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.% H_2O 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.% H_2O 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

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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 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

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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 Herds H2O data, analyzed the samples for CO2 by FTIR, and examined the bubble and crystal textures with petrographic and scanning election 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

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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.

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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 (MFIX). MFIX 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 Boltzmanns 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)

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Bathymetric and acoustic surveys (in 1999), combined with vibracore sampling of lake-bottom sediments (in 2000) reveal much about the latest Pleistocene and Holocene history of Medicine Lake, a 2 km x 1 km, closed-basin lake at the top of Medicine Lake volcano, 40 km SW of Tulelake, CA. Forty high-resolution, seismic-reflection profiles show a prominent reflector interpreted as the volcanic landform (primarily lavas) that would have existed prior to lake formation. A total of 1560 travel-time picks for this reflector reveal the topography of the lake basement. A representative seismic velocity through the sedimentary lake fill is estimated to be 2200 $\pm$ 200m/s based on quantitative analysis of diffraction hyperbolae observed in this single-channel data set. Converting travel-time picks with this interval velocity, volcanic "bedrock" lies between $\sim$ 5 and 85 m below the lake surface (currently 2036 masl) and 1 to 60 m beneath the lake floor. The topography of the horizon is a linear trough with a 70°trend, slightly askew of the 100°trend of the lake itself. The trough is filled partially with 30 x 10^6 m^3 of material, about 2 times that of the lake volume itself. Over 90% of this lake-basin fill is presumed to be locally derived glacial till and landslide deposits; it is very poorly bedded, and contain numerous slumps. It is thickest at the middle of the trough, adjacent to a prominent landslide and crudely defined glacial cirques and fill deposits off of Medicine Mountain, to the south. The top 1-2 m of lake-fill is Holocene sediments, consisting primarily of organic diatomaceous debris interlayered with thin beds of tephra from Medicine Lake volcano, Mazama and (likely) Mt. Shasta.

The lake-bottom bathymetry (water-sediment interface) shows a circular hole at the east end of the lake. The hole appears to be part of the larger trough, but has not yet been filled with sediment/landslide deposits. There is no evidence for creation of the hole through venting or explosive excavation. We speculate that the trough (and hole) result from non-coalescence of adjacent, steep-sided lava flows. The lake is bordered primarily by two late Pleistocene lavas, the $\sim$ 90 ka Lake Basalt and the slightly older andesite of the south rim. To the east of Medicine Lake, these two lavas are separated by a 10- to 20- m-wide valley that appears to have served as an outlet for Medicine Lake during periods where the lake level was 5-10 m higher. A possible explanation for the origin of this valley and the trough within Medicine Lake is that these areas were filled with glacial ice at the time of eruption of the Lake Basalt. The ice would have prevented the Lake Basalt from directly contacting the older andesite. The ice has been absent during the Holocene and the resulting basin has filled with till, landslide deposits, tephra, diatomaceous sediments and Medicine Lake itself.

URL: http://geopubs.wr.usgs.gov/open-file/of00-043/

V11A-1360 0830h POSTER

Digital Geologic Map of Mount Mazama and Crater Lake Caldera, Oregon

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Crater Lake caldera formed $\sim$7700 cal yr B.P. by the eruption of 50 km^3 of mainly rhyodacitic magma and the resulting collapse of Mount Mazama. A new 1:24,000-scale digital geologic map compiled in ArcInfo depicts the geology of this volcanic center, peripheral volcanoes, the caldera walls and floor, and superjacent pyroclastic, talus, and glacial deposits. The geology of the caldera walls was mapped in the field on photographs taken from the lake (see accompanying abstract and poster, "Geologic panoramas of the walls of Crater Lake caldera,Oregon"); the geology of the flanks of Mount Mazama and the surrounding area was mapped on aerial photographs; and features of the caldera floor were mapped on a multibeam echosounding bathymetric map (Gardner et al., 2001; Bacon et al., 2002). Volcanic map units are defined on the basis of chemical composition and petrographic characteristics. Map unit colors were chosen to indicate the compositions of volcanic rocks, cooler colors for mafic units and warmer colors for silicic units. Map unit color intensity indicates age, with more intense coloring for younger units. Ages of many units have been determined by K-Ar and $^{40}Ar/^{39}Ar$ dating by M.A. Lanphere. Several undated units have been correlated using paleomagnetic secular variation measurements by D.E. Champion. Crystallization facies of some of the larger lava flows are mapped separately (e.g., vitrophyre, felsite, carapace), as are breccia and lava facies of submerged postcaldera volcanoes. Also shown on the caldera floor are landslide (debris avalanche) and sediment gravity-flow deposits. A major north-south normal fault system traverses the map area west of the caldera and displaces dated late Pleistocene lava flows, allowing determination of a long-term slip rate of 0.3 mm/yr (Bacon et al., 1999). Faults bounding large downdropped blocks of the south caldera wall are also shown. Where practical, lava flow margins are represented as intra-unit contacts. A number of small intrusions are present in the area as well as dikes in the caldera walls, many of which can be traced into related lava flows. Particularly impressive examples are 216$\pm$4 ka dacite north of Castle Creek, $\sim$50 ka andesite of Devils Backbone, and 50$\pm$3 ka dacite of The Watchman. Because of the long history of glaciation on Mount Mazama and in the surrounding region, there are many examples of ice-marginal lava flows, intracanyon flows, and tuyas. The map shows that Mount Mazama was constructed on a base of older silicic lava flows and domes, and mafic lava flows. The volcano grew by episodic eruption of mainly andesitic and dacitic composite cones that progressed from east to west with decreasing age. The map also shows the distribution of five units of deposits of the climactic eruption that cover much of the area. Using GIS, it is possible to view either the map as depicted with all of the surficial units or showing only "bedrock" features so that the underlying volcanic geology is more clearly revealed.

Bacon, Lanphere, & Champion, 1999, Geology 27:43-46.

Bacon, Gardner, Mayer, Buktenica, Dartnell, Ramsey, & Robinson, 2002, GSA Bulletin 114:675-692.

Gardner, Dartnell, Hellequin, Bacon, Mayer, Buktenica, & Stone, 2001, USGS Water Resources Inv. Rpt. WRI-01-4046.

V11A-1361 0830h POSTER

Geologic Panoramas of the Walls of Crater Lake Caldera, Oregon

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Eleven digital geologic panoramic sections of the walls of Crater Lake caldera have been created to accompany the 1:24,000-scale digital geologic map of Mount Mazama and Crater Lake caldera. The panoramas were constructed from geologic mapping on photographs taken from 11 camera stations on Crater Lake and Wizard Island. Geology was transferred to contoured bases derived from a digital elevation model and registered to each photograph by B.S. Bennett. The panoramas were then adjusted digitally to remove curvature resulting from mosaics of photographs whose centers were elevated relative to the camera stations. Map units and colors match those of the geologic map. Colors range from cool for mafic to warm for silicic units, with the intensity of unit color indicating unit age. Volcanic units are defined on the basis of composition and petrographic characteristics. Ages have been determined by K-Ar and $^{40}Ar/^{39}Ar$ dating by M.A. Lanphere supplemented by paleomagnetic secular variation data obtained by D.E. Champion. Within each map unit, every eruptive unit visible in the caldera walls is shown on the panoramas by an intraunit contact at its base (e.g., lava flow bases). Many dikes are present in the caldera walls, and the thicker of these, as well as intrusive plugs and feeders, also are shown in colors that correspond to related eruptive units (e.g., dacite of Steel Bay, andesite of Merriam Point). Similarly, pyroclastic deposits and cogenetic lava flows can be seen in several places (e.g., dacites of Pumice Castle and The Watchman). Pyroclastic deposits of the climactic, caldera-forming eruption are shown where visible on the caldera rim from the viewing angle. Precaldera geologic units range from $\sim$400 ka at Phantom Ship to the Cleetwood rhyodacite flow that was emplaced immediately before the climactic eruption. In the caldera walls above the lake, Mount Mazama is seen to have begun with the Phantom Cone in the southeast and to have grown by episodic addition of composite cones, fountain-fed lava shields, and ice-marginal and intracanyon lava flows in a generally westward-younging sense. The youngest units are rhyodacitic lava flows $\sim$27-30 ka and $\sim$7900-7700 cal yr B.P. Glaciated surfaces are present many places in the caldera walls. The dated glaciated and overlying lavas, as well as ice-marginal lava flows, bracket times of ice presence that correlate well with glacial periods defined by marine oxygen isotope stages. Although many north-south normal faults are mapped west of the caldera, no tectonic faults have been recognized cutting the caldera walls. A number of caldera-wall-parallel normal faults are present in the south wall where they bound slide blocks. The panoramas allow park visitors to identify geologic features from the caldera rim or from Crater Lake. The panoramas also record the geology of Crater Lake caldera in more detail and with higher resolution than can be shown on the 1:24,000-scale geologic map, for which they unambiguously establish many stratigraphic relations.

