

basaltic scoria samples from Guguan, Pagan and Agrigan islands of the Mariana arc. The MIs studied are olivine-hosted (Fo 68-82), 50-300 m, clear brown glass with no visible evidence of devitrification. We have analyzed these MIs for H<sub>2</sub>O and CO<sub>2</sub> by FTIR, major elements by EMP and trace elements by laser ablation ICP-MS. The MIs range in water content from 1-4 wt.%, but MIs with detectable CO<sub>2</sub> indicate a tighter range of H<sub>2</sub>O concentrations in undegassed inclusions from 2.5-4 wt.% and averaging 3 wt.% H<sub>2</sub>O. The MIs are broadly similar in both major and trace elements to lavas from the same islands, but these new data extend the range of trace element compositions observed in Mariana arc lavas. We have analyzed MIs from Agrigan with trace element systematics nearly identical in Ba/La and La/Sm to that of bulk subducting sediment in the Marianas, and from Guguan with a composition very close to the inferred slab-derived fluid composition. One Guguan inclusion is of particular interest. It has 3.5 wt.% H<sub>2</sub>O with an NMORB REE pattern (La/Sm=0.76), high Ba/La (70) and very high U/Th (1.1). It also has high Pb/U (25) demonstrating a preference for Pb over U in slab-derived fluids. The composition of this inclusion also plots near the y-intercept (zero sediment flux) on global arc-sediment flux correlation diagrams, confirming that it represents close to an average global sediment-free slab fluid composition. Compositions this extreme have never been measured in Mariana arc lavas before. On the other hand, this fluid-rich arc melt has a very different composition from a comparable melt calculated using the H<sub>2</sub>O-rich component of Stolper & Newman (1994) for the Mariana back-arc, which has lower Ba/La (11), U/Th (0.4) and Pb/U (4.2). This contrast in arc and back-arc fluids is suggestive of two potential processes. A similar slab-derived fluid may be added to variably depleted mantle, less depleted in the back-arc and more depleted beneath the arc. Alternatively, the slab may undergo progressive dehydration, where sub-arc dehydration removes fluid-mobile elements and depletes the slab of such elements before further dehydration in the back-arc.

#### V21C-11 1120h

##### Water Abundance in Arc Magmas: Olivine Melt Inclusions From Central America

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Water and CO<sub>2</sub> variation in arc magmas has been investigated using olivine melt inclusions from nine scoria and ash deposits in Central America. Samples from Nejapa and Granada regions of Nicaragua are among the most primitive (bulk MgO 6.9 to 8.8 wt.%), have moderate Ba/La ratios (30 to 60) and contain olivine phenocrysts of composition Fo<sub>91-86</sub>. Melt inclusions within these deposits are characterized by low to moderate water and high CO<sub>2</sub> (2 to 3.5 wt.% and 1,000 to 2,500 ppm, respectively; determined by FTIR). Other Nicaraguan (including Momotombo, Cerro Negro, Telica) and Guatemalan (Fuego) samples are more evolved (bulk MgO 3.4 to 6.4 wt.%), have moderate to high Ba/La ratios (52 to 116) and contain olivine phenocrysts of composition Fo<sub>78-82</sub>. Melt inclusions are characterized by high water contents (generally 3.5 to 4 wt.%) and CO<sub>2</sub> of 1,200 ppm or less. Many samples (including primitive Nejapa and Granada) show evidence of heterogeneity. For example, high-TiO<sub>2</sub> inclusions are sometimes found in low-TiO<sub>2</sub> magmas and vice versa, or low-Ba and Ba inclusions are found in units where high-Ba and Ba inclusions predominate. Also, some individual eruptive units display heterogeneity in water abundance. For instance, some define steep CO<sub>2</sub>-degassing trends at nearly constant water while others show significant H<sub>2</sub>O variation (1 to 1.5 wt.%; ~30% relative) at elevated CO<sub>2</sub> that cannot be explained by degassing. Instead, the heterogeneity in water and major and trace elements suggests that individual eruptive units are comprised of variably admixed magma batches. In the Nejapa and Granada area, where the arc signature is less pronounced, there is an apparent positive correlation between water abundance (average melt inclusion) and bulk-determined (ICP-MS) incompatible elements (K, Rb, Ba, Sr, Pb, U) with low-TiO<sub>2</sub> magmas having higher water abundance than high-TiO<sub>2</sub> magmas. In contrast, volcanic units with stronger arc signatures show no correlation between water and trace elements. The latter observation may be caused by multiple additions of slab-derived material to the magma source region.

#### V21C-12 1135h

##### Pre-eruptive Volatile Concentrations in Rhyodacitic Melt Inclusions From Mt. Mazama: Implications for Eruption Triggering

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At least two (and probably more) episodes of andesite to basaltic andesite magma recharge and differentiation led to the accumulation of the large ~ 45 to 50 km<sup>3</sup> of rhyodacitic magma beneath Mt. Mazama. These recharge events are recognized on the basis of Sr concentrations in plagioclase phenocrysts and matrix glasses in both rhyodacitic pumices and andesitic scoria. Strontium concentrations of plagioclase phenocrysts in rhyodacitic tephra erupted during earlier smaller volume ~ 2 km<sup>3</sup> Llaos Rocks 7015 ± 45 yr.B.P. (Bacon, 1983) and shortly preceding Cleetwood eruptions provide some temporal constraints (200-170 years) on the timing of these magma recharge episodes. An electron microprobe and FTIR study of glassy melt inclusions in rhyodacitic tephra from the climactic, Cleetwood and Llaos Rocks eruptions was initiated in order to observe the temporal variation in dissolved volatiles (H<sub>2</sub>O, CO<sub>2</sub>, Cl, S, F) concentrations in the accumulating rhyodacitic magma body. Dissolved volatiles concentrations and trace element data are used to evaluate the effectiveness of magma recharge as a potential eruption trigger for the climactic eruption.

