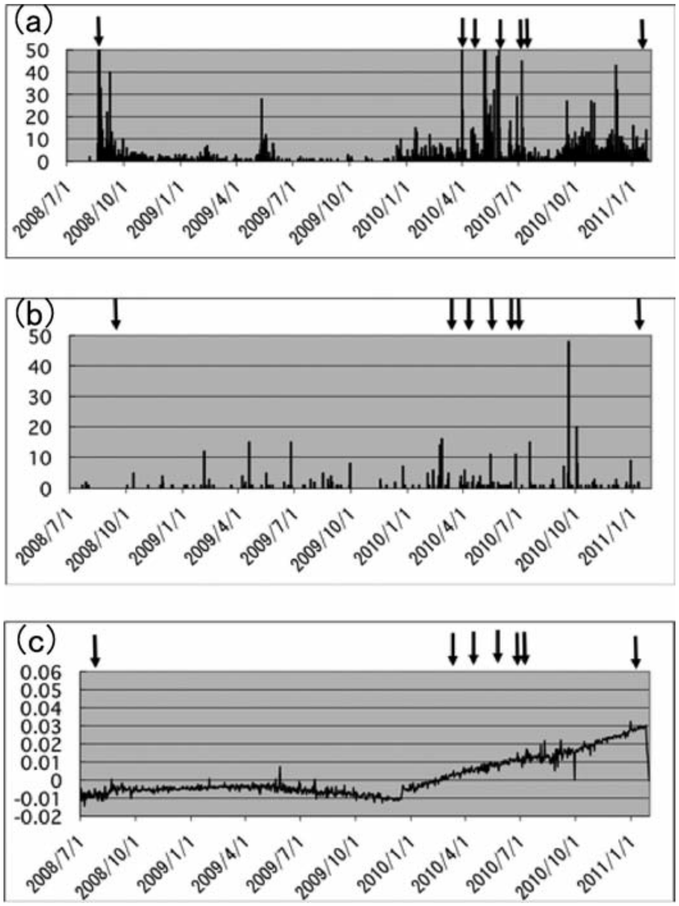

Figure shows daily number of earthquakes from July, 2008 to January, 2011 around Shinmoe-dake (a), western and northern area of Karakuni-dake (b). (c) indicates the inflated crustal deformation around the western area of Karakuni-dake started after the end of 2009. Since the seismic activity around the volcanoes became high at the same time, magma activity such as pressure change of magma reservoir causes the seismic activity to be high.

Okubo, Paul

The hunt for tectonic tremor during Kilauea's slow slip events

Montgomery-Brown, Emily[1]; Okubo, Paul[2]; Thurber, Cliff[1]; Wolfe, Cecily J.[3]

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2. USGS, Hawaiian Volcano Observatory, Hawaii National Park, HI, USA
3. Hawaii Institute of Geophysics & Planetology, University of Hawaii at Manoa, Honolulu, HI, USA

Ten slow slip events have occurred at Kilauea volcano since the installation of the continuous GPS network in 1996. Kilauea's slow slip events are somewhat similar to commonly observed subduction zone slow slip events in duration and magnitude, but occur on a decollement structure 8 km beneath the volcano's surface. In each of the events, fault slip typically lasted about two days, and released an amount of energy similar to a regular Mw 5.4-6.0 earthquake. While slow slip events in subduction zones are commonly associated with tectonic tremor, a persistent but very low amplitude shaking, Kilauea's slow slip events have lacked tremor observations. Instead, Kilauea's slow slip events produce significant triggered earthquakes, which are rarely seen during subduction zone slow slip events. Here we analyze the continuous seismic waveforms during slow slip events, identified geodetically, for evidence of tectonic tremor using several published methods including: waveform envelope cross correlation, beamforming, autocorrelation, template matching, and moving window cross correlation. Although we find ample volcanic tremor, tectonic tremor is not detected using any of these methods. If we are simply not able to observe tectonic tremor, it could be that the background noise levels in Hawaii are too high to detect low-amplitude tectonic tremor, or that the volcano's high attenuation affects the observability of tremor. It is also possible that pressure and temperature conditions on Kilauea's decollement are not conducive to tremor generation.

Orr, Tim R.

Hightlights of Kilauea's recent eruption activity

Orr, Tim R.[1]; Patrick, Matt[1]

1. USGS, Hawaiian Volcano Observatory, Hawaii Natl Park, HI, USA

Over the past 3 decades, Kilauea's eruptive activity has been focused mostly at and near the Pu`u `O`o vent on the east rift zone (ERZ). This activity changed dramatically in the last 5 years, driven, at least in part, by a doubling of the rate of magma supply from the mantle that has since ended. Perhaps the most significant of these changes was the opening of a vent on the SE side of Halema`uma`u Crater, at Kilauea's summit, in March 2008. This marks the first documented period of prolonged, simultaneous ERZ and summit eruptions at Kilauea. The Halema`uma`u "Overlook" vent, initially 35 m across, has evolved since into a 160-m-wide collapse crater containing a semi-permanent lava lake. This lake is currently one of the largest and most dynamic on Earth. Ready access to the Overlook vent has allowed us to compile a comprehensive set of measurements and observations describing the lava lake's behavior. Kilauea's ERZ began to pressurize in late 2010, presumably in response to a slowly developing constriction in the conduit supplying the ERZ eruptive vent active at that time. The Pu`u `O`o crater began to fill with lava, and the lava lake at Kilauea's summit rose to the highest levels recorded to that time. In March 2011, the engorged dike uprift from Pu`u `O`o ruptured, feeding the 5-day-long Kamoamoa fissure eruption. The lava lake in the Overlook vent drained, and the floor of the Pu`u `O`o crater collapsed. Eruptive activity, however, was re-established at Pu`u `O`o after a 3-week hiatus there, and lava was soon overflowing onto the flanks of the Pu`u `O`o cone. Within months, the ERZ showed signs of becoming fully pressurized again. In August 2011, the western flank of the Pu`u `O`o edifice was pushed up as a shallow-dipping dike intruded beneath that sector of the cone, feeding a short-lived breakout near the cone's western base. Following cessation of the breakout, eruptive activity resumed at Pu`u `O`o, and lava was soon overflowing the Pu`u `O`o crater. Again, the ERZ began to pressurize, and, in September 2011, a new fissure eruption began on the eastern flank of Pu`u `O`o. Since then, a new tube system has developed, transporting lava continuously from the vent to a growing flow field. 2011 was an exciting year at Kilauea, each outbreak representing a different eruptive scenario—a fissure eruption up-rift from Pu`u `O`o, a Pu`u `O`o up-rift flank breakout, and a Pu`u `O`o down-rift fissure eruption. Despite these differences, each was preceded by similar and recognizable patterns of activity, specifically, rising lava levels at Pu`u `O`o and the Overlook vent, extension across Kilauea's summit and upper ERZ, and increasing seismic activity along the upper ERZ. Recognition of this pattern allowed scientists at the Hawaiian Volcano Observatory to prepare an eruption response well before each of 2011's eruptive changes. Since September 2011, Kilauea's eruptive activity has been relatively steady, with few notable variations. As of April 2012, however, slowly rising lava levels at both Pu`u `O`o and Kilauea's summit, accompanied by increasing earthquake frequency along the upper ERZ, suggest that the volcano may be building to the next eruptive perturbation. We are watching this activity with heightened interest and preparing a scientific and monitoring response in anticipation of this possible change.

Parcheta, Carolyn E.

Hawaiian Fountain Styles

Parcheta, Carolyn E.[1]; Houghton, Bruce[1]; Swanson, Don[2]

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Hawaiian fountains, named so because Kilauea is the archetypical locality of these weak explosive eruptions, span a wide spectrum of behaviors, often in a single eruption. In defining the style, physical volcanology has focused on and sampled single, circular-sourced, high fountains because they 1) are typically well documented in historical times, 2) produce a significant non-welded tephra deposit in the medial and distal regimes, and 3) pose the largest hazard (compared to weaker, fissure-sourced Hawaiian fountains). Here, for the first time, we present vesicularity and density data for a complete suite of Hawaiian fountaining styles. Our data derives from 4 of the 12 Mauna Ulu episodes in 1969, and compares pyroclast vesicularities and bubble textures of fountains from fissure, dual, and point sources. We also compare pyroclastic vesicularities and bubble textures of low (<100 m), med (100-300 m), and high (>300 m) fountains across multiple episodes. Finally, we contrast vesicle textures through a single episode (pre-fountain spatter, peak discharge, and post-fountain spatter) of the dual up-to 375 m high fountain from episode 5 at Mauna Ulu. This is the most comprehensive and in-depth vesicularity study to date on Hawaiian fountaining eruptions. The following inferences can be linked to magmatic ascent on Kilauea's east rift zone and the factors modulating contrasts in 1) fountain behavior and 2) vesiculation and fragmentation. Bubble number density scales with fountain height, reflecting higher ascent rates in the shallow conduit with a better approximation to closed system behavior. A marked coarsening and decline in bubble number density in melt erupted between high fountaining episodes suggests variation in gas flux is the driving component in defining episodicity of the 1969 fountains.

Patrick, Matthew R.

Tracking the hydraulic connection between Kilauea's summit and east rift zone using lava level data from 2011

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The ongoing eruptions at Kilauea's summit and east rift zone offer the first opportunity to make prolonged simultaneous measurements of lava level for the summit and rift zone, thus providing insight into the nature of the hydraulic connection within Kilauea's magmatic system. We show measurements of lava level during 2011 at the lava lake within the Overlook vent in Halema`uma`u crater (summit) and at the lava surface within Pu`u `O`o crater (east rift zone), which are separated by a distance of 20 km and an absolute difference in elevation of about 100 m. The 2011 time period encompasses three cycles of coupled lava level rise in each vent, with each cycle culminating in a structural failure of the magmatic system and establishment of a new vent. Lava level trends at Halema`uma`u and Pu`u `O`o follow one another closely, attesting to a good hydraulic connection, with the level in the Halema`uma`u Overlook vent being 40-120 m higher than that in Pu`u `O`o at any given time. This height difference may be thought of as "head loss" in a hydraulic system, which normally originates from frictional forces in the system. Assuming a simple pipe flow model and using the Darcy-Weisbach formula, we can relate the frictional force to the diameter of the conduit linking the summit and east rift zone vent. Initial results using this approach suggest reasonable conduit diameters (<10 m), which, in turn, imply magma travel times of hours to several tens of hours between the summit and Pu`u `O`o, given current magma supply rates. We further explore the suitability of this approach, interpreting results in the context of geodetic and petrologic data. The summit-rift hydraulic connection and observed cycles in 2011 have broader implications as well. First, they indicate that the lava level can be a useful proxy for pressurization in the magmatic system, and thus the Halema`uma`u Overlook vent lava lake height serves as a convenient pressure gauge for judging the likelihood of future intrusions in the rift zone. This is supported by the changes in lava level in 2011 that mirror trends in summit tilt and GPS line length. The observations and demonstrated hydraulic connectivity also show that local effects can have a dramatic impact on the system as a whole, illustrated by the partial draining of Halema`uma`u that was triggered by a local structural failure of Pu`u `O`o cone in August 2011. Lava level, therefore, provides an effective tool for anticipating changes in eruptive activity and associated hazards.

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Perttu, Anna B.

Halema'uma'u's Infrasonic Signatures: Reawakening to Present

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Kilauea's volcanic soundscape is rich with infrasonic diversity. Over the last decade of infrasound research, activity at Kilauea has transitioned from one main source region associated with the Pu'u O'o Crater Complex, to a persistent dual source system after the reawakening of Halema'uma'u Crater. The MENE infrasound array (which has provided real-time data since 2006) is located 6.81 km from Halema'uma'u Crater and 12.65 km from Pu'u O'o Crater, with ample angular separation to differentiate acoustic signals from the two source regions. Since the March 2008 vent-clearing burst, the infrasonic signature from Halema'uma'u is predominantly characterized by atonal harmonic tremor punctuated by long-period transients and episodic tremor events. Each of these distinct infrasonic signatures has recognizable temporal and spectral features that are representative of the different fluid-dynamic processes at play. This study considers various physical interpretations of the diverse signal features observed from Halema'uma'u Crater since its recent reawakening.

Pickard, Megan

A Microanalytical Approach to Understanding the Origin of Cumulate Xenoliths from Mauna Kea, Hawaii

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Cumulate xenoliths offer an opportunity to study the differentiation in magma bodies that otherwise might be inaccessible. Accordingly, we examined cumulate xenoliths that erupted with hawaiite Laupahoehoe magma from a post-shield cinder cone on the southern flank of Mauna Kea, Hawaii to better understand and constrain the origin and interaction of magmas in a multi-stage volcanic system. We identified a variety of mafic and ultramafic cumulate xenoliths. Major element compositions of clinopyroxene, olivine and plagioclase in these xenoliths are ambiguous with respect to characterizing whether their parental magmas are tholeiitic, transitional, or alkalic. To help clarify the parental magma compositions, we analyzed incompatible trace element concentrations in clinopyroxene from a variety of xenoliths by LA-ICPMS and calculated the trace element compositions of their equilibrium liquids using published partition coefficients. Calculated liquids all have REE patterns with negative slopes and are enriched in light REE. The REE patterns for liquids calculated from clinopyroxene in pyroxenites, olivine gabbros, gabbros, and gabbronorites are similar to the REE patterns of Mauna Kea post-shield Hamakua tholeitic and alkalic lavas. Concentrations of trace elements calculated for these equilibrium liquids (e.g. Sr 210-600 ppm, Ba 5-625 ppm, Ti 10,000-20,000 ppm, and Zr 10-375 ppm) are also similar to those of the Hamakua lavas. In contrast, calculated liquids for a wehrlite and an olivine gabbronorite have REE patterns and Sr (200-400 ppm), Ba (10-200 ppm), Ti (5000-15,000 ppm), and Zr (10-120 ppm) concentrations similar to those of tholeiitic shield basalts. No calculated liquids match the highly alkalic hawaiite Laupahoehoe post-shield lavas that serve as hosts for the xenoliths. Thus, these Mauna Kea xenoliths are plutonic representatives of shield stage tholeiitic and post-shield Hamakua magmas entrained in the younger Laupahoehoe hawaiite magma. From this, we infer that Laupahoehoe post-shield lavas only sampled cumulates from shield and Hamakua post-shield magmas and propose this is evidence that Laupahoehoe magmas formed at deeper depths than shield and Hamakua magmas. As a result, shield and Hamakua cumulates were entrained as Laupahoehoe magmas rose to the surface. Given the good match between the calculated liquids and erupted shield and Hamakua post-shield lavas, we conclude that this technique of analyzing clinopyroxene in cumulates by LA-ICPMS for trace elements and calculating equilibrium liquids offers the potential for more thorough studies of Hawaiian liquid lines of descent and augments records available from lavas.

