Temporal and spatial variations in Cascade Arc magmatism: The 35 Ma plutonic record

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Granitoid intrusions in the Cascades preserve a record of variations in the chemistry, production rate, and geographic distribution of magmatism over the 35 Ma history of the arc. At least three factors appear to have contributed to these variations: (1) progressive thickening of the arc crust, (2) along-strike variations in mantle composition and/or the flux of a slab component (SC), and (3) changes in subduction parameters including subduction rate and slab geometry.

Thickening of the Arc Crust

With decreasing age Cascade plutonic and volcanic rocks display lower CaO/Na_2O, a trend that is consistent with thickening of the arc crust (Plank & Langmuir, 1988). To quantify this crustal growth we regressed $CaO/Na_2O_{6.0}$ vs crustal thickness in the Plank & Langmuir dataset and used the results to calculate crustal thicknesses for 11 Cascade batholiths and volcanic centers. The results indicate an increase in crustal thickness from 35±3 km (at 35-25 Ma) to 43±1 km (<3 Ma). We are working to better constrain the timing of thickening, but a significant portion may have occurred between 20-12 Ma, a magmatic hiatus at the surface.

Along-Arc Chemical Variation

Cascade granitoids north of ~48° in Washington display a more-pronounced arc signature (e.g., higher Ba, Sr, Ba/Nb, lower Nb) than intrusions to the south. These differences probably reflect variations in the composition of the mafic (underplated) lower crustal source regions and imply the existence of along-strike variations in SC contribution. Persistence of this "greater SC to the north" pattern for >20 Ma suggests it may reflect subduction geometry (linked to the bend in the arc?) rather than slab composition or age.

Temporal Trends in Granitoid Chemistry

Over the interval 32 to 3 Ma plutons in the Chilliwack batholith show decreasing Ba/Nb and increasing Nb. These trends suggest decreasing SC involvement (and consequent decline in degree of melting) through time, and may reflect the ~5-fold slowing of subduction (Verplanck & Duncan, 1987). One implication of this trend is that earlier Cascade magmatism was not as "hot and dry" as more recent activity.

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Location of the Miocene-Pleistocene Cascade arc volcanic front in the Portland Basin

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A discontinuity exists in the Cascade arc volcanic front near the latitude of Portland, Oregon. A westward salient in the volcanic front is defined by Pliocene-Quaternary mafic lavas distributed continuously from the vicinity of Mt. Hood westward into the Portland Basin, and thence discontinuously northeastward to Mt. St. Helens. These lavas, which include both within-plate and arc-like compositions, are called the Boring Lava in the Portland area. The salient is evident also in the distribution of Miocene andesites, which extend west of Mt. Hood toward the Portland Basin but are more areally restricted southward, similar to the Quaternary arc. Limited seismic data suggest the subducting Juan de Fuca plate strikes NNE beneath Mt. St Helens, whereas the plate strikes N-S beneath Mt. Hood, a geometry which requires bending or breaking of the plate at the latitude of the Columbia River.

We have found Miocene (ca. 13-14 Ma) mafic lavas, mapped as Boring Lava by earlier workers, in three locations on the southern and western edges of the Basin. All of the Miocene lavas are arc-like in composition in contrast to the geochemically diverse Boring Lava.

We suggest the Miocene lavas demonstrate the longevity of a salient in the arc front in the Portland area. Plate reconstructions by Doug Wilson show that the most prominent discontinuity in the downgoing plate is a band of pseudo-faults currently subducting northeastward beneath Portland. Fracturing of the plate during repeated southward rift propagation along the Juan de Fuca Ridge generated the band of pseudo-faults. They may represent a fundamental weakness which accommodates the change in strike of the slab at the latitude of the Columbia River. Wilson's plate model suggests the location of the subducting pseudo-fault band hasn't changed since the mid-Miocene, in agreement with our interpretation.

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Overlapping calc-alkaline and tholeiitic magmatism in the southernmost Cascade Range

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The Lassen region of NE California (Clynne and Muffler, in press) consists of <3.5 m.y. volcanic rocks derived from two distinct parental magmas: calc-alkaline basalt, and low-potassium olivine tholeiitic basalt (LKOT). The two parental magmas are derived from distinct mantle sources (Clynne, 1993; Clynne and Borg, 1997; Borg *et al*., 2002). The calc-alkaline basalt dominates in both volume and vent abundance and is related to Cascade arc magmatism. It displays a range of primitive geochemistry produced by flux and decompression melting with variable proportions of mantle- and slab-derived components. Calc-alkaline basalt and its derivative more-silicic magmas built a broad platform 4 km thick of basalts–andesites within which are intercalated a few voluminous long-lived volcanic centers with compositions as silicic as rhyolite (e.g., the Lassen Volcanic Center). LKOT erupted from fissures between the calc-alkaline volcanoes and floods intervening valleys, commonly forming large-volume but thin flows of remarkable chemical and petrographic homogeneity. The few LKOT vents west of the active Cascade arc are of small volume. LKOT is produced by decompression melting of depleted sub-continental peridotite (Borg *et al*., 2002). Vents for LKOT appear to be related to extensional tectonism along the western margin of the Basin and Range geologic province. Edifices containing both calc-alkaline and LKOT rocks are not recognized, even though their vents can be associated in space and time. For example, the vents for the 24 ka Hat Creek LKOT Basalt are only 0.5 km from 46–75 ka vents of the Sugarloaf chain of calc-alkaline andesites.