Several samples from various stratigraphic levels of the climactic, Cleetwood and Llaos Rocks pumice fall sequences were selected for the melt inclusion study. Rhyodacitic melt inclusions in plagioclase and orthopyroxene in climactic tephra range from felsic dacite (68-69 % SiO<sub>2</sub> anhydrous) to rhyolite (70-73% SiO<sub>2</sub> anhydrous). Total dissolved H<sub>2</sub>O concentrations determined by FTIR range from 4.3 wt.% to 6.0 wt.%. Dissolved CO<sub>2</sub> concentrations were below detection level (~ 20 ppm) in all climactic rhyodacitic inclusions. Chlorine concentrations range from 1720 ppm to 3930 ppm in less evolved inclusions. Dissolved sulfur concentrations range from 70 to 300 ppm with highest sulfur concentrations occurring in high Cl and H<sub>2</sub>O inclusions. Dissolved fluorine concentrations range from 200 ppm to 900 ppm but do not exhibit any obvious correlation with other volatiles. Cleetwood melt inclusions span the same composition range as observed in climactic samples (68-73% SiO<sub>2</sub>). Total dissolved H<sub>2</sub>O concentrations by FTIR range from 4.2 to 5.4 wt.%. Dissolved CO<sub>2</sub> concentrations were below detection in most inclusions although one inclusion with 4.22 wt.% H<sub>2</sub>O by FTIR has 60 ppm CO<sub>2</sub>. Chlorine concentrations are similar to those observed in climactic inclusions and range from 1700 to 3950 ppm. Sulfur concentrations in Cleetwood rhyodacitic to dacitic inclusions range up to 500 ppm with several inclusions in the 330 to 450 ppm range. These high sulfur inclusions generally occur in inclusions with > 5.00 wt. % H<sub>2</sub>O and > 2100 ppm Cl. Llaos Rock rhyodacitic inclusions exhibit similar H<sub>2</sub>O concentrations but typically have much lower dissolved sulfur concentrations in the range of 60 to 130 ppm, with Cl concentrations from 1600 to 1800 ppm. Strontium and barium trace element data indicate that high sulfur, chlorine and H<sub>2</sub>O inclusions in Cleetwood and climactic phenocrysts can be attributed to fractionation from high Sr and sulfur basaltic andesite parent liquid(s) which recharged the chamber 170 years (or less) before the climactic eruption.

#### V21C-13 1150h

##### Ore Metal-rich Fluids Degassed from a Fractionating Magma Chamber in the Eastern Manus Basin, Western Pacific: Evidence from Melt Inclusions and Vesicles

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Magmatic fluids are found in vesicular volcanic rocks that host several hydrothermal fields in the eastern Manus backarc basin. Dredged samples of fresh lavas, of basalt to rhyolite composition, define a calc-alkalic trend consistent with fractionation of a common source. Their vesicularity decreases with Si, K, Ba and Zr, and increases with Ca, Mg, Fe and Sr of the bulk samples, suggesting that the degassing of volatiles was

linked to crystal fractionation of the magma. The felsic rocks have much lower vesicularities (<10%) than the mafic rocks (>30%), indicating that the fractionated felsic magma lost most of its vesicles before its eruption. High concentrations of H<sub>2</sub>O (0.9 to 2.5%) and Cl (up to 0.45%) observed in the mafic melt inclusions in phenocryst minerals of the basaltic andesite point to a volatile-rich magma. A separate fluid phase is present in the melt inclusions so the magma must have been saturated with volatiles in the magma chamber. The volatiles exsolved as an immiscible fluid with increasing crystal fractionation, and the composition of the degassed magmatic fluid changed with the evolving magma. The fluid is CO<sub>2</sub>-dominated during the degassing of weakly fractionated mafic magma and becomes a mixture of CO<sub>2</sub> and H<sub>2</sub>O as H<sub>2</sub>O is increasingly exsolved from the highly-fractionated felsic magma. The ore metals in the degassed fluid, as inferred from the compositions (by EPMA, SEM/EDS and TOF-SIMS) of metallic precipitates in the vesicles of melt inclusions and matrix glass, progressively change from Ni+Cu+Zn+Fe in basalt and basaltic andesite, to Cu+Zn+Fe in andesite, Cu+Fe in dacite, Fe in rhyodacite and Fe+Zn (+Pb?) in rhyolite. This trend provides evidence that fluids, released from a fractionating magma, could be an enriched source of metals for various types of ore deposits. In particular, the pre-eruptive degassing of magmatic fluids from felsic magmas could be responsible for the Fe, Cu, Zn and Pb metals in the sulfide chimneys at PACMANUS and Susu in the eastern Manus basin. By analogy, a magmatic fluid can provide a major source of ore metals for large or super large volcanogenic massive sulfides deposits in the geological record of ancient island arcs.

#### V22A MCC: Hall C Tuesday 1330h

##### Melt Inclusions: What Do They Tell Us? II Posters (joint with OS)

**Presiding:** N Shimizu, Woods Hole Oceanographic Institution; C Mandeville, American Museum of Natural History

#### V22A-1212 1330h POSTER

##### Nano-Diamonds in melt inclusions in ortho- and clinopyroxene from mantle xenoliths, Salt Lake Crater, Hawaii.

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We observed nanocrystalline diamonds in magmatic rocks from Hawaii (Salt Lake Crater). They occur in mantle xenoliths (Ga-pyroxenites) in melt inclusions in ortho- and clinopyroxene. The xenoliths are incorporated in the host lava and have been transported from the Earth's interior to the surface by volcanic eruptions. Consequently, such xenoliths allow an insight into the structure, the chemical composition and the P-T conditions of the Earth's mantle. Salt Lake Crater pyroxenites are interpreted as high-pressure basaltic cumulates trapped and adiabatically cooled within the Hawaiian lithosphere at 1000° - 1150°C and 1.6-2.5 GPa (50-80 km). The melt inclusions were investigated by using TEM and AEM.