Pietruszka, Aaron J.

Geometry of the Summit Magma Storage Reservoir of Kilauea Volcano: A View from High-Precision Pb Isotopes *(INVITED)*

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The summit magma storage reservoir of Kilauea Volcano is one of the most important components of the volcano's magmatic plumbing system, but its geometry is poorly known. We will (1) present a summary of previous views on the size, shape, and number of magma bodies that make up Kilauea's summit reservoir, and (2) use high-precision Pb isotopic analyses of historical Kilauea summit lavas (1823-2010) to define the minimum number of magma bodies within the summit reservoir and their volumes. The 206Pb/204Pb ratios of these lavas display a systematic temporal fluctuation characterized by low values in 1823, an increase to a maximum in 1921, an abrupt drop to relatively constant intermediate values from 1929 to 1959, and a rapid

decrease to 2010. These variations indicate that Kilauea's summit reservoir is being supplied by rapidly changing parental magmas derived from a mantle source that is heterogeneous on a small scale. Analyses of multiple lavas from some individual eruptions reveal small but significant differences in 206Pb/204Pb. The extra-caldera lavas from Aug. 1971 and Jul. 1974 display significantly lower Pb isotope ratios and higher MgO contents (10 wt. %) than the intra-caldera lavas (MgO ~7-8 wt. %) from each eruption. From 1971 to 1982, the 206Pb/204Pb ratios of the lavas define two separate decreasing temporal trends. The intra-caldera lavas from 1971, 1974, 1975, Apr. 1982 and the lower MgO lavas from Sep. 1982 have higher 206Pb/204Pb ratios at a given time (compared to the extra-caldera lavas and the higher MgO lavas from Sep. 1982). These trends require that the intra- and extra-caldera lavas (and the Sep. 1982 lavas) were supplied from two separate magma bodies. Numerous studies by HVO scientists (e.g., Fiske and Kinoshita, 1969; Klein et al., 1987) have long identified the locus of Kilauea's summit reservoir ~2 km southeast of Halemaumau (HMM) at a depth of ~2-7 km, but more recent investigations have discovered a second magma body located <1 km below the southeast rim of HMM (e.g., Battaglia et al., 2003; Johnson et al., 2010). The association between the vent locations of the extra-caldera lavas near the southeast rim of the caldera and their higher MgO contents suggest that these lavas tapped the deeper magma body. In contrast, the lower MgO intra-caldera lavas were likely derived from the shallow magma body beneath HMM. Residence time modeling based on the Pb isotope ratios of the lavas suggests that the magma volume of the deeper body is ~0.2 km3, whereas the shallow body holds a minimum of ~0.04 km3 of magma. These estimates are much smaller than our previous calculation of ~2-3 km3 for Kilauea's summit reservoir based on trace element ratios (Pietruszka and Garcia, 1999), but are similar to the volume of the magma body that underlies Piton de la Fournaise Volcano on Réunion Island (Albarède, 1993).

Polacci, Margherita

Vesiculation and degassing in basaltic magmas: an example from Ambrym volcano, Vanuatu Arc

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Scoria clasts collected from a fallout deposit in the inner terrace of Ambrym volcano Benbow active crater were analyzed through series of synchrotron X-ray computed microtomographic experiments, as well as permeability measurements and simulations. Our goal was to reconstruct and visualize scoria textures in 3D and to quantify vesicularity, permeability, vesicle sizes and distributions in order to understand how gas moves in and out of Ambrym basaltic magma. We find that vesicle size distributions in the volume range between ~10^3 and 10^10 μm^3 define two scoria classes. Vesicle size distributions in the low-to-moderately (0.44-0.67) vesicular samples can be fit by power laws with an exponent of 1±0.2; distributions in the highly vesicular (0.86-0.88) samples can be fit by power laws with a higher exponent (1.4 to 1.7), as well as by exponential fits. Highly vesicular samples exhibit a very pronounced large vesicle, consisting of networks of smaller, interconnected vesicles, that is more than three orders of magnitude larger in volume than all other vesicles in each distribution. This type of vesicle is not found in the low-to-moderately vesicular samples. In addition, vesicle number density negatively correlates with vesicularity: less vesicular samples have the highest number density and vice versa, and contain far more numerous small-to-medium-sized vesicles than highly vesicular samples. Measured and calculated viscous (Darcian) permeabilities overlap in the range 10^-13 and 10^-9 m^2, with higher values in the more vesicular samples. We ascribe these differences in the textural and physical properties of the scoria clasts to their derivation from distinct magma portions in the conduit that were driven by convective overturn and underwent different vesiculation histories and gas transport dynamics. Comparing basaltic scoria clasts from Ambrym to those from mild explosive activity at Stromboli volcano (Italy) reveals that differences in their vesicle size distributions may result from the influence of different crystal contents and shapes on the vesiculation and permeability of the respective magmas. Finally, we highlight how rheological properties have a fundamental role in determining the degassing behaviour of basaltic magma at Ambrym and other volcanoes in general.

Poland, Michael P.

Kilauea's magma plumbing system

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Based on the 100-year record of geophysical, geological, and geochemical data collected by the Hawaiian Volcano Observatory and collaborators, we propose a detailed model of Kilauea's magma plumbing that we hope will provide a refined framework for studies of Kilauea's eruptive and intrusive activity. None of the elements of our model is new—each has been proposed previously, but separately, by various authors. In an effort to develop an overall view of magma storage and transport at Kilauea, we present a unification of these models while adding insights from high spatial- and temporal-resolution geodetic data collected over the past decade, which indicate discrete magma storage areas beneath the summit and a continuous molten core along the east rift zone. Kilauea's summit reservoir is made up of at least two hydraulically linked magma accumulation zones. The larger zone is centered at ~3 km depth beneath the south caldera, while a smaller one is located at ~1 km depth east of Halema`uma`u Crater. The main structural rift zones radiate southeast and southwest from the primary storage area, also at about 3 km depth. Magma is occasionally stored where these two rift zones intersect the summit (in the upper southwest rift zone and near Keanakako`i Crater), and both rift zones support a molten core that allows rapid transport of magma from the summit to the flanks. Small, isolated pods of magma exist within both rift zones, as indicated by deformation measurements, seismicity, petrologic data, and geothermal drilling results. These magma bodies are relicts of past intrusions and eruptions and can be highly fractionated. Magma storage within the deep rift zones, between about 3 km and 9 km depth, is hypothesized based on surface deformation that can be interpreted as deep rift opening. Magma that enters the deep rift zone may pass through the summit reservoir system into the molten core, eventually descending to greater depths. Shallow (˜1 km depth) secondary rift systems also branch from the Halema`uma`u magma reservoir, as indicated by alignments of eruptive vents and fracture systems to the east and west from Halemaʻumaʻu Crater. Although inactive in recent decades, large historical eruptions have occurred through these rift systems, including Kilauea Iki in 1959 (east) and Mauna Iki in 1919–20 (west).

Ramsey, Michael S.

Thermal emission from molten silicates: Implications for lava flow emplacement and hazards

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Active basaltic volcanoes produce glass-rich flows that rapidly form a chilled glassy crust after emplacement. This crust on a pahoehoe flow commonly has a lower percentage of vesicles than the lava directly beneath it. With time, the crust will thicken, fold, and cool with the uppermost surface either spalling off due to continued vesiculation and/or the emplacement of new lava below. The crust can also remain intact and later disrupted on a larger scale due to flow inflation. The crust thickness, glassiness, and thermal infrared (TIR) emissivity all combine to directly impact the interpretation of ground, air, and space-based TIR data. The TIR wavelengths are sensitive to the characterization of silicate material because of the presence of strong absorption bands (dominantly Si-O and also Al-O). Furthermore, there is a scientific debate on whether molten materials have dramatically lower TIR emissivities than their solidified counterparts. This unknown not only impacts the derived spectral information, but also feeds into models of the radiative cooling efficiency and flow formation. We have developed a novel laboratory-based micro-furnace to acquire the first measurements of TIR emissivity data of molten silicates. Preliminary results appear to confirm that lower emissivity appears with phase change. We have also collected and analyzed field-based TIR data of active pahoehoe flows at Kilauea volcano, Hawaii over several years. These data have been used to both validate the laboratory-based spectral data as well calculate the thickness and crustal viscosity for the first time on active flows. The results allow us to more accurately model basaltic crust formation, flow emplacement rates, and produce a better understanding of the response of TIR data to these active processes.

Realmuto, Vincent J.

Thermal Infrared Remote Sensing of SO2 Emissions from Kilauea Volcano: Lessons Learned and Future Plans

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NASA’s Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Moderate Resolution Imaging Spectrometer (MODIS) have been collecting data over Kilauea Volcano since early 2000, and a second MODIS instrument has been collecting data since mid-2002. We present an overview of these data records, with a focus on the use of thermal infrared (TIR) radiance measurements to detect and map SO2 emissions from Kilauea. ASTER and MODIS are the heritage instruments for the TIR component of the upcoming Hyperspectral Infrared Imager (HyspIRI) mission, and our study of these data has direct application to the design and development of HyspIRI. The long-term data records illustrate the strengths of TIR-based SO2 mapping together with the challenges of remote sensing in tropical environments. TIR measurements do not depend on solar radiance and the combination of data from day- and night-time overpasses increased the frequency with which we observe the volcano. The spatial resolution of MODIS (1 km at nadir) and ASTER (90 m) affords high sensitivity to SO2, allowing us to resolve and characterize passive emissions of SO2. A more comprehensive study of the ASTER and MODIS data records will include comparisons with SO2 retrievals from other space-borne instruments, ground-based SO2 measurements, and contemporaneous records of ground deformation and seismicity. The strength of the SO2 signal in the TIR is a function of species concentration together with the contrast between the temperatures of the plume and underlying surface, with temperature contrast being the dominant factor. The main challenges to mapping passive emissions of SO2 in warm and humid tropical environments are low contrast between the plume and surface temperature together with cloudy viewing conditions. The high spatial resolution of ASTER increases our sensitivity to SO2, relative to MODIS, and allows us to peer through any openings in a cloud deck. However, constraints on the operation of ASTER limit the frequency with which ASTER observes Kilauea. ASTER can acquire four observations of Kilauea (2 daytime + 2 night-time) every 16 days, but intervals of 10 to 30 or more days between observations are more commonplace. The current design specifications for HyspIRI-TIR call for a 5-day interval between observations at the equator and spatial resolution of 60 m (at nadir) over a swath of ~ 600 km. Our study of the ASTER and MODIS records for Kilauea SO2 emissions will help to define the spectral response of the HyspIRI TIR bands, detection limits for SO2, and operational scenarios for observations of volcanoes in tropical environments. This research was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

Rhodes, John M.

Mauna Loa Magmas in Space and Time

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We have a magmatic history of Mauna Loa volcano that extends back to around 600 ka, based on the record of historical flows (1843 - 1984 AD), ^{14}C constraints on prehistoric lavas (0.2 - 36 ka), the Hawaii Scientific Drilling Project drill core (1.5 - ~ 120 ka) and Ar/Ar dating of submarine lavas (59 - ~ 660 ka). Over this time, the major element compositions of the vast majority of the lavas are defined by strongly linear olivine-control trends. These trends result from mixing olivine (Fo^{87-89}) with an evolved, steady-state, reservoir magma (~7 % MgO) and picritic parental magmas (13 - 18 % MgO). The reservoir magmas are prevalent among lavas erupted along the two subaerial rift zones, but are significantly less frequent among summit overflow lavas, which are thought to reflect periods of high eruption rates. They are relatively rare along the submarine SW rift zone which is dominated by picritic lavas and is also the site of high eruption rates. The remarkable uniformity of MgO-normalized major element concentrations (especially SiO2) over ~600 ka presents something of a conundrum. It implies essentially constant proportions of source lithologies (peridotite vs pyroxenite) and relatively uniform magma generation processes, including temperature, extent of melting and depth of magma segregation. This is at odds with the hypothesis that over the past 600 ka Mauna Loa will have traversed approximately 50 -60 km across a thermally and compositionally zoned Hawaiian plume. Trace element and isotopic data tell a different story. Submarine lavas older than ~ 250 ka tend to have lower incompatible element ratios (e.g. K/Y, La/Yb) and higher Ni at a given MgO, probably indicative of greater melting in the earlier history of the volcano. There are two distinct trends in Nb-Zr-Y systematics and Pb isotopic ratios [Weis et al., 2011] . The dominant trend contains lavas of all ages (<0.1 - ~ 660 ka) and has similar Zr/Nb (13 - 15) and a well-defined Pb isotopic array (^{206}Pb 18.05 - 18.26). In contrast, a diverging trend, restricted to lavas > 250 ka, has variable Zr/Nb (10 - 15). Most lavas on this trend have Pb isotopes trending towards, and overlapping with Loihi values (^{206}Pb 18.40) but some have increasing ^{208}Pb for a given ^{206}Pb. Note, however, that the major element compositions are typical of those of Mauna Loa. These results indicate that the mantle plume source of Mauna Loa was more varied in the past, at a time when it was located 25 - 60 km closer to the present position of Loihi, than in the last 250 ka.

Richter, Nicole

Small-scale deformation associated with the summit eruption of Kilauea Volcano, Hawai'i, from TerraSAR-X Interferometry

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On 19 March 2008, a new eruptive vent formed along the east wall of Halema'uma'u Crater at the summit of Kilauea Volcano, Hawai'i. The ongoing summit eruption is characterized by degassing, seismic activity with varying frequencies (including very-long period), and the presence of an active lava lake within the Halema'uma'u summit vent at a level ranging from 60 – 200 m below its floor. Over time, Halema'uma'u has grown as collapses of the unstable vent rim and wall increased the size of the crater. These collapses are typically accompanied by seismicity and a dusty plume of debris and volcanic gas and often result in the deposition of ejecta on the rim of Halema'uma'u Crater—a significant local hazard. There is currently no method for identifying times of an increased possibility for vent collapses. Synthetic aperture radar interferometry (InSAR) measurements of surface displacements using the German Space Agency TerraSAR-X (TSX) satellite were used to identify and analyze small-scale surface deformation at Kilauea's summit eruptive vent during June 2008 to 2012. The X-band (3.1 cm wavelength) satellite has the advantage of very high spatial and temporal resolutions (pixel size ~ 2 m and repeat time of 11 days; compared to ~ 6 – 20 m and 46 – 35 days for the Japanese ALOS and European Space Agency ENVISAT satellites, respectively). To take advantage of this high spatial resolution, we constructed a 3-m-resolution digital elevation model (DEM) from LIDAR data acquired of Kilauea's summit in 2009. Combining the LIDAR DEM and TSX data allows us to track small-scale surface deformation in the vicinity of Kilauea's summit eruptive vent. We calculated displacements over time using the SBAS approach and found variable subsidence of the vent rim over space and time, which may provide an indication of which portions of the summit eruptive vent are likely to fail in future collapses. Our results demonstrate excellent prospects for continued use of TerraSAR-X as an operational volcano monitoring and

research tool (with low temporal latency between image acquisition and interferogram generation), particularly at locations where small-scale deformation is an important indicator of volcanic activity.