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Basalts and high-Mg andesites from the Northern Cascade arc (Glacier Peak, Washington): Insights into mantle and crustal processes

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Four Quaternary mafic cinder cones and flows are present 5-15 km south of Glacier Peak, a dacitic stratovolcano in the northern segment of the Cascade arc. These include the Whitechuck high-alumina olivine tholeiite (HAOT) and the calcalkaline (CA) basalts and basaltic andesites of Indian Pass, Lightning Creek, and Dishpan Gap. Whitechuck lavas have high Al_2O_3 (>18 wt.%), low K_2O (<0.45 wt.%), and trace element characteristics similar to HAOT in the central and southern Cascades. All of the CA lavas have Mg# >58. Indian Pass lavas are the most primitive, with 51-54 wt.% SiO_2, Mg# 65-68, 260-307 ppm Cr, and 160-217 ppm Ni. Lightning Creek and Dishpan Gap lavas are basaltic andesites with lower Ni and Cr than Indian Pass. Most samples have olivine in equilibrium with bulk rock compositions.

Ba/Nb is lower in the HAOT than for the CA lavas, indicating that they had the least amount of subduction zone enrichment. However, Nb and Ta concentrations are also lower in HAOT than in CA lavas, suggesting a more depleted source (or higher degree of partial melting). Of the three mantle domains inferred beneath the Cascades, only MORB-source mantle and subduction-fluxed mantle are represented beneath the Glacier Peak region. No OIB-like mantle domain is thus-far known in the Cascades north of the Mt. Rainier region. This could indicate a boundary in the mantle between the southern and northern Cascade arc segments.

None of the suites can be related to each other by fractional crystallization or mixing and must be derived from distinct sources. In addition, the range of major and trace element compositions *within* two of the CA suites (Lightning Creek and Dishpan Gap) cannot be modeled by fractional crystallization, but instead show a distinct mixing trend toward Glacier Peak dacite. Sr and La *decrease* with increasing SiO_2 in these suites, and modeling shows that those high-Mg andesites are derived by mixing between primitive magmas and dacite, possibly derived from the crust. Disequilibrium phenocryst textures support this conclusion.

Geochronology and geochemistry of North Sister volcano, Oregon Cascade Range, USA

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North Sister Volcano is the oldest and most mafic of the Three Sisters Volcanoes within the actively extending Central Oregon Cascade Range. It was built during 4 eruptive stages that are compositionally distinct in major elements: the early shield (weighted mean $^{40}Ar/^{39}Ar$ age of 320 ± 66 ka), the interfingered palagonitic tuff and lava stage of subglacial origin ($^{40}Ar/^{39}Ar$ arge range 191.2 ± 28.7 ka and 105.2 ± 38.6 ka), the upper shield stage, and the stratocone stage ($^{40}Ar/^{39}Ar$ age range 71.7 ± 39.6 ka and 57.2 ± 36.8 ka). The Matthieu Lakes Fissure (53 to 60% SiO_2) is a >11 km-long, N-striking series of thick, dike-fed lavas and scoria cones that transects North Sister and has an $^{40}Ar/^{39}Ar$ age range 75.8 ± 31.0 ka and 15.1 ± 11.5 ka.

North Sister's seemingly monotonous basaltic andesite yields trends of decreasing incompatible elements (e.g. La, Ba) with decreasing compatible elements (Mg, Ni). Isotopic variations at North Sister are small, but systematic and reveal that $^{87}Sr/^{86}Sr$ decreases (0.70356 to 0.70369) and $^{144}Nd/^{143}Nd$ (0.51285 to 0.51292) increases with a 2% decrease in MgO. $^{187}Os/^{188}Os$ at North Sister is higher than regional basalts (0.18 vs. 0.14), indicating the magma assimilated a mafic crust. Petrologic modeling to replicate the uncommon compositional and isotopic trends points to a silicic contaminant, depleted in incompatible elements, itself derived by dehydration melting of an amphibole-bearing gabbroic to ultramafic cumulate in the deep crust.

