

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.% SiO₂ 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% K₂O, 0.16-0.33% Cl, and 0.03-1.19% total sulfur as SO₃. 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 CO₂ peaks were detected in any glass inclusion, but a significant 2350 cm⁻¹ CO₂ peak was found for a bubble completely trapped within one inclusion. Total water contents estimated from the 3535 cm⁻¹ 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; ⁸⁷Sr/⁸⁶Sr ratios have a reproducibility of 0.00005. The ranges of ⁸⁷Sr/⁸⁶Sr 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 ⁸⁷Sr/⁸⁶Sr, 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 10⁻⁴ to 10⁻³ 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

these soils undergo incongruent dissolution progressively enriching the oxide toward a FeCr_2O_4 end-member. Chromium occurs in the trivalent state in both the rock and soil samples. The apparent resistance of chromium-oxides to weathering suggests that these phases are not likely sources for chromium in soil solutions and plants of serpentine soils. Chromium-bearing igneous (enstatite and augite) and metamorphic (chlorite) silicate phases in the protolith are more likely sources.

V22B-1233 1330h POSTER

Diffuse soil degassing of radon and mercury from abandoned underground coal mines in Southeastern Ohio

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The exploitation of coal in Southeastern Ohio is associated to the production of acid mine drainage and poor water quality in rivers and streams. Water recharge to the underground coal mines occurs preferentially throughout subsidence features in areas where the overburden is thinner than around 60 feet, usually close to river and streams. Gases released from the coal beds such as methane and mercury, as well as radon generated in the rocks can diffuse throughout the overlying fractured rocks and soils and discharge to the atmosphere. The purpose of this research was to compare the gases released from mined and unmined areas in Southeastern Ohio. Radon and mercury concentrations were measured at 40 cm depth using a Pylon AB-5 Radiation Detector and an Arizona Mercury Analyzer respectively. An area of 59 miles² (151 km²) close to the town of Corning, Ohio, was investigated. Distance between points was around 600-1000 m. Approximately half of the area was mined underground and half was not. Our results indicate that radon concentration is considerable higher in the mined areas. Mercury concentrations are more variable and do not correlate with mined areas. Accumulation of gases released in basements of houses located in zones of high soil radon concentration will be investigated.

V22B-1234 1330h POSTER

The Isotopic Composition of Continental Iron and Implications for the Global Iron Cycle

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Recent advances in the field of iron isotope geochemistry suggest that iron may be fractionated isotopically to a measurable degree by natural abiotic and biotic processes. This finding is especially significant in light of interest in the effect of natural iron fertilization on the global biological pump, and hence global climate. The question of interest is whether variability of iron isotope composition in natural materials can help us elucidate the iron cycle and determine the importance of iron to global climate over geological timescales.

The current work concentrates on bedload stream sediments and stream waters from the west coast of North America. The goal of this work is to understand how iron is transported between geological reservoirs within the continental iron cycle. Stream waters and bedload sediments were collected along a gradient of low to high suspended sediment load from the Russian River in northern California to the Yukon River in western Alaska. Bedload sediment samples were characterized mineralogically by optical microscopy and electron microprobe while stream waters were analyzed by inductively-coupled plasma mass spectrometry for iron concentration as well as major element (Ca, Na, Al, Mg) and trace element (Cr, Ni) concentration.

Preliminary work has shown that the oxide fraction of stream sediments is isotopically heavier than the silicate fraction. This first-order observation suggests that the lattice-related bonding environment of mineral-bound iron affects isotopic composition. The observation also implies that the more easily weatherable oxide fraction of stream sediments contains material that is isotopically distinct from less weatherable silicates. In order to extend our observations to the geological past, we compare the variety of modern weathering environments and catchment types to conditions we might expect during glacial periods. We can then use simple steady-state box models to explain the effect of iron isotope systematics in rivers on the global iron cycle.

V22B-1235 1330h POSTER

Insights Into Ore Deposit Genesis Using Copper Isotopes

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Advances in MC-ICPMS have renewed interest in the analysis of transition metal isotopes to better constrain the processes involved in ore deposition. At WSU we employ sample-standard bracketing to accurately and precisely measure copper isotope ratios of whole mineral dissolutions without normalizing to zinc. This approach bypasses the use of chromatography for samples without significant isobaric interferences avoiding potential fractionation resulting from chromatography. Comparisons of analyses of native copper and chalcopyrite samples with and without chromatographic purification are within error. Reproducibility measured using native copper and chalcopyrite is $\pm 0.03\text{‰}$ (1σ , relative to NIST976) over 2 months.