Rivalta, Eleonora

Effects of Magma Compressibility on Volcano Deformation and Seismicity *(INVITED)*

Rivalta, Eleonora[1]; Maccaferri, Francesco[1]; Passarelli, Luigi[1]; Dahm, Torsten[1]

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Lateral dike injections are often accompanied by the deflation of one or more magma chambers that fed the intrusion. The volume gained by the dikes is often much larger (typically two to four times larger) than the volume lost by the magma chambers. The usual interpretation is that some magma must have originated from additional deep sources, whose deflation cannot be resolved from the inversion of crustal deformation data. In fact, a possibility might be that the interaction between vertically displaced magma chambers results in an ill-posed inversion; this perspective will be discussed on the basis of numerical results. Alternatively, Rivalta and Segall (2008) demonstrated that the volume mismatch can be explained by considering the effects of magma and rock compressibility, and by assuming that mass (rather than volume) conservation holds during the feeding process. In this presentation, I will give an overview of the multiple lateral dike injection events where this type of mismatch has been observed (Kilauea, Hawaii; Manda-Harraro segment in the Afar rift, Ethiopia; Izu Islands, Japan; Fernandina, Galapagos), and illustrate how magma and rock compressibility may cause this ‘volume multiplication’. Additionally, I will show how magma and rock compressibility may be responsible of other recurrent patterns and effects, such as the characteristic trend observed for the seismicity forefront linked to the propagation of the dike tip, or the significant isotropic and CLVD components often found in moment tensor solutions in volcanic areas.

Rivalta, Eleonora

The Stress Shadow Induced by the 1975-1984 Krafla Rifting Event

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Stress changes on seismically active areas can favor or inhibit the occurrence of earthquakes. While increases in earthquake rate have been studied extensively from a theoretical point of view and demonstrated in several cases, stress shadows are rarely observed and addressed. The 1975 - 1984 Krafla rifting event is held responsible for a significant drop in the earthquake rate on the Húsavík Flatey fault (HFF), although this has never been quantitatively demonstrated. Here we model the Coulomb stress change induced by the rifting event to interpret the low seismic activity observed during the last 17 years compared to historical accounts. We find a strong correlation between theoretical predictions from the rate-and-state earthquake nucleation theory and observations from the SIL earthquake catalogue (from 1995 to 2011). We observe the seismicity rate in this time interval to depend strongly on the distance from the dike swarm, and we find significant changes in time for regions of the HFF with small negative ΔCFF values: there, the seismicity rate shows a relatively abrupt recovery during the analyzed time interval, the earlier in time the farer away from the dike swarm.

Rivalta, Eleonora

On the physical links between the dynamics of the Izu Islands 2000 dike intrusions and the statistics of the induced seismicity

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The frequency-magnitude distribution (FMD) of earthquakes has been widely studied in a variety of settings, from global to laboratory scale. The b-value of the FMD is in general close to one on a global scale; however, on a regional scale it is found to deviate significantly from this behavior, for example when linked to different states of stress of the crust: reverse faults tend to have higher b-values than strike-slip faults, which in turn have higher b-values than normal mechanisms. In pure tectonic environments, the seismogenic properties seem stationary over long periods of time; on the other hand, spatio-temporal variations of the b-value have been evidenced around major fault systems, in subducting slabs as well as in volcanic and geothermal areas. In volcanics areas in particular, transient phenomena associated with magma movements can drastically change the state of the stress within the crust; rock fracturing, massive presence of fluids and large temperature gradients can be investigated by studying the variations of the parameters of the FMD. In this study, we focus on the seismic swarm which accompanied the well-studied 2000 Izu islands (Japan) dike intrusion, with the aim of linking the intrusion dynamics to temporal and spatial variations of the b-value of the FMD. In particular we calculate the b-value associated with the seismic cloud accompanying the dike propagation and emplacement. We find the b-value to be spatially varying: it is high close to Miyakejima volcano, in correspondence of the rock volume first interested by the propagation, and it decreases gradually towards the areas reached at a later stage by the dike. The interaction between dike and pre-existing faults also causes the b-value to decrease. A small spatial region at depth with a high b-value can be evidenced, which possibly indicates a second injection point. We also calculate temporal variations of the b-value for the dike propagation phase, which lasted for the first 5 days of the swarm; we find the b-value to be systematically lower for the frontal portion of the propagating seismic cloud (which can be associated with the propagating tip of the dike), than for the rear portion of the seismic cloud (loosely associated with the body of the dike). The b-value linked to the dike 'body' decreases with time, while the b-value linked to the dike 'front' does not vary significantly. Finally, we calculate theoretically the effects of the dike-induced stress on the induced seismicity through a very simple dike propagation model, and compare it with the pattern of the observed seismicity. We find the dike-induced stresses to inhibit seismicity over large areas, with this effect still lasting today, and to cause a moving stress shadow accompanying the propagation.

Roman, Diana C.

Intermediate-term seismic precursors to the 2007 Father's Day intrusion and eruption at Kilauea Volcano, Hawai'i

Roman, Diana C.[1]

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For two days beginning on June 17 (Father's Day), 2007 and following a four-year-long period of summit inflation, magma intruded into Kilauea's East Rift Zone and erupted through a new vent near the Makaopuhi Crater, ~7 km west of the long-lived Pu'u O'o vent. On the basis of concurrent summit deflation and observations of lava chemistry and temperature, the June 17-19 Father's Day event has been interpreted as the result of forcible intrusion driven by high magma pressure at the summit, as opposed to a passive response to rifting (Poland et al., 2012). The Father's Day event was preceded by a) two shallow M4+ normal-faulting earthquakes along the outermost caldera faults on 24 May 2007, and b) a strong swarm of shallow volcano-tectonic (VT) earthquakes beginning on June 17 and signaling the onset of intrusion into the ERZ. However, little is known about any intermediate-term precursors that may have occurred between these two sets of earthquakes. The Hawaiian Volcano Observatory catalog (Nakata and Okubo, 2008) contains 260 located events during this period, approximately 70% of which are shallow and located in the south or east portion of Halema'uma'u caldera, along the south flank of Kilauea, and in the Kaoiki fault zone to the northwest of the caldera. Additionally, small-magnitude earthquakes not in the HVO catalog were identified in several areas along the lower east rift zone (LERZ), including near the site of the Father's Day eruption. Significant peaks in the seismicity rate occur several times during the intermediate-term precursory period. Here, seismic events occurring between May 25-June 16, 2007, are analyzed in detail to shed additional light on the nature of the transition from summit inflation to ERZ intrusion and eruption, and on the relationship between the Father's Day event and rifting processes along the east flank of Kilauea.

Rumpf, Mary E.

Understanding lava–substrate heat transfer on Hawaii and the Moon using thermodynamic modeling and laboratory-scale lava flows

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We have performed numerical modeling and laboratory experiments investigating heat transfer from molten basalt into solid and particulate substrates. This work was motivated by a desire to understand the preservation potential of solar wind particles in the lunar regolith; however, the results also provide insights into lava emplacement and hazards on Earth. The Moon lacks a significant atmosphere and magnetosphere, so the surface regolith passively collects impinging particles from solar wind, solar flares, and galactic sources. Regolith deposits containing implanted particles may be protected from further bombardment by an overlying lava flow, thereby providing a discrete snapshot of solar wind composition and strength. However, the flow will heat the regolith, potentially causing loss of volatiles to some depth beneath the flow. Understanding thermal and mechanical interactions between a lava flow and its substrate is key to determining the preservation potential of extra-lunar particles and for forming exploration strategies during future lunar missions. Our numerical model of lava–substrate heat transfer includes temperature-dependent thermophysical properties and determines the depths reached by a heat pulse within various substrates underlying a lava flow. We find that particulate materials, such as sands, soils, and lunar regolith, act as insulators, resisting the downward passage of heat and helping to maintain high temperatures within the lava core. Implanted particles may survive at relatively shallow depths beneath the flow. In contrast, solid substrates heat up more readily, drawing heat from the interior of the flow. The modeling therefore suggests that substrate material properties can influence lava flow emplacement processes by decreasing the rate of basal cooling and allowing the interior of the flow to remain mobile for longer periods of time relative to flows emplaced over solid substrates. To validate the numerical model, we performed laboratory experiments. In collaboration with the Department of Art & Art History at the University of Hawaii, ~5–6 kg of remelted Kilauea basalt was poured onto particulate or solid basalt substrates housed in boxes constructed of calcium silicate sheeting. The evolution of internal and surface temperature distribution of the system was monitored by an array of thermocouples embedded within the boxes, and a Forward Looking Infrared (FLIR) camera. Fitting simulation results to experimental data has allowed us to refine the definition of the thermal conductivity of our lunar regolith simulant, which was poorly constrained at high temperatures. The experimental data also reveal the latent heat released as the lava crystallizes. Our assessment of the thermal budget of cooling lava, including heat transfer into the underlying substrate, has potentially important implications for lava flow hazard predictions. Lava erupting from Kilauea or Mauna Loa volcanoes may encounter many different terrain types, e.g. solid basalt, tephra, organic soil, and sand. Understanding how each of these substrates may affect the cooling and mobility of the flow is a potentially useful refinement to lava emplacement models.

Seats, Kevin J.

3D Ambient Noise Tomography of the Sierra Negra Shield Volcano in the Galapagos

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This study examines the notion of generating 3D ambient seismic noise tomographic images for Sierra Negra, the most active volcano on the Galapagos Islands. By cross correlating ambient seismic 'noise' data at two stations, noise correlation functions (NCFs) can be extracted, and these NCFs can provide vital information on the seismic velocity structure between the stations, with the added benefit of not requiring seismicity in a region. We use data from a temporary network of 16 seismic stations, from July 2009 to June 2011, combined with a permanent station in the Galapagos, to generate surface wave group velocity estimates for periods between 5 and 40 s. These group velocity estimates, for the 136 station pair combinations, are then inverted for 2D group velocities at each period. We also test the spatial resolution for the network via checkerboard tests. The seismic network provides ample sampling beneath Sierra Negra to generate images of structures beneath the caldera. By comparing results generated with data from different time periods, it is possible to illustrate where and when large structural changes occur. These changes can be compared to other observations of seismicity, and uplift measured from InSAR to gain a better understanding of the physical processes responsible for Sierra Negra's dynamic magmatic processes. The methodology we use is providing excellent results in Yellowstone, and allows exciting research expansions to other geophysically active regions, of all sizes and scales, such as Sierra Negra, or Kilauea in Hawaii.

Segall, Paul

Volcano Deformation, Seismicity, and Magma-Faulting Interactions *(INVITED)*

Segall, Paul[1]

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As magma moves through the crust it deforms the earth's surface in ways that can be measured by both ground and space-based sensors. In the brittle crust these strains commonly generate volcano-tectonic (VT) earthquakes. Deformation and seismicity are thus the main geophysical methods for monitoring volcanoes, and have been extensively studied in Hawaii over the past century. By the early 20th century T.A. Jaggar noted cycles of magma accumulation, "inflation", ending with "deflation" as magma either erupted or intruded into rift zones. Increasing magma pressure stresses the crust, triggering seismicity and ultimately leading to dike injection. Dike intrusions generate characteristic deformation patterns, are usually associated with propagating earthquake swarms, both of which have been observed several hours prior to eruption onset. While it is generally assumed that VT earthquakes are induced by stress changes accompanying diking, quantitative models relating deformation and seismicity have been lacking. I will report on efforts to use models of seismicity rate variations resulting from stress alterations due to J. Dieterich to integrate deformation and seismicity into self-consistent inversions for the spatio-temporal evolution of dike geometry and excess magma pressure. This approach should lead to improved resolution and perhaps improved real-time forecasts. Mechanical analysis of the coupled dike-magma chamber system provides insight into factors determining whether a dike will reach the surface and erupt, or end with intrusion. Hawaiian volcanoes also exhibit earthquakes due to gravitationally driven flank motion, generally believed to occur on a basal décollement in sediments containing over-pressured pore-fluids. The basal fault beneath Kilauea's south flank creeps in a quasi-steady fashion on decadal time scales, but also experiences earthquakes, including the 1975 Mw 7.7 Kalapana earthquake. With the advent of continuous GPS it has become clear that the south flank also exhibits slow slip events (SSE) with durations of roughly 2 days and magnitudes Mw 5.3 to 6.0. SSE are associated with swarms of small earthquakes on the décollement landward of the SSE source areas. Flank earthquakes, including the 1975 aftershocks, are restricted to a narrow band parallel to the coastline, with few if any earthquakes close to the summit magma system, or offshore. Yet, modeling of the tsunami, geodetic, and seismic data require offshore slip in the1975 quake. This suggests that the décollement near the magmatic axis is too hot to deform brittlely, whereas the fault offshore is incapable of nucleating earthquakes. Slow slip events appear to be somewhat intermediate in behavior and location. I will discuss inversions of contemporary geodetic data to assess whether the south flank can be separated into distinct regions of quasi-steady creep and episodic SEE, or whether they must overlap. Repeating sources of moderate earthquakes suggest localized, frictionally unstable (velocity-weakening) fault patches, surrounded by stable (velocity-strengthening) fault. One possibility is that through-going ruptures, such as the 1975 quake, activate high-speed weakening mechanisms (such as thermal pressurization) that allow rupture on nominally stable fault segments.