High-precision argon dating at young arc volcanoes: Understanding the past 40 kyr at Middle Sister, OR

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Precise geochronology of latest Pleistocene (<40 ka) arc volcanoes is difficult because of low radiogenic yields on Ar analyses and limited ^{14}C material high on ice-clad volcanoes, but careful $^{40}Ar/^{39}Ar$ work can produce reliable results. The Three Sisters volcanic cluster in the Oregon Cascades consists of mafic to intermediate (+ minor dacite) stratovolcanoes surrounded by mafic to silicic flows and domes. Growth of Middle Sister (MS) and South Sister (SS) overlap in Late Pleistocene time; North Sister (NS) is middle Pleistocene in age. Abundant Holocene, Late Pleistocene, and older vents flank all Three Sisters. Mapping and geochronology of silicic flank eruptions adjacent to MS are used to resolve precise ages of major eruptive periods.

MS is a 3062m (10,047') Late Pleistocene composite cone with an andesitic base, a 300-500m thick basalt summit cone with no apparent unconformities, and intercalated dacites that issued from lateral vents at high and low elevations. Detailed $^{40}Ar/^{39}Ar$ incremental heating experiments on groundmass from carefully selected lavas yield precise ages on stratigraphically constrained units on and around MS. Young portions of the andesitic base are dated directly on the east and south flanks at 37±9 ka and 23±16 ka and the cone basalt at 21±19 ka; however, the analytical errors (all 1σ) are large due to low-K and difficult groundmass textures. Analytical errors of 1.9 - 2.2 ka on three thick dacite flows (SiO_2 64.0 - 65.4%wt.; K_2O 1.7 - 2.3%wt.) exposed on the flanks of MS bracket the growth of the volcano with far better precision. A distinctive dacite agglutinate unit (26±2 ka) that underlies all MS south-flank andesite and basalt lavas erupted near Chambers Lakes in the MS/SS saddle. To the west of MS, a sub-glacial protrusion of dacite that fed Lane Plateau (21±2 ka) intrudes older andesites, but is overlain by flows of MS summit cone basalt. A thick dacite flow (18±2 ka) that vented from the saddle between MS/NS overlies the MS summit basalts. In sum, laterally-vented silicic flows on the south, west and north flanks of MS bracket the eruption of the basalt cone that built the upper half of MS as younger than 21±2 ka and older than 18±2 ka. A silicic unit on the south flank also constrains the youngest basal andesite package as post-26±2 ka.

Magma storage and ascent at Mount Rainier from 2600 to 2200 ybp

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Mt. Rainier erupted much more frequently in the Holocene than is recorded by its 11 pumiceous tephras. During the 2600-2200 ybp Summerland eruptive period, 6 groups of thin (1-5 mm) Sparsely Vesicular Glassy (SVG) ash layers were deposited, followed by the 0.3 km^3 pumiceous C-tephra at 2200 ybp (Mullineaux 1974). Some SVG groups preserve up to 5 separate ash layers. Two lava groups and one block-and-ash flow (2500 ybp) are known from the Summerland period (any other effusive products are concealed by ice). SVG ash grains have blocky-to-fluidal shapes, are variably rich in plagioclase microlites, and their glasses are high-SiO_2 (66-78%) and low-Al_2O_3 (15-11%). MELTS models and phase equilibrium experiments yield apparent equilibration pressures <75MPa for SVG liquids. Low pressures and vesicle-poor microlitic grains indicate that SVG magmas largely degassed and partially crystallized during slow ascent to shallow levels. SVG ashes probably result from hydromagmatic explosions in the upper-edifice hydrothermal system during lava eruptions. Rare pumice lapilli were codeposited with 3 SVG ash groups and have homogeneous, microlite-free dacitic glasses, one with nonreacted hbl phenocrysts. These pumice result from very small batches of magma that ascended rapidly from reservoir depths, synchronous with or closely between effusive eruptions. The culminating C tephra has 4 juvenile components: dominant porphyritic andesite pumice, crystal-poor andesite scoria, blebs of vesicular white dacite in pumice & scoria, and poorly-inflated crystal-rich dacite (Venezky & Rutherford 1997). Melt inclusions from andesite pumice are dacitic with dissolved H_2O 3.6±0.4% & CO_2 <50ppm (FTIR, n=12), indicating ~100MPa if vapor-saturated, which may represent the top of the magma reservoir. Melt inclusions from white dacite blebs are rhyolitic with variable H_2O 1.9-3.7% & CO_2 150-<50 ppm (n=7), indicating vapor saturation pressures as low as 50MPa. The white dacite probably formed as segregations of interstitial liquid in the conduit, with CO_2 provided by passive degassing of the deeper magmatic system.