We have found the range of $\delta^{65}\text{Cu}$ values in chalcopyrite from a variety of ore deposits to be -0.9‰ to $+3.1\text{‰}$. $\delta^{65}\text{Cu}$ values of native copper and bornite samples are more restricted (-0.8‰ to 1.3‰ , and -1.1‰ to 1.0‰ , respectively). Additional minerals, including chalcocite, mohawkite, azurite and cuprite, have been analyzed from a variety of ore depositional environments.

Variations in $\delta^{65}\text{Cu}$ values of individual mineral species within a single deposit or district have smaller ranges. For example, "hypogene" native copper samples from the Michigan Native Copper district show a restricted range of values (0.2‰ to 0.4‰), over 100km strike of the district. In addition, different genetically related minerals in the same deposit show distinctive trends in $\delta^{65}\text{Cu}$ values. For example, co-precipitated chalcopyrite-bornite pairs from three deposits (Resolution, AZ, Beaver-Harrison Mine, UT, and Ferrobamba, Peru) display consistently higher $\delta^{65}\text{Cu}$ values in chalcopyrite relative to bornite. Results from the Tintaya district, Peru and Resolution, AZ suggest that variations in $\delta^{65}\text{Cu}$ values may be systematic on the deposit scale. In both deposits, $\delta^{65}\text{Cu}$ in chalcopyrite increases with distance from the centers (sources) of the hydrothermal systems, with "proximal" $\delta^{65}\text{Cu}$ values being lower than "distal" $\delta^{65}\text{Cu}$ values. These results suggest fractionation processes are also operating on the scale of the deposit, and under "hypogene" hydrothermal conditions. In addition, copper minerals from the supergene zones of ore deposits, in general, show consistent isotopic variations relative to "hypogene" minerals, thus demonstrating that copper isotopic variations can be used as geochemical tracers in ore deposits.

V22B-1236 1330h POSTER

Geochemistry of Fresh Submarine HSDP-2 Glasses from Mauna Kea Volcano: Unexpected Mobility of 'Immobile' Trace Elements

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The Hawaii Scientific Drilling Project-2 provides the opportunity to investigate the geochemical evolution of the submarine section of Mauna Kea. Our previous analyses of bulk-rock trace element concentrations had revealed relatively high degrees of scatter of trace element ratios such as Th/U, Ta/U and even Nb/Ta, and we suspected that many of the samples had been affected by seawater alteration. Fortunately, fresh glasses are found throughout the drill core in many glass-rich hyaloclastic and pillow basalts with glass proportions up to 10%. We therefore determined incompatible trace elements such as Th, U, Nb, Ta, Zr, Ba, Pb, Rb in carefully handpicked, fresh glasses in 16 samples derived from depths between 1310 m and 3050 m. The samples were crushed to less than 0.425 mm grain size in order to obtain very fresh glass fragments free of contamination by alteration products, olivines or other minerals.

The glass fractions and their corresponding bulk samples were analyzed for major and trace elements by EMP, MIC-SSMS and HR-ICPMS. The differences between glass and bulk are particularly obvious in Pb, Rb, Cs and U. As expected, Pb, Rb and Cs were found to be mobile, with concentrations in the bulk samples

varying by up to a factor of 5 relative to the glass samples. Similarly, U concentrations in glass are up to a factor of 2 higher than in bulk samples. More surprising is the observation that Th and Ta are quite probably mobile, because these elements are normally believed to be immobile. However, these results are consistent with those of Bienvenue et al. (1990), who found that Th appears to be sensitive to seawater alteration.

