

The crater is approximately 300 m in diameter, enclosing a smaller, 150 m diameter ring of vents. Erupted gases and pyroclastic materials often occurred through the ring-shaped arrangement of vents. The largest observed eruption exited through vents spread over nearly the whole dome, while smaller events were emitted through the inner ring vents only. The ring structure is thought to represent the surface expression of a funnel-shaped series of fractures generated from a much narrower conduit at depth. Santiaguito's eruption characteristics are consistent with slug, or intermittent, flow, that is the release of gas pockets from depth. The dome cap appears to be fairly rigid, with no observed flexure during eruptions. Summit fumaroles include two types: those unaffected by and apparently isolated from the main eruptive conduit, and those which are alternately opened and sealed by the eruptive activity. These physical characteristics of Santiaguito's eruptive and passive activity may provide clues to help decipher SO₂ degassing trends.

V72C-04 1415h INVITED

Sedimentation from wind-advected strong volcanic plumes

C. Bonadonna¹ (costanza@soest.hawaii.edu)

J. C. Phillips² (J.C.Phillips@bristol.ac.uk)

¹Department of Geology Geophysics, University of Hawaii, 1680 East-West Road, Honolulu, HI 96822, United States

²Centre for Environmental and Geophysical Flows, University of Bristol, Queens Road, Bristol, Eng BS8 1RJ, United Kingdom

Volcanic plumes are classified as strong and weak plumes, when the characteristic plume velocity is much greater or much smaller than the wind speed respectively. Eruptions like the 1902 Santa Maria Plinian event are characterized by strong plumes, which are less common in nature than weak plumes, but they are typically more hazardous due to the larger volume released and the wider area affected. They are characterized by a sub-vertical convective column that, at the neutral-buoyancy level typically 15 to 35 km (Santa Maria c. 20 km), spreads out as a lateral current that sediments particles of various sizes. Numerical modeling helps understand plume dynamics and is an important tool for hazard assessment. We develop descriptions of key processes influencing tephra dispersal from strong volcanic plumes and describe the propagation of the spreading current due to both gravity and wind advection using scaling arguments and a simplified geometry. New parameterizations are used to describe the wind field below the spreading current, particle aggregation and particle-density variations. We conducted a broad study to investigate the effects of these processes and made comparisons with field observations. The greatest variations resulted from wind advection below the spreading current, which shifts downwind the plume-corner mass accumulation and the position of transitions in fallout regimes. Aggregation makes the deposit thin more rapidly and distal segments, representing fine-particle fallout, can be suppressed. Particle aggregation strongly depends on the initial grainsize distribution. Variations of particle density and lithic content do not significantly affect sedimentation patterns represented on semi-log plots. The model provides acceptable reproduction of observations of the propagation of the spreading current and tephra-fallout deposits.

V72C-05 1430h INVITED

Three types of crust: Inferred emplacement rates and styles of a megablocky flow field surrounding Sabancaya volcano, Peru

Tracy K.P. Gregg¹ (716-645-6800;

tgregg@nsm.buffalo.edu); Mark Bulmer² (mbulmer@jcet.umbc.edu); Steven W. Anderson³ (steveanderson@bhsu.edu); Nicholas H. Warner¹; Cheryl L. Goudy¹; Sean McColley³; Ian Turner²

¹University at Buffalo, Dept. of Geology, 876 NSC, Buffalo, NY 14260-3050, United States

²JCET/UMBC, 1450 S. Rolling R.d, Baltimore, MD 21227, United States

³Black Hills State University, Dept. of Phys. Sci., Spearfish, SD 57799, United States