V11A-1362 0830h POSTER

3D Bathymetry and Magnetic Evidence of no Existence of Volcanic Edifices on the Gulf of Mexico Continental Slope Offshore the Veracruz Coast, Mxico

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In 1974, a regional marine geophysical study in the southwest of the Gulf of Mexico indicated that four volcanic seamounts possibly existed along the continental slope in front of the Veracruz coast in Mexico. Since then the existence of these submarine volcanoes has been accepted in the scientific literature based only on the observed geomorphology from scattered bathymetry profiles and without further test. In April 2002, we realized a marine geological and geophysical study on board the B/O Justo Sierra, research vessel of the National University of Mexico (UNAM) to map the bathymetry and magnetic of the seafloor and collect marine rocks and sediments in four regions where the seamounts suppose to be along the slope. Our objectives with this survey were to characterized the genesis of these seamounts and its possible relation to magmatic activity along the western continental margin of the Gulf, in particular either with the volcanic rocks along the Transversal Chain of volcanoes across Mexico or the Centro-American Volcanic chain through the Tuxtla Volcanic Massif at the southern end of the State of Veracruz. Preliminary results of the bathymetry show forms of erosion relief along the slope that do not appear to be seamounts. Local maps of magnetic anomalies neither show forms that could be associated with edifices of volcanic seamounts in the four regions. Sediments samples were collected across and along the slope, and their initial petrologic analysis has not provided minerals that could be associated to fresh magmatic rocks. These results have not provided any hard evidence to support the existence of four volcanoes at the seafloor along the continental slope of the Gulf of Mexico southwest margin.

V11A-1363 0830h POSTER

Hydrogen Isotopic Composition of Hornblendes From Active Volcanoes of Mexico

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Horblendes (Hb) crystallize in water-rich magmas in magma chambers or in deeper zones. Isotopic composition of hydrogen in OH-groups of Hb represents the water isotopic composition of magmatic fluid or dissolved magmatic volatiles and therefore, is an isotopic characteristics of magmatic water. At lower vapor pressure in conduits and shallower magma chambers, Hb can decompose and loose water with significant isotopic effects.

We measured hydrogen isotopic composition of hornblendes from modern lavas and pyroclastics of El Chichon, Colima and Popocatepetl volcanoes. Hornblendes from the last and previous pyroclastic flows of El Chichon are the more abundant mineral phases (after plagioclase), showing pleochroism from green to brown. They are relatively uniform in composition (close to magnesian hastingsite hornblende), without chemical variations between cores and rims. Using the Johnson and Rutherford (1989) calibration of the Al-in-hornblende geobarometer, the hornblendes show equilibrium with the melt at pressure of 4 kb that correspond to 12 km of depth. These pressure conditions

likely represent the location of the magma chamber below El Chichon volcano, however, these pressure estimates need to be confirmed. The water content of all analyzed Hbs is 1.5-1.8 wt%, but may be higher due to a minor amount of impurities of pyroxenes which sometimes are difficult to separate from Hb. Hydrogen isotopic composition in 10 samples of Hb from El Chichon of different age and facies (pumice, lithic fragments in pyroclastics) was in a narrow range -40 to -37 permil V-SMOW. Such isotopic signature corresponds to so-called "andesitic" waters, i.e. waters from subduction-related magmas, The origin of these waters is suggested to be the recycled water from subducted oceanic sediments. The data for El Chichon volcano are in the range of the already known values for subduction-related magmas though the tectonic setting of El Chichon is more complicated. The measured isotopic ratios D/H of the least altered Hb from the 14 Ka Tutti-Frutti pyroclastic deposits of the Popocatepetl volcano and from the 1913 pyroclastics of Volcan de Colima (with H2O content > 1.5 wt%) are surprisingly "heavy", in the range -17 to -15 permil. More study and a larger collection of Hb are needed to interpret such high D/H ratios in Colima and Popocatepetl Hb, which are the heaviest ones ever measured in magmatic unaltered Hb.

V11A-1364 0830h POSTER

Volcanoes of México: An Interactive CD-ROM From the Smithsonian's Global Volcanism Program

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The Smithsonian Institution's Global Volcanism Program is nearing completion of an interactive CD-ROM, the Volcanoes of México. This CD is the second in a series sponsored by the U.S. Department of Energy Office of Geothermal Technologies to collate Smithsonian data on Quaternary volcanism as a resource for the geothermal community. It also has utility for those concerned with volcanic hazard and risk mitgation as well as an educational tool for those interested in Mexican volcanism. We acknowledge the significant contributions of many Mexican volcanologists to the eruption reports, data, and images contained in this CD, in particular those contributions of the Centro Nacional de Prevencion de Desastres (CENAPRED), the Colima Volcano Observatory of the University of Colima, and the Universidad Nacional Autónoma de México (UNAM).

The Volcanoes of México CD has a format similar to that of an earlier Smithsonian CD, the Volcanoes of Indonesia, but also shows Pleistocene volcanic centers and additional data on geothermal sites. A clickable map of México shows both Holocene and Pleistocene volcanic centers and provides access to individual pages on 67 volcanoes ranging from Cerro Prieto in Baja California to Tacaná on the Guatemalan border. These include geographic and geologic data on individual volcanoes (as well as a brief paragraph summarizing the geologic history) along with tabular eruption chronologies, eruptive characteristics, and eruptive volumes, when known. Volcano data are accessible from both geographical and alphabetical searches.

A major component of the CD is more than 400 digitized images illustrating the morphology of volcanic centers and eruption processes and deposits, providing a dramatic visual primer to the country's volcanoes. Images of specific eruptions can be directly linked to from the eruption chronology tables. The Volcanoes of México CD includes monthly reports and associated figures and tables cataloging volcanic activity in México from the Bulletin of the Global Volcanism Network and its predecessor, the Scientific Event Alert Network Bulletin, as well as early event-card notices of the Smithsonian's Center for Short-Lived Phenomena. An extensive petrologic database contains major-element analyses and other petrological and geochemical data for 1776 samples. The user also has access to a database of the Global Volcanism Program's map archives. Another option on the CD views earthquake hypocenters and volcanic eruptions from 1960 to the present plotted sequentially on a map of México and Central America. A bibliography of Mexican volcanism and geothermal research includes references cited in the Smithsonian's volcano database as well as those obtained from a search of the Georef bibliographic database. For more advanced queries and searches both the petrologic database and volcanic activity reports can be uploaded from the CD.

V11A-1365 0830h POSTER

$^{39}Ar/^{40}Ar$ Chronology and Volumes of Eruptive Products Over the Last 1 Myr in the Tequila Volcanic Field, Jalisco, Mexico

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The Tequila volcanic field, located within the western Trans-Mexican arc, covers an area of 1036 km^2 and includes a central, andesitic stratocone, Volcan Tequila, as well as cinder cones, domes, and fissure-fed flows. Sixty-nine high precision ^{39}Ar-^{40}Ar dates reveal that major activity in the Tequila volcanic field began at approximately 1 Ma. From 1 Ma to 200 ka, rhyolite (> 73 wt. % SiO_2) and alkali basalt (51 wt. % SiO_2) were the only compositions erupted in significant volumes (29 $\pm$ 5.7 km^3 and 12 $\pm$ 1.2 km^3, respectively). At approximately 200 ka, the andesite comprising Volcan Tequila erupted within 30-40 kyr, producing a volume of 30 $\pm$ 2.0 km^3. Additional andesitic flows (11 $\pm$ 1.4 km^3) erupted to the northwest and southeast of the stratocone between 140 and 20 ka. The total volume of dacite that erupted at the Tequila volcanic field is small (1.3 $\pm$ 0.03 km^3) and occurred largely (88%) within the last 70 kyrs. Unlike the andesites and dacites, the basalts and rhyolites did not erupt within narrow time intervals, but extruded over the entire last 1 Myr, producing a total volume of 12.6 $\pm$ 1.2 km^3 and 32 $\pm$ 6.1 km^3, respectively.