Specimen preparation was performed by focused ion beam technique (FIB) at the GeoForschungsZentrum Potsdam (GFZ). Promising melt inclusions in pyroxene have been selected from thin sections. FIB technique uses oil-free vacuum to avoid contamination of the foil. The resulting TEM foil has the dimensions 20 μm x 10 μm x 100 nm. Coating of the TEM ready foil with carbon was not necessary.

Nanocrystalline diamonds are embedded in melt droplets, which are enclosed in pyroxene crystals. The melt inclusions with an average diameter of about 5 μm are always associated with a fluid phase or gas. The matrix of the melt inclusion consists of amorphous material (basaltic glass) containing very small inclusions of e.g. ZnS, Fe-Pd-S, Ag and Ir-rich minerals, native nanocrystalline iron and copper. Most of the diamonds occur in approximately rectangular shaped aggregates of polycrystalline diamonds, between 20 and 500 nm in size. The grain size of individual diamonds within each aggregate varies from 5 to 50 nm. The diamonds have been identified by X-ray analysis, electron diffraction and by EELS. The carbon K-edge in the EEL spectra allows to discriminate diamond, graphite and amorphous

carbon. Some of the diamonds are single crystals; most of them are polycrystalline. Electron diffraction of the latter show a ring pattern, which can be indexed by (111), (220), (113), (400) according to the space group Fd-3m of diamond. A weak preferred orientation of the very small crystallites is indicated by maxima in the ring pattern. Beside the diamond inclusions there are other inclusions, of similar or smaller grain size, like corundum, aragonite or orthopyroxene.

The first observation of diamonds in melt inclusions in Hawaiian lava might give insights both into the formation of diamonds and the geochemical processes operating in the mantle beneath the Hawaiian Island chain.

## V22A-1213 1330h POSTER

### Cooling Rate and Isothermal Crystallization Effects on Melt Inclusion Formation in MORB High-An Feldspar and High-Fo Olivine

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The uncertainty regarding the nature of entrapment mechanisms is an important issue in melt inclusion studies. One example of this problem involves melt inclusions within high-An feldspar and high-Fo olivine phenocrysts that are commonly present in MORB lavas. Such inclusions are valuable potential sources of information on the diversity of MORB parent magmas, and in many cases their major element compositions are consistent with a parental relationship with the host. However, some of the inclusions in N-MORB phenocrysts are anomalously depleted in some minor and trace elements, and it is not clear whether this diversity can be attributed in any way to the entrapment process.

We have addressed this problem through a series of experiments using anorthite/ferroite saturated anhydrous mafic liquids cooled to 1230° and 1210° C from 1300° C. The liquids were cooled at rates of 1°, 5°, and 10°/min. followed by 0-24 hours isothermal periods. We observed that primary melt inclusion formation is related to crystal morphology, which is a function of the degree of undercooling, cooling rate, and length of the isothermal period. Hopper and skeletal morphologies form during the cooling period, and planar overgrowth of these textures during the isothermal period forms the majority of inclusions. Our results indicate that 1° and 5°/min. cooling rates are the most favorable for hopper and skeletal crystal morphologies, and the greatest frequency of inclusions occurs with 5°/min. (for feldspar) and 1°/min (for olivine) cooling, followed by 6 hours isothermal time. With increasing isothermal time past 6 hours, the frequency of inclusions decreases and the size of the crystals increases. This may indicate that Ostwald ripening plays a role in controlling inclusion frequency during longer isothermal periods. The length of the isothermal period required for the formation of most inclusions precludes the trapping of a boundary layer or diffusional profile, and all inclusions in olivine and plagioclase formed during the isothermal period have compositions identical to the surrounding glass. Significantly, no difference between K<sub>2</sub>O contents of host glass and melt inclusions was observed and there is no evidence for the formation of low-Ti inclusions.

We propose that primary inclusion formation may result from a moderate amount of undercooling followed by a short isothermal period and subsequent quenching. Such circumstances could occur in nature when a partial melt rises in a conduit into cooler crust and stagnates at shallow levels for a short period before an eruption.

## V22A-1214 1330h POSTER

### Ca-rich Plagioclase in Island Arc Tholeiite: Approaches from Hydrrous Melting Experiments and Melt Inclusion Study

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Ca-rich plagioclase phenocrysts (~An90) are often observed in island arc tholeiite. As the Ca/Na partitioning between plagioclase and dry basalt magma do not allow the crystallization of such Ca-rich plagioclase from bulk composition, they are considered to have crystallized from hydrous and/or primitive Ca-rich magma. However, their crystallizing conditions are

not constrained well, partly because the previous melting experiments at hydrous condition do not cover the compositions of the low-K island arc tholeiites. For this reason, the hydrous melting experiments on low-K island arc tholeiite from the Izu-Oshima volcano, Japan, were performed to understand the effect of water on the phase relation and the origin of the Ca-rich plagioclase.

Two kinds of relatively undifferentiated basalt with different Ca/Na ratio were prepared as starting materials: aphyric MA44 and porphyritic MA43. The experiments were performed under 2.5 kbar and Ni-NiO buffer using an internally heated pressure vessel. Water content was varied from 0 through 6 wt.%.

The plagioclase was consistently the first liquidus phase for the porphyritic sample MA43 for any water content, but augite replaced plagioclase as the first liquidus phase with increasing water for the aphyric MA44. The Ca/Na partitioning coefficient between plagioclase and melt increases with increasing water content in the melt and no temperature effect was detected and this was confirmed by the calculation of the MELTS program. The obtained results suggest that more than 3 wt.% of water in the melt is necessary to crystallize plagioclase of ~An90 from the bulk composition.