Our glass data indicate that Ta/U (3.7 ± 0.2) is uniform along the sequence, in contrast to the bulk data which show a large scatter ($3.7-6.5$). Th/U ratios in the glasses show a maximum (~ 3.5) at a depth of ~ 2100 m, whereas low ratios of about 3 were found in depths of 1300-1400 m and 2800-3000 m. The high Th/U ratios in the 2100 m region are associated with low SiO_2 contents, high $^{208}\text{Pb}^*/^{206}\text{Pb}^*$ (Eisele et al., 2002; Blichert-Toft et al., 2002) and high $^3\text{He}/^4\text{He}$ ratios (Kurz, personal comm., Althaus et al., 2002). Thus, it appears that the high Th/U values are not caused by melting effects but are features of an anomalous source chemistry sampled by the volcano at this stratigraphic level.

V22B-1237 1330h POSTER

Mass balance attending gel palagonitization of hyaloclastites in the HSDP 2 Phase 1 core

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In the HSDP 2 core, the alteration of hyaloclastites is multi-episodic, but the predominant, "normal" alteration process recorded in samples from depths between 1573 m and the bottom of the hole at over 3000 m entails the conversion of rinds of sideromelane-rich shards to gel palagonite and growth of pore-filling chabazite. This reaction must occur relatively rapidly, because point-count porosity in the zone of normal alteration approaches zero within 200 m of the top of this zone and remains very low to the deepest samples. Furthermore, thickness of palagonite rinds does not increase down hole.

Using modes from point counts on thin sections, major element analyses by electron microprobe, and trace element analyses by LAM-ICPMS, we have modeled the elemental mass balance for the normal palagonitization process in the HSDP hyaloclastites. Petrographic evidence suggests that this reaction does not involve solids other than sideromelane, gel palagonite, and chabazite and that the conversion of sideromelane to gel palagonite is isovolumetric. We used literature values of density: 2.80 g/cc for sideromelane, 2.00 for gel palagonite, and 2.075 for chabazite.

The major elemental balance calculated for these conditions, and averaged over 10 samples shows net addition of K_2O (by 17%), TiO_2 (19%), and water, with net losses of MgO (73%), P_2O_5 (52%), MnO (29%), CaO (17%), Na_2O (36%), SiO_2 (19%), FeO (15%), and Al_2O_3 (18%). Individual samples show similar patterns. Decreasing the gel palagonite density (to 1.9 g/cc) and allowing for a 5% volume decrease reduces the TiO_2 uptake (to 8%), but also increases the apparent loss of other "immobile" elements (FeO to 23% and Al_2O_3 to 22%). Normalized REE patterns for sideromelane versus gel palagonite show no systematic fractionations, although the normal reaction requires net gains on the order of 10-20% for most REEs. HFS elements are enriched in gel palagonite, relative to values in sideromelane, but LIL elements are depleted. LIL ions concentrate in chabazite.

Our results imply that elemental balance is not attained on the thin section scale and thus significant mass transport even of presumed "immobile" elements must attend diagenesis of these hyaloclastites. Thus it is likely that mass balance in this system may only be attained over large intervals of time and depth.

V22B-1238 1330h POSTER

Element Mass Balance in Soils: the Mount Cameroon Case

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Mount Cameroon is an active volcano located in Central Africa. Its location in a tropical climate area leads to abundant vegetation and intense weathering conditions that favor rapid alteration. Soils develop rapidly on the flanks of the volcano. We measured major and trace element contents as well as Pb, Nd and Sr isotopic compositions in three soil sections developed on basaltic tuffaceous units. Each section comprises 2-3 units, the upper portions of which are altered to soil (Andepts). The starting material is pyroclastic alkali basalt characterized by marked enrichment in trace elements. To determine the element flux during soil formation, two corrections have to be performed: (1) the parental rock composition has to be determined and (2) addition of Saharan dust as evidenced by [1] has to be corrected for. The starting rock composition is constrained using the Al/Fe vs C.I.A. relationship and the uppermost part of each soil is corrected for its eolian dust contribution (*10%). The budget for each element can then be estimated in the soils. Calculations are performed relative to an immobile element whose concentration is assumed to be unchanged during soil formation. We chose Th as a reference because its behavior during magmatic processes is similar to those of U, Rb, Ba, Cs and K which are known to be mobile during weathering processes. Results of the element budget calculations show that: alkali and alkaline earth elements are leached out of the soils (~ 50%). Silica losses (~ 30%) are also clear in all samples. For the other elements, systematic differences exist between bottom and top parts of each soil. The uppermost levels display significant changes Ni, U, Pb, P, Ni and Co contents. These mobilities are most probably related to hydrolysis of primary magmatic minerals triggered by the biological activity. Since the three studied sections correspond to the superposition of several soils where new tephra cover an older soil to be the basis of the formation of a new and younger soil, the element mass balance depends both on the paleoclimate conditions that prevailed during exposure to surface conditions, and on the duration of the exposure to air before the soil was covered by a new eruption.