This detailed eruptive history, combined with the observed phenocryst assemblages (0-10 vol. %) in the small-volume andesite, dacite, and alkali basalt flows, suggest that they were erupted directly from the lower (or middle) crust, without prior storage in an upper crustal chamber. In contrast, the voluminous burst of andesitic volcanism that produced the phenocryst-rich (35-45 vol. %) lavas of Volcan Tequila was likely fed from a short-lived (< 40 kyrs) upper crustal chamber. This scenario is supported by the complex, disequilibrium textures seen in the phenocryst assemblage of the Volcan Tequila lavas, indicative of magma mingling within an upper crustal chamber (Wallace and Carmichael, 1994).

The total volume of erupted material at the Tequila volcanic field is 89 $\pm$ 12 km^3, of which 49% is andesite, 35% is rhyolite, 13% is basalt, 1.5% is dacite, and 0.8% is basaltic andesite. These proportions of lava types contrast sharply with the results from the neighboring Ceboruco-San Pedro volcanic field (100 km to the northwest), where 64.5% andesite, 1% rhyolite, 20% dacite, and 14.5% basaltic andesite erupted over the last 1 Myr (Frey et al, 2002). In addition, the lava accumulation rate at the Tequila volcanic field is nearly twice that of the Ceboruco-San Pedro volcanic field (88 m/Myr vs. 43 m/Myr). These results demonstrate considerable diversity in both the proportion and volume of lava types within adjacent segments of a volcanic arc with similar subduction parameters (e.g., crustal thickness and rate of slab subduction).

V11A-1366 0830h POSTER

Experimental petrology applied in deposits of the 550 yr b.p. eruption at El Chichon volcano, Chiapas.

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The 550 years ago a plinian-type eruption took place at El Chichn volcano, this event produced a 1.5 km3 pumice fall deposit. Contrary to the 1982 eruption, this event occurred under open vent conditions similar to the present crater. Comparing the pre-eruptive conditions of these two events would shed new lights on the location of the magma chamber, and the magmatic evolution. In order to determine the pre-eruptive conditions (P and T) of the 550 yr BP magma, laboratory experiments were carried out under fixed pressure and temperature conditions at the University of Alaska at Fairbanks. For this purpose fresh samples of the pumice were crushed, pulverized and saturated with water. The sample was then placed into 2mg experimental tube charges of Ag70Pd30 of 2mm diameter. Our results indicate that prior to the 550 plinian the magma has a temperature of 825-830°C. and at approximated pressure of 2500 bars. This pressure estimate differs from the 4000 bars estimated with the geobaromether of Al-hornblende. The water contents obtained in the experiments were oversaturated similar to the calculated with the plagioclase-melts equation (5.3-6.1 percent in vol.)

V11A-1367 0830h POSTER

Oxygen Isotope Evidence for the Role of Crustal Contamination in the Evolution of the Chalupas Caldera System, Northern Andes, Ecuador.

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Of particular interest to the study of the generation and eruption of large volumes of silicic magma are the relative roles of crustal assimilation, fractional crystallization, magma supply and magma storage. The Chalupas caldera, located in the eastern Cordillera of the Ecuadorian Andes is a 12km diameter caldera which formed approximately 200 kya with the eruption of ~200km^3 of rhyolitic pyroclastic material. Continental crust beneath the northern volcanic zone (NVZ) of the Andes is not as thick as that of the Central Volcanic Zone (CVZ) and consequently, NVZ lavas do not show strong chemical signatures of crustal contamination. In addition, systems that generate large volumes of rhyolite are relatively rare. However, isotopic and trace element data from many NVZ volcanic centers, including the Chalupas caldera system, require the addition of some crustal material. Here we present new oxygen isotope data from the Chalupas system and some other Ecuadorian systems that are consistent with the involvement of crustal material during the early evolution of the magmas.

Lavas from the Chalupas system have $\delta^{18}O = +7.0$ to +7.8, a range of values significantly elevated above the average value for island arc lavas (+6.0 $\pm$ 0.3) and at the upper end of the range reported for lavas from the NVZ (+6 to +7.7). The high $\delta^{18}O$ of the Chalupas lavas can only be explained by assimilation of crustal material or by incorporation of subducted sedimentary material. Trace element abundances are not consistent with the incorporation of large amounts of sedimentary material into the mantle source. Crustal rocks from the region have $\delta^{18}O$ of around +9 to +16. A degree of contamination of 15 to 20% by this type of crustal material can account for the oxygen ratios of the Chalupas lavas. This value is consistent with Sr and Nd isotopic values and trace element abundances from the Chalupas system. $\delta^{18}O$ correlates well with $^{87}Sr/^{86}Sr$ and does not vary greatly between the Chalupas lavas. This is consistent with a two-stage model of magmatic evolution whereby crustal contamination occurs while the magma is traversing the lower crust. Once the magma evolves to andesite it is transported to the upper crust where it is either erupted or evolves by fractional crystallization alone to more silica rich magma types.

The continental crust beneath the Eastern Cordillera in Ecuador is relatively thick (~50km) and of continental affinity. Beneath the Western Cordillera, the crust is thinner and of oceanic affinity. Although Sr isotope ratios do not vary across the arc, Nd isotope values of lavas from Western Cordillera volcanoes are significantly higher. Oxygen isotope ratios do not vary greatly between the Western and Eastern Cordillera but lavas from the Eastern Cordillera appear to reach higher values ($\delta^{18}O > +7$) suggesting that variations in the thickness and composition of the continental crust do have an effect on the composition of Ecuadorian lavas.

V11A-1368 0830h POSTER

Northern Migration of Arc Volcanism in Western Panama: Evidence for Subduction Erosion?

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$^{40}Ar/^{39}Ar$ laser age dating of subduction-related volcanic and plutonic rocks from western Panama range from 1.22 $\pm$ 0.09 to 60.89 $\pm$ 0.47 Ma and show that the volcanic arc migrated away from the trench with

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decreasing age. Vulcan Baru, which belongs to the Cordillera Central volcanic arc running through central western Panama, is still active. Our ages from the Cordillera Central extend its age to 8.6 ± 0.4 Ma. An age of 34.4 ± 0.5 Ma was obtained from a basaltic andesite sample south of the Cordillera Central just north of the Sona Peninsula. Further south in southern Azuero and Sona Peninsulas and on Coiba Island, calcalkaline rocks range from 48.8 ± 0.4 to 60.89 ± 0.47 Ma. Arc volcanism migrated ~120 km northwards (away from the trench) over the last 40-50 Ma, yielding a rate of ~2.7 mm/yr. This migration could either reflect: (1) Subduction erosion resulting from the subduction of the Galapagos hotspot track, as has been recently proposed off the coast of Costa Rica [1], or (2) a shallowing of the angle of the subducting slab, possibly resulting from the subduction of progressively younger and more buoyant oceanic lithosphere through time. Preliminary geochemical data suggest that the fluid flux of the Eocene-Paleocene arc and the Miocene-Holocene arc was relatively constant pointing to a uniform subduction angle. Our data favor a migrating arc due to subduction erosion over the last 40-50 Ma. Additional geochemical studies are underway to further distinguish between the aforementioned models.

Literatur [1] Ranero, C.R. & von Huene, R., 2000, Subduction erosion along the Middle America convergent margin. - Nature 404: 748-252.

V11A-1369 0830h POSTER

Differentiation Timescales and Processes for Products From Recent Eruptions of Arenal Volcano, Costa Rica (1968-1999)

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Arenal Volcano in Costa Rica has continuously erupted since 1968 exhibiting a variety of eruption behaviors and evolving in a complex interplay between crystal fractionation, magma mixing, degassing, and wall-rock interaction (Reagan et al., 1987; Cigolini, 1998). We performed a pilot study of trace-element variations and U-series disequilibria in five whole rocks and, in three cases, mineral separates over the course of the eruption from 1968 to 1999. Mineral phases (pyroxene, plagioclase, magnetite, and glass fractions) from a 1970 and two freshly collected 1999 rock samples were analyzed for U-Th disequilibria by TIMS and a complete suite of trace elements by ICP-MS. Plagioclase from the 1999 samples was analyzed for ^{210}Pb-^{210}Po disequilibria.