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Eruptive history of Mount St. Helens, Washington – A summary with new data

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Many previous investigators, using geologic mapping, tephrastratigraphy, radiocarbon geochronology, dendrochronology, and paleomagnetics, established the general eruptive history of Mount St. Helens (MSH). New geologic mapping and radiometric age data allow us to refine and extend their framework. The eruptive history of MSH is strongly episodic and dominated by a variety of hypersthene-hornblende dacites. Four stages of intermittent activity separated by hiatuses are recognized: Ape Canyon (300–35 ka), Cougar (21–18 ka), Swift Creek (13–10.5 ka) and Spirit Lake (4–0 ka). During the Ape Canyon stage, dacite domes characterized by quartz, and in many rocks biotite, erupted west of the present edifice, and an extensive hydrothermal system was present. During the Cougar stage, a debris avalanche was accompanied by voluminous pyroclastic flows, dacite domes and a 0.75 km^3 px andesite lava flow. During the Swift Creek stage, 3 extensive fans of fragmental debris were emplaced from dacite domes. The bulk of the pre-1980 edifice was constructed during the Spirit Lake stage, which is subdivided into the Smith Creek (4–3.3 ka), Pine Creek (3–2.6 ka), Castle Creek (2.6–1.9 ka), Sugarbowl (1,150 years BP), Kalama (1480 to 1725 CE), and Goat Rocks (1800 to 1857 CE) periods. The most voluminous pyroclastic eruption in MSH history, about 4 km^3 (DRE), took place during the Smith Creek period; dacite domes also erupted. The Pine Creek period included emplacement of extensive fans of fragmental material from dacite domes and debris avalanches. The Castle Creek period produced a diverse array of px and ol andesite lava flows, px dacite domes and pyroclastic flows, and ol basalt lava flows. During the Sugarbowl period, dacite domes erupted on the W, N and E flanks. A large pyroclastic eruption initiated the Kalama period and was followed by dacitic pyroclastic flows, domes and lahars, px andesite lava flows, and a large dacite dome. The Goat Rocks period produced a px andesite lava flow, dacite dome and a pyroclastic fan.

Field geology and petrology of the 2004-2005 Mount St. Helens dome

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The 2004-5 eruption of Mount St. Helens began with intense seismic unrest and uplift of crater floor and glacial ice during late Sept. 2004. Following phreatic steam and ash eruptions in early Oct., spines of new lava extruded and uplift expanded to the south and east. By 27 Oct., windows of hot lava breached the eastern area of uplift, and by 4 Nov. an elongate wedge of new lava emerged and rose to a height of ~100 meters. This "whaleback" had a smooth east face mantled by white fault gouge, dipped 40-60 degrees east, and was marked by dip-parallel striations and dark colored "bathtub rings," the latter recording periods of weathering during uplift. During Nov. and Dec., the whaleback moved southward in conveyor-belt-like fashion, transporting new lava from the north end, and shedding it as hot talus to the south and west. Fractures developed by early Dec., and by early Jan., 2005, the whaleback was segmented.

Helicopter assisted bucket or dredge sampling and short-duration landings allowed rock collections on 20 Oct. (talus at the base of one of the initial spines), 27 Oct. (face of one of the spines and a rock ridge to the west), 4 Nov. (talus at the south end of the whaleback), and 3 Jan. (southwestern summit of the whaleback). 20 Oct. and the 27 Oct. rock-ridge samples were cold when collected, and are interpreted as 1986 dacite, based on chemistry, phenocryst assemblages, microphenocryst abundances and presence of variable thickness reaction rims on amphibole. The hot samples are new lava. They lie off the high end of the SiO_2-time trend for 1980-86 lavas, have lower Fe-Ti oxide temperatures (850°C), higher abundance of small plagioclase microlites, very thin or no reaction rims on amphiboles, and partly to fully devitrified matrix glass. Low abundances of volatiles in glass inclusions and matrix glass, and low emissions of SO_2, H_2S and CO_2 indicate early and extensive degassing. These features favor slow cooling, degassing and phenocryst growth in the magma at depth, followed by slow ascent to the base of the 1992-2004 shallow seismic zone at about 3 km (while remaining within the stability field for amphibole), then by more rapid and mainly steady-state ascent to the surface, accompanied by final degassing and cooling -- a multi-stage history that led to an extremely viscous, gas-poor, and crystal-rich extrusion, accompanied by limited explosive activity.