Sehlke, Alexander

Characterizing Kilauea: The role of chemistry and crystallinity on rheology

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The rheology of silicate magmas, controls the eruption style of volcanoes and the emplacement of lava flows, is governed by the temperature, chemical composition of the melt and volume fraction of crystals (ϕc) and bubbles (ϕb). We studied a water quenched pahoehoe lava flow erupted from Kilauea in 1999 by parallel plate and concentric cylinder viscometry to determine lava properties as a function of temperature, chemistry and crystal fraction. The natural lava was remelted in a high temperature box furnace at 1600°C under atmospheric conditions to produce anhydrous and crystal-free remelts. Viscosity data (η) were collected above the liquidus (between 8 Pa.s at 1594°C and 130 Pa.s at 1309°C) and on supercooled melts above the glass transition temperature (between 3.7×10^{8} Pa.s at 739°C and 2.5×10^{11} Pa.s at 665°C). The viscosity is markedly non-Arrhenian, as is typical for basaltic melts. The chemical composition of natural rock glass matrix and remelt glass has been analyzed by electron micro-probe and shows that early crystallization only produces significant changes in SiO_2 and MgO content, which show respective increase and decrease in the residual melt. The calculated degree of melt polymerization, which is correlated to viscosity, expressed as NBO/T (nonbridging oxygen, NBO, per tetrahedrally coordinated cation, T), decreases from 0.81 in the remelt to 0.74 in the glassy matrix of naturally quenched samples. These calculations assume all iron is Fe^{2+}, whereas in fact iron in the melt will become more oxidized during emplacement in air, which in turn increases the amount of Fe^{3+} and the polymerization of the melt. For example, wet-chemical ferrous iron determination yields a $Fe^{2+}/\Sigma Fe^{2+}$ of 0.77 ±0.03 for the natural lava, while the sample remelted in air for 2 hours is more oxidized with a lower ratio of 0.56 ±0.01. During the early stages of lava emplacement, viscosity increases due to a combination of cooling and increasing polymerization of the residual melt are relatively minor. The evolving lava viscosity is also strongly affected by the physical effect of crystals and vesicles. To investigate the effect of crystal fraction (ϕc) on viscosity, we are conducting a series of annealing experiments, allowing the magma to crystallize to different degrees, after which time the viscosity is measured by the parallel-plate method. Data on lava from Stromboli indicate that the effect of crystals on basaltic magma viscosity is much greater than predicted by current physical models (~4 orders of magnitude increase in apparent viscosity for ~40% crystals), although this is in part driven by changing residual melt composition. Experimental data on samples from Kilauea and Mauna Ulu will be presented, and compared with current models for melt viscosity and magma rheology.

Shapiro, Nikolai M.

Studying Piton de la Fournaise Volcano Based on Correlations of Ambient Seismic Noise ***(INVITED)***

Shapiro, Nikolai M.[1]; Brenguier, Florent[1, 2]; Clarke, Daniel[1]; Campillo, Michel[3]; Ferrazzini, Valerie[2]; Nercessian, Alexandre[1]; Kowalski, Philippe[2]; Boissier, Patrice[2]

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Nowadays, the seismic networks are producing continuous recordings of the ground motion. These huge amounts of data consist mostly of so called seismic noise, a permanent vibration of the Earth due to natural or industrial sources. Theoretically, the time correlation of the seismic noise measured at two distant points allows retrieving the Green function between the points when the noise sources are distributed randomly and homogeneously. We use this property to develop imaging and monitoring methods. Surface waves extracted from correlations of ambient seismic noise lead to subsurface imaging on scales ranging from thousands of kilometres to very short distances. We applied this approach to continuous records by permanent seismological stations run by the Piton de la Fournaise Volcanological Observatory. Our results clearly show an intrusive high velocity body located below the main caldera between the surface and the likely depth of the shallow magma reservoir. This structure is surrounded by a low-velocity ring interpreted as effusive products associated to the construction of the Piton de la Fournaise volcano on the flank of the older Piton des Neiges volcano (Brenguier et al., 2007). One of the advantages of using continuous noise records to characterize the earth materials is that a measurement can easily be repeated. This led recently to the idea of a continuous monitoring of the crust based on the measurements of wave speed variations. The principle is to apply a differential measurement to correlation functions, considered as virtual seismograms. The technique developed for repeated earthquakes (doublets), proposed by Poupinet et al., 1984, can be used with correlation functions. In a seismogram, or a correlation function, the delay accumulates linearly with the lapse time when the medium undergoes a homogeneous wave speed change and a slight change can be detected more easily when considering late arrivals. With using the coda waves, it is possible to measure very small velocity changes (< 0.1%). The application of that method to Piton de la Fournaise Volcano shows velocity decreases preceding eruptions (Brenguier et al., 2008). Moreover, analysis of noise cross-correlations over 10 years allow to detect transient velocity changes that could be due to long-lasting intrusions of magma without eruptive activity or to pressure buildup associated to the replenishing of the magma reservoir (Brenguier et al., 2011). The strongest observed seismic velocity reduction is likely related to the widespread flank movement observed during the strong 2007 eruption.

Shea, Thomas

Post shield-stage volcanism at Hualalai (Hawaii): shifts between explosive and effusive activities during the Pu'u Wa'a Wa'a-Pu'u Anahulu eruption (~114 ka)

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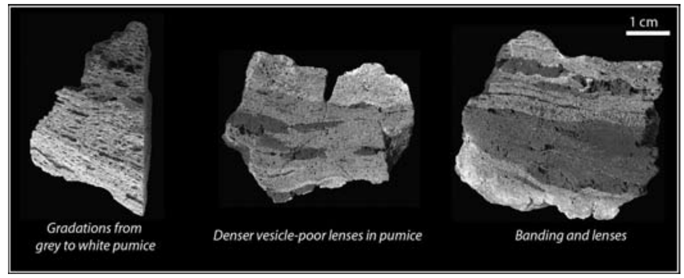
The Pu'u Wa'a Wa'a trachytic pumice cone (~1.6 km in diameter) and the associated thick (>275 m) Pu'u Anahulu trachytic lava flow represent a puzzling feature of Hawaiian volcanism. Combined, these two landforms amount to the largest known single-volume eruption known within Hawaii (~5.5 km^3, Moore et al., 1987). While its age and geochemical traits are established (Cousens et al. 2003), its eruptive characteristics are comparatively unconstrained. Proximal fall deposits at the cone contain a range of clast types, from pumice to obsidian, including some scoria, all within a single stratigraphic level. Previous chemical analyses have shown that pumice and obsidian from the cone have indistinguishable compositions that are also similar to lava flow samples (Table 1). Individual pumice clasts often display spectacular textural heterogeneities (shear-zones, banding and localized formation of vesicle-free obsidian, Figure 1), that reveal spatial variations in degassing during magma ascent. Preliminary measurements of H_2O in samples recently collected between the pumiceous zones (~2.5-3.5% wt.), and the denser zones (~0.5% wt.), suggest important degassing differences at the clast scale. Herein, we examine the transition from explosive activity and closed-system degassing (i.e., trachytic pumice) to effusive activity and open-system degassing (i.e., trachytic flow) using both field evidence and volatile analyses (H_2O, Cl) in addition to major element geochemistry. We also address the perplexing observation that products reminiscent of effusive activity (i.e., obsidian) are enclosed within pumice layers: are they the fragmented products of an initial effusive phase, or did they form by shear-induced outgassing during magma ascent?



Major element analyses of Pu'u Wa'aWa'a and Pu'u Anahulu samples (from Cousens et al. 2003)

Sample	PWW-3	PWW-4	PWW-5	MH83-75
Locality	Puu Waawaa	Puu Waawaa	Puu Waawaa	Puu Anahulu
Type	Black pumice/scoria	Gray pumice	Black obsidian	Lava flow
SiO_2	60.66	60.55	60.87	61.82
TiO_2	0.37	0.36	0.36	0.37
Al_2O_3	17.22	17.19	17.28	17.27
Fe_2O_3t	4.63	4.6	4.66	4.64
MnO	0.34	0.34	0.35	0.32
MgO	0.39	0.37	0.4	0.44
CaO	0.79	0.78	0.8	0.84
Na_2O	7.73	7.74	8.13	7.22
K_2O	5	5.08	5.13	4.8
P_2O_5	0.14	0.14	0.15	0.16
LOI	1.45	1.8	0.83	1.3
Total	98.72	98.95	98.96	99.18

Shearer, Peter M.

Characterizing fault zones and volcanic conduits at Kilauea and Mauna Loa volcanoes by large-scale mapping of earthquake stress drops and high precision relocations

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Because of ongoing time-dependent variations in volcanism, geodetically observed deformation, and earthquakes, Hawaii's value as a natural laboratory for studying the interactions between magmatic and tectonic processes has long been recognized. We describe initial results of a comprehensive analysis of waveforms from the seismic network operated by the Hawaiian Volcano Observatory (HVO) between 1992 and 2009, using methods similar to those we have successfully applied to network data in southern California. Our analysis includes records from over 130,000 earthquakes at a variety of depths, including shallow seismicity associated with Kilauea volcano and the east rift zone, intermediate depth events along magma conduits, deeper events along a detachment fault zone near 30 km depth, and long-period earthquakes near 40 km depth beneath Mauna Loa. We have converted all the waveform data to a standard format and are now applying both waveform cross-correlation and spectral analysis to the HVO waveforms. While prior studies have focused on individual regions, our analyses provide the first comprehensive catalog of relocated earthquakes across the entire Island of Hawaii. The results provide a sharper view of fault (tectonic) and conduit (magmatic) structures, including improved characterization of detachment faults on the south and west flanks of Hawaii. In addition, we are performing a systematic analysis of P-wave spectra to characterize the varying frequency content of the sources and to estimate Brune-type earthquake stress drops. Spatial variations in stress drop provide insights regarding the relationship between stress drop and fault geometry. In addition, there have been several large earthquakes, dike intrusions, and slow slip events that provide targets to investigate possible temporal variations in stress drop that may be associated with changes in absolute stress levels.

Shirzaei, Manoochehr

Aseismic faulting of the south flank of Kilauea revealed by wavelet analysis of InSAR and GPS time series

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The Hilina Fault System (HFS) is located on the south flank of Kilauea volcano and is thought to represent the surface expression of an unstable edifice sector that is active during seismic events, such as the 1975 Kalapana earthquake. Despite its potential for hazardous landsliding and associated tsunamis, no fault activity has yet been detected by means of modern geodetic methods since the 1975 earthquake. Using wavelet transforms in a statistical framework, we jointly analyze InSAR and continuous GPS deformation data from 2003 to 2010 to resolve a subtle deformation signal about the HFS normal fault scarps. This integrated analysis reveals localized deformation components in the InSAR deformation time series that are overprinted by the coherent motion of Kilauea's south flank, and contaminated by artefacts such as atmospheric turbulences. The analysis of InSAR and GPS data reveals that the temporal properties of the deformation field vary over the Hilina fault system. This result suggests a block-wise movement across the Hilina fault system. Since no significant shallow seismicity is observed over the study period, we conjecture that this deformation occurred aseismically.

Sinton, John M.

Kaʻena: The most recently discovered Hawaiian volcano and its effect on the evolution of the island of Oʻahu, Hawaiʻi

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The submarine Kaʻena Ridge extends >80 km to the northwest of the island of Oʻahu, Hawaiʻi. It's anomalous bathymetry and location suggest that it is unlikely to be a submarine extension of the NW rift zone of the nearby Waiʻanae Volcano. Rather we propose that it represents a previously unrecognized Hawaiian shield volcano that evolved independently from volcanic systems that form the present island of Oʻahu. New geological observations, samples and geophysical surveys support this alternative hypothesis as follows: (1) The extension of the Waiʻanae NW rift zone occurs as a dike complex ~6 km to the south of the Kaʻena Ridge topographic axis. (2) A significant (~50 mgal) gravity anomaly is displaced more than 15 km to the north of the Waiʻanae rift zone anomaly, suggesting a separate, long-lived magma system in this area. (3) Petrologic data indicate that Kaʻena evolved from tholeiitic to transitional (late-shield) stage of evolution while still submarine; the submarine to subaerial transition occurred within the late-shield stage, reaching a maximum ~500 m above sea level. (4) Kaʻena samples are isotopically distinct from Waiʻanae in having higher 208Pb/204Pb and lower epsilon Nd for a given 206Pb/204Pb. (5) Preliminary age data suggest the transition to late-shield compositions occurred ~3.6 Ma, ~ 0.5 Ma prior to the transition of Waiʻanae. Thus, structural, petrological and geochronological data all indicate that Kaʻena represents a previously unrecognized major Hawaiian shield volcano that is distinct from Waiʻanae Volcano and that aborted in a barely subaerial, late-shield stage of evolution. Recognition of an independent Kaʻena Volcano lying to the NW of, and providing a pre-existing buttress to, Waiʻanae explains several previous enigmas of Hawaiian Ridge structure, including spacing of volcanoes east of Kauaʻi, why the Waiʻanae Slump failed to the south, and why dikes of the buttressed Waiʻanae NW rift zone are so strongly aligned while those in the unbuttressed south are more radial.

Soule, Samuel A.

Airborne Laser Swath Mapping (ALSM) and Physical Volcanology of Hawaiian Volcanoes

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The history of volcanic activity and the dynamics of individual eruptions of Hawaiian Volcanoes are recorded on their surfaces in the form of superposed lava flows, volcanic cones, eruptive fissures, and tectonic faults. The long tradition of field-based mapping on the Hawaiian Islands has generated a comprehensive catalog of these features. Satellite remote sensing has added to this catalog by providing regional scale information on the relief, roughness, and spectral character of volcanic surfaces. Recently, airborne laser swath mapping (ALSM) has provided a new tool for characterizing volcanic surfaces that provides the benefits of regional-scale coverage along with increased resolution relative to satellite-derived data that can resolve small-scale features relevant to lava flow emplacement. We describe four new high-resolution ALSM surveys on Mauna Loa and Kilauea Volcanoes that support sub-meter resolution gridded elevation and backscatter intensity data. We demonstrate the utility of these data for improving geologic mapping of volcanic surfaces and the identification and interpretation of intra-flow volcanic and tectonic features. Specifically we use these data to discriminate lava flow boundaries, characterize roughness related lava flow surface morphology, and identify faults and fissures, proximal vent facies, lava channels, channel overflows, flow stagnation fronts, longitudinal folding, and pyroclastic deposits. The four surveys are conducted over well-studied regions and lava flows so that we may unambiguously evaluate our interpretations. They include: Kilauea Caldera, the July 1974 eruption of Kilauea's SW Rift Zone, Moku'aweoweo Caldera (Mauna Loa), and the upper portion of the 1984 lava flow of Mauna Loa. For each of these data sets, we use laser backscatter intensities to define lava flow boundaries for comparison to existing geologic maps. Backscatter intensities increase with eruption age, but are modulated by local climate and its influence on re-vegetation. In addition, each of these data sets offers a unique opportunity to evaluate the ability of ALSM to resolve specific volcanic and tectonic features on Hawaiian volcanoes. For the summit caldera of Mauna Loa and the Kilauea July 1974 flow (i.e., Koae fault zone), we use the data to identify faults that are difficult to resolve in satellite remote sensing or aerial photography due to their small size. For the Kilauea July 1974 eruption and the Mauna Loa 1984 eruption we examine along-flow changes in surface roughness. We find that signatures of surface roughness, although dominated by flow margins and channel levees, show variability with flow surface morphology (pahoehoe and 'a'a) and may be used as a tool to discriminate channel overflows and down-flow morphology transitions related to cooling and crystallization. In the Kilauea Caldera data set we examine the morphologic signature of pyroclastic deposits. Collectively, these data sets illustrate the power of ALSM for investigating the physical volcanology of Hawaiian eruptions.