[1] Chauvel C., Dia A & Bulourde M., GCA, Vol 66, 14A, p A132, 2002.

V22C MCC: 121 Tuesday 1330h

Statistical Analysis of Data Recorded on Active Volcanoes: Advancements and New Perspectives II (joint with S)

Presiding: W Marzocchi, Universita di Bologna; **S McNutt**, University of Alaska, Fairbanks

V22C-01 1330h

Short-term (1998-2002) Geochemical Evolution of the Piton de la Fournaise Volcano, Reunion Island

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After a six years quiet period, the Piton de La Fournaise showed an intense volcanic activity between Mars 1998 and January 2002. A long-lived eruption (six and a half months) initiated this period and was followed by eight distinct eruptive events (one week to one month long). Systematic sampling of the freshly erupted lavas was performed during the entire period. Forty-one samples covering the nine events were selected and analyzed for trace-element concentrations (ICP-MS in Grenoble) and Pb isotopic composition (MC-ICP-MS in Lyon). Three periods can be distinguished based on trace-element chemistry:

I) The long-lived 1998 eruption is characterized by a 10-20% progressive increase of the most incompatible element contents (U, Th, Ba, La, Ce). La/Yb increases continuously from 8.33 to 9.45 during the eruption.

II) During the six following eruptions (July 1999 - April 2001), the trace element concentrations display an overall general decrease. Within each eruption, no systematic evolution can be resolved.

III) The most recent events (June 2001 and January 2002) differ by the occurrence of olivine-rich lavas less enriched in trace elements. This effect increases during the course of the two eruptions. Trace-element concentrations drop to 40-50% of the starting level in the latest lavas. During stages II and III, La/Yb oscillates between 9.3 and 10.1 (around the value reached at the end of the eruption of 1998).

Lead isotopic ratios display small but systematic variations (²⁰⁶Pb/²⁰⁴Pb: 18.874-18.913, ²⁰⁷Pb/²⁰⁴Pb: 15.587-15.606 and ²⁰⁸Pb/²⁰⁴Pb: 38.975-39.032). The three stages differ in Pb isotopic signatures: stage I lavas have the highest Pb ratios and stage III lavas the lowest. Stage II samples are characterized by a distinctive correlation in ²⁰⁸Pb/²⁰⁴Pb vs. ²⁰⁶Pb/²⁰⁴Pb space.

The 1998-2002 chemical and isotopic variations of Piton de la Fournaise lavas represent 20 to 40% of the total range defined by the last 530 ky activity of the volcano. The three identified periods are thought to correspond to the initiation, the steady-state regime and the vanishing stage of a plume pulse.

V22C-02 1345h

Doppler radar observations at Merapi volcano, Indonesia: Insight into eruption mechanisms

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The mechanism of dome instability events at high risk volcanoes like Merapi volcano in Indonesia is still a matter of research. The main problem is centered around the question if instabilities start gravitationally or by explosive gas outbursts. In October 2001 we installed a FM CW Doppler radar system at Pos Babadan about 4.8km away from the summit of Merapi volcano to observe the activity at the dome of the volcano. The instrument is collecting data since then. The spot covered by our radar system is about 80m in diameter and data are interrogated every 3s. The instrument measures the velocity of material breaking off the dome as well as the approximate amount of material passing through the beam. In addition we also detect amount and duration of rain fall near the dome. A first processing of a subset of the data (Oct.- Dec. 2001) indicates two different instability types: A) purely gravitational instabilities and B) gravitational instabilities that are followed immediately by a gas outburst. The velocity spectra (reflected energy vs. velocity) of type A show only one peak, which is expected for a gravitational event, where some of the material moves at high speeds, the bulk at medium speeds and a small amount of material at low speeds. Combined events (type B) start also gravitationally with only one peak in the velocity spectrum. After 6-10s we observe a second peak at much higher velocities that disappears after a very short time (3-5s), and after that the signal looks like a purely gravitational event again. By comparing the recorded data to theoretical calculations we are confident that this is an explosive gas outburst overprinted onto a gravitational event. We expect that instability events may also start explosively but so far this has not explicitly been observed. In general the speed of material along the beam that broke off the dome during an instability event varies between 4 und 12m/s and the duration of such instabilities is between 10 and 30s. So far only minor instabilities have been observed with runout distances of about 2.5km and the duration of the events varies between 10 and 30s. Up to now we did not detect a regular pattern of instability events in the data, but a close followup of events seems to be somewhat common.