The nature and origin of the MSH 2004 Eruption from sample petrology and experiments

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Samples of the Mount St. Helens 2004-05 lava dome have been studied analytically and experimentally. The magma is a dacite, about 2wt% more silica-rich (Pallister et al., 2004) than that of1980-86. Samples of the lava were kindly supplied by USGS-CVO staff. Questions we attempt to address are (1) what are the conditions in and the storage depth of the magma being erupted, (2) is there evidence of a mingled in high-T magma, and (3) how rapidly is the magma ascending? The new magma is a hornblende-Opx-plagioclase dacite; coexisting Fe-Ti oxides indicate the temperature of last phenocryst equilibration was ~850°C (11/04 sample), about 10°C cooler than the 1986 magma. In the 11/04 sample, plagioclse rims range down to An_{38}. Experiments at 850°C suggest pressures of 180-140 MPa, but more are needed to determine the pre-eruption pressure. The temperature may also need to be reconsidered. MSH350-1 collected on 1/3/05 contains Ti-magnetite crystals adjacent to ilmenite with Lo-Ti cores zoned to hi-Ti rims, and yield temperatures up to 950°C. These zoning profiles suggest a recent (within 1-2 months) thermal effect from a high-T magma in the pre-existing cooler (older) one. While the previous samples of the 2004-5 dome contained amphibole with no rims indicating a relatively rapid magma ascent from a storage zone at greater than 100 MPa (850°C), the 1/3/05 samples have hornblende with a very fine (2 micron) rim adjacent to melt. If the magma T was at 850°C, the rims would suggest a decreasing ascent rate. However, if the T is 935°C, the ascent rate probably has not decreased, and the experiments on amphibole stability requires this magma was >200 MPa.

LA-ICP-MS trace element and Pb-isotope analysis of Mt. St. Helens dome material from 1981-1985 and 2004-2005 eruptive episodes

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Renewed eruptive activity at Mount St Helens, Washington, provides a unique opportunity for petrologic and geochemical studies of an erupting silicic volcano. We report results from ongoing trace element and isotopic studies of lava and ash material from the 1980-1985 and 2004-2005 eruptive episodes. To date the work has focused on the relationship between recently erupted material and that from the 1980-1985 dome growth. Trace element contents in minerals (feldspar, hornblende and pyroxenes), groundmass and glass were determined by laser ablation ICP-MS techniques using a 193 nm ArF Excimer laser and VG PQII ExCell ICP-MS quadrupole mass spectrometer. Pb isotope compositions in feldspar and groundmass were measured using the same laser coupled with a NuPlasma multicollector ICP-MS.

Trace element contents of newly erupted material are largely similar to dome samples from 1980-1985, with some important differences. Feldspars from dome and fragmental material sampled on the 4 November 2004 have markedly elevated Li contents (40-60 ppm), compared to dome samples collected in October 2004 and from 1980-1985. Li enrichment may relate to volatile enrichment, but is significantly larger than that observed in feldspar associated with the May 1980 plinian eruption (Berlo et al., 2004 Science). The samples taken from the new dome flank in October 2004 are probably fragments of uplifted older material in the conduit or crater floor, but a small proportion of feldspars from fragmental samples associated with October steam explosions also have elevated Li. $^{208}Pb/^{206}Pb$ ratios measured in groundmass also differ between October (2.0477±0.0017) and November (2.0425±0.0011) dome samples, arguing against simple closed-system magmatic differentiation as the source of compositional variation between these magmas. Feldspars from both samples also show a more diverse range of Pb isotope compositions than groundmass.

Petrology and geochemistry of Mount St. Helens ash before and during continuous dome extrusion

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Ash samples of the current Mt. St. Helens dome building event have been collected since the initial eruption on October 1, 2004. Analysis of dome material collected periodically, beginning October 20, 2004, establishes a frame of reference for evaluating the time-series of ash samples collected prior to and since the first appearance of new lava in the crater on October 11. The ash deposits are comprised predominantly of feldspar crystals accompanied by amphibole, pyroxene and fragments of crystalline groundmass and glass.

Comparisons of major- and trace-element phase chemistry and groundmass textures in ash deposits reveal a progression of sources from a heterogeneous assemblage dominated by fragments of older crater material, toward a more homogeneous assemblage derived from fragmentation of the new lava dome. Early ash emissions had glass compositions ranging from basaltic andesite to high-silica rhyolite. Distinct clusters of analyses, especially evident in TiO_2 and MgO, clearly indicate mixed populations of glass fragments in early events. Variability in melt inclusion and glass fragment major-element chemistry in ash however is more restricted and better reflects juvenile dome compositions with ongoing dome growth.