In order to confirm this estimation, the chemical compositions and the water content of the melt inclusions contained in the natural Ca-rich plagioclase phenocrysts from the Izu-Oshima volcano were examined. The melt inclusions show a wide range of composition suggesting the inclusions were enclosed at various stage of differentiation although the host plagioclase composition is relatively homogeneous. The water contents of the melt inclusions were only 1 wt.% at maximum. The compositional variation within melt inclusion overlaps with the differentiation trend obtained from the analysis of bulk rock chemistry of the Izu-Oshima volcano. The chemical composition and water content in the melt inclusions suggest that the origin of Ca-rich plagioclase can be explained neither by the presence of the extremely Ca-rich melt nor the equilibrium crystallization from the hydrous melt of more than 3 wt.% H<sub>2</sub>O.

## V22A-1215 1330h POSTER

### High-Ca Melt Inclusions in Primitive Shoshonites: Magma-Wall Rock Interactions?

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Pliocene absarokites from Tavua and Astrolabe Group volcanoes (Fiji) contain olivine phenocrysts Fo 93-72. Primitive olivines (>Fo 85) show a significant range in CaO content (0.1-0.47 wt% CaO), with high-Ca olivine (>0.35 wt% CaO) being most abundant. Melt inclusions (MI) hosted by high-CaO olivine are large and numerous. On the other hand, low-CaO primitive olivines are either devoid of MI, or MI tend to be smaller and comparatively less abundant. Prior to analysis, MI have been reheated to 1160-1325 °C for 3-5 min. and quenched to glass. MI hosted by evolved olivine (<Fo85) have compositions that match evolved rocks of the suites. In contrast, primitive high-CaO olivine hosts contain MI with very high CaO (up to 19 wt%), low SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>, resulting in extreme CaO/Al<sub>2</sub>O<sub>3</sub> ratios (up to 1.95). The less abundant and comparatively smaller MI, hosted by primitive medium-CaO olivine (CaO 0.25-0.35 wt%) have compositions representative of primitive shoshonitic melts. They have higher SiO<sub>2</sub> and 'normal' CaO (10-14wt%) and Al<sub>2</sub>O<sub>3</sub> (13-17wt%), resulting in CaO/Al<sub>2</sub>O<sub>3</sub><1. Low-CaO olivines (<0.25 wt%) contain rare low-CaO, low-SiO<sub>2</sub> MI with high Na<sub>2</sub>O, K<sub>2</sub>O and TiO<sub>2</sub> contents. Occurrence of large and numerous MI in high-CaO olivines reflects rapid magma cooling and olivine growth. An environment where this can occur is at margins of a hot magma body where it interacts with colder wallrocks. The high-CaO MI in these olivines may then represent hybrid melts formed during localised assimilation. Less abundant, smaller primitive MI with "normal" compositions are likely trapped within the slow-cooling bulk of the magma, and are under represented due to a sampling bias phenomenon whereby hybrid melts are preferentially trapped during fast crystallisation.

## V22A-1216 1330h POSTER

### Source of Detrital Chrome Rich spinels with melt inclusions from the Cretaceous greywackes of the eastern Tethyan Himalayas: hot spot volcanics, not ophiolites

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Chrome rich spinel is a detrital component in turbidites from the well-exposed, mid-late Cretaceous Tianba Flysch sequence in the Nieru Valley, southern Tibet. Microprobe results indicate that the spinels have a well-developed Fe-Ti trend, and have Cr/(Cr+Al) 0.4-0.65, Mg/(Mg+Fe<sup>2+</sup>) 0.3-0.9, and TiO<sub>2</sub> >1 wt.%. The compositional range of these detrital spinels closely matches that of spinels from intraplate basalts, and is very similar to spinel inclusions in olivine from Hawaii and Disko Island. In addition, 5% spinels contain melt inclusions of 0.005-0.06 mm diameter, glassy or partly crystallized. To homogenize the crystallized melt inclusions for subsequent analysis by electron microprobe, spinels were heated at 1250 °C for 96 hours at controlled oxygen fugacity (FMQ) and quenched. Compositions of homogenized melt inclusions are (in wt.%): SiO<sub>2</sub> (42-55), TiO<sub>2</sub> (1.5-3), Al<sub>2</sub>O<sub>3</sub> (11.5-15), MgO (9-13), CaO (6-12), Na<sub>2</sub>O (2-2.5), K<sub>2</sub>O (0.5-1.1), and CaO/Al<sub>2</sub>O<sub>3</sub> (0.7-1.0), which indicates an alkali basalt affinity. The compositions of melt inclusions correlate well with the compositions of host spinels, and both show a possible cocrystallization of olivine and spinel in the parental magma. Based on palaeo-tectonic reconstruction, presence of mid-late Cretaceous fossils in the strata, and the chemical compositions of spinels and associated melt inclusions, we conclude that volcanics of the Rajmahal, which are associated spatially and temporally with Kerguelen hotspot activity on India about 117 Ma ago, were the source for these Cr-rich spinels. Although the Tianba Flysch looks in the field like a typical collisional product, and the presence of Cr-rich spinels might suggest an ophiolitic source and a Cretaceous ophiolite-obduction on the northern Indian continental margin, our detailed work shows clearly that the Tianba Flysch is neither ophiolite-derived, nor related to the start of the India-Asia collision.

## V22A-1217 1330h POSTER

### Melt Inclusion Volatile Contents, Pressures of Crystallization for Hawaiian Picrites, and the Problem of Shrinkage Bubbles