Sabancaya volcano is a complex edifice located ~70 km NW of Arequipa, Peru. It is surrounded by a large (~64 km²) andesitic/trachyandesitic lava flow field comprising 39 identifiable lobes that were emplaced during the Holocene. Flow morphology is distinct from that observed on evolved lavas in North America, providing an important foil to these well studied examples. The Sabancaya flows are channeled, and are characterized by steep, thick (>120 m) margins. Underlying slopes range from 10° near the vent to <1°

distally. Surface folding, with multiple fold generations, is common. Fold wavelengths and amplitudes are on the order of 25 m and 5 m, respectively. The flows are covered with angular blocks ranging in size from 40 cm to several meters. Preliminary data suggest that block-size distribution within a single lobe is more dependent on the proximity of fold crests than on distance from the vent. Fold amplitude (~5 m) suggests a minimum thickness for a ductile surface crust during emplacement; in contrast, the largest block size on the surface (>3 m) reveals the thickness of the brittle deforming surface crust.

Hand-sample analyses reveal large (>>0.5 cm) plagioclase phenocrysts in a glassy, a vesicular matrix with occasional cm-sized inclusions of basaltic andesite. Crystal-size distributions in the groundmass determined from samples collected along the flow length are essentially constant, suggesting that the lavas experienced little cooling during emplacement, consistent with a well insulated lava flow. Model results indicate that the flow lobe interior could have remained hot, and possibly molten, for thousands of years. Thus, the Sabancaya flows display 3 types of surface crust: a brittle, thin (3-5 m) surface layer that generated the large, angular blocks observed on the surface; a ductile, thicker (>5 m) layer that deformed during emplacement to generate the observed folds; and the thermal crust, which may have been several tens of meters thick. Morphologic, petrologic and geochemical evidence suggest that these flows were erupted at high temperatures and emplaced relatively rapidly; these characteristics can be better understood in light of recent observations of active flows at the Santiaguito dome.

V72C-06 1445h

Modelling the Effusive Eruption of Volcan de Colima, Mexico 2001-02

Nick R Varley¹ (nick@ucol.mx)

Juan Carlos Gavilanes-Ruiz² (gavilan@ucol.mx)

¹Facultad de Ciencias Universidad de Colima, Av. 25 de Julio 965 Col. Villa de San Sebastian Apdo. Postal 25, Colima, Col 28045, Mexico

²Centro Universitario de Investigaciones en Ciencias del Ambiente Universidad de Colima, km 9 Carretera Colima-Coquimatlan, Coquimatlan, Col 28400, Mexico

Volcan de Colima has produced frequent eruptions during historic times; both effusive, with dome growth and blocky lava flows, and explosive, e.g. the plinian event of 1913. In general, the mechanisms that influence an eruption to change from effusive to explosive or vice versa remain poorly understood. Field measurements and monitoring at Volcan de Colima have allowed the development of a model of its most recent effusive eruption, which started with the formation of a lava dome on 8 May 2001 and continues to the present. Based on physical characteristics, the eruption has been divided into seven phases. Digital models of the different stages of dome growth were used to calculate the volume and the associated extrusion rates. The initial stages included the filling of the large crater, which had been formed by the three major explosions that occurred in 1999, and the smaller inner crater formed by the 22 February 2001 explosion. Later stages followed the over-spilling of the crater rim and the development of several short blocky lava flows with associated rockfalls.

The 2001/2 eruption has been characterised by a low rate of effusion (maximum 0.62 m³ s⁻¹). The rate of degassing has been variable, with the flux of SO₂ varying from 50 to 900 t d⁻¹. The location and temperature of the summit fumaroles have undergone migration associated with the development of different lobes of the dome. In addition, the seismicity has varied from extremely low levels at the beginning of the eruption, to extended periods of harmonic tremor in May 2002. These parameters, along with temporal geochemical variations within the local spring waters and monitoring of diffuse degassing of CO₂ at several locations, have been combined to form a model of this eruption.

V72D MCC: 270 Sunday 1515h

From Magma to Tephra: Crystallization, Fragmentation, and Flow I

Presiding: M J Davis, Schott Glass Technologies

V72D-01 1515h

Short Timescales for Crustal Residence, Transport and Contamination of Flood Basalt Magma: Crystal Isotope Stratigraphy of the Columbia River Basalt Group.