LA-ICP-MS analysis of feldspar crystals in freshly extruded dacite show that despite consistent Ba concentrations, Li concentrations are significantly greater than observed in 1980 to 1986 dome lavas as well as dome samples from October 2004. This enriched Li signature is significant in that it may be a useful indicator of juvenile material in ash deposits despite the high variability in major-element glass chemistry. Ash deposits may also provide material from otherwise unsampled components of hotter near-vent and flow-interior facies of dome lava, and may provide the first indication of new magma compositions. Our ongoing ash studies are demonstrating the utility of collection and analysis of tephra for tracking magmatic changes during prolonged dome extrusion.

U-series crystal ages in Mt St Helens lavas, 2000 ybp-2004 AD

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U-series ages of crystals in volcanic rocks can provide information on the duration of crystal residence in crustal reservoirs and can also be used as tracers to track crystal populations that may be recycled within the same volcanic system. We have previously reevaluated crystal ages in recent (<~2ka) Mt St Helens lavas [1, 2] based on differences in chemical behavior of Ra and Ba. Model ^{226}Ra-^{230}Th crystallization ages for plagioclase in 5 of 6 samples are 2-4 ka, indicating storage of crystals for hundreds to thousands of years prior to eruption. In two out of those five samples, ^{226}Ra-^{230}Th and ^{230}Th-^{238}U ages are discordant, a pattern consistent with protracted and/or episodic crystallization spanning tens of thousands of years. Finally, in the sixth sample (of the 1982 dacite dome), Ra in plagioclase is anomalously enriched relative to Ba. This pattern could be produced by rapid crystal growth, resulting in suppressed fractionation of Ra and Ba relative to that predicted for chemical equilibrium.

We are currently in the process of analyzing ^{226}Ra-^{230}Th and ^{230}Th-^{238}U disequilibria in mineral separates (plagioclase and amphibole) and groundmass from a sample of the Mt St Helens Nov. 2004 dome. We anticipate that the dataset will be complete by the time of the meeting, and we predict that 1) If the 2004 dome taps residual magma from the 1980's, 2004 plagioclase should show anomalouly high Ra/Ba, as observed in the 1982 dacite and consistent with ^{210}Pb-^{226}Ra data suggesting recent crystallization; 2) If petrographic differences between the 1980's and 2004 samples (e.g., fewer sieved cores in plag and the absence of reaction rims on amphibole in 2004) indicate that different crystal populations are being sampled, crystal ages could delimit the storage time; and 3) If the 2004 crystals contain a significant proportion of old (>10 ka) cores overprinted by young growth, ^{226}Ra-^{230}Th and ^{230}Th-^{238}U ages will be discordant.

References

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Plagioclase zoning in dacites of the current Mt. St. Helens eruption

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Mt. St. Helens' current activity started in late September 2004 with periodic phreatic steam blasts and minor ash eruptions followed by the appearance of a new lava dome in late October. Juvenile dacite samples collected in the crater on November 4, 2004, and January 3, 2005, are geochemically and petrographically distinct from 1980-86 dome rock. We have performed a textural and compositional analysis of plagioclase in new juvenile dacites to obtain additional constraints of magmatic processes leading up to and occurring during the current dome extrusion.

The dominant plagioclase population consists of euhedral, clear 0.5-1 mm phenocrysts making up >80% of all phenocrysts. Similarly sized phenocrysts and rare large crystals (1-3 mm) with a sieved core (rarely coarse) are subordinate. Plagioclase crystals of the dominant population reveal weak oscillatory zoning associated with only minor relief patterns on Nomarksi images. Furthermore, many plagioclase crystals indicate a characteristic rim that 1980-86 dome dacites lack. The rim is commonly emphasized by a zone of acicular opx inclusions typically aligned with their long axis parallel to the plagioclase rim. Nomarski images reveal that opx-enriched zones in plagioclase are typically inboard of a resorption surface that separates the rim from the rest of the crystal. Microprobe data indicate that plagioclase composition directly inside the resorption surface is An_{35-40} before experiencing abrupt increases by 5-20 mol% in adjacent overgrowth. Zoning within the rim is typically normal with return to An_{35-40} composition at the outermost rim.

Our data can be interpreted as evidence for a rise in temperature, perhaps due to influx of hotter magma, causing resorption of the plagioclases, which in turn could lead to a higher Ca/Na ratio in the adjacent melt. Renewed plagioclase crystallization of a Ca-enriched melt would lead to the initial higher An plag before equilibrium growth with reduced Ca/Na ensues. Our results may indicate introduction of hotter magma prior to ascent to the surface.