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The H<sub>2</sub>O and CO<sub>2</sub> contents of melt inclusions can potentially be used to infer pressures of crystallization and inclusion entrapment because the solubility of mixed H<sub>2</sub>O-CO<sub>2</sub> vapor has been determined experimentally for basaltic and rhyolitic melts. However, melt inclusions commonly develop shrinkage bubbles caused by the greater thermal contraction of the melt compared with the host mineral during post-entrapment cooling. Because the solubility of CO<sub>2</sub> in silicate melts is much less than that of H<sub>2</sub>O, resulting in relatively high vapor-melt partition coefficients for CO<sub>2</sub>, formation of a shrinkage bubble can strongly deplete the coexisting melt of dissolved CO<sub>2</sub> that was present at the time of entrapment. To investigate the loss of CO<sub>2</sub> into shrinkage bubbles, we have experimentally reheated large melt inclusions in olivines from a Mauna Loa picrite in order to redissolve the vapor in the bubble. The olivines were sampled from Puu Wahi, a scoria cone situated at ~3000 m elevation on the NE rift zone of Mauna Loa. The olivines (Fogge) come from reticulite scoria and so were naturally quenched to glass during eruption, but all inclusions contain shrinkage bubbles < 3 vol% of the inclusion. Reheating to 1400°C remobilized the shrinkage bubble into the melt, but even with rapid quenching a small vapor bubble formed during quench. CO<sub>2</sub> contents measured by FTIR spectroscopy and recalculated for melt in equilibrium with the olivine host are 300-600 ppm (n=11) for reheated inclusions, much higher than the CO<sub>2</sub> contents of the naturally quenched inclusions (60-180 ppm; n=8), which all contain shrinkage bubbles. Dissolved H<sub>2</sub>O contents of the melt inclusions are very uniform (0.36 ± 0.05 wt%). Pressures of inclusion entrapment

calculated from the H<sub>2</sub>O and CO<sub>2</sub> data for the re-entrapment inclusions range from 0.5 to 1.3 kbar, indicating that olivine crystallized at very shallow depths beneath the surface of Mauna Loa. Large (< 100 microns in diameter) fluid inclusions in some olivines appear to contain relatively low density CO<sub>2</sub>, consistent with the interpretation based on melt inclusions that olivines formed at low pressures. Such surprisingly low pressures of crystallization have also been inferred for olivines erupted in the 1959 Kilauea Iki picrite (Anderson and Brown, 1993, Am. Min.) and for abundant F<sub>088-90</sub> olivine in the Keanakaoi ash deposits at Kilauea (Hart and Wallace, 2000, AGU abstract). Eruptions of olivine-rich lava are relatively rare on the sub-aerial portions of both Kilauea and Mauna Loa but are more common on the submarine parts of both volcanoes. As has been proposed for Kilauea Iki, the eruption of olivine-rich lava high on the NE rift zone of Mauna Loa probably resulted from magma following an unusual pathway to the surface, thus bypassing mixing and density filtering within the summit magma system. Our results for Pui Wahi olivines demonstrate that to accurately infer original pressures of crystallization requires inclusions with shrinkage bubbles to be experimentally rehomogenized in order to redissolve CO<sub>2</sub> lost to the bubble during post-entrapment cooling.

## V22A-1218 1330h POSTER

### Melt Inclusion from Volcn Colima and Popocatepetl: melt generation by combined fractionation and degassing

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#### Abstract

The volcanoes of Mexico display considerable variation in their magmatic style and products across the Trans Mexican Volcanic Belt. Volcán Colima and Volcán Popocatepetl are two such volcanoes on opposing sides of the belt. Volcán Colima is considerably closer to the Middle America Trench and is situated over much thinner crust than Volcán Popocatepetl. Despite this, both produce chemically similar andesites. Although they display differences in mineral assemblages and eruptive styles, processes such as magma mixing, assimilation of crustal material, fractional crystallization or a combination of these have been used to explain such differences. This study examines melt inclusions from Colima and Popocatepetl phenocrysts in order to better understand pre-eruptive dynamics. Melt inclusions from both volcanoes are andesitic to rhyolitic. Trends in major element and water data are easily correlated with other Mexican volcanics including those presumed to be derived directly from primitive melts. Water contents in Colima and Popocatepetl melt inclusions overlap (0.3 and 3.4 wt. % H<sub>2</sub>O) and correlate negatively with SiO<sub>2</sub> and K<sub>2</sub>O. These trends are consistent with vapor saturated crystallization during ascent. Melt inclusion water contents suggest that this occurs between a minimum of ~ 50 and ~ 800 bars (near surface to ~ 2.4 km depth). We suggest that the entrapped melt has mainly undergone fractionation occurring contemporaneously with degassing in the upper portions of the crust. Our data further suggests Colima and Popocatepetl melt inclusions are derived from a source similar to that of other Mexican volcanoes.

## V22A-1219 1330h POSTER

### Pre-eruptive Volatile Content of Miyakejima 2000 Eruption

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Vigorous and continuous SO<sub>2</sub> emission observed at the summit crater is a puzzling episode of Miyakejima 2000 eruption. Melt inclusions in phenocrysts from several volcanic events have been examined by EPMA and FTIR to understand the behavior of volatile elements during the evolution of magma batch. Samples were collected from three volcanic events; (1)submarine eruption on June 27, 2000, (2)summit eruption on August 18, 2000, (3)lateral fissure eruption in 1983.

Chemical variation observed in melt inclusions from the summit eruption on August 18 can be explained by post-entrapment crystallization of host, and no

evidence is recognized on the occurrence of magma-mixing. On the other hand, element concentrations of melt inclusions derived from the submarine eruption on June 27 and the lateral fissure eruption of 1983 suggest their common source having a signature of supply of less-evolved magma into a differentiated one. The less-evolved magma is likely to be identical to the parental magma of the summit eruption. Sulfur content varies from 0.35 to 0 wt% SO<sub>2</sub> possibly reflecting pre-entrapment degassing. However, no significant difference in the highest S concentration was observed among the three events.

Measured S<sub>6+</sub>/Stotal ratios in almost all melt inclusions with SO<sub>2</sub> higher than 0.1 wt% yield pre-eruptive redox conditions of dNNO=+0.2 - +0.5 log unit, and show no correlation with sulfur content. On the other hand, melt inclusions with SO<sub>2</sub> less than 0.1 wt% indicate redox conditions of dNNO=0 - -0.5 log unit. Simple degassing model cannot explain wide scatter of volatile contents. The chlorine content (570-1100 ppm) increases with increasing incompatible elements. This suggests little chlorine is lost during the evolution of magma batch. On the other hand, no correlation can be seen among S, H<sub>2</sub>O (2.5-0 wt%), and Cl contents. A plagioclase-globule (Fe,Cu,S) was casually found in a plagioclase-hosted inclusion having the most primitive composition (low TiO<sub>2</sub> (1.0-1.1 wt%) and high MgO (5.6 wt%). This inclusion shows a very low S<sub>6+</sub>/Stotal ratio and relatively high sulfur and water content (about 0.28 wt% SO<sub>2</sub> and 1.5 wt% H<sub>2</sub>O), and may be a key to know a cryptic source composition.