Staudacher, Thomas

60 years of volcanic eruptions at Piton de la Fournaise volcano

Staudacher, Thomas[1, 2]; Di Muro, Andrea[1, 2]; Peltier, Aline[2]; Roult, Geneviève[2]; Team, Ovpf[1, 2]

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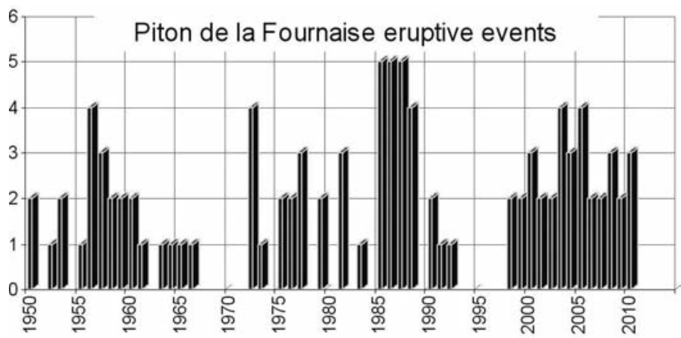
Ile de la Réunion is situated at 21°S and 55°30'E in the western Indian Ocean. It is composed by three volcanoes. The main volcano, Piton des Neiges (3070m), was active until about 15000 years ago. The volcan des Alizés, which was highlighted by magnetic and gravimetric studies, (Malengreau et al., 1999; Lénat et al., 2001) is completely eroded. The presently active volcano is the Piton de la Fournaise. Since 1980, date of the creation of the volcanological observatory du Piton de la Fournaise, the Institut de Physique du Globe de Paris is in charge of the survey of the volcano and the research on volcanology at Piton de la Fournaise. For this purpose several networks have been implemented on the volcano, in particular a seismic network and deformation networks, tiltmeter, extensometer and since 2004 a permanent GPS network. With 99 eruptions within the last 50 years Piton de la Fournaise is amongst the most active volcanoes in the world in terms of number of eruptions. It produced some 1000 Mm3 of lava within the last 50 years, including 470 Mm3 within the last decade. Duration of eruptions vary between 8 hours (Nov. 2009) and 6½ months (March to Sept. 1998) with an average of 23 days. The erupted volumes range between 0.1Mm3 (Nov. 2008) and 240Mm3 (April 2007) with a mean volume of 10Mm3. On average Piton de la Fournaise is active for 32 days per year and produces about 15Mm3 of lava. Most of the eruptions occur inside the U-shaped Enclos Fouqué caldera, which is open to the sea. They take place either within the summit crater or start in the summit crater and progress outside of it, or they start on the flank of the central cone. Some cross the national road in the Grand Brûlé area and reach the sea, but represent no direct danger for inhabitants. Only few eruptions take place in the so-called "north east" and "south east" rift zone outside of the caldera. In 2007, the Dolomieu crater collapsed into the magma chamber during the most important eruption of the last two centuries. Since then the eruptive activity remains at a low level.



Staudacher, Thomas

Permanent and cinematic GPS network at Piton de la Fournaise

Staudacher, Thomas[1]; Peltier, Aline[2]; Kowalski, Philippe[1]; Di Muro, Andrea[1]; Lauret, Frédérick[1]; Brenguier, Florent[1]; Walpersdorf, Andrea[3]

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The Piton de la Fournaise volcano at La Réunion Island in the western Indian Ocean is amongst the most active volcanoes in the world with a mean over 2 centuries of one eruption every 9 month. Since 1998 up to 4 eruptions occurred per year. The volcanological observatory (IPGP) is in charge of the monitoring of the volcanic activity and the prediction of eruptions. We will focus here on the DGPS network. The permanent GPS network consist in 23 stations, 5 stations around the summit craters “Bory” and “Dolomieu”, 5 stations at the base of the central cone and 6 stations on the eastern flank of the horseshoe shaped caldera of Enclos Fouqué. Four basis stations are situated farther away outside of the caldera Fouqué at high and low elevation. First permanent GPS data were obtained since 2004; the central network, covering the volcanic cone was upgraded till 2006. In 2010 the steep and highly vegetated eastern flank was equipped for the first time. GPS data are recorded every 30 seconds. Data files are transmitted by radio every day and evaluated on real-time. Software upgrade from Winprism to Gamit produces in some cases more precise results, in particular when stations with very contrasting elevations are compared. The cinematic GPS network consists today in 78 sites, equipped with stainless steel rods cemented in the rock or fixed on metallic tripods. These sites are measured routinely one or two times per year, or more often in case of eruptions or particular events. The GPS data, and in particular the base line changes, which seem to be slightly more precise than DGPS, allowed to forecast eruptions, but also to follow the general behaviour of the volcanic massif. The later shows a systematic change after the 2007 collapse of the Dolomieu crater. After eliminating rapid and short-lived deformations due to eruptive and intrusive events, the base lines show a general increase (or inflation) of Piton de la Fournaise central cone in the period 2004-2007, while after the summit collapse in 2007 a continuous and still ongoing deflation is recorded. The continuous monitoring of Grandes Pentes and the Grand Brûlé areas reveals a continuous and slow eastward translation of the eastern flank of Piton de la Fournaise with a rate of up to 2.8 cm per year and a subsidence of up to 4 cm per year.

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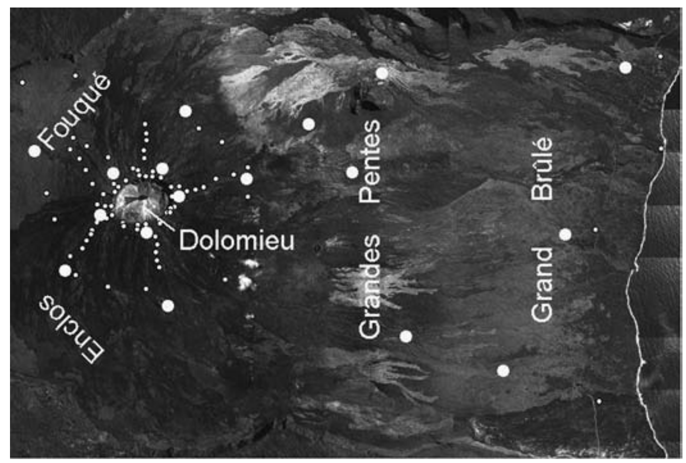

Sutton, A J.

Eruptive processes revealed by variations in Kilauea gas release highlight the value of thoughtful care and feeding of long running datasets

Sutton, A J.[1]; Elias, Tamar[1]; Poland, Mike[1]; Miklius, Asta[1]; Patrick, Matt[1]; Okubo, Paul[1]

1. Hawaiian Volcano Observatory, USGS, Hawaii National Park, HI, USA

This presentation considers the multi-year buildup to the 2008 Halema`uma`u summit eruption and the ensuing summit and rift interplay, 2008 – 2012 from a gas studies perspective, but with eyes towards using integrated geochemical and geophysical data and observations to interpret eruptive processes. Volcanic emission monitoring techniques at Kilauea have faithfully recorded gas release attending the volcano’s enduring east rift eruption. In addition to recording discrete geophysical events associated with activity at and near the rift zone eruption site at Pu`u `O`o, such as eruptive pauses or escalation of activity, these regular measurements of ambient gas concentrations, bulk gas emission rates and fumarole gas chemistry established a nearly twenty-year-long baseline of passive summit emissions data against which Kilauea’s summit magmatic renewal could be readily studied. The gas time series data revealed a systematic increase in CO2 emitted from Kilauea’s summit, beginning in 2003. This increase, along with coincident geophysical data streams showing the renewed extension and uplift across the summit caldera after a 20-year period dominated by deflation, indicated that the magma supply to the volcano had increased (Poland et al., 2012). Record-high

east rift SO2 emissions and accelerated inflation of the summit demonstrated convincingly that supply outpaced effusion between 2004 and 2007, as magma accumulated beneath Kilauea's summit caldera. This accumulation reached a critical point in June 2007 when magma withdrew from beneath the summit to feed an upper east rift intrusion and eruption. The overall trend once again switched to deflation. The decompression attending the magma withdrawal caused summit SO2 emissions to spike, then revert to a steady but somewhat elevated baseline for several months (Poland et al, 2009). As this deflation progressed through the end of 2007 and into early 2008, summit seismicity ramped up, and summit SO2 flux increased fourfold. Along with this, and more than a month prior to the official start of the summit eruption, fumarole emissions had already evolved to a 0.2 molar CO2/SO2, Type II eruptive gas state. Noteworthy, the first FTIR analyses of gases released from the newly formed summit "Overlook Vent" also carried this signature. The dynamic character of the summit eruption buildup and the continued activity through 2012 required monitoring techniques and the design of experiments be consistent and stable enough for long term measurements, and at the same time responsive to sometimes dramatic changes in the nature of gas release. One clear message throughout the course of the many eruptive events occurring from 2000 through 2012 is that the eruptive insights were gained, in large part, because consistent, long term datasets were available to test models and hypotheses.

Swanson, Donald

Effusive and Explosive Cycles at Kilauea: What do They Mean? ***(INVITED)***

Swanson, Donald[1]; Rose, Tim[3]; Mucek, Adonara[2]; Garcia, Mike[2]; Fiske, Dick[3]; Mastin, Larry[4]

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Kilauea's eruptive behavior for the past 2,500 years can be divided into alternating cycles of dominantly effusive and dominantly explosive activity, each cycle lasting several centuries. This interpretation is based on nearly 200 calendar-calibrated ^{14}C ages split evenly between lava flows and tephra. One effusive cycle, underway in 500-200 BCE, was succeeded by an explosive cycle that formed the Uwekahuna Ash and lasted for 1200 years (200 BCE to 1000 CE). It was followed by a 500-year-long period of effusion from 1000 to 1500 CE, which built the Observatory shield. The next cycle returned to mostly explosive activity, producing the Keanakako`i Tephra during a 300-year period ending in the early 1800s. The modern period of dominantly effusive activity has lasted for about 200 years. Most (though not all) significant Kilauea explosive eruptions are thought to be phreatomagmatic or phreatic, driven by superheated groundwater at or just below the water table. The long durations of the two explosive cycles (about 300 and 1200 years) therefore suggest either extended periods when parts of the caldera floor were about as deep as the water table (today ca. 615 m below the high point on the caldera rim and ca. 500 m below the present caldera floor), or episodic partial fillings followed by collapses that dropped the floor to water table depths. Comparison of erupted volumes calculated from a geologic map of Kilauea shows that magma supply rate to the subaerial edifice during dominantly explosive cycles was 1-2 percent that during dominantly effusive cycles. What would cause these supply rates to drop so drastically during the presence of a (perhaps episodically) deep caldera? There is no obvious reason why the collapse of a caldera by classical means (large eruption or intrusion into one of the rift zones) would decrease the succeeding magma supply. If, however, the caldera collapsed because of diminished supply, the two processes of collapse and lessened supply rate could be linked. A reduction in magma supply by 50-100 times seems extreme, however. Alternatively, the supply rate could have remained steady if most of the magma never reached the shallow summit reservoir, instead diverting at greater depth to erupt on the submarine flanks or intrude the volcanic edifice or underlying oceanic crust. Microprobe analyses of some glassy ash show relatively high MgO, up to almost 11 percent in the Keanakako`i and almost 13 percent in the Uwekahuna. These are the most magnesian glasses found on subaerial Kilauea in the past 10 ka. They suggest that storage in a shallow magma reservoir was minimal prior to eruption and that the reservoir system was only partly developed during periods of a deep caldera. Kilauea is not a steady-state volcano, as its past 2,500 years of cyclic activity shows. This has important ramifications not only for understanding the processes that drive Kilauea's eruptions but also for dealing with the hazards created by centuries-long cycles of dominantly explosive activity.

Syracuse, Ellen M.

High-resolution seismic imaging of Kilauea volcano's summit region: Combined datasets, comparison of tomographic methods, and updated seismic velocity models

Syracuse, Ellen M.[1]; Okubo, Paul G.[2]; Thurber, Clifford H.[1]

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2. USGS – Hawaiian Volcano Observatory, Hawai'i National Park, HI, USA

Kilauea's East Rift Zone and south flank areas have been the subjects of several recent small-scale local earthquake seismic tomography studies (Haslinger et al., 2000; Hansen et al., 2004; Syracuse et al., 2010). A number of larger or regional-scale studies have imaged all of southern Hawai`i (Okubo et al., 1997; Monteiller et al., 2005; Park et al., 2009). At the same time, however, Kilauea's summit region has not received much seismic imaging attention since a moderately high-resolution seismic velocity model was developed from data acquired during a temporary deployment of dozens of seismometers within the summit caldera (Dawson et al., 1999; Okubo et al., 2009). Considering the ongoing activity at Halema'uma'u within Kilauea's summit caldera, we might reasonably expect to be able to resolve not only small-scale velocity heterogeneity indicating where magma possibly accumulates, but also time-varying distributions of velocity heterogeneity reflecting magma movement. We have assembled a unique local earthquake dataset including data from a number of temporary array deployments and the permanent HVO network, with the goals of determining updated 3D models of P- and S-wave velocity and Poisson's ratio (from Vp/Vs) and exploring the feasibility of 4D seismic imaging of Kilauea's active summit caldera complex. In order to evaluate the robustness of results and assess the strengths of respective approaches, we also employ two different tomography methods: the double-difference tomography code of Zhang and Thurber (2003) and the finite-difference code of Benz et al. (1996). The combined datasets allow us to image the caldera and surrounding area at a scale of about a kilometer, and to also assess the potential for imaging temporal changes in seismic velocity structure afforded by local earthquake tomography and network stations in and around the caldera.