(^{210}Pb)/(^{210}Po) activity ratios at the time of collection (9/15/99) are ~2 for both 1999 plagioclase separates. Both samples produce the same calculated date of initial plagioclase crystallization (3/5/99) assuming complete ^{210}Po degassing. The presence of (^{210}Pb)/(^{210}Po) disequilibria in plagioclase either implies that the mm-sized plagioclase crystals grew within a very short time of eruption or that ^{210}Po continuously diffuses out of already formed plagioclase crystals right up until the time of eruption from a Po-degassed magma.

The observed ^{238}U-^{230}Th disequilibria are consistent with the differentiation process operating on a timescale much less than that of ^{230}Th decay. All measured (^{230}Th)/(^{232}Th) activity ratios are identical indicating that mineral formation in both early and late eruptions (1970, 1999) is instantaneous with respect to ^{230}Th and that none of the minerals are older than ~10^4 years (they are not pre-Holocene "xenocrysts" or restites). (^{234}U)/(^{238}U) disequilibria results generally indicate that post-eruptive alteration is not a problem (with the exception of one pyroxene sample). Despite the (^{230}Th)/(^{232}Th) activity ratios remaining constant, Th/U consistently changes from low values in the early samples to a constant, higher value from 1986 to present. This implies that mantle-derived magmas entering the Arenal magma chamber through time have changed from more ^{238}U-enriched to less ^{238}U-enriched, or that assimilation has changed the Th/U but not the (^{230}Th)/(^{232}Th) activity ratios.

Results from our trace elements analyses show that as Th/U increases with time, LREE/MREE ratios increase slightly indicating addition of a more enriched magma, consistent with the model of Reagan et al. (1987). LREE/MREE ratios, however, have not changed after 1986. Absolute abundances do show important differences between 1986 and 1999 samples with the 1986 sample more differentiated than both 1999 samples. The more differentiated 1986 sample may reflect slowing replenishment activity in the Arenal magma chamber and domination by differentiation processes leading up to 1986. Following 1986, absolute abundances decrease which suggests increasing replenishment rates and a decreasing role for differentiation mechanisms.

V11A-1370 0830h POSTER

Geophysical Investigation of the Hydrogeologic Structure and Magma at Masaya Volcano, Nicaragua

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Current volcanic activity at Masaya caldera is characterized by degassing of a shallow magmatic system that is in equilibrium with groundwater. Masaya volcano has degassed quiescently for decades, only occasionally entering typically brief periods of explosive eruptive behavior. It is most certainly the interaction of magma, magmatic gasses, and groundwater that leads to a variety of heat and mass transfer conditions, some of which result in explosive volcanism. With the aim of understanding the magma-hydrogeologic parameter variation of this system, a preliminary geophysical survey was conducted in November, 2001. The relationship between groundwater saturation, temperature variations in groundwater and volcanic rocks (extending to phase transitions between magma and solidified basalt), and electrical conductivity was exploited using the electromagnetic techniques of TEM and VLF. An interpreted profile of TEM central-loop soundings from Santiago crater extending three kilometers to the north, reveals structural controls on groundwater. Distortion occurs near the crater, due to the three-dimensional geometry of the magma body. A conductive structure, likely channelized groundwater, separates a shallower conductor near the crater from the saturated groundwater zone toward the north. VLF current density sections indicate other structures likely to represent preferential groundwater flow paths, resulting from dilation-induced fracturing on the north flank of Santiago vent. Of particular interest is a VLF response we have interpreted to result from ring currents circulating through the shallow magma body. Using a current filament modeling approach, the size of the magma body has been estimated and correlates well with geometry of the active pit crater. These results place boundary conditions that will be used to model magma-groundwater interactions at Masaya.

V11A-1371 0830h POSTER

Experimental Calibration of Amphibole Break Down Rates in Response to Decompression and Heating: Examples From the 1989-1990 eruptions of Redoubt Volcano, Alaska

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Amphiboles are an important mineral common to a variety of magmas, and are especially sensitive to subtle variations in the water content and temperature of the surrounding melt that induces disequilibria through changing pressure (via ascent) or heating (via magma mixing events). For example, as magma rises toward the surface, hydrous amphiboles, stable at high water pressures, react with their surrounding degassing melt to form anhydrous minerals. Also, when magmas of intermediate composition mix with more primitive magmas of higher temperature, hydrous amphiboles, stable at lower temperatures break down by reacting with the resulting hybrid melt. Only a handful of studies have been performed that directly address the stability of amphiboles as an indicator of the rate at which magmatic processes such as mixing and ascent occur. We examine the stability of amphibole through a series of decompression and heating experiments using dacitic and andesitic magma erupted from Redoubt volcano, Alaska in 1989-1990. Redoubt dacite contains magnesio-hornblende and orthopyroxene, whereas the andesite contains pargasitic amphiboles and clinopyroxene. Both contain plagioclase, magnetite, and ilmenite in rhyolitic glass. The stability limits of the hornblende and pargasite were first constrained by phase-equilibrium experiments. For the dacite, experiments indicate that the magma last equilibrated at approximately 840°C and 155 MPa. Isothermal decompression experiments were thus carried to examine the growth rate of reaction rims on the hornblendes in response to the degassing melt. All decompression experiments were initially held at 840°C and 150 MPa for approximately 5 days before decompression. These experiments show that during a 840°C constant rate decompression from 6 km to the surface, no reaction rims developed on amphibole in 2 or 3.5 days (10-20 cm/s), a 2-um rim developed in 5.5 days (1 cm/s), and a 9-um rim developed in 20 days (0.5 cm/s). The third series of experiments performed in this study were isobaric thermal breakdown experiments to calibrate amphibole breakdown rates induced by heating. These experimental data are different compared to other comparable studies (i.e. 1980 Mount St. Helens dacite, 1995-97 Soufriere Hills andesite), despite the overall similarity in amphibole chemistry. This suggests that breakdown reactions in amphiboles relate predominantly to melt composition and viscosity (water content, temperature, and water pressure), rather than to chemical variability of mineral phases.

V11A-1372 0830h POSTER

A Detailed Geochemical Study of Island Arc Crust: The Talkeetna Arc Section, South-central Alaska

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The Talkeetna arc section in south-central Alaska is recognized as the exposed upper mantle and crust of an accreted, Late Triassic to Middle Jurassic island arc. Detailed geochemical studies of layered gabbronorite from the middle and lower crust of this arc and a diverse suite of volcanic and plutonic rocks from the middle and upper crust provide crucial data for understanding arc magma evolution. We also present new data on parental magma compositions for the arc.

The deepest level of the arc section consists of residual mantle and ultramafic cumulates adjacent to garnet gabbro and basal gabbronorite interlayered with pyroxenite. The middle crust is primarily layered gabbronorite, ranging from anorthosite to pyroxenite in composition, and is the most widespread plutonic lithology. The upper mid crust is a heterogenous assemblage of dioritic to tonalitic rocks mixed with gabbro and intruded by abundant mafic dikes and chilled pillows. The upper crust of the arc is comprised of volcanic rocks of the Talkeetna Formation ranging from basalt to rhyolite. Most of these volcanic rocks have evolved compositions (<5% MgO, Mg# <60) and overlap the composition of intermediate to felsic plutonic rocks (<3.5% MgO, Mg# <45). However, several chilled mafic rocks and one basalt have primitive characteristics (>8% MgO, Mg# >60).

Ion microprobe analyses of clinopyroxene in mid-crustal layered gabbronorites have parallel REE patterns with positive-sloping LREE segments (La/Sm(N)=0.05-0.17; mean 0.11) and flat HREE segments (5-25xchondrite; mean 10xchondrite). Liquids in REE equilibrium with the clinopyroxene in these gabbronorite cumulates were calculated in order to constrain parental magmas. These calculated liquids(La/Sm(N)=0.77-1.83; mean 1.26) all fall within the range of dike and volcanic rock(La/Sm(N)=0.78-2.12; mean 1.23) compositions. However, three lavas out of the 44 we have analyzed show strong HREE depletion, which is not observed in any of the liquid compositions calculated from clinopyroxene in the gabbronorite samples. Three lavas have Mg# 50-63 (49-57 % SiO2) and two of these are in REE equilibrium with calculated liquids of cumulate gabbronorites. Five chilled samples (three dikes and two mafic inclusions) have Mg# 54-64 (48-52 % SiO2) and lie just below the calculated liquid REE patterns. The most primitive mafic dike (SiO2 =48.1; MgO =8.1 ; Mg# =62.0; Ni =73) represents a well-constrained potential parental magma to the gabbroic cumulates in the mid-crust of the arc, although, like the three primitive basalts, it is not in Fe/Mg equilibrium with the gabbros.The Mg# is too high. Presumably, this parent has lost Ni and MgO to fractionation of ultramafic cumulates at deeper levels of the arc. The average dike REE pattern is nearly identical to the calculated primary magma composition of DeBari and Sleep(1991) for the Talkeetna arc, as are the REE patterns for the chilled pillows.