## V22A-1220 1330h POSTER

### Glass Inclusion and Groundmass Glass Compositions in a Boninite

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The major and trace element compositions of groundmass glass and glass inclusions in orthopyroxene were studied in a MgO-rich boninite from Chichi Jima, Japan. The sample is a typical low-CaO boninite with 56.5% SiO<sub>2</sub>, 17.8% MgO, 0.07% TiO<sub>2</sub>, 0.25% K<sub>2</sub>O and CaO/Al<sub>2</sub>O<sub>3</sub> of 0.6, and abundant (>30%), large (>1mm) orthopyroxene phenocrysts with glass inclusions. Orthopyroxene compositions range from En 80 to En 88. Groundmass and groundmass glass compositions range from 61-66% SiO<sub>2</sub>, 1.3-3.9% MgO, 0.07-0.17% TiO<sub>2</sub>, and 0.43-0.73% K<sub>2</sub>O. Glass inclusions in orthopyroxene have similar compositions, but generally lower K<sub>2</sub>O for a given SiO<sub>2</sub>. Among both groundmass and glass inclusions, K<sub>2</sub>O, TiO<sub>2</sub>, and Al<sub>2</sub>O<sub>3</sub> contents increase regularly with increasing SiO<sub>2</sub> and decreasing MgO, FeO.

Major element trends in groundmass glass and glass inclusions are consistent with crystallization of orthopyroxene and clinopyroxene from melt. Clinopyroxene, which is found within orthopyroxene crystals and in glass inclusions, has compositions: Wo 30-40, En 35-52, Fs 15-24. Amphibole is present in a few glass inclusions, attesting to the high water content of the trapped melt.

Most published groundmass or pillow rim glass analyses from Chichi Jima boninites reveal extensive exchange with seawater, which affects abundances of alkali elements, H<sub>2</sub>O contents and O-isotopes. The glass inclusion analyses permit detailed interpretation of mobile trace element abundances without these effects.

## V22A-1221 1330h POSTER

### Melt Volatile Contents in Basalts From Lathrop Wells and Red Cone, Yucca Mountain Region (SW Nevada): Insights From Glass Inclusions

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In July of 2002, the U.S. Congress approved Yucca Mountain as the nation's long-term repository for high-level nuclear waste. Among the controversial geological concerns about this decision is the scenario of a magmatic dike propagating vertically into the network of repository tunnels. The volatile contents of the magmas are clearly relevant to their explosivity and their potential to disrupt and disperse the stored radionuclides. A recent modeling study assumed 2 wt.% H<sub>2</sub>O in the invading magma based on experimental analogs to the phenocryst assemblage of olivine and minor amphibole.

The goal of this study is to provide insight into the volatile contents of late-Quaternary basaltic magmas

erupted in the vicinity of Yucca Mountain through direct analysis of 16 olivine-hosted glass inclusions from the ~80 ka Lathrop Wells cone (LW: n=13) and the ~1 Ma Red Cone (RC: n=3). The olivines range in Mg# from 75.2 to 78.9. Mean analyses of the LW & RC glass inclusions by electron microprobe are: SiO<sub>2</sub> 49.5 & 50.3 wt.%, TiO<sub>2</sub> 2.1 & 1.5%, MgO 5.4 & 4.7%, K<sub>2</sub>O 2.1 & 1.6%, P<sub>2</sub>O<sub>5</sub> 1.2 & 1.1%, total S as SO<sub>2</sub> 0.45 & 0.42%, and Cl 0.06 & 0.07%. Among the 16 analyzed glass inclusions is one with normative quartz, 4 with normative nepheline, and the 11 others with normative hypersthene.

Total water contents were determined by Fourier-transform infrared (FTIR) spectroscopy on 12 inclusions using either the mid-IR peak at 3535 cm<sup>-1</sup>, or the sum of the near-IR peaks at 5200 and 4500 cm<sup>-1</sup>. Three inclusions, two of which clearly leaked, have total water contents of 0.22-0.75 wt.%. The other nine inclusions have total water contents of 1.9-4.6% (mean 3.5%). These are consistent with electron microprobe glass totals that fall below 100% by 1.0-5.8% (mean 3.8%). Clearly resolvable carbonate peaks at 1435 and 1515 cm<sup>-1</sup> are present in six samples and correspond to preliminary CO<sub>2</sub> contents of 230-930 ppm, which correlate roughly with total water contents. The glass inclusions typically have vapor bubbles of roughly constant proportional size (2-5 vol.%). One glass-inclusion wafer wholly contained a vapor bubble and FTIR analysis through it revealed a peak at 2350 cm<sup>-1</sup>, corresponding to CO<sub>2</sub> gas. Hazard modeling scenarios should be revised to assume ~4% water and >1000 ppm CO<sub>2</sub> in the invading magma.