Darren L Tollstrup¹ (509-335-7621; darrentollstrup@yahoo.com)

Frank C Ramos¹ (509-335-7857; frames@wsu.edu)

John A Wolff¹ (509-335-2825; jawolff@wsu.edu)

¹Department of Geology, Washington State University, Pullman, WA 99164, United States

Geochemical studies of continental flood basalt magmas provide evidence for contributions from one or more enriched reservoirs. There is, however, no consensus on the role of continental crust as a major source of enriched signatures. With its stratigraphy defined and mapped at the scale of individual flows, the Columbia River Basalt Group (CRBG) is the most thoroughly studied continental flood basalt province in the world. Its tectonic position (overlying both thin accreted Mesozoic crust and thick ancient cratonic crust) makes the CRBG ideal for isolating the contribution of crust in the petrogenesis of continental flood basalts. Many flows are plagioclase-phyric. Because plagioclase in basaltic magmas can be assumed to have grown at crustal pressures, growth layers in plagioclase phenocrysts record changes in the chemical and isotopic composition of the magma occurring at crustal depths.

We have initiated a micro-sampling study utilizing laser ablation multicollector ICP-MS (ThermoFinnigan Neptune) to analyze ⁸⁷Sr/⁸⁶Sr variability in plagioclase and clinopyroxene phenocrysts (where present) and associated groundmass. Initial results are: 1) plagioclase and clinopyroxene phenocrysts within CRBG lavas are overall less radiogenic than host groundmass and 2) plagioclase phenocrysts are commonly zoned from less radiogenic cores to more radiogenic rims. The rims may have similar compositions to, or be less radiogenic than, host groundmass. One-dimensional diffusion modeling applied to observed ⁸⁷Sr/⁸⁶Sr zoning and crystal/groundmass gradients constrains phenocryst residence times, and the timescale of crustal-level petrogenetic events that modified CRBG magmas. Residence times for phenocrysts in their final host liquid may be as little as 10 years prior to quenching.

These results require that the ⁸⁷Sr/⁸⁶Sr composition of the CRBG magmas increased rapidly with time at crustal pressures during and after phenocryst growth. This could result from mixing between magmas from isotopically distinct mantle reservoirs. If so, some involvement of the isotopically more enriched magma must always occur after the initiation of crystallization in the less enriched magma, in order to generate the monotonic crystal-groundmass variations observed. More likely, our results indicate crustal contamination is occurring during and after phenocryst growth in crustal magma chambers, and/or during transport to the surface as the magma is erupted.

V72D-02 1530h

Apparent Viscosity of Andesites Links Eruption Style to Crystallinity

Luc D Lepage¹ (L.Lepage@hotmail.com)

Thomas H Pearce¹ (Science@kingston.net)

¹Department of Geological Sciences, Queens University, Kingston, ON K7L 3N6, Canada

Magmatic viscosity varies in function of pressure, temperature, silica content, and volatile content, whereas apparent viscosity depends also on size, shape and concentration of its crystals and vesicles.

The primary effect of high crystallinity is to physically increase the apparent viscosity depending on the packing type, size distribution, and aspect ratio of its crystals. Although a crystal concentration of <5% has virtually no effect on apparent viscosity, the high crystal concentrations found in the common arc-type andesite, can play a very significant role, for they not only act as chemical and physical buffers but also as movement inhibitors.

The Einstein-Roscoe equation $\eta = \eta_0(1 - \Phi/\Phi_m)^{-2.5}$ can be used to determine the apparent viscosity η of a liquid with an initial viscosity η_0 that contains a known

concentration Φ of particles, which have a known maximum packing Φ_m value. Limitations? The formula works only for Φ being $<50\%$ of Φ_m , which translates into a viscosity increase of 5 orders of magnitude.