Least-squares mass-balance calculations of mid-crustal gabbronorites indicate pl + cpx + opx + mgt + amph represent the bulk of removed solids. Fractionation of these phases using the most primitive mafic

dike described above as the parental composition can produce many of the more evolved volcanic rocks. Fe-Ti oxide accounts for 0.05-12.3 wt% (mean 5.92 wt%) of the sampled cumulates and amphibole represents 0.97-40.1 wt% (mean 16.4 wt%). Fractionation of the observed phases in the cumulate gabbronorite is reflected by TiO2 depletion in the volcanic and intermediate to felsic plutonic rocks of the middle and upper crust.

V11A-1373 0830h POSTER

The 1931 Eruption of Aniakchak Volcano, Alaska

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One of the largest Aleutian Arc eruptions of the 20^{th} century was the 1931 intracaldera eruption of Aniakchak Volcano, with an erupted volume of 0.3 to 0.5 km^3. The eruption, which varied in intensity, style, and composition, persisted for approximately 6 weeks, dispersing ash as far as 600 km to the north. The eruption was first noticed when a large plume was seen over the volcano on May 1^{st} and persisted for 10 days. A particularly large explosion was followed by a few days of quiescence and then resumed explosive activity for over a week. Six weeks after the initial eruption, observers described lava apparently flowing from 2 vents and steam from 3 additional vents. Four of those vents form an arc that parallels the caldera rim. Our detailed fieldwork has refined our knowledge of the dynamics of the eruption. The 2 effusive vents erupted volumetrically small rhyodacitic flows prior to and after the explosive phases of the eruption. The main crater contains 40 m of pyroclastic deposits that most likely record an early plinian phase of the eruption. This section contains 9 rhythmic packages of thick lithic-rich surge layers, which indicate a significant phreatomagmatic component to the eruption. This section is overlain by 40 m of alternating spatter agglutinate and lithic-rich, highly stratified layers, which represent the strombolian eruptive phase. The eruption ended with lava fountaining to form spatter agglutinate, which covers the inner wall and floor of the main crater. The composition of all the erupted products ranges from the initial rhyodacitic lavas to the last-erupted andesitic spatter agglutinate, which suggests emptying of a zoned magma chamber. The tephra from the main crater wall changed gradually in composition from dacite to andesite. Despite the abrupt transition from the plinian to strombolian eruptive phases, an abrupt compositional change is not apparent.

V11A-1374 0830h POSTER

Field Evidence for Subaqueous to Subaerial Volcanism in Okmok Caldera, Alaska

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Okmok, a 10-km diameter late Holocene caldera, with basaltic to rhyodacitic products, is located on Umnak Island in the central Aleutians. Field relationships of subaqueous and subaerial volcanic products from cones C and D in Okmok caldera were mapped in an effort to determine the volcanic history of Okmok after the 2050 y.b.p. caldera forming event. The two cones in the eastern half of the depression are characterized by gently sloping ($\sim 5^{\circ}$) subaerial pahoehoe flows giving way to steeply dipping (20-40°) lava tubes flowing over 50-100 m high cliffs and displaying evidence for water interaction (e.g. glassy margins, radial fracture patterns and sparse pillows). Atop the benches are 200 m high spatter/cinder cones. Lacustrine clays and surge deposits mantle the upper sections of the benches.

There are at least two possible scenarios for the development of the cones: they were growing concurrently with a caldera-filling lake, analogous to Wizard Island, Crater Lake, Oregon; or they were emplaced englacially, following analogs in Iceland, Antarctica and British Columbia, Canada. The profiles of cones C and D are similar to sub-lacustrine features at Wizard Island but the scarps are >100 m smaller at Okmok and the observed flows are typically only 2 m thick, as opposed to flows hypothesized to be up to 20 times thicker in Crater Lake. The aspect ratio of height to width of Okmoks cones is much less than that for the typical Icelandic or Canadian tuya. Both sub-lacustrine and englacial tuyas can have broad, flat lava benches surrounded by steep sided margins.

We pursue this question by developing glacial and lacustrine models to determine if enough ice and/or lake water could have formed in the available time frame. We also examine lava tube morphology and microlite textures from lava tube margins to constrain cooling rates in the system, and identify a subaerial to subaqueous transition zone. The young age and excellent exposure of the cones makes them useful tools for understanding more about the development of volcanic edifices in aqueous and glacial environments.

V11A-1375 0830h POSTER

Widespread Lahar Inundation Around Mount Veniaminof Volcano: Evidence for a Major Late Holocene Eruption Involving Snow and Ice

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Explosive eruptions at ice-clad volcanoes almost always results in the generation of lahars. In some cases, the extent of a lahar deposit is an indicator of the eruption magnitude as well as the volume of snow and ice available for interaction with hot eruptive products. At Mount Veniaminof volcano on the Alaska Peninsula, we have recently discovered a sequence of lahar, lahar-runout, and hyperconcentrated-flow deposits that are associated with a significant eruption dated at about 3700 yr. B.P. Lahar deposits of late Holocene age are present in all of the major valleys that head on the volcano. The deposits are thick, valley filling accumulations of silt, sand, and boulder-rich volcaniclastic debris and record complete inundation of large glacial valleys. Typical lahar deposits consist of massive, matrix-supported, clay-poor diamict that form near vertical bluffs where incised by modern streams. Most of the lahar deposits exhibit downstream changes in particle size, texture, and thickness that record flow transformations initiated by sedimentation of the coarser size fractions or as a result of entrainment of preexisting alluvium. In the Muddy and Sandy River valleys on the northwest flank of the volcano, the lahar deposits cover an area of about 800 km^2 and extend from the terminus of Cone Glacier at the base of the volcano, to the Bering Sea, a distance of about 45 km. Lahar inundation of this magnitude requires a substantial amount of water to mobilize loose, erodable, volcaniclastic debris from the north flank of the volcano and transport it to the Bering Sea coast. Although Mount Veniaminof volcano, like many large stratocones in the Aleutian arc, has an extensive snow and ice cover, typical valley glaciers on these volcanoes have too low an ice volume to produce a lahar as large as the flow that produced the deposit in the Muddy and Sandy River valleys. It is possible that the most recent large eruption of Mount Veniaminof volcano about 3700 yr. B.P., occurred when an ice-filled summit caldera already existed and the combined ice volume of the caldera and its outlet glaciers could have supplied enough water to produce the massive lahar inundation we observe on the distal flanks of the volcano.

V11A-1376 0830h POSTER

Possible Multiple Late Quaternary Caldera-Forming Eruptions at Mount Veniaminof Volcano, Alaska Peninsula

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Mt Veniaminof volcano, an Alaska Peninsula andesitic stratovolcano that has an ice-filled, 10-km diameter summit caldera, is one of the largest (300 km^3) and historically most active volcanic centers in the Aleutian Arc having erupted at least 12 times in the past 200 years. Previous work indicated that a large caldera-forming eruption from Mt Veniaminof volcano about 3,700 C^{14} yr. B.P. resulted in widespread scoria-rich pyroclastic flows that reached both the Pacific Ocean and Bering Sea coasts. We have now identified at least two older late Quaternary pyroclastic-flow deposit units, a Holocene scoria-rich pyroclastic-flow deposit and an even older Late Pleistocene pyroclastic-flow deposit, whose distribution and thickness indicate they, like the 3700 yr. B.P eruption, were derived from large (10-25 km^3), probably caldera-forming eruptions. The two Holocene pyroclastic-flow deposits are quite similar in composition and lithology consisting chiefly of scoriaeous pyroclasts of andesitic (57% SiO_2) composition in an ash- and lithic-rich matrix. The younger deposit is incipiently welded and columnar-jointed at many locations higher on the flanks of the volcano. The Holocene pyroclastic flow deposit units each have proximal thicknesses of up to 30 m and are found at distances of 50 km from the summit caldera. The older Holocene deposit is separated stratigraphically from the 3700 yr. B.P. deposit by the highly distinctive 4700 C^{14} yr. B.P. Black Peak tephra and a 1-2 m thick soil-tephra complex. The Late Pleistocene pyroclastic-flow deposit contains distinctive iridescent glassy pyroclasts of probable andesite-dacite composition and is overlain by moraine of late Wisconsin age and by glaciated Late Pleistocene lava flows. Proximal deposits of this unit are up to 30 m thick on the northwest flank of the volcano and other deposits have been found >30 km from the rim of the present caldera.