## V22A-1222 1330h POSTER

### Source Variations in Kamchatka Back-Arc Volcanism Inferred from a Mineral and Melt Inclusion Study of the South Cherpouk Monogenetic Center

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Major, trace, and volatile element analyses were obtained of melt and solid phase inclusions in olivine from the Kamchatka back-arc South Cherpouk volcanic center in order to assess the compositional changes in mantle source and fluids during formation and evolution of the host rocks. South Cherpouk is a monogenetic cinder cone located 21 km southwest of Ichinsky volcano in the Sredniny Range and lies 200 km from the arc front and 400 km above the subducted slab. It has an extensive (22-km long) lava flow, an estimated eruptive volume of 2.5 km<sup>3</sup>, and an age of 6,500 <sup>14</sup>C yr B.P. South Cherpouk rocks are olivine-plagioclase basaltic andesite and represent the most mafic material of the Ichinsky volcanic center. Previous work has suggested two types of mantle sources for the Late-Pleistocene monogenetic centers of the Kamchaka back arc: typical island-arc sources (MORB-like) and Ti-, K-, Nb-enriched OIB component (Churikova et al., 2001). We studied samples from two portions of lava from the same eruption. Detailed mineralogical data indicates that the eruption was fed from at least two mantle sources. Olivine-spinel compositions from two samples form distinct fields on Fo-Cr#(Cr/(Cr+Al)) in a spinel diagram; the sample with higher Fo content in olivine has substantially lower Cr# in spinel hosted by these olivines: Fo 80-81 with Cr# 0.52-0.56 and Fo 82-84 with Cr# 0.4-0.45. Because these mineral associations cannot be described in terms of fractional crystallization and partial melting processes of the same mantle source, we argue for the existence of two melts arrived from the distinct sources but erupted close in time and from one vent. Field relations supports this suggestion in that the cinder cone has two craters and at least two lava flows. The absolute age difference between these flows is unknown but the lack of a gap between associated tephra suggests the eruptions were close together. Another intriguing feature of the studied lavas is the very high S content (up to 7000 ppm) in melt inclusions, suggesting an additional source for this volatile element. Trace element data from both whole rock and melt inclusions in olivine indicate an additional subduction component was involved in the formation of South Cherpouk lavas. The possible causes for all mantle source and fluids would be considered in terms of both major and trace elements. Scoria of the first stage of the South Cherpouk eruption was more

basic than subsequent lava flows. Following a scenario proposed for Trident volcano in Alaska (Coombs et al., 2000), we suggest a rapid injection of a basalt dike first triggered the eruption and then the basalt magma passed through the basaltic andesite magma chamber. A calmer effusive eruption of basaltic andesite then followed.

#### V22A-1223 1330h POSTER

##### Glass Inclusions and Melt Volatile Contents in the Late-Quaternary Basanites and Minettes of Colima (Mexico)

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Olivine-hosted glass inclusions from fine tephra collected at three basanite-minette cinder cones on the lower flanks of the Colima Volcanic Complex in western Mexico were analyzed by electron microprobe and Fourier-transform infrared spectroscopy (FTIR). These nepheline-normative rocks have elemental-abundance patterns that mimic those of the volumetrically dominant subduction-related andesites, but at much higher abundance levels. Sr, Nd, and Pb isotopic ratios are also similar for the two suites. We interpret the Colima basanites and minettes as recording the "essence" of subduction-zone geochemistry, produced by nearly pure melting of phlogopite-rich veins in the mantle wedge, and erupted in western Mexico only because of its unusual upper crustal extensional regime. Similar melts impart the subduction-zone geochemical flavor to the dominant andesites, which differentiate from basalts produced by higher degrees of mantle wallrock melting.

Olivine crystals separated from the basanite-minette tephra have Mg#s that range from 81.5 to 90.7. The 34 glass inclusions studied contain 49-60 wt.% SiO<sub>2</sub> and include 2 with normative quartz, and 6 with normative hypersthene, with the remaining 26 containing up to 11.5% normative nepheline. The glasses also contain 2.8-8.4% K<sub>2</sub>O, 0.16-0.33% Cl, and 0.03-1.19% total sulfur as SO<sub>3</sub>. Comparison of Fe/Mg values of glass and host olivines indicates 1-5% crystallization of olivine from the inclusions following entrapment. FTIR measurements were made on 26 of the inclusions. No reliable carbonate or CO<sub>2</sub> peaks were detected in any glass inclusion, but a significant 2350 cm<sup>-1</sup> CO<sub>2</sub> peak was found for a bubble completely trapped within one inclusion. Total water contents estimated from the 3535 cm<sup>-1</sup> peak range from 0.2% to 2.0%, with only 8 values above 1%. These relatively low water contents are surprising, especially for the phlogopite-bearing minettes. A value of 2.0% water corresponds to water saturation at a pressure of 415 bars, equivalent to a depth of 1600 m. We consider the possibility that the magmas ascended through much of the crust in a superheated condition, and stagnated in the uppermost crust where the bulk of the olivine crystals grew in a rapid skeletal fashion trapping the glass inclusions. Such stagnation is consistent with the complete lack of ultramafic xenoliths at these cones. Published phase-equilibrium experiments on an olivine-bearing minette imply that phlogopite is stable down to pressures of 200-400 bars, also consistent with this interpretation.

#### V22B MCC: Hall C Tuesday 1330h

##### Geochemistry of Soils, Ore Deposits, and Waste Sites Posters

**Presiding:** I Chou, U.S. Geological Survey

#### V22B-1224 1330h POSTER

##### Comparison of Two Methods for Determination of Strontium Isotopes in Pore Water at Yucca Mountain, Nevada

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The proposed radioactive waste repository at Yucca Mountain, Nevada would be constructed in the high-silica rhyolite member of the Topopah Spring Tuff,

an ash-flow tuff within the ~500-m-thick unsaturated zone. Dry-drilled rock cores from this unit have been packaged to preserve their water content. Two methods have been used to extract the strontium contained in the pore water for isotopic measurements. In the first method, samples of dried core were crushed, and the 0.25 to 2.4 mm size fractions were leached with ultrapure water for about 1 hour to dissolve the salts left behind by the evaporated pore water. Concentrations of strontium in the pore water were calculated from determinations of porosity and saturation on adjacent core and the measured strontium concentration in the leachate. In the second method, pore water was extracted from sealed core using an ultracentrifuge, minimizing evaporation of water from the core at all steps in the process. The centrifugation of 150 to 200 g of welded tuff at 15,000 rpm for 6 hours typically results in the recovery of as much as 3 ml of pore water for analysis.