V22C-03 1400h

Statistical Studies on Summit Explosions and Volcanic Tremor, Arenal Volcano, Costa Rica

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From May 1995 through February 1999, UCSC and OVSCORI-UNA collected time-continuous seismic and

geodetic data at Arenal Volcano, Costa Rica. Arenal, a young active stratovolcano located in northern Costa Rica, began erupting in 1968 after a 450 year period of quiescence and is currently in a Strombolian phase, producing small summit explosions, intermittent lava flows, and occasional pyroclastic flows. Seismic signals recorded at Arenal include long period (1-3 Hz) transients related to summit explosions and almost continuous, and frequently harmonic, volcanic tremor. Daily statistics calculated for explosions and tremor provide a near continuous record of seismic activity at Arenal and show a decrease in summit activity from 1995-99, possibly reflecting a change within the volcano's magmatic system.

We present a number of statistical relationships within the explosion and tremor datasets to better understand interactions between the physical mechanism(s) producing these seismic signals within the volcanic system. Frequency-amplitude analysis for summit explosions indicate explosions may follow power-law scaling, analogous to the Gutenberg-Richter relation for earthquake occurrence, suggesting a scale-invariant process produces summit explosions. Previous work on Arenal's volcanic tremor suggests a scale-invariant process produces tremor as well [Julian, 2000]. We explore temporal relationships between volcanic tremor amplitude and frequencies and summit explosion occurrence to lend further insight into the degassing processes active within the volcano during periods of high and low summit activity.

V22C-04 1415h

Time Evolution Analysis of Volcanic Tremor Amplitude at Mt. Etna: Implications for Magma Dynamics

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Volcanic tremor is a seismic signal continuously recorded at persistently active, open conduits volcanoes, like Mt. Etna. Tremor time series from Mt. Etna are studied here over an unusual large temporal scale - namely from 1983 to 1999 - where the data were sampled at daily intervals. The time evolution of tremor amplitude was investigated both according to the periods, during which Mt. Etna was characterized by different volcanic activities and for fixed time spans. Time series analysis, among which phase space embedding, spectral and rescaled range analysis, were applied. The results show that volcanic tremor presents 1/f-noise correlation and may be modelled as an auto-regressive process, with exception of the signals recorded during paroxysmal explosive events. In case of lava fountains from summit craters, volcanic tremor depicts an intermittent behaviour, which can be approximated to a moving average process. Further investigations, however, exclude that intermittence in the tremor amplitude is dominated by low-dimensional chaotic behaviour. The relation between tremor amplitude patterns and shallow magma dynamics (the diffusing magma flows into the crater conduits) is discussed.

V22C-05 1430h

Volcanic Tremor and its use in Estimating Eruption Parameters

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Volcanic tremor, a continuous seismic signal, accompanies virtually all eruptions. Several published studies have examined the relation between tremor reduced displacement (DR, a normalized amplitude measure) and the Volcanic Explosivity Index (VEI) or ash plume height. The goal of these studies is to determine the physical relationship between tremor and eruptions and to use DR time histories or peak values to provide real-time estimates of eruption parameters. This study examines tremor for 50 eruptions from 31 volcanoes. Several systematic trends are observed: 1) large eruptions produce stronger tremor than small ones; 2) fissure eruptions produce stronger tremor than circular vents for the same fountain height; 3) eruptions with higher gas content produce stronger tremor than those with low gas content at the same volcano; and 4) phreatic eruptions produce stronger tremor than magmatic eruptions for the same VEI.

The task of using tremor DR to estimate eruption parameters is fundamentally a statistical problem with several factors contributing to uncertainties. First, tremor occurs when volcanoes do not erupt as well as when they do. Based on a worldwide sample, 60 to 80