Cascade volcanic arc of southern Washington: The early years

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Three geochemically distinct suites of subaerially erupted basalts were produced in close proximity during the first 2 m.y. of Cascade arc volcanism in southwestern Washington:

Kalama River Basalt (KRB)

Ol±pl-phyric low-K tholeiite formed a large shield volcano about 39 Ma; unexposed source vents probably lie buried south of Mount St. Helens. These flows overlie mafic to silicic volcanic and volcaniclastic rocks representing the earliest activity of the Cascade arc. KRB basalts are products of extensive (Mg#=71-43) shallow-level differentiation of primitive basalt (MgO=11 wt %, K_2O=0.10 wt %, Ni = 230 ppm, Cr = 400 ppm). Incompatible-element ratios (Ba/La<9, Ba/Nb<10, La/Ta=14, Zr/Y>4.4, $(La/Yb)_n$=2.2-2.7, Ba/Zr<1, Zr/Nb=11-13) indicate genesis of parental magmas by melting of EMORB-source asthenospheric(?) mantle with no subduction-zone input.

Wolf Point Basalt (WPB)

Ol±cpx-phyric basalt and basaltic andesites (Mg#=74-54) erupted from scattered vents in the arc about 39-38 Ma, shortly after cessation of KRB volcanism. Primitive basalts (MgO=9.5-11.0%) vary widely in K_2O (0.3-2.6%) and incompatible-element ratios (Ba/La=4-13, Ba/Nb=8-44, La/Ta=32-101, Zr/Y=4-14, $(La/Yb)_n$=3.9-18.2, Ba/Zr=0.6-2.8, Zr/Nb=7-26), probably reflecting varying contributions from slab fluids; quartz xenocrysts in some basaltic andesites record crustal contamination of mantle-derived basalts.

Grays River Volcanics

Cpx±ol-phyric high-TiO_2 (2.2-3.9%) basalts erupted from fissure vents in the adjacent forearc. They overlap in age with the other two nearby suites (40-37 Ma). They are more evolved than KRB and WPB lavas (Mg#=57-35) and carry a strong OIB-type chemical signature (Ba/Nb=4-6, Zr/Y=6-8, Ba/Zr<1.1, Zr/Nb=4-6).

The close spatial and temporal juxtaposition of diverse late middle Eocene mafic lavas – and the implied juxtaposition of oceanic and arc-type mantle sources - indicates an exceptionally complex tectonic environment for the infant Cascade arc of SW Washington. This complexity may reflect a combination of subduction of a segment of the Kula-Farallon ridge, overriding of a hotspot, breakup of the subducting slab, and intra-arc rifting.

Geochemical profiling, Nomarski imaging, and crystal size distribution analysis of mixed magmas from Lassen Peak, CA

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Plagioclase crystals from a suite of mixed rocks from the 1915 Lassen Peak eruption were analyzed using a combination of imaging and geochemical techniques. Measurements of plagioclase from four rock types (dark andesite, quenched andesitic inclusions, black dacite, light dacite), produced by variable mixing between intruding basaltic andesite and reservoir dacite reveal insight into magma mixing and eruption dynamics. Crystal size distribution (CSD) analysis of the four rock types reveals three plagioclase populations: phenocrysts (0.5–3.0mm), microphenocrysts (0.1–0.5mm), and microlites (<0.1mm). CSD slopes identify distinct nucleation and growth environments for each population. Independent of rock type, plagioclase phenocrysts appear to have crystallized under near equilibrium conditions characterized by relatively slow growth and nucleation rates as indicated by gentle CSD slopes. Only unreacted phenocrysts (i.e., those relatively unaffected by the temperature increase from mixing) were used for size and chemical analysis in order to assess pre-mixing conditions. CSD slopes of the microphenocryst and microlites are steeper, respectively, indicating non-equilibrium nucleation and growth. Major element analysis confirmed plagioclase populations to be independent of host whole-rock composition: phenocrysts An_{29-40}; microphenocrysts An_{59-82}; microlites An_{40-67}. Nomarski imaging was correlated with major element traverses, elucidating the growth characteristics of plagioclase populations. Near-homogenous compositions and relatively simple growth textures suggest that the pre-mixing reservoir was relatively thermally and chemically isolated prior to the 1915 event. Following mafic recharge and initial mixing, temperatures in the hybrid magma caused nucleation of the An-rich microphenocryst population; steeper CSDs and acicular morphology indicate rapid nucleation and growth at undercooled conditions. Microlites show correlations with whole-rock composition and were likely nucleated in the mixed magmas shortly before eruption.

A 7400-sample geochemical-geospatial database for Oregon Cascade Range volcanic rocks

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We have compiled a whole-rock geochemical database containing 7400 analyses of Cenozoic volcanic rocks from the Cascade Range of Oregon. The database comprises 5700 analyses from publications, theses, and dissertations, and 1700 of our own previously unpublished analyses. The majority of the 7400-sample suite has been analyzed for 27 major and trace elements. Each sample is assigned to one of eleven age groups – five from period 0-2 Ma and six more for period 2-45 Ma; these groupings correspond to the map units on the Oregon Cascade geologic map (USGS I-map 2569). Over 70 percent of the entries have corresponding geospatial coordinates, including many that were generated exclusively for this database by extensive consultation with the data-source authors.