Strontium isotope compositions were determined by thermal ionization mass spectrometry; <sup>87</sup>Sr/<sup>86</sup>Sr ratios have a reproducibility of 0.00005. The ranges of <sup>87</sup>Sr/<sup>86</sup>Sr ratios determined by the two methods are identical: 0.71215 to 0.71267 in the leachates (n = 35) and 0.71214 to 0.71266 in the extracted pore waters (n = 21). However, the calculated strontium concentrations in the leachates average 300 µg/L, whereas those in the extracted pore water average 1440 µg/L, indicating that a substantial portion of the pore-water salts remain in the crushed rock after leaching.

The strontium data determined on extracted pore water shows that the leaching of pore-water salts results in accurate <sup>87</sup>Sr/<sup>86</sup>Sr, but that a substantial correction to the strontium concentration is required due to the inefficiency of the leaching procedure and the small pore sizes in the welded tuffs. The strontium isotope data obtained on leachates can be used to constrain models of water-rock interaction and estimates of travel times in the unsaturated zone.

#### V22B-1225 1330h POSTER

##### Preliminary Evaluation of the Effects of Buried Volcanoes on Estimates of Volcano Probability for the Proposed Repository Site at Yucca Mountain, Nevada

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Probability models that calculate the likelihood of new volcano formation in the Yucca Mountain (YM) area depend on the timing and location of past volcanic activity. Previous spatio-temporal patterns indicated a 10<sup>-4</sup> to 10<sup>-3</sup> probability of volcanic disruption of the proposed radioactive waste repository site at YM during the 10,000 year post-closure performance period (Connor et al. 2000, *JGR* 105:1). A recent aeromagnetic survey (Blakely et al. 2000, *USGS OFR 00-188*), however, identified up to 20 anomalies in alluvium-filled basins, which have characteristics indicative of buried basalt (O'Leary et al. 2002, *USGS OFR 02-020*). Independent evaluation of these data, combined with new ground magnetic surveys, shows that these anomalies may represent at least ten additional buried basaltic volcanoes, which have not been included in previous probability calculations. This interpretation, if true, nearly doubles the number of basaltic volcanoes within 30 km [19 mi] of YM. Moreover, the magnetic signature of about half of the recognized basaltic volcanoes in the YM area cannot be readily identified in areas where bedrock also produces large amplitude magnetic anomalies, suggesting that additional volcanoes may be present but undetected in the YM area.

In the absence of direct age information, we evaluate the potential effects of alternative age assumptions on spatio-temporal probability models. Interpreted burial depths of >50 m [164 ft] suggest ages >2 Ma, based on sedimentation rates typical for these alluvial basins (Stamatakos et al., 1997, *J. Geol.* 105). Defining volcanic events as individual points, previous probability models generally used recurrence rates of 2-5 volcanoes/million years (v/Myr). If the identified anomalies are buried volcanoes that are all >5 Ma or uniformly distributed between 2-10 Ma, calculated probabilities of future volcanic disruption at YM change by <30%. However, a uniform age distribution between 2-5 Ma for the presumed buried volcanoes increases recurrence rates by 3 v/Myr, which essentially doubles most probability estimates. If the ten buried volcanoes formed in a single episode of intense activity at about 4 Ma, then recurrence rates may increase to 17 v/Myr. This

recurrence rate increases the point-event probabilities up to a factor of five. Additional analyses are ongoing to evaluate alternative event definitions and construct numerical models of all relevant magnetic anomalies.

This abstract is an independent product of the CN-WRA and does not necessarily reflect the views or regulatory position of the NRC.

#### V22B-1226 1330h POSTER

##### Mineralogical controls on uranium immobilization at Tono Uranium Deposit, Japan

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The Tono uranium deposit, located in central Japan, is thought to have formed when oxidizing groundwater leached uranium from the underlying Toki Granite and transported it to the overlying host sedimentary formations where it precipitated under reducing conditions. Fission-track dating shows that this uranium mineralization took place 10 million years ago and has remained immobilized despite episodes of sedimentation, uplift, subsidence, major faulting, and erosion.

In order to understand the mineralogical controls on uranium immobilization, this study is gathering data on the mode of precipitation and adsorption of uranium within the various host lithologies. Optical petrography done on samples has shown a predominance of volcanoclastic deposits, containing glass shards within a fine-grained phyllosilicate matrix. Tephra that were formerly glass lack axiollitic devitrification textures and are altered to similar fine-grained mineralogy as in the matrix. X-ray diffraction data indicates that the majority of this fine-grained mineralogy is chlorite and the Mg, Ca smectite, saponite. Electron dispersive spectroscopy and back scattered electron data will create a map of the uranium concentrations and show any mineralogical affinities. Scanning and transmission electron microscope data will resolve the nature, crystallinity, and host sites of the uranium mineralization and help resolve the paragenesis in these tuffaceous rocks. This paper will address data gathered on samples across the host sedimentary formations and with depth to establish what mineralogical controls, if any, have influenced uranium precipitation and immobilization.

#### V22B-1227 1330h POSTER

##### Importance of Dust Deposition and Fe-oxides to the Geochemistry of Uranium in Soils Along a Hawaiian Chronosequence

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The fate of U in a chronosequence of Hawaiian soils was studied as a result of soil development processes including leaching, parent material weathering, dust deposition and subsequent weathering, adsorption and/or precipitation, and secondary mineral formation. The long-term mass balance of U in these systems was quantified by two different approaches, and the association of uranium with specific mineral phases was investigated by a sequential extraction procedure as well as by XRD. Despite intense leaching conditions, U concentrations were found to increase 30-fold with age along the chronosequence, from 0.2 ppm at the 2.1 ka site to 6 ppm at the 4100 ka site. An open-chemical-system transport function comparing U to an index least mobile element (Nb) was used to calculate net U gains or losses. Results show net leaching (up to 21%) occurred in younger soils (<150 ka) and net addition of U (up to 428%) occurred in older soils (>150 ka) as a result of