The secondary effect of crystallisation is to increase the volatile and silica content of the magma, respectively reducing and increasing its liquid viscosity. Likewise, the primary effect of vesiculation is to physically decrease the apparent viscosity but its secondary effect is to dramatically increase it by dehydrating the surrounding liquid and creating a high viscosity framework throughout the magma. By comparison, a decrease of 4wt.% H₂O would increase the viscosity of an andesite by a 0.5 order of magnitude, the equivalent to a 9% increase in crystal content. In rhyolitic liquids however, 4wt.% H₂O would be equivalent to adding 30% more crystals to a pure liquid!

Since eruption style is directly linked to explosivity, and explosivity depends directly on the magma's ability to store potential energy, should there be a connection between apparent viscosity and eruption style? Classically, a faint distinction can be observed by comparing the bulk silica content of the rocks, but one could argue that bulk silica content is an illusive representation of the actual interstitial liquid's true composition, especially for rocks that are $>50\%$ crystalline.

In the well-documented deposits of Mt Pele (Martinique), there are significant physical distinctions between the different volcanic products of the last 4500y. The most striking distinctions are crystallinity and vesicularity, which can be directly linked to their apparent viscosity, thus to the explosivity of their respective eruption style i.e. plinian, pelean, or vulcanian.

V72D-03 1545h

Crystallization Measurements Using Thermal Analysis Methods

Mark J Davis (mark.davis@us.schott.com)

Schott Glass Technologies, 400 York Avenue, Duryea, PA 18642, United States

Thermal analysis experiments described herein apply two methodologies by which to estimate absolute nucleation rates and/or temperature dependencies using a multi-component glass-ceramic as a test material. In particular, the Marotta and the Ray et al. methods were applied to the low-expansion material Zerodur and both provided valuable insight into a relatively complicated crystallization process. Previous nucleation and crystal growth rate data were used in a comparative manner. Although the Marotta method accurately predicted the maximum nucleation temperature, the nature of the technique precluded an estimation of absolute nucleation rates. The Ray et al. technique provided reasonable quantitative nucleation rates, but failed to provide useful estimates of the number of quenched-in nuclei, in part due to a substantial "blank" contribution coming from additional, unwanted nucleation during heating and cooling stages of the DTA technique.

V72D-04 1600h

Changes in Microtextures and Volatile Contents of Pyroclastic Obsidian During the 1340 A.D. Mono Craters Eruption

Alison C Rust¹ (arust@darkwing.uoregon.edu)

Katharine V Cashman¹

¹Dept. Geological Sciences, 1272, University of Oregon, Eugene, OR 97403, United States

Pyroclastic obsidian, a common product of rhyolite eruptions, could provide unique information on conditions of magma ascent and eruption if the origin of these clasts were known. Current models suggest that pyroclastic obsidian may form syn-eruptively by quenching against conduit walls, by degassing and collapse of bubbly magma in the conduit interior or by incomplete vesiculation of magma prior to fragmentation. Alternatively, these clasts could be remnants of a previous eruption. Here we test these models by combining FTIR measurements on obsidian clasts with analysis of bubble and crystal textures in the same samples to constrain the degassing and crystallization history.

The classic study by Newman et al. (JVGR, 1988) on the volatile content of obsidian from the 1340 A.D. eruption of Mono Craters shows a trend of decreasing H₂O and CO₂ content as the eruption progressed. They also inferred a change from closed- to open-system degassing styles across the explosive-extrusive transition. Our samples are 41 obsidian pyroclasts (3-5 clasts from each of 10 beds) that were analyzed for H₂O by R. Herd (1997). We have reproduced Herd's H₂O data, analyzed the samples for CO₂ by FTIR, and examined the bubble and crystal textures with petrographic and scanning electron microscopes.