Some broad geographic correlations are obvious and consistent with Cascade Range-wide geologic maps. For example, Quaternary andesite and dacite are predominant at the stratocones, and Quaternary mafic lava--basalt and basaltic andesite--forms the extensive background along the arc in Oregon. But many geochemical findings from this geospatial database reveal significant regional variation reflective of tectonomagmatic trends. Some big-picture items:

(1) Low-K tholeiite is found along the entire arc in Oregon since 8 Ma. In northern Oregon these basalts become younger northward along the arc. In southern Oregon they span the age range 0-8 Ma with no apparent age progression.

(2) K-rich basalt is widely but sporadically distributed along the arc, and a wide range in basalt composition is found at any latitudinal position.

(3) The composition of 0-8-Ma mafic lava changes systematically along the arc, in a manner compatible with decreased partial melting northward—such as lower Ca/Al ratio and higher concentrations of Na and incompatible elements.

Helium isotope systematics in geothermal fluids of the Cascade volcanic arc

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Helium isotopes are excellent tracers of magmatic processes, but also processes at the geothermal-hydrological interface, and are therefore uniquely suited to study magmatic and geothermal interactions in the Cascade volcanic arc. Results are presented here of an on-going study to characterize the $^3He/^4He$ systematics of geothermal fluids of the Cascade volcanic arc.

The $^3He/^4He$ ratios of geothermal features at or near the summit of most Cascade volcanic centers fall within the range of 6.8 – 8.6 Ra (Ra is the $^3He/^4He$ ratio in air) typical for subduction zones. Mt. Shasta (5.5 Ra) and Mt. St. Helens (5.7 Ra) are noted exceptions. Moving away from the volcanic crest, $^3He/^4He$ ratios in fluids from thermal and chemically anomalous non-thermal features systematically decrease. This observation is consistent with the thermal fluids that feed the hot springs far (> 25 km) to the west (and east) of the volcanic crest deriving their heat and helium from a magmatic source centered on the volcanic crest.

The new $^3He/^4He$ data combine with existing literature and unpublished data to cover a period of more than 20 (in some cases even 30) years of sporadic sampling. Comparison with the older data shows that many features appear to have remained relatively stable over that period of time. However, several features, most notably summit features at Mt. Hood, Mt. Shasta, and Newberry Caldera, show significant variation in their $^3He/^4He$ systematics on a decadal time scale. For these particular cases, changes in the shallow geothermal system can be excluded as the cause for the observed variations. So the most likely cause is changes in the shallow magmatic plumbing system of the volcanoes.

These observations illustrate the value of building up a helium isotope (and other fluid chemistry) history for these volcanic centers. Since changes in fluid chemistry are usually closely associated with changes in the activity level of the volcano, such a database will lead to a better understanding about the causes of events like periods of bulging, subsidence or earthquake swarms that are still poorly understood.

Compositional relationships between mafic inclusions and host andesite at Mount Hood (Oregon), Cascade Range, USA

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Mount Hood has erupted compositionally similar calc-alkaline andesite, in which slightly more mafic inclusions are found within the andesite (host lavas), but are not found in lavas erupted from satellite flank vents (flank lavas). We investigated six inclusion bearing sites (23 inclusions and 15 host lavas) younger than 150 ky. Major mineral phases present in the inclusions and host lavas are plag + opx ± cpx ± amp + oxides, whereas the mineral assemblage of the flank lavas, contain olivine rather than amphibole. The average silica content of samples analyzed range from 57.6 to 62.7 wt %; however the incompatible trace element compsosition is more variable at lower silica contents leading to “enriched” and “depleted” samples and becomes less variable at higher silica contents.

Petrogenetic modeling of the compositional relationships among mafic inclusions and host lavas suggest the following. Fractional crystallization and AFC processes may explain some relationships but both fail to explain the overall key geochemical feature of constant or decreasing incompatible trace element abundances with increased silica contents. On the other hand, the greater variability in the degree of incompatible element enrichement at lower silica is likely due to variability in trace element concentration among mafic end members similar to those erupted as flank lavas and during the Pliocene in the vicinity of Mount Hood. Flank lavas and Pliocene mafic lavas compositionally overlap with modeled mafic endmembers. This suggests that various mafic magmas have been fed into the Mount Hood magmatic system and yield inclusion and host andesite compositions through mixing ± fractionation. Increased mixing causes evolved magmas to become increasingly compositionally focused and monotonous towards increased silica contents leading to great similarity among Mount Hood andesites and suggesting that silicic mixing endmembers are compositionally narrow.