Teasdale, Rachel

Opportunities for classroom use of near-real-time monitoring data of Kilauea Volcano with the Volcanoes Exploration Project: Pu'u 'O'o (VEPP)

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3. HVO, USGS, Hawaii NP, HI, USA

The Volcanoes Exploration Project: Pu'u 'O'o (VEPP) Web site is an educational resource that provides access, in near-real time, to geodetic, seismic, and geologic data from the Pu'u 'O'o eruptive vent on Kilauea Volcano, Hawai'i, along with background and context information. Real- and near-real-time datasets are an increasingly common tool for monitoring Earth processes, particularly geohazards, and are commonly available via the Internet. Such monitoring information represents an important potential resource for geoscience education, but relatively few comprehensive datasets are available, and for those that are, background information to aid interpretation is often lacking. To provide an on-line, near-real-time educational resource, the U.S. Geological Survey's (USGS) Hawaiian Volcano Observatory, in collaboration with NASA and the University of Hawai'i, Mānoa, established the VEPP Web site (http://vepp.wr.usgs.gov). A time series query tool allows users to interact with continuous geophysical data, while an archive of Webcam images allows visual assessment of changes in volcanic activity. Lava flow field maps and results from episodic kinematic GPS campaigns are posted as data are collected. Background information on volcano surveillance and the history of the 1983-present Pu'u 'O'o - Kupaianaha eruption put the available monitoring data in context. In July 2010, a week-long workshop was held at Kilauea Volcano with 25 participants representing a diverse cross-section of higher learning. The workshop resulted in the creation of over 20 new teaching modules based on the VEPP Web site that have been posted for community use (http://www.nagt.org/nagt/vepp/index.html), hosted by National Association for Geoscience Teachers. The primary goal of the VEPP Web site is to take advantage of high visibility monitoring data for use as an educational resource. In doing so, the VEPP project provides a geoscience education tool that highlights state-of-the-art technology, demonstrates the dynamic nature of volcanoes, and promotes excitement about the process of scientific discovery through hands-on learning. Instructors have used VEPP in classroom activities at a broad spectrum of institutions including University of Puerto Rico, Penn State, University of Wisconsin, Oshkosh, California State University, Chico, Pasadena City College, and UC Santa Cruz. Implementation of one activity developed during the workshop indicates that a majority of students learn about new techniques affiliated with volcanic monitoring, and students enjoy the use of real data and working with data sets used by USGS geologists. In a paired t-test analysis, these shifts in attitude were found to be statistically significant with a moderate effect size ($t = 2.23$, $p = 0.05$; $d = 0.31$). This indicates the strength of developing classroom lessons that are peer- reviewed and created collaboratively with volcanologists and educators. With continued availability of near-real-time VEPP data, the collaborations between field geologists and classroom instructors provide well-supported learning opportunities for students.

Thelen, Weston A.

A MODEL FOR RECENT SEISMICITY ON KILAUEA'S UPPER EAST RIFT ZONE

Thelen, Weston A.[1]; Patrick, Matthew[1]

1. Hawaiian Volcano Observatory, Hawai'i National Park, HI, USA

Earthquakes are common on the upper east rift zone (UERZ) of Kilauea during pressurization of the summit and prior to eruptions on the middle east rift zone. Previous studies have attributed this seismicity to intrusions into the upper east rift. Typically, no transient deformation is associated with the swarm activity. Analyzing seismic data from between September 2010 and November 2011, we find that the seismicity on the UERZ is dominated by multiplets (repeating earthquakes). Many multiplet sources exist and their occurrence spans different episodes of eruptive activity. This repeatability excludes an intrusion as the source of the seismicity, as an intrusion would probably destroy the seismic source as it passed and permanently alter neighboring stresses. Relocated seismicity outlines a linear trace between the Kilauea summit and Mauna Ula, and focal mechanisms, when available, are dominantly left-lateral strike slip with one fault plane following the trace of the relocated earthquakes UERZ. Comparing event rates on the UERZ to the lava level within the Halema`uma`u eruptive vent at Kilauea's summit indicates an increase in seismicity when the lava lake is less than approximately 100 m below the rim of the collapse pit. Further, when the lava lake level fluctuates to depth less than 100 m we see a correlation between event rates on the UERZ and lava lake depths. Assuming hydrostatic pressure conditions and a perfect plumbing connection between the summit and Pu'u 'O'o eruptive vents, we estimate average pressure changes within the plumbing system associated with the fluctuations in magma level to be approximately 1.7 MPa. With such small pressures affecting the seismicity rates on the UERZ and the repeatability of seismic sources across episodes, we favor a model of faulting on strike-slip faults above a slightly dilating structure that transports magma to Pu'u 'O'o.

Thornber, Carl R.

Petrologic Testament to Changes in Shallow Magma Storage and Transport Associated with Prolonged Recharge and Eruption at Kilauea

Thornber, Carl R.[1]; Orr, Tim R.[2]

1. USGS-CVO, Vancouver, WA, USA
2. USGS-HVO, Hawaii Nat'l Park, HI, USA

The current Kilauea eruptive era began with summit eruptions in 1982. By 1983, magma pathways were forged through the east rift zone to Pu'u 'O'o. The ensuing eruption, still ongoing, constitutes the most prolific shield-building activity in over half a millennia. Since 2008, simultaneous summit and rift eruptions attest to a burgeoning supply of magma, and identical trace-element signatures confirm magmatic continuity between the vents. Petrology of ongoing eruption products provides insight into how the plumbing system that feeds and regulates vent activity has evolved to accommodate 30 years of surges and lulls in magma recharge and lava effusion. Most rift lava erupted prior to 2001 was olivine-phyric. Cyclic bulk-MgO variations during ebb and flow of steady-state effusion were consistent with changes in eruptive vigor and summit deformation. Bulk MgO limits of 9.8-7.5 wt% constrain olivine-saturated end-member conditions steadily tapped from a circulating open-system summit reservoir. A persistent MgO difference between bulk lava and matrix glasses erupted at 1170 – 1150°C is partly inherited from the summit chamber but largely the result of equilibrium growth of olivine during rift-conduit transit in ~40 hours. In 2001, after bulk MgO declined from a 1998 high of 9.5 down to 7.5 wt%, Pu'u 'O'o lava shifted from olivine-phyric to olivine-pyroxene-plagioclase-phyric. From 2003–2007, coincident with a surge in magma supply to the edifice (Poland et al. 2012), Pu'u 'O'o issued steady volumes of low-temperature (1145-1140°C), low-MgO (6.8 7.5 Wt %) multi-phyric lava. Phenocryst texture and mineralogy, along with assessments of low-pressure magmatic sulfur degassing tracked by melt-inclusions, indicate a disruptive and dynamic shallow regime of co-magmatic mingling between hotter, sulfur-rich magma and denser, cooler, degassed magma. Such magma-mingling suggested forced flushing of cooler multi-phyric zones along active rift-magma pathways during the surge in supply. Edifice inflation culminated in June 2007 with a small up-rift eruption of more primitive magma (8.0-9.0 wt% MgO), setting the stage for emergence of similar olivine-phyric magma at the summit in March 2008. A corresponding pulse of "olivine-only" lava moved through the rift zone to erupt at Pu'u 'O'o with a maximum of 8.0 wt% MgO in Fall 2008, before effusion gradually returned to a quasi-static low-MgO, multi-phryic condition during 2009-2010. Effects of an over-pressurized shallow rift-zone plumbing system continued to impact eruptive behavior throughout 2011. Continued effusion of comingled magma at the lowest bulk-MgO sustainable by olivine-saturated recharge of a multi-tectic magma points to a persistent and volumetrically significant open-system reservoir that was either activated or developed during the surge. This reservoir serves as a buffer-zone for magma moving down-rift and, like an "aneurysm" along the conduit, may have burst and bled through older dike magma during the March 2011 Kamoamoa eruption. While the presence of an active shallow open-system reservoir uprift of Pu'u 'O'o is apparent, its exact location is not, although magma storage in the vicinity of Makaopuhi has been suggested by geophysical data.

Tilling, Robert I.

Hawaiian Volcano Obseratory: Its First 100 Years Of Advancing Volcanology ***(INVITED)***

Tilling, Robert I.[1]

1. Volcano Science Center, USGS, Menlo Park, CA, USA

At the dawn of the 20th century, geologist Thomas A. Jaggar had a vision: To establish America's first volcano observatory. He chose Hawaii as the site for both pragmatic and scientific reasons, especially the abundant opportunities to study its frequent earthquakes and eruptions. Jaggar's vision became the Hawaiian Volcano Observatory (HVO), now celebrating its centennial in 2012. Jaggar considered the observatory's primary functions to be two-fold: 1) "see or measure the whole volcano inside and out with all of science to help"; and 2) "the main object of the work should be humanitarian...prediction and methods of protecting life and property on the basis of sound scientific achievement." Since its founding, HVO has adhered to these axioms and has utilized multi-disciplinary approaches and the best available techniques in volcano-monitoring studies, hazards assessments, and related topical research to better understand how Hawaiian volcanoes work—before, during, and after eruptions. Then as now, HVO scientists have collaborated extensively with colleagues in many academic and other organizations. HVO's contributions to volcanology have involved the long-term measurement and documentation of the seismic, ground-deformation, eruptive, and gas-emission processes of the active Hawaiian volcanoes (principally Kilauea and Mauna Loa). For example, the variation in summit tilt at Kilauea has been recorded essentially continuously since 1912, and the time-series of SO2 emissions at Kilauea acquired from 1979 to the present constitutes the longest-duration dataset of its type for any volcano in the world. Data from such long-term monitoring define the "baseline" behavior of the volcanic system, thereby enabling diagnostic, early detection of any departures that might augur atypical, and possibly, hazardous activity. Also of special importance is HVO's systematic collection of eruptive products for petrologic, geochemical, and isotopic analyses, thereby affording opportunities to compare variations in the time-series analytical data with real-time or near-real-time seismic and other geophysical monitoring data. Long-term geophysical datasets, combined with reconstruction of eruptive history and detailed documentation of eruptions, constitute the basis for eruption forecasts and hazards assessments. HVO regularly and effectively disseminates observatory-acquired data to the global scientific community, emergency-management authorities, and the media and general public. Collaboration with the public and civil agencies has had a direct impact on reduction of volcano risk. Although HVO is an ideal natural laboratory for studies of basaltic volcanism, the data it collects also provide context and "ground truth" in the design and interpretation of theoretical, experimental, and modeling studies of magma/eruption dynamics of volcanoes in intraplate as well as other tectonic settings. Equally important, as evident from the broad topical foci of this Chapman Conference, studies conducted in and around the Hawaiian Islands—by HVO and other groups—have implications that extend well beyond volcanology and help refine our understanding of deep Earth processes—such as magma generation and ascent, plate tectonics, and mantle convection and thermal plumes ("hotspots").

Trusdell, Frank

Does Activity at Kilauea Influence Eruptions at Mauna Loa?

Trusdell, Frank[1]

1. USGS, Hawaiian Volcano Observatory, Hawaii National Park, HI, USA

Currently, we are in Mauna Loa's longest inter-eruptive interval in HVO's 100 years of operation. Some observers have stated that Mauna Loa is a dying volcano. However, it erupts frequently—over the past 3,000 years it has erupted lava flows, on average, every 6 years. Since 1843, Mauna Loa has erupted 33 times, averaging one eruption every 5 years. When will the next eruption of Mauna Loa take place? Historically, several researchers (Moore 1970; Klein 1982; Rhodes and others 1989) have noted that eruptive periods at Kilauea and Mauna Loa volcanoes appear to be inversely correlated. These observations were based on historical accounts—approximately 170 years of eruptive activity. I concur with these initial observations and present a long-term look at Mauna Loa's eruptive history, through geologic mapping and radiometric dating, that spans the last 2,500 years. In the past, when Mauna Loa was exceptionally active, Kilauea was in repose, recovery, or in sustained lava-lake activity. Swanson and co-workers noted that Kilauea's eruptive behavior over the past 2,500 years cycles between periods dominated by explosive activity, followed by periods dominated by effusive activity. Specifically, Swanson and co-workers, using 200 newly acquired and published radiocarbon ages, identify the time periods between 200 B.C.E.–1000 C.E and 1500–1800 C.E. as explosive. They also provide evidence for low magma supply and few flank eruptions on Kilauea's subaerial surface during these periods. During the former explosive period, Mauna Loa was exceedingly active, covering approximately 37% of its surface—an area larger than Kilauea. This period is also marked by nearly 500 years of sustained summit activity at Mauna Loa. In the 1500–1800 C.E. period, Mauna Loa was conspicuously active, with 29 eruptions. In the late 19th and early 20th century, Kilauea was dominated by nearly continuous lava-lake activity. Conversely, Mauna Loa was frequently active, with 24 eruptions from 1843 C.E. to 1919 C.E., for an average repose time of 3.5 years. What is the reason for this apparent inverse activity level between the volcanoes? Could it be related to magma piracy, where one volcano snatches the magma supply from the other? From a geochemical perspective, the magmas supplied to the volcanoes are distinct, and thus piracy cannot be the reason. Furthermore, there are numerous intervals in which both volcanoes were in eruption (e.g., 1855–56, 1859, 1880–81, and 1984), thus arguing against magma piracy as the principle mechanism for the inverse activity between volcanoes. Periods of explosive or lava lake activity at Kilauea do not seem to impact Mauna Loa's ability to erupt. All of the previously mentioned paired eruptions occurred during Kilauea's lava lake activity. I propose a hypothesis that eruptive activity at one volcano may affect eruptions at the other, due to factors that include magma supply, volcanic plumbing, magma pressure, and flank motion (deformation). This hypothesis is predicated on the notion that rift-zone eruptions of Kilauea drive its mobile south flank seaward. Mauna Loa's southeast flank is, then, no longer buttressed. Consequently, asymmetrical spreading of Mauna Loa occurs, resulting in dilation of the magma storage centers, culminating in decreased magma pressure and, therefore, lessened ability to erupt.

Tuohy, Robin M.