The first obsidians erupted are relatively dry (<0.7 wt.% H₂O) and have abundant microlites. Preserved vesicles vary from non-existent to isolated, near-spherical bubbles to numerous irregular, elongate bubbles. The next obsidians erupted have lower crystallinities and higher H₂O and CO₂ contents than basal

samples and contain sparse ellipsoidal bubbles. The average and maximum volatile content of the glasses then decreases upward, with microlite abundance and volatile content inversely correlated. Bubbles are more numerous than in early-erupted clasts. Most of these bubbles have irregular shapes, including multicuspate forms that we interpret to have partially collapsed. Obsidian pyroclasts from the uppermost bed show a small increase in volatile content and decrease in bubble number density, with values similar to samples of the two basal layers. However, the later clasts differ from the early obsidian in having more highly deformed bubbles and more equant feldspar microlites.

We agree with previous interpretations that the observed changes in volatile content with time may reflect changes in fragmentation depth during the eruption. Our textural data provide additional insight into the origin of this obsidian. First, the observation that clasts from lower and upper beds are texturally distinct despite similar volatile contents makes a xenolithic origin unlikely. Second, the high crystallinity and low H₂O content of the basal obsidian clasts suggests that they represent magma that stalled and degassed at shallow depths during initial stages of magma ascent. Third, finely crushed xenolithic material found in 25% of the obsidian clasts suggests obsidian formation and shearing along conduit walls. Finally, irregularly-shaped bubbles prevalent in samples with the highest bubble number densities provide evidence for bubble collapse and gas escape from a formerly vesicular melt. However, a model of degassing through, and subsequent collapse of, permeable bubble networks seems inconsistent with the high CO₂ content of the glasses, as CO₂ is rapidly stripped from melt under conditions of open-system degassing. This discrepancy may be resolved by considering spatial and temporal scales of degassing, which, together with shear rate information supplied by bubble deformation and kinetic information from crystal growth, may allow constrain time scales of degassing and conduit flow.

V72D-05 1615h

Behavior of fragmentation front in a porous viscoelastic material

Mie Ichihara¹ (mie@rainbow.ifs.tohoku.ac.jp)

Kazuyoshi Takayama¹
(takayama@rainbow.ifs.tohoku.ac.jp)

¹Shock Wave Research Center, IFS, Tohoku University, 2-1-1, Katahira, Aoba-ku, Sendai 980-8577, Japan

We are developing laboratory experiments to investigate dynamics of magma fragmentation during explosive volcanic eruptions. Fragmentation of such a mixture as magma consisting of viscoelastic melt, bubbles and solid particles, is not known yet, and experiments are necessary to establish a mathematical model. It has been shown that viscoelastic silicone compound (Dow Corning 3179) is a useful analogous material to simulate magma fragmentation. In the previous work, a porous specimen made of the compound was rapidly decompressed and development of brittle fragmentation was observed. However, there were arguments that the experiment was different from actual processes which produce fragments as small as volcanic ash, because in the experiment the specimen was broken into only several pieces. This time, results of the improved experiments are presented.

The experimental apparatus is a kind of a vertical shock tube, which mainly consists of a high pressure test section and low pressure chambers. The test section is made of acrylic tube of which inner diameter is 25 mm. The internal phenomenon is recorded by a high-speed video camera. Pressure is measured in the gas above and beneath the specimen by piezoelectric transducers.

The specimen is prepared in the following way. First, an acrylic tube filled with the compound is put in a nitrogen tank and kept at 45 bar for more than 8 hours. The compound absorbs the gas and equilibrates with the nitrogen. Next, the tank is decompressed back to the atmospheric pressure slowly. Nitrogen exsolves and bubbles are formed in the compound quite uniformly. Finally, the expanded compound sticking out of both ends of the tube is cut down, and the tube containing the specimen is attached to the shock tube.

The specimen is rapidly decompressed by 24, 16, and 8 bars. The high-speed video images demonstrate a sequence of the fragmentation process. We observe propagation of a clear fracture front at 50 m/s for 24 bar of decompression and at smaller speed for smaller decompression. The pressure change associated with development of the fragmentation is analyzed and effects of over pressure in the pores and permeable gas flow on fragmentation behavior are discussed.