Historical eruptions at Mt Veniaminof volcano have been strombolian in character and of relatively modest proportions. The identification of three widely distributed and apparently voluminous pyroclastic-flow deposits on the flanks of the volcano indicate at least 3 major eruptions in late Quaternary time. At least one and probably all of three of these eruptions were associated with caldera formation. The recognition of multiple pyroclastic-flow deposits indicates a more complex and explosive history of the volcano than previously recognized and a new appreciation of its associated hazards.

V11A-1377 0830h POSTER

New Evidence of Tsunamis from Augustine Volcano, Alaska

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Historical records suggest an eruption of Augustine Volcano generated a tsunami as much as 6-9 m high in 1883 when a debris avalanche travelled 6 km into the waters of Cook Inlet. No trace of tsunami deposits from this event has previously been reported from the Cook Inlet area, leading to suggestions that the historical record is in error and that the hazard from future Augustine Volcano tsunamis is minimal. We report here on several sites that appear to provide evidence of the 1883 and older tsunamis. At several sites on Augustine Island, the 1883 debris-avalanche deposit is overlain by water-rounded pumice, shells, and sands recording wave action at elevations more than 9 m above MSL. At the native village of Nanwalek, 80 km east of Augustine, we found sand, water-rounded cobbles and granules buried by Augustine 1883 tephra, consistent with reports by observers in 1883. The Augustine deposits underlie Katmai 1912 tephra and a sheet of sand and cobbles deposited by the well-documented tsunami of the 1964 Alaskan earthquake. Dendrochronologic evidence indicates that a sand horizon intercalated with peat at the Red River on the mainland north of Augustine also dates to 1883. We also report evidence for a second volcanic tsunami, evidently produced by the ca. 500 ya West Island debris avalanche. A zone of wave-eroded sediment and ash extends to an elevation of more than 15 m above MSL on the southwest side of Augustine Island. At Nanwalek and Seldovia, 80-100 km east of Augustine Volcano, deposits older than 1883 of sand and water-rounded granules occur more than 5 m above MSL, where they are intercalated with numerous tephra layers in peat. We speculate that these deposits may be from a tsunami generated by the West Island debris avalanche.

V11A-1378 0830h POSTER

Intra-caldera Events: A Look at the Hydrovolcanic Deposit Stratigraphically Located Between two Caldera-Forming Eruptions of Okmok Volcano, Umnak Island, Alaska

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Within the 10 km diameter caldera that characterizes Okmok Volcano, a field of post-caldera cones and deposits demonstrate many features associated with water-magma interactions. A unit deposited prior to the formation of the present caldera provides evidence for large explosive hydrovolcanic eruptions in the past as well. This unit is referred to as the Middle Scoria Unit as it is stratigraphically located between the ~9000 BP Okmok I and 2050 BP Okmok II caldera-forming events. Here, we present data on the stratigraphy, geochemistry, and eruptive mechanisms of the Middle Scoria Unit, which averages a thickness of 2.5 meters. The basal layer of the Middle Scoria consists of moderately well sorted, highly inflated juvenile clasts of basaltic composition (53.88 wt.% SiO_2) that average 3 to 5 cm in size. Capping the base is a sequence of layers alternating between oxidized reddish lithic fragments and poorly vesicular scoria averaging 1 mm to 3 cm in size. The contacts between the scoria and lithic layers are less discrete in the top section, with a higher proportion of mixing averaging up to 75% for a clast-rich layer. The upper layers of the unit also show reverse grading and contain dense, poorly vesicular scoria fragments and lithic fragments of 2 mm to 1.5 cm in size. The Middle Scoria unit has been found on the neighboring Unalaska Island, approximately 30 km to the East, revealing a wide dispersal. Our results indicate that this eruption began as a highly explosive, purely magmatic and rare basaltic Plinian eruption. With time, the eruptive series evolved to incorporate external water, as demonstrated by the successions of oxidized lithic lapilli and poorly vesicular scoria layers. Our preliminary interpretations of the Middle Scoria indicate that Okmok Volcano may be capable of highly explosive basaltic Plinian and hydrovolcanic eruptions.

V11A-1379 0830h POSTER

Characterization and Discrimination of Holocene Tephra Deposits at Mount Spurr Volcano, Alaska

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Correlation of distal tephra deposits with their respective sources is known to be problematic in the Cook Inlet region of Alaska. Existing correlations are heavily weighted on glass shard geochemistry, which is not always the most distinguishing characteristic in a region where eruption frequency is high and volcanoes are closely spaced. A multi-parameter approach to characterizing tephra deposits enhances the potential for recognition and long-distance correlation and provides an improved means of identifying source volcanoes. Previous studies were focused on providing a regional inventory of tephra deposits in the Cook Inlet region. These studies show that tephra erupted from Mount Spurr volcano and its satellite vent Crater Peak, are well preserved in this region (35 deposits in 6000 years) yet correlations using major-element glass geochemistry between distal tephra and proximal reference samples are often inconclusive. Tephra deposits preserved on the proximal (<10 km) flanks of Mount Spurr volcano and Crater Peak, constitute a record of explosive eruptions from these sources during the past ~5,000 years. This study provides detailed descriptions of all preserved tephra deposits from three proximal locations on the southern and southeastern flank of Mount Spurr volcano. These data suffice as a reference dataset for Mount Spurr volcano and Crater Peak tephra and include: 1) field characteristics (precise field location, photographs, unit thickness, grain shape, sorting, maximum grain size, and Munsell color), 2) mineral assemblages, 3) glass shard characteristics (photomicrographs and backscatter images), 4) major-element glass geochemistry, and 5) radiocarbon ages. Because no single set of parameters is known to characterize a tephra, a multi-parameter approach provides a more robust means of identifying source volcanoes in the Cook Inlet region and likely at other Aleutian arc regions. These data will be presented in a digital format for collaboration purposes so that they can be easily accessed, and manipulated to facilitate the likelihood and accuracy of future correlations.

V11A-1380 0830h POSTER

Rare Earth and HFSE Constraints on Basalt Source Regions and Melting Conditions in the Garibaldi Volcanic Belt, Northern Cascadia Subduction System

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Garibaldi belt (GVB) basalts were erupted above the relatively young (<24 Ma) Juan de Fuca plate, subducted oceanic lithosphere that becomes progressively younger (22-13 Ma), and presumably hotter, northward along the Cascadia convergent margin. Mafic lavas of the 15-km-wide volcanic belt range from high-alumina olivine tholeiites and magnesian andesites near Glacier Peak, northwestern Washington, through transitional basalts to alkali-olivine basalts and basanites in the Bridge River-Salal Glacier areas, southwestern British Columbia.

Significant strike-parallel variations characterize REE and HFSE contents of these (GVB) basalts and provide insight into the nature of mantle source heterogeneities that may characterize subduction regimes. Lavas of more northerly volcanic suites tend to have (1) somewhat higher Ti, Nb, Ta, Zr, Hf, La, total REE, La/Yb, Sm/Yb, Nb/Y, Zr/Y, Y/Sc and Zr/Yb and (2) lower Th/U, La/Nb, and Th/Yb. The basalts have subchondritic to chondritic Na/Tb (6-21) and chondritic to super-chondritic Zr/Hf (up to 55.90) ratios. Only Mount Baker and Glacier Peak basalts exhibit the distinctive negative Na-Ta anomalies associated with arc lavas.