Magma Transport, Storage, and Energetic Fountaining during Kilauea's 1955 Puna and 1960 Kapoho Eruptions

Tuohy, Robin M.[1]; Wallace, Paul[1]

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The classic model of Kilauea's eruptive and deformation behavior is based on observations made by the Hawaiian Volcano Observatory during the 1955 and 1959-1960 eruptions. Although the 1959 Kilauea Iki eruption produced the highest lava fountain observed at Kilauea (580 m), the 1960 Kapoho eruption on Kilauea's lower East Rift Zone (ERZ) produced fountains >400 m in height. Lava fountains are common to Hawaiian-style volcanism, but the mechanisms that produce fountains are still debated (e.g., exsolving volatiles or collapse of bubble-rich foam). A possible explanation for high fountains on the lower ERZ is that they involve a component of undegassed, CO2-rich magma that has bypassed the summit reservoir and shallow rift system. Alternatively, they may involve rapid supply of magma to the rift zone from the summit magma chamber. This project is going to test whether any of the energetic mid-20th century Kilauea eruptions on the lower ERZ were fed by deeply sourced magmas, with high CO2 concentrations, that had bypassed the summit and shallow rift systems. We are investigating this hypothesis by determining crystallization pressures for melt inclusions in olivine from the 1955 Puna and 1960 Kapoho eruptions on the lower ERZ. Melt inclusions commonly develop shrinkage bubbles during post-entrapment cooling due to both crystallization along the inclusion walls and the greater thermal contraction of the melt compared with the host mineral. Because of low CO2 solubility in silicate melts, formation of a shrinkage bubble can strongly deplete the melt of dissolved CO2 that was present at the time of entrapment. To investigate the loss of CO2 into shrinkage bubbles, we will experimentally reheat naturally glassy melt inclusions to redissolve the CO2 in the shrinkage bubble. The inclusions will then be analyzed for H2O and CO2 by FTIR. The results will allow us to calculate the pressures at which the inclusion-bearing olivines formed, and thus infer the pressures of magma storage. While we expect to find olivines that have mostly formed at low pressure within the shallow rift zone, we will look specifically at high fountain phases to see if there is any component of higher-pressure olivine that was sourced at greater depths. This study will complement ongoing efforts to measure the CO2 in shrinkage bubbles from Kilauea melt inclusions using Raman spectroscopy (Sides, Edmonds, MacLennan, unpublished data). The results from our study will establish magma storage depths within Kilauea volcano that can be compared with the results of geophysical studies. Our data may also provide insights on hypothesized cumulate-rich zone depths in the lower East Rift Zone that were flushed from the rift zone during high flux events such as the 1960 Kapoho eruption.

Unglert, Katharina

Towards a parameter space for volcanic tremor: Dependence of tremor amplitude on magma rheology

Unglert, Katharina[1]; Jellinek, A. M.[1]; McNutt, Stephen R.[2]

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Volcanoes exhibit a variety of seismic signals before, during and after eruptions[1]. Volcanic tremor is one type of seismic signal that is characterized by its emergent onset and relatively low frequencies (0.5 - 10 Hz)[2]. It is typically harmonic or monochromatic and can have a duration ranging from minutes to weeks. We investigate tremor characteristics such as amplitude, frequency, and temporal evolution in relation to magma rheology. To a first order, higher SiO_2-content can be indicative of higher magma viscosity, which in turn tends to result in higher explosivity of volcanic eruptions[3,4]. SiO_2-content of erupted products for a set of volcano eruptions is taken from the literature. Reduced displacement (RD) as a measure for tremor amplitude[5] has been calculated for each eruptive episode based on the maximum amplitude value[2]. The data suggests a tendency towards higher tremor amplitudes for higher weight percent SiO_2 (Fig. 1). For a set of volcanoes with similar amounts of SiO_2 (e.g. around 50 wt. % for Shishaldin, Alaska; Kilauea, Hawaii; Piton de la Fournaise, La Réunion; and Pacaya, Guatemala), however, a range of RD values can be observed (Fig. 1). Further research will include more data to validate a relation between RD and SiO_2-content, and will reveal which other rheological factors (e.g. volatile content, bubble content, crystallinity) could be responsible for the range of tremor amplitudes observed at volcanoes with similar SiO_2-content. We will investigate why Kilauea appears to reach the same maximum tremor amplitude over the course of several months, whereas Shishaldin tremor exhibits peak amplitude variations of half an order of magnitude within just a few days. References: [1] McNutt, S. Annual Review of Earth and Planetary Sciences (2005). [2] McNutt, S. and Nishimura, T. Journal of Volcanology and Geothermal Research (2008). [3] Gonnermann, H. and Manga, M. Annual Review of Fluid Mechanics (2007). [4] Giordano, D., Russell, J., and Dingwell, D. Earth and Planetary Science Letters (2008). [5] Aki, K. and Koyanagi, R. Journal of Geophysical Research (1981).

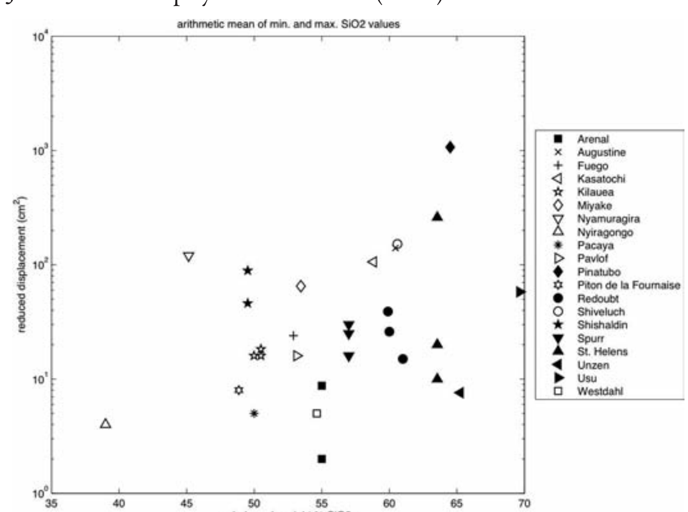

Figure 1: Reduced displacement versus weight % SiO_2.

Uno, Itsushi

Eruption of Mt. Kilauea impacted Cloud Droplet and Radiation Budget over North Pacific

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Mount Kilauea Volcano began to erupt on 19 March 2008 and continued to release large amounts of volcanic gas until the end of 2008. The volcanic SO2 was oxidized to sulfate aerosol. The impact of the sulfate aerosol from this eruption on cloud microphysical properties was clearly observed by MODIS satellite. Mt. Kilauea is located in a clean maritime environment characterized by the steady easterly trade wind, ubiquitous cumulus clouds and without any large anthropogenic emission sources. This condition is ideal for studying the impact of aerosol on cloud physical and radiative properties. Here we report our original findings for the 2008 eruption of the Mt. Kilauea volcano and its impact on cloud properties. Figure 1 shows the MODIS AOD measurements for August 2008. A significant increase in AOD is evident in the downwind region extending from the Hawaiian Islands to the western North Pacific, with a zonal extent of 5000 km and a meridional extent of 1500 km. The volcanic aerosol layer persisted over a large area of the remote North Pacific, where cumulus clouds are ubiquitous. The effect of aerosol particles on the cloud radius (CDR) and properties is known as the Twomey effect. We examined that the CDR distribution and the difference between August of average in 2003 – 2007 and 2008. Over the study region, the average CDR was 17.6 μm in 2003 – 2007 before the eruption and decreased to 13.7 μm (~23 % decrease) during the eruption. Meanwhile, the averaged cloud fractional coverage increased from 9.1% in 2003 – 2007 to 13.4% in 2008 (a relative increase of ~37 %). The aerosol index (AI; product of AOD and the Ångström exponent) is a measure of the aerosol column number concentration. It is approximated by CDR = 10.8 AI^(-0.19) based on MODIS measurements. The CDR rapidly decreased as the volcanic aerosol number increased. This relationship between the CDR and the surrounding sulfate aerosol will provide an important foundational reference for climate change studies.

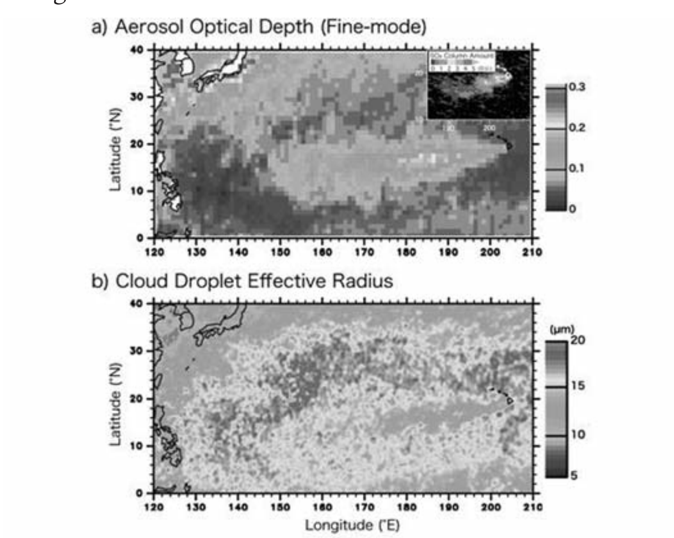

Fig. 1. (a) Fine-mode aerosol optical depth (550 nm) for August 2008 from the standard monthly MODIS level 3 products and (b) Cloud effective radius retrieved from the MODIS 3.7-μm band measurements using the Comprehensive Analysis Program for Cloud Optical Measurements algorithm.

Vergniolle, Sylvie

From Reservoirs to Conduits: the Role of Bubbles in Driving Basaltic Eruptions ***(INVITED)***

Vergniolle, Sylvie[1]

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Gas in basaltic systems have long been recognised as a key factor in driving eruptions. Different technics are now available to constrain the amount of gas at the surface and at depth from geological samples to geophysical or chemical measurements. The gas volume at the vent can be estimated by using: 1) a FTIR, which constrains gas ratios such as CO2/SO2, H2O/SO2, ect..., asociated with a direct measurement of the SO2 flux; 2) a radar which measures the gas velocity; 3) acoustic records by either using acoustic power, a series of 2 successive integrations of acoustic pressure or by inverting acoustic waveforms. Combining these technics with video or thermal images has also been very fruitful to constrain physical processes at the vent. The range of bubble sizes in basaltic eruptions is enormous, from microns to millimeters in shallow magmatic reservoirs or in basaltic scoria to several centimeters up to several meters at the vent. The different processes responsible for such a large range will be reviewed, including bubble nucleation, growth and coalescence both in reservoirs and in conduit. Magma reservoirs, viewed as a large structure or as a network of sills and dikes, play a crucial role in the initiation and the behaviour of an eruption. The question and the size of large reservoirs, deduced from petrology or geochemistry, will be discussed versus the lack of their seismic detection. Open systems such as lava lakes, can also be useful in understanding shallow magma reservoirs as they provide a window into their behaviour. In particular, the level of lava lakes fluctuates in response to changes in volume at depth, either by adding or removing new magma within the plumbing system or by forming or growing new bubbles. Long-time recording of the lava lake level can be done directly or by using satellites. Some volcanoes, such as Etna, Piton de la Fournaise or Erta Ale, shows that the series of eruptions known for more than a century present decadal cycles. These cycles can be interpreted as resulting from a single large magmatic reinjection at depth every few decades, which generates eruptions associated with a large volume of magma. These major eruptions are followed by several successive eruptions associated with a smaller magma volume, which can be explained by a self-induced mechanism producing new bubbles without invoking a new magmatic reinjection. The question of whether each eruption on a basaltic volcano is necessarily triggered by a magmatic reinjection from depth will be also discussed.

Wanless, V. Dorsey

Petrogenesis of High-Silica Magmas in Basalt-Dominated Systems

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Ocean island volcanoes, which typically produce basaltic lavas, can also erupt high-silica dacites and rhyolites. However, despite decades of debate, there is no overall consensus on how these high-silica lavas form in these basalt-dominated systems. Petrologic processes that may be involved in their formation include 1) extensive fractional crystallization from a basaltic parental magma, 2) partial melting of crustal material and/or 3) assimilation and fractional crystallization (AFC). To better understand how high-silica lavas are formed at ocean islands, we compare these lavas to dacites erupted at several mid-ocean ridges (East Pacific Rise, Juan de Fuca Ridge, and Galapagos Spreading Center). Mid-ocean ridge dacites have remarkably similar major and trace element compositions that are consistent with petrogenesis by AFC processes. Chlorine concentrations are too high and oxygen isotope ratios are too low to be produced by fractional crystallization alone and instead, require assimilation of seawater-altered crust. In contrast, high-silica lavas erupted at ocean islands have a wide range of compositions, suggesting that numerous processes may be involved in their formation. For example, extensive fractional crystallization of basaltic parent magmas has been advocated for the formation of dacites at Alcedo Volcano in the Galapagos Islands, which is supported by magmatic oxygen isotope ratios in the erupted lavas. However, both assimilation and fractional crystallization are required to explain the oxygen isotope signatures observed in lavas erupted from several Icelandic volcanoes. Mid-ocean ridge dacites are only erupted in unique ridge environments, such as segment ends and propagating ridge tips, where the balance between magmatic and crustal temperatures facilitates both extensive fractional crystallization and assimilation. This suggests that the tectono-magmatic environment is critical for dacite petrogenesis on mid-ocean ridges. Here we compare both the compositions and geologic settings of several high-silica lavas erupted from ocean islands and mid-ocean ridges, to determine if the tectono-magmatic setting inhibits or promotes crustal assimilation in ocean island magmas. We hypothesize that assimilation on ocean islands may be greater in rift zone settings or at the edges of magma chambers, which may be analogous to segment ends at mid-ocean ridges.

Wauthier, Christelle

Magma Sources Involved in the 2002 Nyiragongo Eruption, as Inferred from an InSAR Analysis

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On 17 January 2002, Nyiragongo volcano (Dem. Rep. of Congo) erupted along a 20 km-long fracture network extending from the volcano to the city of Goma. InSAR data from the ERS-2 and RADARSAT-1 satellites captured the ground deformation associated with the eruption. A combination of 3D mixed boundary elements numerical modeling and inversions is used to analyze these displacements. A model with two subvertical dikes is the most likely explanation for the 2002 InSAR deformation signal. A first, shallow dike, 2 km high, is associated with the eruptive fissure, and a second, deeper dike, 6 km high and 40 km long, lies about 3 km below the city of Goma. As the deep dike extends laterally for 20 km beneath the gas-rich Lake Kivu, the interaction of magma and dissolved gas should be considered as a significant hazard for future Nyiragongo eruptions. A likely scenario for the eruption is that the magma supply to a deep reservoir started ten months before the eruption, as indicated by LP events and tremors. Stress analysis indicates that the deep dike could have triggered the injection of magma from the lake and shallow reservoir into the eruptive dike. The deep dike induced the opening of the southern part of this shallow dike, to which it transmitted magma though a narrow dike. This model is consistent with the geochemical analysis, the lava rheology and the pre- and post-eruptive seismicity. We infer low overpressures (1 – 10 MPa) for the dikes. These values are consistent with lithostatic crustal stresses close to the dikes and low magma pressure. In this area of the East African rift, magmatic activity is intense enough to relax tensional stresses associated with the rift extension.