V72D-06 1630h

A Comprehensive Rheological Multiphase Flow Model for Geophysical Granular Gravity Currents. Applications to Pyroclastic Flows.

Sebastien Darteville¹ (906-487-3097; sdartev@mtu.edu)

William Rose¹ (906-487-2367; raman@mtu.edu)

John Stix² (514-398-5391; stix@eps.mcgill.ca)

¹Michigan Technological University, Dept. Geological Mining Engineering, 630 Dow Building, 1400 Townsend Dr., Houghton, MI 49931, United States

²McGill University, Dept. Earth Planetary Sciences, 3450 University St, Montreal, QC H3A 2A7, Canada

For many decades, volcanologists and sedimentologists have debated whether pyroclastic flows and other geophysical gravity currents are emplaced from highly expanded, dilute turbulent flows or from concentrated, frictional, and poorly fluidized flows. Numerous models exist for these two end-members but none are capable of modeling the full range of possible grain concentrations (dilute to highly concentrated). The task is difficult as the rheological behavior of the granular phase will be dependent on the loading conditions (dilute vs. concentrated). We have modified -to geophysical applications- a multi-phase flow model developed by the U.S. Dept. of Energy (MFIIX). MFIIX specifically accounts for the full range of grain concentrations and rheologies depending on the loading conditions. The model solves the equations of continuity, momentum and energy of all the phases and species in the system (steam, air and particulate) assuming the continuum hypothesis for the dispersed phase. In the dilute to moderately concentrated part of the flow (< 50 vol.% solids), grains randomly fluctuate, translate, and collide which gives rise to a viscous kinetic and collisional dissipation. This behavior is modeled through Boltzmann's statistical mechanics approach as done for gas kinetic theory. For the highly loaded part (> 50 vol.% solids), grains endure long, sliding and rubbing contacts, which gives rise to a very different form of dissipation and stress. This frictional behavior is modeled through the plastic potential and critical states theories (visco-plasticity). We define a total stress tensor which is the sum of the kinetic, collisional and frictional stress contributions. As predicted by the theory, the plastic stress tensor is rate-independent, while the kinetic-collisional is rate-dependent. Overall, this complex, non-linear rheological behavior is non-Newtonian (for more details, see the granular.org website).

We carried out two-dimensional cylindrical simulations of collapsing ash-laden pyroclastic fountains with initial conditions of 3 vol.% solids, 1000 K, and an upward velocity of 30m/s, which represents a small volcanic event. All our simulations show that the gravity current has a basal poorly fluidized and visco-plastic undercurrent several meters thick, overlain by a thicker (several tens of meters) dilute current with concentration between 10-8 to 5 vol.% solids. The deflation zone is very restricted, and deflation occurs rapidly over short distance (a few meters). The dynamical behavior of both parts of the gravity current is clearly different but closely related. Our experiments support the need of a multiphase flow model with a comprehensive granular rheology to fully understand pyroclastic flows and other phenomena such as turbidity currents and snow avalanches.

URL: <http://www.granular.org>

V11A MCC: Hall C Monday 0830h

Arc Magmatism I Posters (joint with T)

Presiding: N L Green, University of Alabama

V11A-1359 0830h POSTER

Bathymetric and Seismic-Reflection Profiles Hint at the Origins of Medicine Lake, CA (USA)

Jacob B. Lowenstern¹ (650-329-5238;

jlownstrn@usgs.gov); G. A. Barth¹

(gingerbarth@mail.attbi.com); J. R. Childs¹

(jchilds@usgs.gov); P. E. Hart¹ (hart@usgs.gov);

J. Donnelly-Nolan¹ (jdnolan@usgs.gov); D. W.

Ramsey¹ (dramsey@usgs.gov); J. E. Robinson¹

(jrobin@usgs.gov); R. L. Phillips¹

(lphillips@usgs.gov); S. W. Starratt¹

(sstarrat@usgs.gov); J. A. Barron¹

(jbarron@usgs.gov)