REE systematics suggest that the more northerly basaltic suites formed as lower degree melts of mantle sources typically containing 1) garnet + spinel peridotite rather than spinel peridotite and 2) slightly more garnet (4% versus 2%) than in garnet-bearing source regions beneath more southerly eruptive centers. Inverse REE modeling suggests that the Bridge River-Salal Glacier lavas may have been derived from at least two distinct source regions (garnet-bearing and garnet-free). Nb/Ta exhibits slight positive correlations with Nb, Ta, La/Yb, and Th/Yb in some GVB basaltic suites, implying the role of a residual mineral, most likely rutile, in controlling extremely low HFSE partitioning into suduction-related fluids that equilibrated with basalt source regions in the mantle wedge.

V11A-1381 0830h POSTER

Eocene Adakites Associated With Initiation of Cascade Subduction, Puget Lowlands, WA

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Hornblende-bearing dacites from two localities in the Puget Lowlands have geochemical traits of adakites and represent a previously unrecognized early phase of Cascade arc magmatism that occurred ~90 km west of the main volcanic front. In the Bremerton Hills area (BH) these dacites occur as dikes up to 4m wide that intrude 50 Ma Crescent Formation basalts. Sixty kilometers to the north, in the Port Townsend area (PT), chemically similar dacites occur as clasts up to 1m in diameter within monolithologic lahar deposits that underlie the ~40 Ma Lyre Formation. Samples from BH and PT are porphyritic (amph + plag + quartz) and range from 62-69 wt.% SiO_2. On spider diagrams they have Ta and Nb depletions characteristic of arc magmas, and they share a broad spectrum of adakite characteristics including high Al_2O3 (15.4 - 17.9 wt.%), high Na_2O (4.2-6.1 wt.%), high Sr/Y (>40), high La/Yb_N(13-22), low Yb (<1 ppm) and low Y (5-11 ppm). However the PT samples are distinguished from BH samples by lower CaO and Na_2O, and by higher Th and U. The lack of bedrock exposures between BH and PT has made it impossible to determine whether the two localities are part of a magmatic belt, two isolated volcanic centers, or remnants of a single center that was subsequently displaced along the Bremerton fault.

The adakites are chemically distinct from the Crescent Formation rocks, which have OIB / MORB affinities and are interpreted to have originated in a rift setting. Ongoing Ar-Ar dating and Sr and Nd isotopic analysis of BH adakites will better constrain the timing of this transition in magmatism and geodynamic setting.

Generation of modern adakites is commonly associated with subduction of young lithosphere and/or with the initiation of subduction; both conditions likely applied in this region during the Eocene. In addition, heating of the lithosphere by possible plume magmatism during the preceding episode of OIB-like Crescent Formation magmatism may have played a role.

V11A-1382 0830h POSTER

Petrogenesis of Western Cascades Silicic Volcanics Near Sweet Home, Oregon

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Silicic lavas in the Menagerie Wilderness east of Sweet Home, Oregon are Oligocene to Miocene in age and range in composition from dacite (low K) to trachydacite (high K) and rhyolite (medium K). Three distinct silicic centers have been distinguished through a combination of field observation, chemistry and petrography. Phenocryst assemblages in rocks of the centers are plagioclase-hornblende-magnetite (Rooster Rock rhyolite), plagioclase-quartz-magnetite (Soda Fork rhyolite) and quartz-plagioclase-biotite-hornblende-magnetite (Moose Mt. rhyolite). The silicic volcanics in the study area are similar in terms of mineral content and overall chemical composition. Despite this, chemical evidence suggests that the three centers are petrologically unrelated. REE variations and least squares modeling of major element compositions are consistent with fractionation of plagioclase and hornblende. The rhyolites have moderate Eu anomalies and have flat MREE and HREE signatures. Least squares models and bivariate plots of major and trace elements also suggest fractionation of the aforementioned phases for both the andesite to dacite, and dacite to rhyolite steps. Comparisons with similar silicic centers show the Menagerie rocks share affinities with High Cascades rocks thought to have been derived through fractional crystallization (Crater Lake and South Sister).

Plots of ratios of incompatible trace elements were utilized to determine if assimilation played some role alongside fractional crystallization in differentiation. Plots of Ba/La vs. Ba, Rb/Zr vs. Rb and Rb/Th vs. Rb show systematic positive increases in the ratios between a plausible parent magma (icelandite) and the rhyolites. These increases are not easily explained by fractional crystallization but can be modeled by assimilation of silicic crust.

Overall, it seems likely that the three centers evolved independently through similar petrogenetic processes from an andesitic parent. The most plausible petrogenetic scenario involves some combination of fractional crystallization and assimilation of partial melts of silicic crust.

V11A-1383 0830h POSTER

Geochemistry and field geology of shoshonitic magmas in the Late Cretaceous foreland fold and thrust belt of southwestern Montana: Results from the North Doherty Mountain Intrusive Complex

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The North Doherty Mountain Intrusive Complex (NDMIC) is one of several satellite plutons related to the areally extensive Boulder batholith of southwestern Montana. The Boulder batholith comprises multiple plutons and intrusive phases, and the magmatism has long been thought to be the result of subduction due to its calc-alkaline granodioritic composition. The batholith is situated in the Helena salient, which differs from other parts of the North American Cordilleran foreland because there, magmatism spatially and temporally overlaps with deformation in the foreland fold and thrust belt. The North Doherty Mountain Intrusive Complex (NDMIC) is one of several satellite plutons related to the Boulder batholith and represents an ideal microcosm of the batholith for petrogenetic and structural studies because it exposes both mafic and felsic units and was emplaced in the limb of a major thrust related fold. We present new geologic mapping and detailed trace element geochemical analyses to show that the entire mafic-to-felsic suite of rocks in the NDMIC are cogenetic and shoshonitic in character. Shoshonites are unusual magmas that are distinguished by their high concentrations of K, Rb, Sr, Ba, Zr, and Th contents, and are thought to represent partial melting at great depths within the mantle wedge above a subducting slab. The presence of shoshonitic magma in the Cordilleran foreland fold and thrust belt provides important clues into the nature of the formation of this unusual magma type and can provide insights into our understanding of magmatism in foreland structural settings.

V11A-1384 0830h POSTER

Sr, Nd and Pb Isotope Geochemistry for the Volcanic Rocks From the Aono and Abu Volcanic Groups in the SW Japan arc

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Although, there is no deep seismic activity beneath the W. Honshu Island in the SW Japan arc, recent seismic studies have revealed the existence of an aseismic slab beneath the area. Thus, the volcanism in the W. Honshu Island is considered to be related to the subduction. Since the subducting Philippine Sea plate caused inter-arc spreading, the volcanism of the Aono and Abu volcanic groups in the W. Honshu Island are inferred to be produced at the high temperature condition. The Aono volcanic group is one of volcanic groups, which comprise the volcanic front on the SW Japan arc, while the Abu volcanic group is on rather backarc side of the Aono volcanic group. In order to evaluate the origin of the volcanic rocks from the Aono and Abu volcanic groups, Sr, Nd and Pb isotopic and trace element compositions were determined. Nb troughs on a spider diagram indicate that these rocks are related to subduction process. Furthermore, high Sr/Y ratios and low Y concentrations of these rocks indicate that these are adakitic magma, which suggests that the magmas were produced by altered oceanic crust melting. Isotopic compositions of these rocks are situated between those of the Shikoku basin basalt and mantle xenoliths from the SW Japan arc on 87Sr/86Sr vs. 143Nd/144Nd and Pb-Pb diagrams. These show that geochemical characteristics of these rocks were produced by the mixing of a depleted slab derived component with an enriched mantle component. A 1/Sr vs. 87Sr/86Sr diagram designates that the depleted and enriched components have high and low Sr concentrations, respectively. Considering phase assemblages during melting processes of mantle peridotite and subducting altered oceanic crust, lower and higher Sr concentrations reflect lherzolite and eclogite melting respectively. This is consistent with the isotopic composition. To test the altered oceanic crust melting as a possible mechanism for the production of Aono and Abu volcanic rocks, melting calculations were conducted. The result reproduces trace element compositions of the Aono and Abu volcanic rocks without sediment contribution. Thus, we conclude that subducted Philippine Sea plate melting produced the Aono and Abu volcanic rocks.