Weis, Dominique

What Do We Know About Mantle Plumes, What Can Hawaiian Volcanoes Tell Us About The Earth's Mantle And How Do They Compare to Other Oceanic Islands? *(INVITED)*

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The origin, scale and source of mantle heterogeneities have been the subject of debate since their first documentation through the study of ocean island basalts (OIB) 50 years ago (Gast et al., 1964). One of the most common approaches is to analyze the geochemistry of oceanic basalts brought to the surface by mantle plumes, sampled either on oceanic islands or by drilling oceanic plateaus. Improved analytical precision for radiogenic isotopes, combined with statistical data treatment, has provided a finer resolution necessary for identifying fine-scale geochemical variations in OIB that relate to shallow and deep plume structure. A key factor is the acquisition of continuous datable sequences of lavas (DePaolo & Weis, 2007). The Hawaiian mantle plume represents >80 Myr of volcanic activity in a pure oceanic setting and with a high magmatic flux. Identification of two clear geochemical trends (Loa and Kea) among Hawaiian volcanoes (Tatsumoto, 1978; Abouchami et al., 2005) in all isotope systems (Weis et al., 2011), together with the recurrence of similar isotopic signatures at >350 kyr intervals identified in the HSDP cores, have implications for the dynamics and internal structure of the Hawaiian mantle plume conduit (Farnetani & Hofmann, 2009, 2010). In this review, I will present a compilation of recent isotopic data for samples from shield lavas on Hawaiian volcanoes, focusing specifically on high-precision Pb isotopic data (MC-ICP-MS or DS, TS-TIMS) integrated with Sr, Nd and Hf isotopes. All isotopic systems indicate source differences for Loa- and Kea-trend volcanoes that are maintained throughout the ~1 Myr activity of each volcano and that extend back in time on all the Hawaiian Islands (to ~5 Ma). The Loa-trend source is more heterogeneous in all isotope systems than the Kea-trend source by a factor of ~1.5, and this heterogeneity can be traced to the core-mantle boundary. When projected to the CMB, many mantle plumes occur at the edges of ultra-low velocity zone (ULVZ) material. The Hawaiian mantle plume overlies the boundary between typical Pacific lower mantle on the Kea side and a sharp, seismically defined, layer of apparently different ULVZ material that occurs on the Loa side of the plume. The geochemical differences between the Kea and Loa trends reflect preferential sampling of these two distinct sources of deep mantle material at the core-mantle boundary. Similar indications of preferential sampling at the edges of the African ULVZ are found in Kerguelen and Tristan da Cunha basalts in the Indian and Atlantic oceans, respectively. The anomalous low-velocity zones at the core–mantle boundary store geochemical heterogeneities that are enriched in recycled material (EM-I type) and are sampled by strong mantle plumes such as Hawaii and Kerguelen. Smaller islands in the Pacific such as Samoa, Marquesas, Societies (Huang et al., 2011; Chauvel et al., sub.; Payne et al., sub.) also show geochemical zoning, at a much smaller scale and sample different mantle zones (i.e. not ULVZ). Implications for the origin of oceanic mantle components will be discussed.

White, Robert S.

Magma Migration through the Crust beneath Iceland

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We have tracked magma rising 30 km through the crust beneath three Icelandic volcanic systems: Askja, Upptyppingar and Eyjafjallajökull. The magma route from the mantle to mid-crustal sills and shallow magma chambers is marked by well-defined microseismicity with typical local magnitudes of ~1. Askja is an evolved central volcano in the Northern rift zone, part of the mid-Atlantic Ridge passing through Iceland. Mid-lower crustal microseismicity at depths of 12-30 km has recurred consistently in the same locations beneath Askja during our 6 year monitoring period. This suggests that magma pathways from the mantle are used repeatedly, feeding magma sills at different levels in the mid-crust. Earthquakes occur in the normally ductile part of the crust, below the brittle-ductile boundary, so we postulate that the seismicity is caused by high strain rates generated by melt movement. At Upptyppingar, east of Askja, melt injection was a once-off event lasting 10 months, with 10,000 earthquakes above magnitude 0.8. The melt migrated episodically up from 18 km along a 5 km wide, ~1 m thick dyke before freezing at 13 km below sea level. Moment tensor solutions show that the fractures causing the microearthquakes lie in the same plane as the macroscopic dip of the dyke itself. Surprisingly, alternations from thrust to normal faulting on the same planes occur within a minute for events that are co-located to within the accuracy of our double difference relocations (approx. 50 m). We interpret this as due to fragments of frozen melt in the 50° dipping conduit breaking along either the top or the bottom boundary of the dyke. The stresses set up by the mid-crustal intrusion led to a subsequent burst of right-lateral strike-slip faulting in the overlying 6 km thick brittle crust. The shallow faults re-used rift-parallel fractures already in existence, but which were originally left-lateral. We show that this reversal can be modelled by the stresses generated by opening the dyke at depth. Beneath Eyjafjallajökull, a stratovolcano in the propagating southeastern rift zone, we have mapped microearthquakes caused by magma migration preceding and during the flank and summit eruptions in March–May 2010. The majority of the 10,000 microearthquakes produced immediately before and during the eruption come from the shallow magma chambers and associated feeders at less than 6 km below sea level. But a sequence of 386 microearthquakes produced during the summit eruption, located by double-difference relative relocation, defines a sub-linear trend inclined ~5–10° from vertical extending from the upper mantle at ~30 km depth to the summit crater. All the microearthquakes display characteristics of brittle fracture, with several subsets of events exhibiting closely similar waveforms within clusters. This suggests similar, repetitive source processes. This sequence includes two major clusters at ~19 km and ~24 km depth, each containing >100 earthquakes. Like Upptyppingar, they may be caused by fracturing solidified magma plugs that form constrictions in an otherwise aseismic melt conduit. Or they may occur at exit points from melt sills, in which case they indicate positions of magma storage at depth.

Whittington, Alan G.

Thermo-rheological feedbacks during cooling and crystallization of basaltic lava

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Magma has two potential end-member fates: to crystallize, or quench to glass. Many thin basaltic sheet intrusions and lava flows achieve only partial crystallization before solidifying, where solidification implies cooling below the glass transition temperature of the interstitial melt, and/or crystallizing to the extent that increasing effective viscosity and/or yield strength prevent flow. The thermal and rheological histories are intimately related by various feedback mechanisms, and a combination of internal factors (e.g. crystallization kinetics, latent heat of crystallization, non-Newtonian rheology) and external factors (e.g. magma flux, insulation via lava tubes), add additional dimensions that make simple parameterization of rheology as a function of temperature difficult even for a single lava composition. We are quantifying the thermophysical properties of basaltic lavas, including tholeiites from Hawaii, Iceland, and the East Pacific Rise. These include viscosity (η), heat capacity (C_p), latent heat of crystallization (ΔH), thermal diffusivity (D) and thermal conductivity ($k = D\rho C_p$), where ρ is density. Melt viscosity is a strong function of temperature and composition. Both C_p and D are strongly T-dependent for glasses and crystals, and melts have higher C_p and lower D than crystals or glasses, suggesting that changes in thermal properties accompanying partial melting of the mantle or crystallization of basalt may be important. Basaltic melts have exceptionally low thermal diffusivities, so that melt-lined conduits and lava tube systems will be particularly efficient thermal insulators, facilitating rapid transport. We modeled the two end-member scenarios for a cooling basaltic sheet intrusion: simple quenching without crystallization, and equilibrium crystallization (including latent heat release, implemented numerically as extra heat capacity over the crystallization interval). Models confirm field observations that basaltic sheet intrusions almost always crystallize, even at sheet margins, because their emplacement temperature (~1200 °C) is sufficiently high that the country rock adjacent to the sheet will be raised above the T_g of the melt (~650 °C). The long period of time spent above T_g, combined with the rapid crystallization kinetics of basaltic melts, ensures that crystallization is near-complete, even if the crystal size is small, except where unusually rapid chilling occurs due to efficient convective or radiative losses (for example subaerial, subaqeous or subglacial lava flows). The rheological history of the intrusions is more complex, because solidification is achieved in the case of quenching by cooling to T_g, and in the case of crystallization by increasing crystal fraction such that effective magma viscosities become too high. Crystallization results in a longer cooling timescale (due to latent heat release), but a short mobility timescale (due to crystals) than quenching. Equilibrium crystal fractions exceed 60% within 50-100 °C of the liquidus temperature, before residual melts become silica-rich in the later stages of crystallization. This suggests that the main controls on the rheology of flowing basaltic lava are crystal and bubble fractions.

Wooten, Kelly

Controls of DEM quality on lava flow modeling: Test cases from Kilauea Volcano, Hawai`i, and Piton de la Fournaise volcano, Réunion Island

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4. Geology & Geophysics/SOEST, University of Hawaii, Honolulu, HI, USA

Lava flow modeling can be a powerful tool in hazard assessments; however, the ability to produce accurate models is usually limited by a lack of high resolution, up-to-date DEMs. Using test cases on Kilauea Volcano, Hawai`i, and Piton de la Fournaise volcano, Réunion Island, we examine the effects of using an updated versus an outdated high spatial-resolution DEM on the trajectory and extent of modeled lava flows. We used the Harris and Rowland (2001) FLOWGO model to recreate three recent lava flows, then examined their topographic profiles to understand the effect of the DEM on the model. In our first case study, we modeled the initial flow from Fissure D during the July 21, 2007 fissure eruption on Kilauea's east rift zone. The flow was modeled and recreated successfully using the 30 m resolution, 2000 SRTM DEM of Hawai`i Island. Because there were no subsequent lava flows emplaced in close proximity to the fissures after the DEM was created (i.e., "post-DEM"), both the modeled and actual flow simply followed a topographic low created by older lava flows. Our second case looked at the Thanksgiving Eve Breakout (TEB) flow, which originated from the same vent, four months later. We were able to recreate the upper portion of this flow field using the same DEM, but on the coastal plain, the modeled flow incorrectly sent the lava straight to the ocean. The actual flow encountered considerable post-DEM topography (many years' worth of inflated pahoehoe), and curved well to the east toward the town of Kalapana before heading to the ocean. In the third case, we conducted a comparison study to examine a similar-style flank eruption on Piton de la Fournaise. First we modeled the lava flow paths from the October 2010 eruption using a high resolution, 7.5 m lidar DEM from 2008-2009, and a discharge rate found by MODIS imagery. We then compared the modeled flow field area with an InSAR-derived lava thickness map of the eruption. Finally, we used a 2012 DEM (7.5 m resolution) to model a new eruption with the same vent location and discharge rate. This procedure allows us to understand the influence the new topography has on the emplacement of subsequent lava flows. These results show that DEMs can quickly become out-of-date at active volcanoes after the emplacement of new flows, and highlight the importance of using updated DEMs for modeling lava flow hazards.

Wright, Robert

Imaging Volcanic Plumes Using a Sagnac Interferometer

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This presentation will provide an overview of how an imaging interferometer can be used to provide high spectral and spatial resolution image data regarding the composition of volcanic plumes. Traditional approaches for remote sensing of volcanic plumes have relied on either high spectral resolution non-imaging techniques (OP-FTIR, COSPEC-type) or imaging techniques which are either specific to one plume component (UV cameras) or sensitive to more than one plume component but of low spectral resolution (the "FLIR plus filter-wheel" approach). The technique we propose offers the possibility to allow high spectral resolution imaging of volcanic emissions in the thermal infrared, a region in which silicate ash, sulfur dioxide and carbon dioxide have spectrally distinct (and measureable) absorption features. The instrument (THI: Thermal Hyperspectral Imager) has been developed for inclusion on a small satellite platform. THI acquires approximately 40 separate spectral bands in the 8 to 13 micrometer wavelength region, at 15 wavenumber resolution. Rather than using filtering or dispersion to generate the spectral information, THI uses an interferometric technique. Light from the scene is focused onto an uncooled microbolometer detector array through a stationary interferometer (Sagnac configuration), causing the light incident at each detector at any instant in time to be phase shifted by an optical path difference that varies linearly across the array in the along-scan dimension. By scanning across the scene at 30 Hz (equal to a spatial sampling of one pixel per frame), an interferogram can be generated for each scene element. Spectral radiance as a function of wavelength is subsequently obtained for each scene element using standard Fourier transform techniques. The sensor yields image data with signal-to-noise ratios of approximately 100:1 at approximately 9 microns, but as high as 500:1 in the 10-12 micron region, and takes about 10 seconds to acquire an image cube. This presentation will provide an overview of the instrument as configured for space-flight, the image acquisition technique, and some laboratory and field data illustrating how the instrument could be used for ground-based imaging of volcanic plume composition at high spectral and spatial resolution.

Zurek, Jeffrey M.

Linking Gravitational Spreading and Magma Chamber Growth through Gravity Studies

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We revisit the hypothesis of a link between the movement rate of Kilauea's south flank and magma chamber growth based on recent gravity and deformation studies. A Bouguer gravity study within the summit caldera displayed a positive 20 mGal oval-shaped anomaly offset northeast from Halema`uma`u Crater, within Kilauea caldera. Inversions of the gravity data suggest a cylindrical region with an anomalous density contrast that begins ~500 m above sea level (asl) and continues to the bottom of the model (-1000 m asl). Using density from down-hole geophysical surveys at Keller Well, the model was converted to true density by assuming separate zero density contrasts (1200 to 600 m asl at 2330 kg m^{-3}, 600 to 100 m asl at 2500 kg m^{-3}, and 100 to – 1000 m asl at 2600 kg m^{-3}). The results show that 8% of the model (equivalent to a volume of 5.5 km^{3}) has a density of 2800 kg m^{-3} or greater, probably representing a large intrusive complex. While the inversions help to describe subsurface density structures, they do not explain why the Bouguer anomaly is offset from the summit chambers, nor if the density structure of the subsurface has implications for caldera formation. A recent dynamic gravity study shows a positive anomaly that grew to 450 μGal over 33 years (1975 to 2008), irrespective of volcanic activity, centered just east of Halema`uma`u. The study's preferred model to explain the continual mass increase is the slow accumulation of magma in void space that was initially created as a result of the 1975 M7.7 earthquake. An alternative hypothesis is that rifting of the summit, accompanied by magma infilling, results in the observed dynamic gravity increase and may be responsible for the position and shape of the positive Bouguer gravity anomaly within the caldera. Deformation studies indicate seaward motion of Kilauea's south flank as a result of either rift zone intrusions or gravitational spreading, or a combination of the two processes. The south flank instability causes rifting of the summit region. Simple gravitational spreading models, assuming summit extension of 3 cm yr^{-1} (at least after 1975) and magma infilling, can account for 330 μGal of the dynamic gravity signal. This suggests that south flank movement plays an important role in the evolution and growth of Kilauea's summit magma storage system. Furthermore, this raises the possibility that magma chamber growth due to gravitational spreading is a factor in caldera formation. However, a longer dynamic gravity dataset in conjunction with deformation measurements is required to test this hypothesis.