V11A-1385 0830h POSTER

Geochemistry of Obsidian from Northern Hokkaido

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The northern half of Hokkaido forms the back-arc side of the Kurile arc. Two phases of volcanic activity are present here; the first phase is dated to 10-15 mya, and the second phase to 2-9 mya. Coeval andesites, basalts, granites and rhyolites were all formed during these two phases of volcanic activity. While the geochemistry of the rhyolites and basalts of northern Hokkaido was the subject of numerous studies, there has been a paucity of studies on the massive obsidian deposits. From a geologic and economic perspective, obsidian may be of limited importance, but for archaeologists they are of major significance. The purpose of this paper is to report on the results of a geochemical study of 133 obsidian samples collected from the six deposits at Oketo Mountain, Shirataki Mountain and the Shirataki valley, and Tokoro Mountain. Energy dispersive x-ray fluorescence (EDXRF) was the analytical technique used to quantitatively measure the minor and trace elements.

On the Rb-(Y+Nb) discrimination diagram, the composition of the obsidians indicates that they are from an I-type silicic magma. As with other island-arc volcanics when compared to N-MORB, the LIL elements are enriched, and there is a depletion of Nb and other HFS elements. For this particular set of samples though, most are also depleted in Sr. A plot of the Sr/Y vs. Y places all the samples within the Island Arc field. Examination of Rb/Y-Nb/Y and Nb/Zr-Th/Zr plots suggests that there is very little melt related enrichment, and fluid related enrichment is dominant. While there was no directional gradient found in the elemental ratios associated with the fluid-related enrichment, the Sr/Y content does decrease as one goes northwards and eastwards. The results presented here would support the arguments in favor of a hydrous metasomized origin for the Hokkaido rhyolites.

For the archaeologist, the quantitative data presented here can be used to source obsidian tools found in the Japanese archipelago and the Russian Far East. Examination of bi-variate plots of the incompatible elements, or incompatible element ratios, or the principal component scores illustrates that there are 4 statistically distinct, geochemical groups in the data. Two groups consist of the obsidian from the Shirataki Mountain and valley, while the other two groups are Oketo and Tokoro Mountain respectively. Stepwise discriminant analysis indicates that Rb, Sr, Y, and Zr are the most discriminating elements for these 4 groups.

V11A-1386 0830h POSTER

Origin of the Silicic Ash-flow Sheets in Southern Nicaragua

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Abundant silicic ash-flow sheets occur in southern Nicaragua yet little is known about their distribution, age, and geochemistry. Their origin is a matter of considerable interest because the generation of silicic magma is generally attributed to the assimilation and/or melting of an underlying continental crust. However, no continental crust occurs in this area. This southern part of the Central American Volcanic Arc is located in the Chorotega block, which is composed of a thickened oceanic crust (Hauff et al., 2000). This is in contrast with the northern section of the arc, the Chortis block, which is underlain by continental crust. Here, we describe the occurrence and composition of silicic ash-flow sheets in southern Nicaragua. Seven ash-flow sheets were identified based on their chemical characteristics. These ash-flow units are Apoyo, Las Maderas, Las Sierras, and 4 informally named units referred here as: Coyol, Monte Galan, Ostocal, and San Rafael, all belonging to the Coyol Formation. The age of the Apoyo unit is 23,000 (Sussman, 1982) whereas the other ash-flow units maybe as old as Miocene (Ehrenborg, 1996). The composition of pumice fragments from these sheets range from 50.9 to 71.5 wt. % SiO_2. The most frequent occurring compositions (mode) in six of these units ranges from 65 to 70 wt. % SiO_2, whereas the Las Maderas unit has a mode at 63% SiO_2. Plots of Rb, Sr, Zr, total alkalies, $Fe_2O_{3(t)}$, MgO, and K_2O versus SiO_2 for each of these ash-flow sheets define distinct chemical trends. REE spider plots are relatively flat. Some ash-flow sheets (Ostocal, Las Maderas and Las Sierras) contain a small negative Eu anomaly (0.77 to 0 .90), whereas the Apoyo contains a slight positive Eu anomaly (1.09 to 1.13). Chemical variations among these sheets cannot be related by fractional crystallization. Overall the trace element variations (e.g. U/Th, Ba/Nb ratios) of these silicic sheets mimic the variation in the trace element variations in the modern arc, which to us, means there is a genetic relationship between the modern arc and the silicic magmatism. Because it is difficult to generate large-volume silicic magmatism by fractional crystallization of mantle melts, we are evaluating models where silicic magmas are produced by partial melting of previously emplaced arc-related igneous rocks.

V11B MCC: Hall C Monday 0830h

From Magma to Tephra: Crystallization, Fragmentation, and Flow II Posters

Presiding: **D Sahagian,** University of New Hampshire

V11B-1387 0830h POSTER

Volatile Concentrations in Pyroclastic Obsidian: Two Case Studies

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Pyroclastic obsidian is abundant in fall deposits associated with Mt. Mazama's Cleetwood eruption and South Sister's Rock Mesa eruption. Measured concentrations of H_2O_{total} and CO_2 in >300 obsidian samples from these two eruptions provide important information about both the style of degassing (open- vs. closed-system) and changes in eruptive conditions through the course of both eruptions. Obsidian clasts preserve a range of total H_2O contents, with samples from lower stratigraphic levels displaying a wider range of water concentrations than those from the uppermost tephra layer sampled. All samples from the Cleetwood section contain $\leq$1 wt% water, with those from the top of that deposit containing <0.4 wt%. Obsidian from the basal ash layer of the subsequent climactic eruption contains 0.1 - 0.8 wt% water. Obsidian fragments from the Rock Mesa eruption show a broader range in H_2O_{total} contents (from 0.1 to >3 wt%) than those from the Cleetwood eruption. At Rock Mesa, maximum total water contents generally decrease with increased stratigraphic height. However, this decrease is not strictly monotonic: fluctuations in maximum total water contents correspond to stratigraphic unit boundaries. In addition, the Rock Mesa event produced abundant obsidian with very low H_2O_{total} concentrations throughout the eruption. Dissolved molecular CO_2 levels are below the detection limit in all of the Cleetwood and Mazama samples. This is not surprising, given the low initial CO_2 measured in Cleetwood and Mazama melt inclusions by Bacon et al. (1992). CO_2 concentrations in the Rock Mesa clasts range from <5 ppm to ~44 ppm, and are positively correlated with H_2O_{total} concentrations. Fluorine concentrations in Cleetwood and Mazama climactic obsidian clasts vary between ~510 and ~695 ppm, with climactic samples averaging slightly lower concentrations than Cleetwood samples. Fluorine concentrations in Rock Mesa obsidians are uniformly low (~300 to ~510 ppm). Chlorine contents of Cleetwood and Mazama climactic samples range from ~1400 ppm to ~1610 ppm. The Rock Mesa samples all contain less chlorine (~510 to ~1120 ppm) than the Cleetwood and climactic samples, and in the Rock Mesa obsidian, chlorine and total water are positively correlated.

Stratigraphic variations in the volatile contents of pyroclastic obsidian support previous work suggesting that obsidian forms along the margins of the volcanic conduit and is eroded from the conduit walls by fragmenting magma. Both the Cleetwood and the Rock Mesa deposits indicate initial evacuation of shallow vanguard magma followed by a rapid increase in fragmentation depth. Both deposits also show a gradual decrease in the fragmentation depth through time, consistent with subsequent effusive activity in both cases. More puzzling is the apparent closed-system degassing trend defined by the H_2O-CO_2-Cl relations in the Rock Mesa obsidian samples, despite the loss of volatiles required for obsidian formation. This suggests that volatile data may also provide information on the relative time scales of volatile exsolution and loss and obsidian formation.

V11B-1388 0830h POSTER

Determination of 3D Crystal Size Distributions From 2D Measurements: an Application of Stereological Correction Routines to Prismatic Microlites in Obsidian

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Crystal size distributions (CSD) in igneous rocks are traditionally constructed on the basis of measurements of two-dimensional (2D) intersection length and crystal area number density. Transformations of 2D data into "true" three-dimensional (3D) CSDs are complicated by errors arising from the cut effect and intersection probability problem. Correction routines have been developed to alleviate these stereological effects. Here we test published CSD conversion techniques by applying them to intersection length measurements made on prismatic microlites in obsidian for which we have corresponding 3D data. Our results show that large systematic errors in population density arise from shape (aspect ratio) variability in the population. Aspect ratio varies by more than an order of magnitude owing to relatively rapid growth of the long crystal dimension. Thus, aspect ratio varies strongly with length and weakly with width. Conversion programs, which assume a constant shape, overestimate the number of small crystals due to a large number of intersections along the short crystal dimension. In the real population, these intersections correspond to a wide range

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